STRESS ON LAND

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STRESS ON LAND IN CANADA

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PREFACE

The economy and society of the nation are built upon its resource base. Land is a fundamental resource, the host for the social and economic activities of mankind – the environment within which we must live. In the pursuit of our activities, we have significant impacts on the land resource. We use this resource as a place to work, and live, as a repository for our wastes, and as a nutrient source. But often we put less back than we take out, or what we do return to the land is incompatible with the long-term sustained use of the land base. With increased use of the nation's land resource, Canadians are bringing greater and greater pressures on what is a fragile ecosystem. Over time, the cumulative impact of our activities will have serious implications for the long-term maintenance of the land as the basic resource.

The objective of this publication is to focus on what Canadians are doing to their land resource. It examines several of our activities which produce pressures on the land, contributing to land degradation, or reducing the utility of the land. Previous publications of the Lands Directorate have examined how the land resource of the nation is allocated, and whether its use suits the inherent capability of that resource. Other works have focused on the means of allocation of the resource and on control measures such as planning or zoning which ensure that the land is in socially productive uses. This work constitutes one of the first ventures into the next phase of the analysis of land use in Canada – the analysis of how people use the land once its use has been allocated, and what the results of their management practices mean for the resource as a whole. As a first step, it identifies several of the more visible pressures which are brought on the land resource and examines how important these are in terms of the maintenance of the capability of the resource base itself.

Stress on Land is part of a continuing program of the Policy Research and Development Branch of the Lands Directorate designed to inform Canadians about important issues relating to land. If this publication creates interest in the way in which we manage our land resource base, it will have succeeded. In a sense, we are all the masters of what happens to our natural resource base. Our land heritage is determined through the individual choices of landowners, industrialists, governments, and social groups. As is evident from the research presented in this publication, we have yet to bring a consistent responsible conservation ethic to the way in which we treat our land resource. Through further research, and through the sensitization of these millions of decision makers to the problem, it is hoped that Canadians in the future will come to appreciate the value of the sound husbandry of their precious land resource.

M. Cormack

R.J. McCormack
Director General
Lands Directorate

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The Lands Directorate's research officers responsible for the co-ordination and production of this publication are recognized for their supervision of individual chapters. Wendy Simpson-Lewis is acknowledged for her supervision of: Land Stresses Associated with Federal Airport Facilities; Pits and Quarries – Their Land Impacts and Rehabilitation; and Stresses on Land Under Intensive Agricultural Use. Ruth McKechnie is acknowledged for her supervision of Coastal Oil Spills and Their Impact on Land; The KURDISTAN Incident: The Onshore Impacts of an Offshore Oil Spill; Inland Oil Spills and Their Impact on Land; and Forestry Practices and Stress on Canadian Forest Land. V. Neimanis is acknowledged for his supervision of the following chapters: The Land Impact Associated with the Disposal of Radioactive Wastes and Land as the Subject of Environmental Law.

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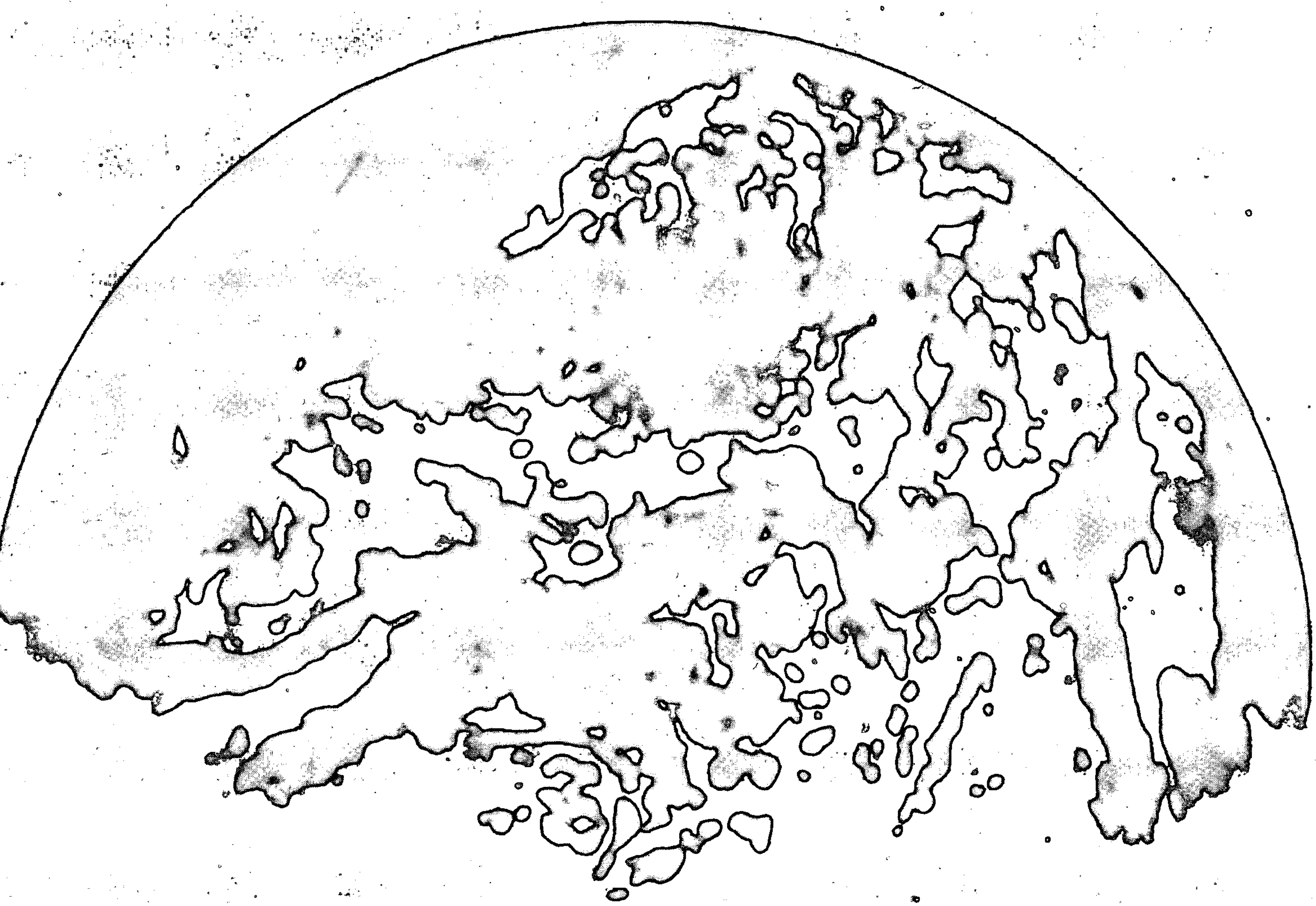

"Each generation has its own rendez-vous with the land,
for despite our fee titles and claims of ownership,
we are all brief tenants on this planet."

Stewart L. Udall
The Quiet Crisis

INTRODUCTION TO THE CONCEPT OF STRESS ON LAND

V. Neimanis, Ruth McKechnie, and Wendy Simpson-Lewis*

* *The authors are research officers with the Lands Directorate, Environment Canada, Ottawa, Ontario.*

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ONLY ONE EARTH

"The earth is one" exulted the American astronauts on seeing it floating in space as they voyaged to the moon. "Thus earthlings, for the first time in world history, confirmed with their own eyes the lesson the ancient sages sought to impart: indeed, the earth is one, a single inextricable whole of rocks and minerals and air and water and plants and animals - including man himself" (Marzanni, 1972). The earth is, in fact, a closed, infinitely complex system interlinking land, air, and water with all its inhabitants, one of which is the frequently egocentric, terrestrial man. The scales used to measure this total environment present a paradox: the expanses are vast yet small; the resources abound, yet there are not enough to go around. There is only this small speck in the universe, earth, that is capable of sustaining man's existence.

"Seventy-one percent of the earth is oceans and seas. The balance is land which must support nearly four billion people and a world of wildlife" (Vicars, 1982). Mankind is born, lives and dies on the remaining twenty-nine percent. The consequences of our actions must be closely monitored as we are affecting a total system on which we have influence but far from adequate knowledge and certainly no absolute control. The responsibility lies with humanity, to ensure its own preservation and protection – protection from ourselves.

How we use and manage the land resource has long-term implications for its ability to sustain certain uses. Some of man's activities place a strain on this finite resource, affecting its use and value either temporarily or permanently. This publication introduces the concept of stress in relation to land. In order to discuss this concept, the elements of land and stress will first be examined separately.

Land

What is land and how does it differ from soil? Soil, with its various physical properties and capabilities for different uses, is usually seen as part of natural science. Land, on the other hand, is a much broader term which encompasses not only the physical component of soil but also many social, political, environmental, and, particularly, economic aspects. Some of these aspects are described below (Committee on Soil as a Resource in Relation to Surface Mining for Coal, 1981).

Land is soil:

> Soil is a product of climate, native vegetation, and parent rock material. It is the natural medium and life-support system for natural and managed ecosystems. The mineral and organic components of the soil, its productivity, cannot always be renewed or are renewed at an exceedingly slow rate. It can take, on average, an estimated 200 years to form 1 cm of soil. Soil is the very thin living skin of the earth.

Land is a storehouse:

> Land, the solid part of the earth, is 2 900 km deep. It contains fossil fuels and other minerals which have propelled our industrial advancement. Occasionally the exploitation of these subsurface materials or resources leaves the surface resource – the land in a more narrow context – in a condition that precludes any other use.

Land is capability:

> Land has a finite ability to accommodate a number of particular human uses or activities without sustaining permanent damage. Capability links the land's intrinsic characteristics to a given activity or use.

Land is a space:

> Land is more than a physical entity. It is part of our space, space in which to live, move, grow, and pursue any number of activities. "Personal space" is largely provided by land, whether we realize it or not.

Land is a place:

> Land gives us a sense of place, so important to humans. We often define ourselves by location, be that a country, a point of longitude and latitude, a street address, or a landmark. Location gives us a relationship with other things.

Land is a commodity:

> "The desirability and therefore the value placed on a parcel of land, all things being otherwise equal, is dependent upon the functional pattern of human life" (Peltier, 1981). We, individually and together, determine the value of land. Land is real estate, its worth measured in dollars. Land, as a good, is bought and sold by area or space. Certain natural resource characteristics such as structure, topography, and fertility, make some land inherently better for some uses, such as agriculture. However, the land's other "properties" such as location, accessibility and space may determine that the parcel is used for a parking lot. Thus, its value, in either dollar terms or intangible measures, is a function of whether or not it can fill specific uses, how well it meets those needs, and which use can pay the most for it. It has been said by one of the foremost conservationists "We abuse land because we regard it as a commodity belonging to us" (Leopold, 1966).

Land is a finite resource:

> Land is a limited resource that includes the thin, fertile skin of soil and the many kilometres beneath it. Not all land was created equal. Its characteristics of physical capability and productivity, aesthetic quality, location, etc., vary and with these factors its value for all uses. The land's qualitative ability to bear various uses is finite, as is its quantity.

Land is all of these and more. How we perceive land depends on a complex mix of social, political, physical, environmental, and personal influences. Above all, this limited resource is unique for another reason. Unlike air and water, this resource which serves both individual and society, is viewed primarily in economic terms. Although land is subject to individual ownership, it is a common good and must meet the needs of the planet as a whole. Problems arise when there are conflicts between society's and the individual's perceptions of land.

Settlers who moved to the "new world" of North America left behind the feudal system of land tenure but they did bring with them a keen awareness of the value of land. The new land seemed endless and the first task was to claim or settle a piece of it.

> *"A cultural background had planted in the spirits of the early settlers and a wild and boundless wilderness nurtured a fierce sense of individualism. The fewness of the settlers in relation to the work that had to be done in subduing the wilderness tended to magnify the importance of every individual ... and the right to accumulate property gave people of the most humble origin opportunities to rise to the top in a colonial society ... The individual emerged as a unique center of power and value who,*

> *it might be said, is king of his own household and master of his own domain"* (American Association of School Administrators, 1964).

A profound sense of worth and personal satisfaction has always been firmly attached to land ownership and to this day property rights are jealously defended. Society's "resource" view of land and individual's "commodity and personal" views of land come into conflict, just as values and principles held by individuals often come into direct opposition with the common interest.

Land is but one element of the concept of stress on land. The second element of this concept is stress.

What is stress?

Seldom do we pick up a magazine or newspaper these days that does not have a headline including the word "stress". We often read of the stresses of over-work, inflation, unemployment, strikes, and poverty. There are articles on how to cope with stress and what to do to reduce it; on how it can cause various negative physical and psychological effects, depending on the person, and on how it may be used positively to achieve a certain goal. The word stress is used in many fields: including engineering, medicine, psychology, biology, geology, physical education, and linguistics. Everyone is familiar with this word and we use it often in our daily vocabulary but seldom do we try to define it.

Dr. Hans Selye is well known for his contributions to the medical concept of stress. He defines stress as "the nonspecific response of the body to any demand made upon it" (Selye, 1973). A nonspecific demand requires the body to readjust itself or adapt to a problem regardless of what that problem may be. He elaborates further, "From the point of view of its stress-producing or stressor activity, it is immaterial whether the agent or situation we face is pleasant or unpleasant; all that counts is the intensity of the demand for readjustment or adaptation" (Selye, 1974).

> *"Psychological stress is used as a generic term to designate unpleasant emotional states evoked by threatening environmental events or stimuli (Janis, 1958; Janis and Mann, 1968). A 'stressful' event is any change in the environment that typically induces a high degree of unpleasant emotion (such as anxiety, guilt, or shame) and affects normal patterns of information processing...."* (Janis and Mann, 1977).

Geologists define stress as:

> *"1. Force per unit area, found by dividing the total force by the area to which the force is applied.*
>
> *2. The intensity at a point in a body of the internal forces or components of force which act on a given plane through the point. As used in product specifications, stress is calculated on the basis of the original dimensions of the cross section of the specimen"* (American Geological Institute, 1962).

The word stress is often used in conjunction with other words: stress relief, stress crack, stress mineral, stress corrosion, stress amplitude, stress ratio, stress lines, stress field, stress tensor, stress range and stress intensity. In fact, there is even a problem-oriented programming language called STRESS, used to solve structural engineering problems.

The engineer speaks of stress as a force per unit area exerted between contiguous bodies or parts of a body and is measured in newtons per square metre.

Hence stress is a pressure or force that causes a change or readjustment of the object or person under stress.

Stress on the individual and on society

Stress is a common term used particularly by urban industrialized societies. The pace of life has increased rapidly over the past decade; we are constantly rushing to go somewhere, get something completed, or do something faster than before. People's impatience is evident as they wait in lines at banks, theatres, bus stops, subways, restaurants, and grocery check-outs. Competition in every sphere, from sport and education to jobs and social status, causes stress on the individual. Society too is under stress or pressure to produce more, faster, using less energy. Our rapidly developing technological society is continually changing and developing new and better techniques, all in the name of progress. Yet with progress comes stress. Nations compete against nations economically, so our resources come under stress as we continue to industrialize. The new technologies introduced to increase productivity have reduced labour requirements while at the same time the world's population continues to grow and demands on our finite resources increase. These concerns are not new: "There have been dire predictions ever since Robert Malthus published his classic Essay on Population in 1798. The central proposition of the Malthusian hypothesis is that human population tends to increase more rapidly than the means of subsistence and that the excess numbers must eventually succumb to the effects of starvation, disease, or violence" (American Association of School Administrators, 1964).

Stress on the earth's resources

Lester Brown, President of Worldwatch Institute stated:

> *"We are now in a situation where the growth in world population, the increase in human demand for products of these systems, is beginning to exceed the sustainable yield. The result is overfishing, deforestation, over-grazing, and soil erosion... At some point the stress will become economic in the form of inflation or perhaps physiological in the form of malnutrition"* (Anon., 1979).

The Global 2000 Report to the U.S. President, in its major findings and conclusions, states:

> *"If present trends continue, the world in 2000 will be more crowded, more polluted, less stable ecologically, and more vulnerable to disruption than the world we live in now. Serious stresses involving population, resources, and environment are clearly visible ahead. Despite greater material output, the world's people will be poorer in many ways than they are today"* (United States Council on Environmental Quality and the Department of State, 1980).

> *"The mixed economies of North America developed in a climate of ample, even surplus resources. Unrestrained growth and technological advances based on these resources have long been the cornerstones of our economic systems. The public has been conditioned to expect that more–or different–resources will always be available to support any foreseeable level of economic growth. Waste, despoliation, and accelerated consumption have been unpleasant byproducts of this attitude toward unlimited resources"* (Soil Conservation Society of America, 1980).

Historically, environmentalists have expressed their concerns about the stresses placed on resources in books and articles on pollution. Considerable pollution research was amassed by experts and with media coverage there was increased public and governmental awareness of pollution in the 1960s and 70s. Conservationist and environmentalist groups sprang into being voicing their concerns about these stresses and governments responded with studies identifying and analysing the various sources of pollution. By far the greatest volume of literature produced on pollution dealt with two specific types: air and water. The results of research on air pollution caused by industrial and automotive emissions led to the implementation of emission control measures. Findings of research on the second pollution, water pollution, led to the creation and enforcement of laws requiring industries to treat their wastes before dumping them into natural waterways. The increased public awareness of pollution of air and water resources has caused them to be identified as key environmental resource issues. However there is a third pollution, land pollution, which is also a significant resource issue but is seldom mentioned in discussions of environmental quality. There is some consideration of soil degradation in the literature but little has been written on the subject of land pollution which results from various forms of stress affecting the land resource.

The concept of stress on land

The land resource is much more than just soil. Because land has multiple characteristics, it is important to realize that the stress on land concept refers to a large range of negative impacts that may affect land use, its value or its capability. Stress on land can be either natural or man-made. Volcanic eruptions, such as Mount St. Helens, hurl tons of particulates and acid-laden gases into the air and spread molten lava and ash on to the surrounding landscape creating a natural stress on the land. The scars of such a stress leave their marks on the evolving landscape for years to come. Forest fires sparked by spontaneous combustion or lightning, natural oil leaks, landslides, mudslides, tornados and hurricanes are all examples of naturally occuring stresses over which man has no control.

However, this publication addresses only the man-made stress on land. It introduces the concept of stress on land, and emphasizes land stress as an important environmental issue. **Stress on land** is defined as man's activities which have a negative impact on the land resource, affecting land use, land value, and land capability.

Every human activity has an impact on the land, but impacts vary in terms of their intensity and severity. Certain activities, such as extraction, have a long-term impact on the land while others, such as oil spills, have relatively short-term impacts depending on their severity or scale. Impacts also differ as a consequence of cleanup procedures, reclamation operations, management practices, and the land's ability to adapt to change over time. This is where the concept of stress comes into play - the land may adapt to the stress over time; the period will vary depending on the nature and scale of the stress. Some stresses may not be evident during our lifetime but may occur in later generations. One of the aspects of stress seldom considered is that some activities have cumulative effects that in time can have severe impacts.

Perception is an important component of stress on land because individuals and societies perceive stress on the land differently. Activities may occur locally, regionally, or nationally and differ in scale. Perceptions also vary over time and with location. Each individual has a different perception of land, how it should be used, and whether a certain activity should or should not be labelled as stress. The media are often responsible for causing people to perceive specific occurrences as major stresses or sources of pollution even though they may not be. This publication includes activities and events that are perceived to be stressful but, in fact, range in their severity of impact. It is significant that the stress may vary in the intensity of its impact, and management practices can often reduce or modify the impact. By documenting seven significant stresses on land we hope to instil interest and awareness of this concept.

FRAMEWORK

The framework shown in Figure 1 was designed to permit a systematic approach to the concept of stress on land. It is a simple but comprehensive structure that can accommodate a wide variety of possible stresses. This section will describe the framework as well as the rationale for including certain topics in this publication.

To understand our approach to the concept, one must first examine the definition of stress on land. There are two types of stresses (Level II). Natural stress originates from the operations of earth's systems. Although such disruptions can be deemed catastrophic from man's perspective, they are, nevertheless, part of an evolving and ever-changing natural system; a system which man influences but certainly does not control. Man-made stress, on the other hand, originates from man's activities which have an impact on the land resource, affecting land use, land value or land capability. Man certainly has the capacity to control his activities and thereby control the stress he originates. This publication focuses only on man-made stresses.

How then do our activities translate to the land resource? Quite simply through land-use practices. Virtually all of our actions can be traced directly or indirectly to land-use activities (Level III). It is important to recognize that a single activity at any one location may have either a major or a minor impact. Furthermore, the cumulative collection of activities may have profound impacts that extend beyond its immediate limits, to interactions with other activities.

A simple inductive approach was used to categorize all land uses. Basically, any land use can either add to or subtract from the land. Land uses which add to the land (additions) are defined as – actions by man which deposit, construct, or otherwise increase elements, substances, or materials, on or into, the land resource. Whereas, subtractions from the land occur as a result of actions by man which remove, extract or otherwise deduct elements, substances, or materials from the land resource (Level IV).

Both the additions and subtractions, in turn, have two subcategories which further classify the land uses (Level V). The additions to the land can be grouped into units of waste or infrastructure. What is meant by these terms? Waste is defined as the solid, liquid, or gaseous materials remaining from human activities, particularly from the production, processing, and consumption of goods. Infrastructure is composed of the public and private structures and service systems which support human settlements. Such facilities include water and sewerage systems, energy systems, transport systems, etc. In simplest terms, the land additions section describes activities which either build or construct on the land, or use land as a receptor for discards.

The subtractions from the land can be grouped into the categories of extraction or depletion. Extraction refers to the removal of any part of the land resource. Depletion refers to actions which negatively affect the land resource's ability to produce to its maximum potential, hence the quantity or quality of the resource may be reduced or exhausted. In simplest terms, subtractions from the land either remove major elements from the land or degrade its potential to produce.

Each of these four latter categories can have a virtually inexhaustible list of man's activities. The components listed in Level VI of Figure 1, reflect the actual contents of this publication. Clearly, these are only a small sample of the possible topics in each of these categories.

WHAT'S IN THIS BOOK AND WHY?

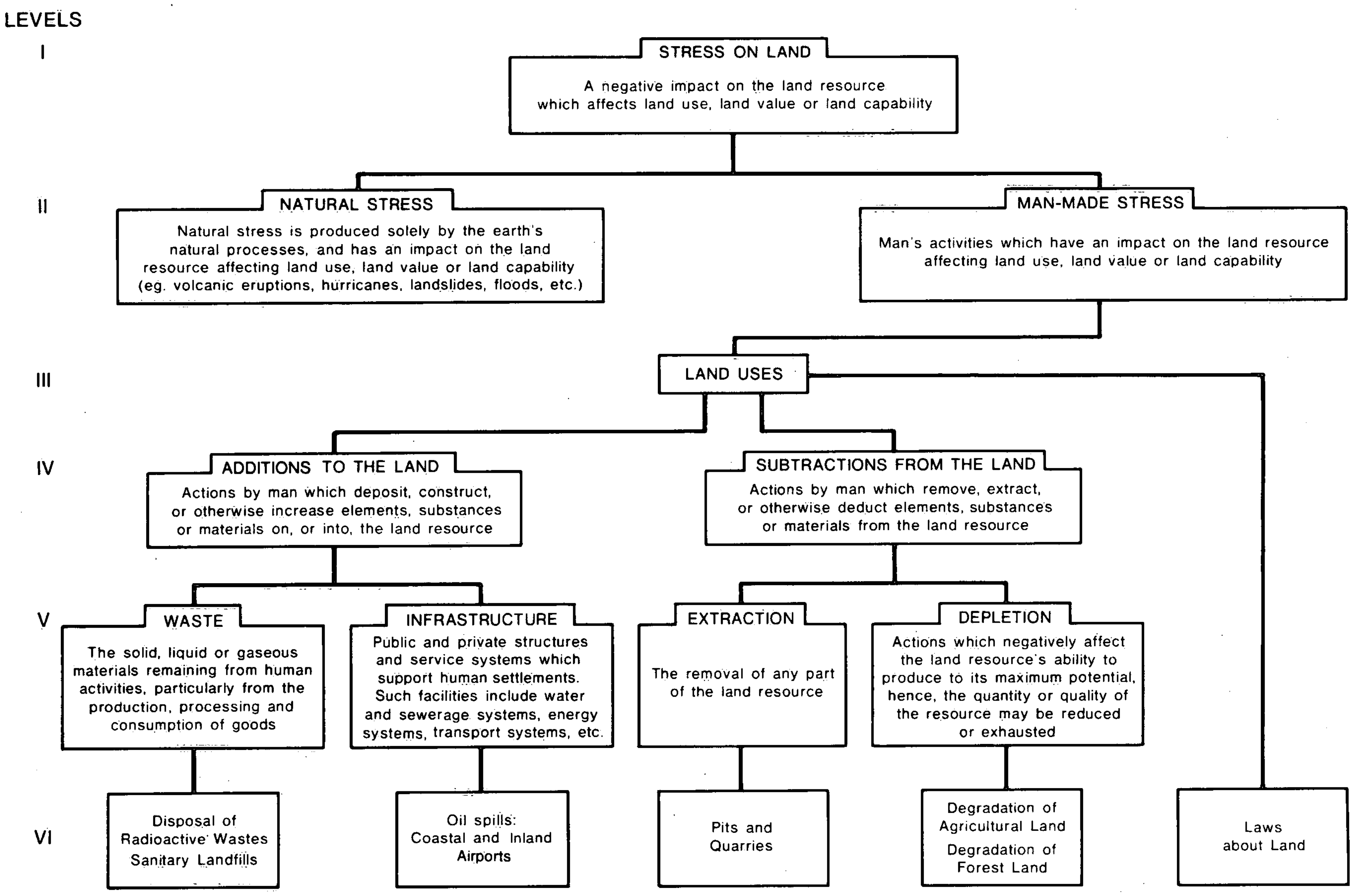
The chapters included in this report were selected for their topical nature and for various operational reasons. All Level V categories (Figure 1) had to be represented in this volume to illustrate the complete range and types of possible stress. Cumulatively these stresses have and will have the potential to affect the utility of the land resource for future generations. It is important to recognize the impacts of man's activities on the land resource, and to pursue proper management techniques in order to maintain this vital resource. It would be less than productive to rationalize the lists of topics not covered other than to indicate that this report presents a new concept and develops it with a selected range of examples. However, it is important to indicate why each particular topic was selected.

Disposal of radioactive wastes

The very word "radioactive" elicits a preconceived response! Yet it is important to realize that radioactive elements are found naturally in the environment and it is not until they are concentrated that they require special handling. Radioactive wastes constitute just one of the many types of hazardous wastes generated today in Canada. Because such wastes fre-

FIGURE 1.

Framework



quently arouse controversy, it is particularly important to objectively examine the origin and probable destination of these wastes. As the land resource is frequently cited as a storage or disposal medium, it is equally important to document the range of associated stresses. The degree and extent of such stresses have not previously been documented in a single non-technical report.

The chapter entitled "The Land Impact Associated with the Disposal of Radioactive Wastes" examines the land impacts associated with the disposal of three important types of radioactive waste generated in the nuclear fuel cycle: low-level radioactive wastes, high-level radioactive wastes, and uranium mine and mill tailings. To further illustrate the land concerns, a case study of Elliot Lake, the largest uranium-producing area in Canada, has been included.

The chapter provides a national profile on the origin and destination of radioactive wastes in Canada. A range of land resource impacts are examined including productivity, land use, land value, rehabilitation and the short- and long-term implications of current or proposed methods of disposal.

Sanitary landfills

Each and every Canadian contributes a share of the national total volume of garbage generated daily. Yet for most Canadians the waste magically disappears once the garbage truck rounds the corner. These wastes have to be disposed of in some manner and in Canada one of the most environmentally sound methods of waste disposal is sanitary landfilling. Sanitary landfills require land and this land must be accessible to population centres to keep transportation costs to a minimum. But no one wants a sanitary landfill in their backyard. Regrettably the public often perceives sanitary landfills to be undesirable land uses because it mistakenly associates the term with dumps.

The chapter entitled "Sanitary Landfills and their Impact on Land" defines what sanitary landfills are, explains how they differ from other forms of waste disposal, and describes the trench, area, and ramp methods of operation. A sanitary landfill is a temporary land use; when it has reached its maximum capacity the land may be rehabilitated and used for another purpose.

In the late 1950s the first sanitary landfill was established in Metropolitan Toronto. Today sanitary landfills operate in all the provinces and range in size from 0.2 to 163 ha. The chapter forms a comprehensive national investigation of the range of land stresses associated with sanitary landfills. It looks at sanitary landfills from coast to coast to see how they are sited, operated, and rehabilitated. Major sections on land impacts itemize the concerns about adjacent land uses, land values, landscape alteration, perception, and aesthetics. The physical considerations and steps in siting a sanitary landfill are documented. Two significant environmental concerns, leachate contamination and methane gas, are examined and the engineering controls frequently implemented are outlined.

Throughout the stages of siting, operation, and rehabilitation, sanitary landfills influence land uses in many ways. The nature and extent of the impact will vary with and depend on the location of the site and whether the facility is operating or closed. There are also different impacts on the site itself and in the surrounding area. Just as the location of a new disposal facility is affected by existing land uses, a new disposal site effects certain impacts on existing and future land uses.

To illustrate the range of impacts, three case studies are included. One highlights the City of Winnipeg's efforts to establish a regional park and a sanitary landfill in the same area. A second study on Keele Valley illustrates the approval process and technical requirements that must be met before a potential site can become an operational sanitary landfill. A third example illustrates the public controversy in selecting a site for a sanitary landfill in eastern Canada.

In order to have a complete national perspective on Canada, a special section highlights waste management concerns in northern Canada. Here, sanitary landfills cannot be established because of physical limitations, hence other waste disposal methods used in the North are examined.

Oil spills: coastal and inland

Oil spills are well publicized events that may occur during any one of the numerous stages of oil exploration, extraction, production, transportation, marketing, or storage.

> *"In recent years, a number of accidents involving oil tankers, storage tanks and pipelines have resulted in the introduction of relatively large quantities of oil into our environment. Incidents of this type, together with the growing use and transportation of petroleum products throughout the world, have created an almost global awareness of the risks and damage associated with oil spills. Nevertheless, consumption of vast quantities of oil is one of the necessities of our modern industrial society"* (Fingas, *et al.*, 1979).

Oil spills are significant phenomena, whose impacts and stresses on the environment will occur in the future as we continue to consume oil and oil products and search for oil resources in the eastern and northern offshore environments. The possibility of oil spills will increase as decisions are made on how to transport this oil to the consumer. Whether transported by tanker or pipeline, the more oil that is transported the greater the likelihood of a spill and the greater the potential stress on the environment.

Oil spills differ in type of oil spilled and in volume. Depending on the location of the spill, they affect the natural and human environments in varying levels of stress. In this publication we examine the stress of oil spills from two different geographical perspectives: coastal and inland. Coastal oil spills receive much more media attention than inland spills yet both can have impacts on the land resource.

Coastal oil spills usually occur as a result of shipping accidents, blowouts, bilge pumping, transfer accidents, or terrestrial spills that reach the coastal zone. Oil spills in the coastal zone place stress not only on the natural environment but also on human activities that use this land-water interface for fishing, recreation, settlements, etc. The public's main perception of the impact of oil spills is that they spoil the appearance of the coastal environment. But oil spills can be toxic to organisms, flora, and fauna and these stresses can have wide implications for the coastal ecosystem. Canada has had very few large coastal oil spills; the most frequent type of accident involves relatively small volumes of oil. The largest coastal oil spill in Canada occurred in 1970 when the tanker ARROW spilled 9 000 t of Bunker C fuel oil into Chedabucto Bay, Nova Scotia. However, it is impossible to define a level of stress that can be related to all spill events. Stress is greatest in environments where the oil concentrates in relatively confined areas and in areas of highest biological productivity such as marshes or estuaries. The cleanup techniques employed for most spill events also have an impact on the environment. The recovery time for each environment affected by an oil spill differs but the severity is rarely long term.

Inland oil spills, as opposed to coastal spills, represent a stress on the land where the oil comes into contact with soil and surface vegetation. Inland spills occur during transportation by motor vehicle, trains, aircraft, and pipelines, and during exploration, production, marketing, and storage. The impact of inland oil spills depends on the physical properties of the soil, the volume of oil, the duration and season of the spill, the type of oil spilled, reclamation methods, etc.

Oil spills from pipelines are much more difficult to confine than spills of refined products from storage facilities, which occupy a limited space. Pipelines traverse a wide range of landscapes, release mostly crude oil when ruptured and affect more land area.

The extent of the land-use impacts from oil spills is determined partially by the length of time oil persists in the soil. The first stage in removal of oil from the soil is usually biological. Hence, factors affecting the biological activity influence the land-use impacts of oil spills. The effects of oil spills on vegetation may only last a season, in the case of a light spill, or up to several decades where an entire forest system has been destroyed. Oil spills on agricultural or forest lands may reduce or eliminate the capability of the land for production of certain crops for months or decades following the spill if no appropriate reclamation is undertaken. If appropriate reclamation is carried out, the land's capability is not affected in the long term. In fact, oil is biodegradable in varying degrees and in some instances may actually improve land capability.

The stress of inland oil spills on wildlife is greatest through the loss of habitat. The section on inland oil spills discusses the significance and stress of oil spills in agriculture, forest, and arctic environments. It is important to note that the amount of land affected by an oil spill is seldom documented, only the volume of material spilled. As research continues into the control and reclamation of oil spills the long-term impacts will continue to decline.

Airports

Air transportation has had a significant influence on our lives since 1909, when the first heavier-than-air flight in Canada occurred at Baddeck, Nova Scotia. The first Canadian airports were built and operated with little serious impact on the environment. They were few in number, small in scale, located well away from large population centres, and many played a military role. Early airports existed without major conflicts with other land uses.

However, both air transportation and urbanization expanded rapidly. Aircraft technology advanced; larger planes required longer runways and more space. At the same time, natural population growth, immigration, and the rural-to-urban migration produced outward expansion of cities into rural areas. Many airports, such as Toronto's, once located in rural, agricultural settings became surrounded by urban development. Major conflicts arose and airport projects such as Pickering became the centre of community opposition.

What kind of stresses does an airport put on land? During the survey and construction stages, the airport site itself is stripped of vegetation cover and topsoil, the physical and aesthetic nature of the landscape is changed, and ecosystems and habitats are destroyed. The previous land use, often farming, is displaced with the resulting loss of high capability agricultural soil close to the urban market. During operation, airports may add a variety of pollutants to soil, air, and water. Concern about noise and property values are also spill-overs of airport operation and expansion.

Impacts on land and people extend well beyond the boundaries of the airport site. Airports encourage and accelerate the development process within their sphere of influence, which can be very large. Airports attract aviation-related services; the availability of large amounts of relatively inexpensive suburban land and the nearby labour pool attract secondary development. These land uses require more land and there is a steady conversion of rural, agricultural land to commercial and industrial uses. Demands for improved highway networks, convenient housing developments, and retail, educational, and recreational services increase.

Although some businesses benefit from the presence of an airport, other uses are less compatible neighbours. Land-use restrictions in the vicinity of airports are necessary to ensure navigational safety and to reduce conflicts arising from the health and nuisance aspects of airport noise and operations. The expansion of air transport networks largely preceded the development of sophisticated regional planning techniques and as a result airports and many other land uses make unhappy neighbours. In particular, noise caused by aircraft can result in property devaluation especially for residential purposes.

For years, the planning of major transportation projects proceeded without much public participation. Increasing public concern for air and noise pollution, loss of prime agricultural land, and lack of public consultation combined with the growth of the environmental awareness movement to produce confrontations over airport projects.

Airports are one part of a large and spatially complex transportation network, which itself comprises only part of today's infrastructure. Like other parts of this infrastructure, airports provide much needed services. As a subject involving federal, provincial, and local governments as well as the public in general, airports are an apt example of the stresses that the built environment imposes on people and land, both on-site and well beyond site boundaries.

Pits and quarries

Aggregate resources (sand, gravel, and crushed stone) are required for building and road construction as well as for large-scale projects such as pipelines, airports, and power plants. In Canada, the annual per capita consumption or requirement for structural materials is 13 t. As a result of post-war developments, urbanization, and resource exploration, the amount of land disturbed or left abandoned by the extraction of construction aggregates in Canada is at least equal to, if not greater than, the land disturbed by all other forms of mining. As one example, a survey in southern Ontario revealed that pits and quarries were responsible for 93% of all examples of land destruction and 75% of the land area destroyed.

The impacts of pits and quarries early in Canadian history were usually restricted to the vicinity of major construction projects. Throughout the late 19th and early 20th centuries, pockmarks left by aggregate extraction spread around fledgling cities. Growth was desirable and sands and gravels were required for the construction of necessary infrastructure. Because aggregates are high-bulk, low-value commodities, they are costly to transport. Therefore, extraction sites close to the large urban markets are most advantageous. However, in their preferred locations, pits and quarries are in competition and conflict with other less damaging land uses. Today, many of the innumerable pits and quarries in Canada are in and around high-density urban or suburban areas. Frequently these excavations constitute eyesores, hazards to safety, and abuse or misuse of the land resource.

Extraction sites vary in size from 1 to 600 ha. Some commercial operations may last for 20 to 50 years, hence the "interim" use and disruptive nature of the activity are significant. The cumulative impacts of sites juxtaposed to other land uses are considerable. The past record of pit and quarry operations is poor – poor planning, no topsoil retention, inadequate consideration for future land uses, and little or no rehabilitation.

Regardless of scale or location, most pits or quarries begin with removal of all surface vegetation, topsoil, and overburden, with the attendent disruption of ecosystems and landscapes. The removal of the subsurface aggregate materials normally results in the complete alteration of the surface resource – the land. In addition, much of the prime agricultural land found adjacent to Canada's major population concentrations is underlain by high quality sands and gravels. As a consequence, farmland is often removed from agriculture to permit more profitable aggregate extraction and, until very recently, the resulting devastated land has been unfit for a return to agriculture or any other uses. The presence of high quality aggregate resources can threaten the existence of valuable recreation, wildlife, residential, agricultural, or other lands.

In addition to the stresses on the physical landscape, there are considerable ancillary impacts associated with pits and quarries. Such despoliation affects the aesthetics of the countryside. For people living near the extraction site or along haulage routes, truck traffic, noise, dust, safety, and road maintenance costs cause considerable concern. As with many other land uses that impose stress, there are serious concerns about devaluation of property values and declining quality of lifestyle and environment.

On the other hand, rapid urban expansion in the past sterilized much rural land before aggregate resources could be removed. Such land-use pressures and conflicts, combined with increasing public opposition and lack of appropriate legislation, has brought about some recent improvements. Through more effective and forceful legislation, sensitive and comprehensive site planning and extraction, more rigorous monitoring of operations, progressive rehabilitation and a multiple resource approach, much progress is evident. Furthermore, valuable sand and gravel are not lost to haphazard urban sprawl, and land used for extraction can be rehabilitated to appropriate after-uses. The true test is turning good theory into good practice.

Degradation of agricultural land

In New Brunswick, up to 12 cm of topsoil have been lost from potato fields in the past 20 years. Crop yields have been reduced by as much as 70% on some wind-eroded soils in Saskatchewan. It has been estimated that in Ontario 1.3 million tonnes of topsoil are washed from farmland each year. In large part, these stresses on land under intensive agricultural use are due to poor soil management. Productive and very limited agricultural lands are being used for short-term economic gain without sufficient concern for long-term land conservation.

Loss of soil materials through erosion is a serious problem. Removal of the protective cover of native grasses, plants, and trees makes the soil more susceptible to wind and water erosion. The results are loss of the most valuable soil constituents, reduction in topsoil, declining water-holding capacity, uneven crop growth, and siltation of surface drainage. Soil erosion is particularly serious where summerfallowing, increasing field size, removal of windbreaks, and intensive monoculture cash cropping of corn and potatoes exist. Measures such as contour ploughing, terracing, crop rotation, and zero tillage, which can help reduce loss of soil materials, are less attractive to farmers who are caught in the cost/price squeeze.

Organic soils develop slowly; this process is reversed if the soil conditions are changed by drainage and cultivation for agriculture. Only in a few areas are organic soils suitable for agriculture and here they are used for production of high-value crops such as market vegetables. However, the draining of such soils has resulted in subsidence, shrinking, and compaction. Without actions to improve the situation, some organic soils will reach such a state of depletion that they will be rendered unsuitable for vegetables and are likely to be turned over to field crops. At what cost will new sources of fruits and vegetables be found? Will it be possible to find lands which can be substituted? Will they require larger inputs of energy, time and money?

Although chemical deterioration of land occurs naturally, soil salinization, acidification, and contamination have increased significantly as a result of human intervention. In arid areas the removal of native grasses, their replacement by grain crops, and the use of summerfallowing and irrigation exacerbate salinization. Increasing use of ammonium-based nitrogen fertilizers and the high acidity contained in precipitation both contribute to soil acidification, which can have adverse effects on productivity and crops. Soil contamination from atmospheric fallout, sewage and industrial sludge, and pesticide residues continues to present potential long-term problems.

Lastly, physical deterioration of agricultural land is a common result of the continuing trend to more specialized agricultural systems, increasing pressures on farmers to improve productivity while keeping expenses down, and the continuing conversion of prime farmland to urban uses. Soil compaction from repeated use of heavy machinery is detrimental to root growth and contributes to surface ponding, run-off, and soil erosion. Soil disturbance is often a consequence of surface mining, aggregate extraction, pipeline installation, or highway construction. Even with great care, these disturbances may seriously lower the productivity of the land for many years and such disturbances often occur on high-quality farmland.

Loss and deterioration of cropland are not new problems. Many civilizations have flourished and perished as a consequence of their land management. A significant factor in the decline of the Mayans is thought to have been their failure to recognize the carrying capacity limits of the land resource on which their agricultural production was based.

Even under favourable conditions, nature may take hundreds of years to create a few centimetres of topsoil. Yet man, together with nature, also serve to deplete or destroy this same topsoil. With the evolution of agriculture, which began nearly 10 000 years ago, the man-land relationship has changed at an increasing rate. With 71% of the planet under oceans and seas, the remainder must support the estimated 6 billion people expected by the year 2000. But in Canada, as elsewhere in the world, only a small portion of the land is capable of sustaining agriculture.

Just as demands for food and fibre are increasing, the quality and quantity of cropland are declining. High production costs and marginal profits in today's tight economic conditions lead to less soil conservation. Rationalization in agriculture leads to exploitation of land under intensive agriculture. These stresses all have costs, both hidden and obvious, just down the road.

Degradation of forest land

Initially the forests were regarded as hindrances by the early settlers who cleared the forest lands to create farmland. Today the forests of Canada are a valuable renewable resource.

> *"Canada is a major exporter of forest products. Exports of wood, wood products and paper in 1978 amounted to $9.6 billion which was 19% of the value of all commodity exports"* (Statistics Canada, 1981).

In 1981 the forestry sector contributed directly or indirectly $2 212 000 000 to the Gross Domestic Product (Statistics Canada, 1982). Canada has an enormous area of forest land, 37% of the total land area, and a great diversity of forest species and climates. But these forest lands must be properly managed if this resource is to continue to be of economic and environmental significance to Canada. Until recently, Canada had a surplus of wood and thus there was little incentive to practise better forest management. It was easier and cheaper to travel a little farther into the hinterland for the wood or to change standards of utilization than to invest in planting trees. Now, however, both government and industry are trying to improve forestry practices through forest management.

Some of the forestry practices adopted in Canada have created a stress on the forest lands, resulting in a reduction in soil fertility, loss of tree species and associated plant and animal species, decrease of unique or valuable habitat, and deterioration of landscape values. However, stress in one forest may not be stress in another. Stress on forest lands occurs at two levels: the stand and the forest.

Historically the forests have always been disturbed naturally by fires, hurricanes, insect infestations etc. Today, human activities have also had an impact on the forest lands through the various forestry practices employed. For example, logging practices have changed through time and these changes have brought new and different stresses on the forest lands. The earliest logging in eastern Canada was conducted during the winter months on snow and there were no real land impacts. Then, as the equipment was developed and grew in size, the export of valuable nutrients from the forest, caused by logging techniques, became an issue. The impacts of logging equipment and intense management practices on erosion, water flows, recreation, fish and wildlife populations, and scenic values all became important. Today the amount of environmental control over logging operations is proportional to the degree of public interest and access to the areas concerned.

Current national concerns about the stresses created by logging focus on the future economic impacts of the lack of regeneration. Of the 800 000 ha cut annually, less than 1/3 receives any treatment, and unstocked or poorly regenerated (backlog) areas are accumulating at an alarming rate. At the same time, timber supply shortages are forecast.

According to Rowe's classification, Canada has 10 forest regions, including the tundra, and each of these regions experiences its own stress. For example, in Newfoundland skidder logging has caused deep ground disturbance and destruction of young trees. Other stresses that occur in various forest regions are road construction, which causes erosion and other stresses; lack of regeneration on cutover lands; wildfires following logging; depletion of soil fertility on low fertility sites, which is caused by the use of slash fires that remove the humus layer; mineral soil exposure by logging practices; mis-managed clearcutting practices, etc.

This chapter outlines the stresses at both the forest and stand levels. The stresses that occur in each Canadian forest region are discussed and the specific issues creating stress on Canadian forest land are outlined. This chapter indicates there is a need for greater forest management in Canada and more co-operation between governments and industry to maintain this valuable resource.

Laws about land

Virtually all human actions can be traced directly or indirectly to land based activities, which can cumulatively be referred to as land use. The types of land use as well as the number of individual land use participants are virtually limitless. However, within this seemingly endless spectrum, there does exist a set of regulations defining norms and socially acceptable limits which are called laws. Laws also impose societal limits on land use; however, they have been and continue to be produced piecemeal in different jurisdictions at different times. Nonetheless, the relationship between law and land is important.

In this publication, the chapter entitled "Land as the Subject of Environmental Law" explains the link between laws and land. It provides a brief description of how Canadian law has evolved and how laws are being applied with respect to land, and highlights some of the salient pieces of legislation that relate to land degradation. Numerous federal and provincial statutes and ordinances are cited; however, orders, regulations and municipal by-laws are not included. In order to inform the non-legal reader the legal context is explained in simplified terminology and many of the legal intricacies associated with individual cases of land pollution have been excluded.

Many professions are involved with land use – ecologists, geologists, geographers, economists, planners, and others – yet frequently this link between law and land is neither fully nor widely appreciated.

Summary

The following chapters discuss seven types of stress on land, and document how they affect our land resource. The final chapter is an exception, as it explains the link between laws and land, but does not relate environmental law as a type of stress.

The net result of our actions, unless controlled or directed, will produce a less flexible, less productive and more limited land resource base. In the longer term the result of cumulative degradation may diminish the capacity of the land to supply the fundamental demands of Canadian society in the future.

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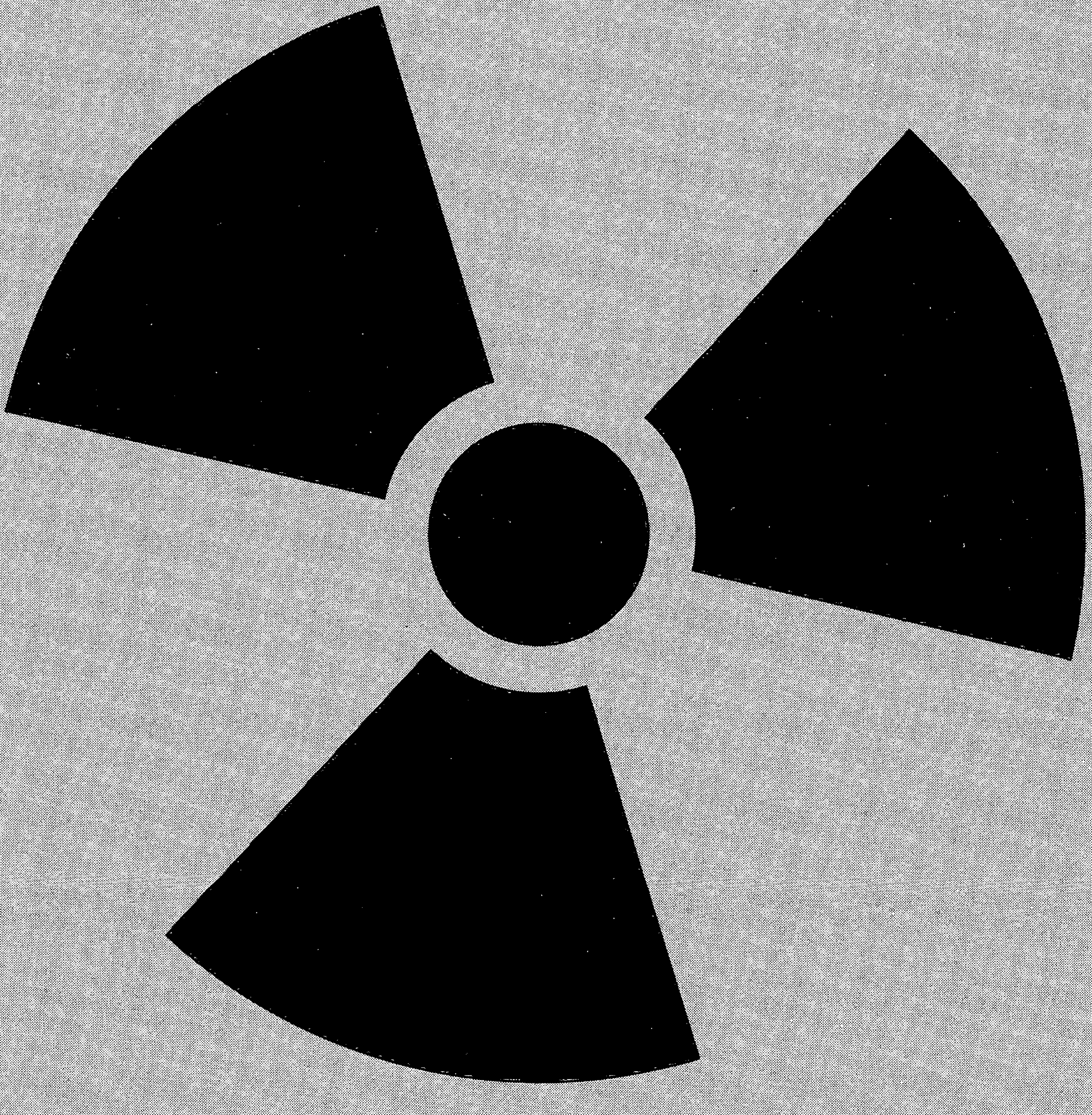
DISPOSAL OF RADIOACTIVE WASTES



Symbol: Radioactive

THE LAND IMPACT ASSOCIATED WITH THE DISPOSAL OF RADIOACTIVE WASTES

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INTRODUCTION

High-level radioactive wastes, low-level radioactive wastes, and uranium mine tailings are the undesirable by-products produced by the various stages of the nuclear power industry. These by-products are generated starting at the mining and milling of uranium ore, through the processing of the fuel, to the actual use of the uranium in the reactors for power generation. The types of waste are differentiated according to the intensity of radiation they emit. Figure 1 illustrates the nuclear fuel cycle and the operations from which wastes are generated.

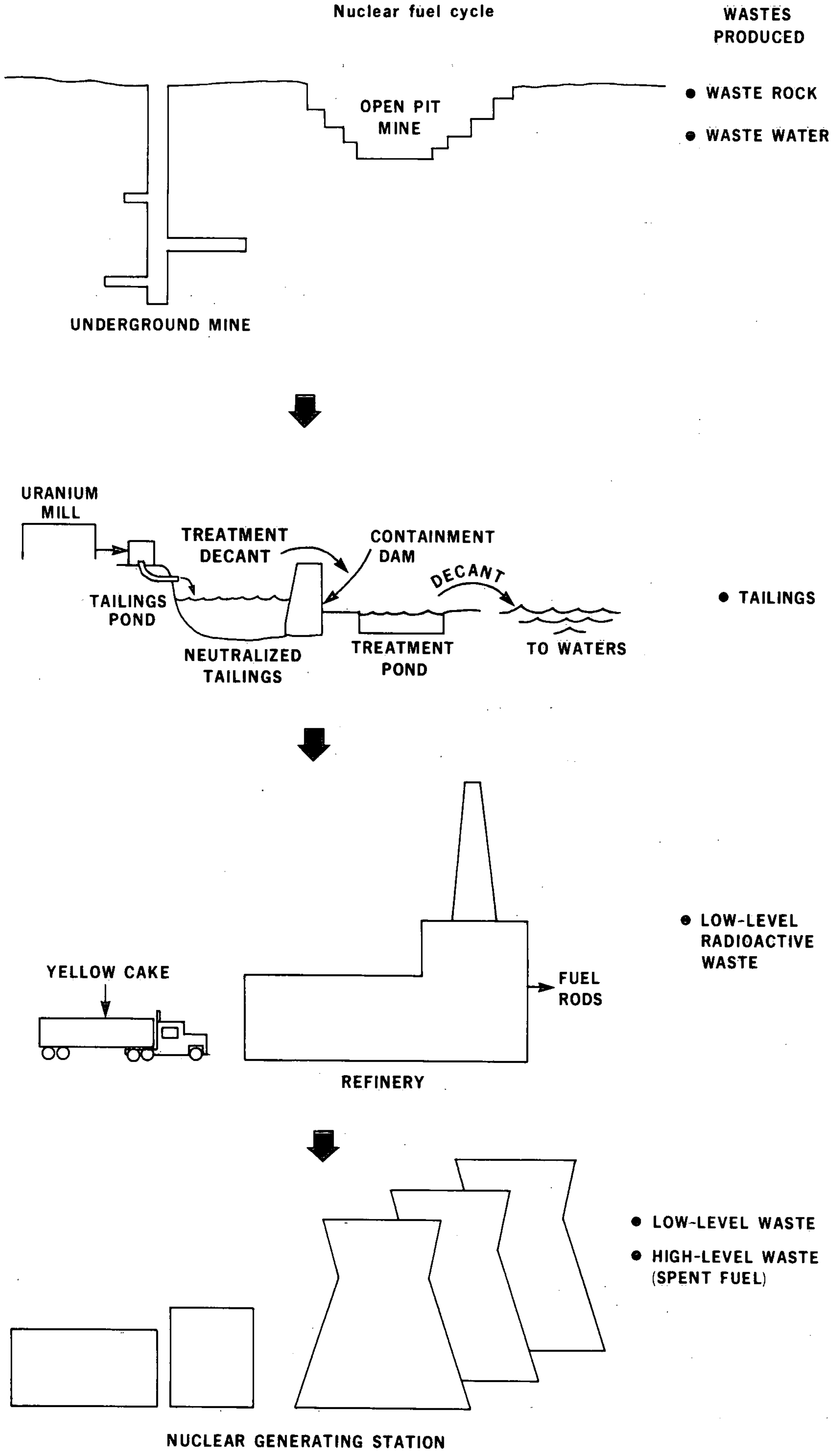
High-level radioactive wastes are generated by the operation of nuclear reactors. Spent reactor fuel contains highly radioactive elements, over 99 percent of the total radioactivity from all waste products in the entire nuclear fuel cycle (Aikin *et al.*, 1977).

Low-level radioactive wastes are composed primarily of articles that come in contact with radioactive material during the operation and maintenance of the reactor. These wastes are composed of such things as filters, mops, swabs, clothing, and other maintenance materials.

Tailings are a by-product of a mine which removes a metallic mineral from a large amount of ore. In this instance, it is the extraction of small amounts of uranium from huge amounts of ore. Uranium mill tailings are composed predominantly of common minerals such as quartz, feldspar, micas, pyrite, calcite, etc., plus very minor quantities of unrecovered radioactive minerals (e.g., radium-226, lead-210, thorium-232) which do represent a fair amount of radioactivity. These solids, along with liquid wastes such as contaminated waters and reagent chemicals from the milling processes are pumped as a liquid/solids slurry to large settling ponds.

To appreciate the land stresses that radioactive wastes may produce, it is necessary to determine their relationship with land. Radioactive elements are found naturally in the environment and they are also formed in nuclear reactors; it is not until they are concentrated by man or produced in reactors that their existence requires special handling. The storage and disposal of radioactive wastes affects land use and land value. The currently proposed practice for disposal is the burial of both high- and low-level wastes to isolate their radioactive content effectively. Uranium tailings are currently stored on

FIGURE 1.
Nuclear fuel cycle



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* The label "historic waste" refers to those wastes that were generated outside the present regulatory process. Usually, the wastes were generated inadvertently and were disposed of by various means. It is estimated that there are 1 000 000 m³ of historic wastes in existence in Canada (Hickling-Partners Inc., 1981).

the surface of the land, precluding affected areas from other uses. In addition, because the wastes are radioactive, a public apprehension is created that can have an effect on surrounding land uses and land values.

How is land stressed?

The amounts of the various radioactive wastes are continuously growing as more and more power is generated through the use of nuclear energy. At present, the only land being utilized for the storage of the wastes is at the sites of nuclear power generating stations, for high- and low-level wastes, and the land adjacent to uranium mines and mills in the case of tailings and the land in the vicinity of the uranium refinery in Port Hope.

Existing storage sites for high- and low-level wastes do not occupy large amounts of land, since the amount of materials is relatively small. Uranium mine tailings, however, need hundreds of hectares of land. In addition to land directly utilized for the storage of the wastes, there may be a need for future buffer zones to separate them from adjoining land uses once a method of permanent disposal is decided.

The most important aspect affecting the disposal of nuclear wastes stems from their radioactivity. Any land utilized for the disposal of the wastes is likely to be unsuitable for other uses for anywhere from a few years to several thousand years, depending on the waste type occupying the land. Clearly, use of land for the storage and disposal of radioactive wastes may influence it beyond site boundaries and restrict its usage for other purposes for some considerable time to come.

History

Since the beginning of nuclear industry in Canada in the early 1940s, radioactive wastes have been produced without full consideration being given to their disposal. The industry began during the Second World War with the mining of uranium ore for military uses. The demand increased after the first atomic bombs were used in 1945 and especially as the American-Soviet arms race accelerated and more nuclear weapons were developed. The subsequent use of uranium for the generation of electricity further increased the volumes of wastes being produced. As more nuclear power plants came into operation, it became evident that there was a more pressing need for a disposal method.

Uranium is a significant source of energy. With a finite limit to the world's fossil fuels and the majority of economically exploitable waterways already developed for hydro-electric energy, alternative energy sources are being actively promoted; nuclear energy is one such alternative. At present, nuclear energy accounts for approximately 3.5% of the total energy consumption in Canada and is likely to increase (Ward, 1981). Over 21% of Ontario's energy is now generated in this manner (EMR, 1981*a*). Any increase in nuclear energy production implies an increase in the generation of radioactive waste, the safe permanent disposal of which is of increasing urgency.

LOW-LEVEL RADIOACTIVE WASTES

Profile

Low-level wastes are generated by a number of sources. These include reactor operations and maintenance; uranium refineries and fuel fabrication; Atomic Energy of Canada Limited research and development activities; users of radioisotopes; and incidental sources such as medical and research uses. The major quantities of low-level wastes, however, are produced in nuclear reactor operation. In reactor operations, small quantities of fission products escape from the fuel elements and, together with traces of activation products, contaminate the coolant. The contaminated coolant is treated to remove the radioactive components. Materials used in the cleaning and maintenance of the reactor plant, in treating the coolant, and in the servicing and replacing of worn-out parts and equipment are all considered to be low-level radioactive wastes. The radioactivity in these low-level wastes can range from barely detectable to high values, with hazardous lifetimes from a few hours to thousands of years.

Radioactive wastes have two distinct characteristics; their level of radioactivity and their hazardous lifetime which determine the extent and period of isolation from both the biosphere and man. Radioactive wastes must remain isolated during their hazardous lifetime. Radioactive wastes containing radionuclides with short half-lives (the term half-life is the period that would have to pass before the radioactivity of the radioactive element would be halved) experience relatively rapid decreases in radioactivity. Radioactive wastes containing nuclides with high or moderately high levels of radioactivity but with long half-lives pose concerns for a much longer duration as isolation from man must be ensured for much longer periods of time.

Low-level wastes stress land because their disposal will utilize land directly, either by burial in the ground, or by the construction of a waste storage facility. Existing wastes from the Ontario nuclear generators are stored on-site at the Bruce Nuclear Power Development project in a specially designed facility. No decision has yet been made on a permanent disposal method. In order to evaluate the stresses on land which would result from their disposal the quantities of wastes produced and their composition need to be defined. The low-level wastes likely to be produced by the year 2000 are shown in Table 1.

TABLE 1
Volumes of low-level wastes

	To be accumulated by year 2000 (Volume in 1 000 m^3)
Contaminated soil and incidental waste (bulk, loose waste)	900.0
Refinery residue	280.0
Refinery and fuel fabricator garbage	35.0
Reactor and AECL maintenance waste	76.0
University, hospital, industrial	18.0
Total	1 309.0

Source: EMR, 1982.

All Canadian reactors are of CANDU design, with all of the operating plants presently located in Ontario (Map 1). Several other sites are committed or under construction. Table 2 lists the Canadian nuclear plants with their corresponding generating capacities.

The generating capacities of these stations are important in the determination of the rates of waste production. Another main source of low-level wastes is the uranium refining process. There is only one uranium refinery in Canada, and it is situated at Port Hope, Ontario. Additional uranium refining and conversion facilities are planned for Port Hope and Blind River, Ontario. Thus, most low-level wastes produced in the country originate from locations in Ontario.

By the year 2000 some of the smaller reactors, such as those at Douglas Point and the NPD site at Chalk River, will be going out of service and will need to be decommissioned. Decommissioning requires the dismantling and disposal of the reactors and the buildings that house them. The low-level wastes thereby produced cannot, for the most part, be incinerated or compacted to reduce their volumes because they will be made up of machinery and concrete structures. They will therefore require that some land be used for their disposal.

Formation, composition, and management of low-level wastes

In reactor operation, the fission process - the splitting of the atomic nucleus for the produc-

MAP 1.
Location of nuclear power plants

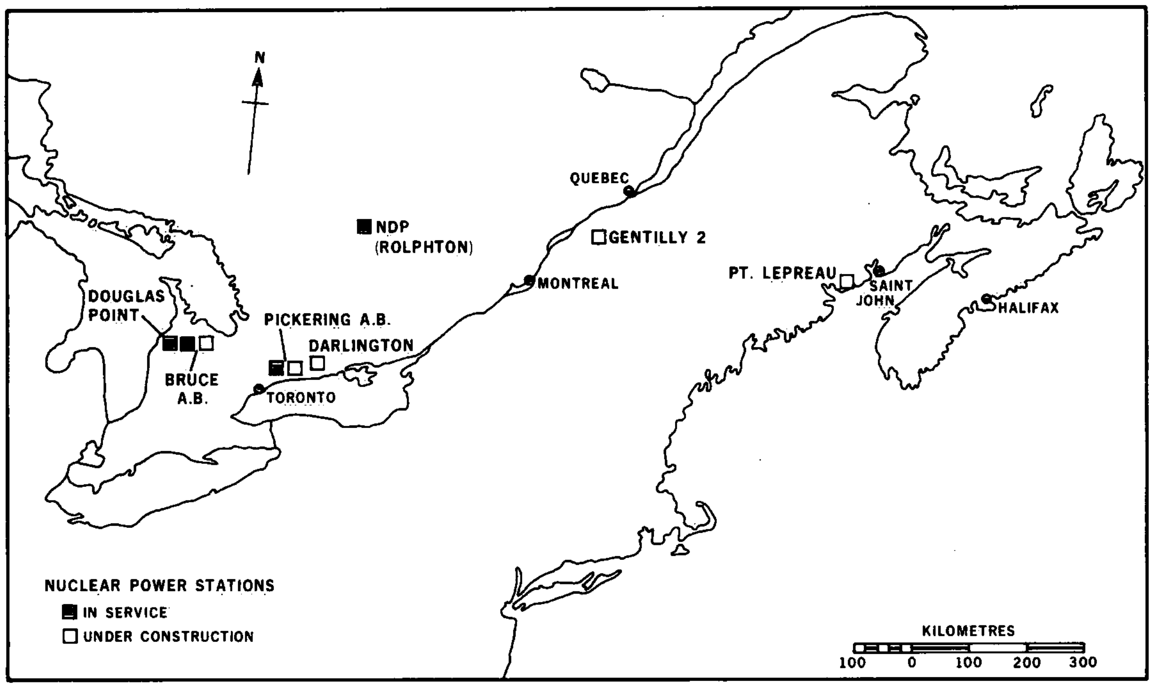


TABLE 2
CANDU generating stations in operation, under construction, or committed

Station	Location	Number of reactor units	Net Generating capacity (MW(e))	Date of first power
NPD (Rolphton)	Ontario	1	22	1962
Douglas Point	Ontario	1	208	1967
Pickering A	Ontario	4	2 056	1971-73
Bruce A	Ontario	4	2 984	1976-79
Gentilly 2	Quebec	1	600	1982-83
Point Lepreau	New Brunswick	1	600	1982-83
Pickering B	Ontario	4	2 064	1983
Bruce B	Ontario	4	3 000	1984
Darlington A	Ontario	4	3 200	1988-91

tion of energy - generates a large number of highly radioactive fission products. Radioactive elements are also formed by neutron activation of the fuel, of the primary heat transfer and the moderator medium (heavy water), of corrosion products, and of reactor components. Radioactive elements which find their way into the heat transfer medium are continuously removed giving rise to low-level wastes. Depending on the origin of the waste, the composition and activity level of the low-level wastes may vary considerably.

The radiation levels in the waste are posing a health and environmental hazard. Low-level wastes must be monitored and controlled until radiation levels will no longer constitute an environmental hazard.

Low-level wastes from reactor operations are solid wastes of varying radioactivity levels with lower levels associated with dry garbage, i.e. waste paper, used protective clothing, metal and plastic scrap materials. Higher levels of radioactivity are associated with those materials that were in close contact with the reactor system.

TABLE 3
Breakdown of radioactive wastes from reactor operations

Type	Volume (%)	Radioactivity (%)
Non-processable wastes	12	98.4
Processable wastes:		
(a) combustibles	63	0.05
(b) non-combustibles (compacted)	25	1.55

Source: Muller, 1980.

These would include discarded filters, ion-exchange columns, and reactor components. These wastes are currently stored in on-site concrete trenches. Solid wastes are further subdivided into two categories: processable wastes - those that can be incinerated or compacted - and non-processable wastes, such as machinery, which are simply stored as they are (Table 3).

Table 3 shows that the greatest amount of radioactivity is found in those wastes that are not suitable for volume reduction; those that can be reduced contain less than 2% of the total low-level radioactivity. Table 4 further illustrates the effectiveness of volume reduction.

Incineration and compaction greatly reduce the volumes of some wastes; however, there is little that can be done to the non-processable wastes to further reduce their volume. All wastes are taken to storage facilities.

Existing storage methods

Some major storage sites are situated in Ontario, such as at the Bruce Nuclear Power Site and at Chalk River (Map 2). Refuse produced in the nuclear power generation cycle is stored at a site within the Bruce Nuclear Power Development project. The wastes are stored in an area of approximately 8.5 ha (Ontario Hydro, 1978), which accommodates the wastes from the Bruce plant as well as those from the Douglas Point and Pickering generating stations. The site has a capacity of approximately 3 700 m^3 (Ontario Hydro, 1978). Because it is located within the project it has no effect on neighbouring lands different from that of the power plant itself. Other than restricted access, no restrictions have been placed on the site because of the presence of the waste. Chalk River accommodates reactor wastes as well as wastes from other sources. No special isolation precautions are in evidence other than the signs warning trespassers and the fencing around the entire Chalk River plant.

Low-level wastes stored at various facilities are stored on an interim basis until a decision has been reached on their final disposal.

Potential disposal methods

No disposal method has been developed for low-level radioactive wastes, but several options have been proposed. These include:

a) depositing the wastes, suitably contained, into the sea;
b) shallow land burial;
c) burial in sanitary landfill sites; and
d) placement in inactive mines.

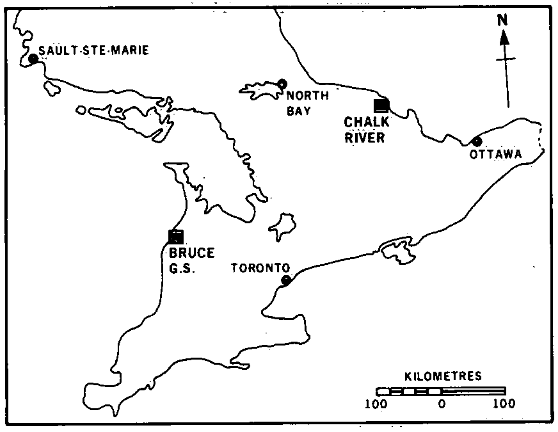
The methods most technologically promising for Canada are shallow land burial or utilization of existing sanitary landfill sites. The appropriateness of a disposal site will depend on the characteristics of the site and the nature of the wastes.

TABLE 4
Annual production of radioactive waste types from a 2200 megawatt CANDU generating station

Waste type	Volume (m^3) Before treatment	Volume (m^3) After treatment	Estimated Radioactivity (Curies)
Incinerable	500	8.3	160
Compactable	300	60	96
Not suitable for volume reduction	200	200	13 000
Total	1 000	268.3	13 256

Source: Muller, 1980.

MAP 2.
Existing Canadian low-level waste storage sites



Land needs for the disposal of low-level radioactive wastes

It is possible to make some quantitative statement as to the future amount of land that could be required by one method of disposal of low-level radioactive wastes. Assuming that 1 309 000 m^3 of low-level waste will exist by the year 2000 and that the waste in any particular facility will be deposited some 7 m high, 196 000 m^2 of land area or 19.6 ha will be required by that time. The average Canadian football field is approximately 1 ha in size, thus the total amount of land required is close to 20 football fields, a relatively small area in a national and regional context.

Long-term effects

The radioactivity level of a particular waste and the nature of radionuclides contained in the waste will determine how long a particular site will have to be excluded from other uses. The stress, in terms of removing land from other uses may last through many human lifespans.

Physical impacts on land

Existing storage facilities have little physical impact on the land other than those associated with the construction of the structures accommodating the waste. Soil is likely to be compacted or disturbed, but these impacts are not unique to the storage of low-level wastes.

The decommissioning of existing facilities, themselves, once operation ceases will require that the structures on the site be disposed of, as they, too, would be radioactive. It is likely, then, that these lands formerly housing such wastes would remain unused until such time as the radioactivity and their hazardous lifetime has passed.

Physical effects on the land stem from the design of a particular near surface disposal facility. Any such facility would require the digging of a pit or a trench into the native soil, altering an existing landscape. One potential physical effect may be the contamination of the groundwater regime due to the leaching of radioactive elements in addition to the other subsurface physical effects. Low-level wastes could result in significant contamination and long-term consequences. Pollution of groundwater may therefore be a long-term concern for near surface disposal facilities.

Aesthetic effects

Existing storage facilities at the Bruce Nuclear Power Development Site have little visual impact as they appear as engineered structures similar to other buildings far within the plant area; no special design features are employed that would distinguish them.

There are no indications of any visual or aesthetic effects on the land as a result of the disposing of some low-level waste, for example in a landfill site. Any such effects would be common to any landfill site, and, as such, they are not dealt with here.

Effects on land value

Changes in land value, if they occur, will result mainly from the public's perception of the problems associated with radioactive wastes. It is likely that the value of land containing the waste, as well as that of the surrounding area may drop, as was the case at Port Hope and Scarborough.

The events at Scarborough are perhaps exemplary of public attitudes. During World War II, a wartime contractor, based in Toronto, needed a convenient location to dump refuse from his aircraft dial factory. He owned a farm in Scarborough where the waste containing radioactive luminous paint was sent and buried. Much later, a subdivision was built on that very land. In 1980, radioactive soil was discovered in the backyards of 22 homes in suburban Scarborough and residents demanded that 4 400 t of earth be removed and disposed of in some other area. The most polluted area, including three backyards, contains an amount of radioactivity that would require someone to sit on it constantly for 4 months before maximum annual permissible dose for radiation would be reached. Original disposal plans were for the soil to be transferred to a uranium mine site in Bancroft. However, Bancroft residents opposed the plan and successfully blocked it. A second site, an abandoned weapons range at Camp Borden, near Barrie, Ontario, also met with opposition and was eventually abandoned. The use of the Chalk River national nuclear research facility has been proposed, but no final decision has yet been made. Meanwhile, the soil sits in Scarborough.

Changes in productivity

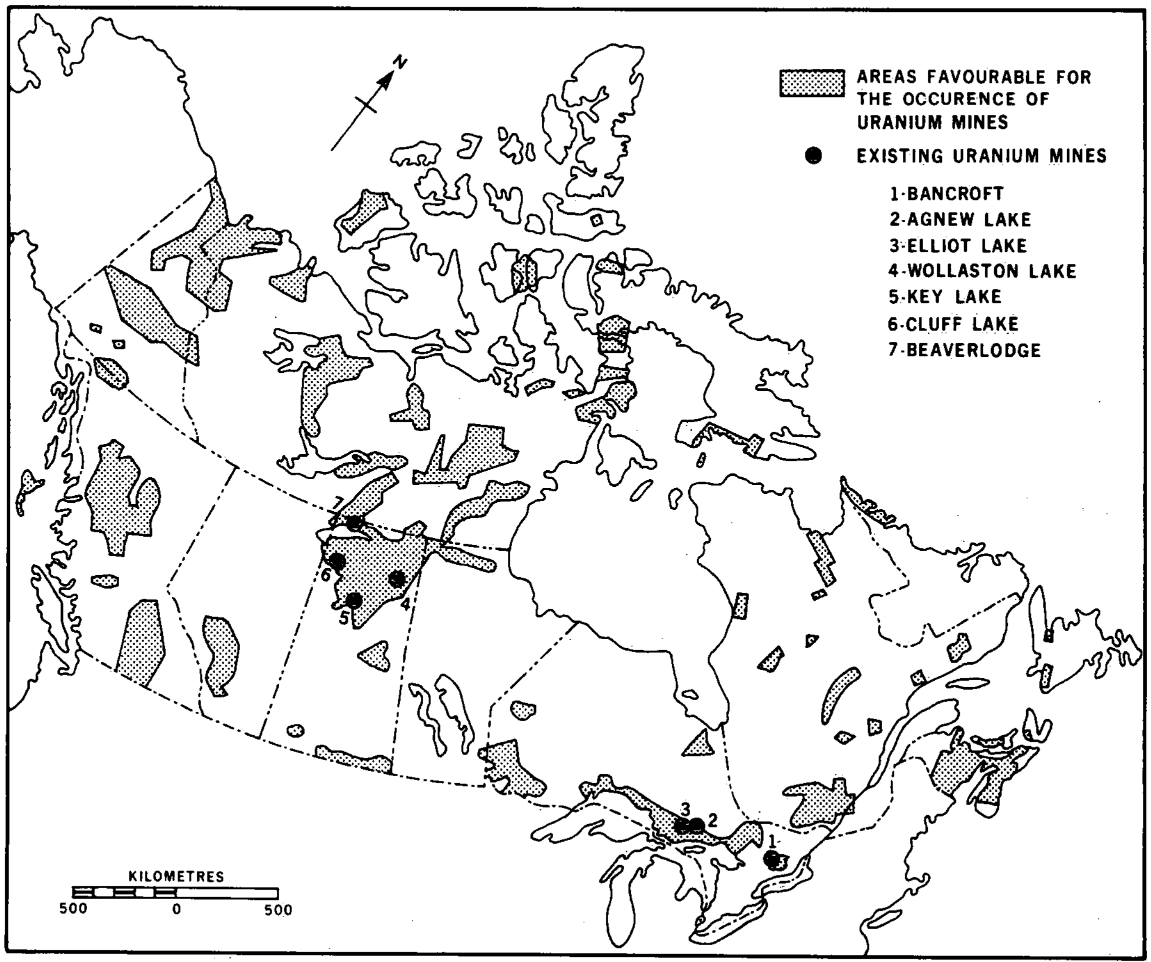
Because no method of disposal for low-level wastes has been adopted, it is difficult to predict how land productivity will be affected. If for example some sanitary landfill scheme were put into practice, it could use a landfill site already in existence and there would therefore be no productivity loss due to the presence of low-level wastes on the site itself. However, losses could occur on surrounding lands if some sort of buffer zone were created. There is also a possibility that adjoining landowners may take their lands out of production for fear of a perceived threat to themselves and to the use or utility of the land.

Wastes containing short-lived radionuclides only require land for a limited time basis. The land housing low-level wastes could be returned to its original use or put to another use after an appropriate monitoring period. Whether or not there is an impact on surrounding lands will depend on the method of burial.

URANIUM MINE AND MILL TAILINGS

Uranium mine and mill tailings constitute the largest volume of wastes produced by any segment of the nuclear fuel cycle. The milling of uranium ore produces enormous volumes of sandy tailings with low levels of radioactivity, which are currently placed over large areas of land near the mines and mills. As with high- and low-level wastes, it is their radioactivity that distinguishes these wastes from the tailings produced by other mineral mines. Current uranium mining areas in Canada are located in the Canadian Shield: Bancroft and Elliot Lake in Ontario and Beaverlodge and Rabbit Lake in Saskatchewan (Map 3). Deposits in British Columbia, Newfoundland and Nova Scotia may also be considered for future development.

MAP 3.
Existing mines and uranium deposits in Canada



Adapted from: Energy, Mines and Resources, 1981a.

At present, there are six uranium mining operations in Canada, two open pit mines and four underground mines. The open pit mines, Rabbit and Cluff, are both found in Saskatchewan, at Wollaston Lake, and Cluff Lake respectively. The underground mines include Denison Mines Ltd. and Rio Algom's Quirke, Panel and Stanleigh mines, which are situated at Elliot Lake, Ontario. The Agnew Lake mine near Espanola, Ontario has applied to the Atomic Energy Control Board for the authority to shut down and close out its waste disposal sites, and will probably have ceased production by the time this document is published. Madawaska Mines has been mothballed, awaiting improved market conditions. Although new mine developments in Northern Saskatchewan may soon be nearing completion, Eldorado Nuclear has ceased production at Beaverlodge in the summer of 1982 and is being decommissioned. As of January 1983, there were six operating mills in Canada, four in Ontario and two in Saskatchewan (Cluff Lake, and Wollaston Lake).

The mining and milling process

Mining

Most Canadian uranium ore is now obtained from underground mines. This entails the removal of the ore from the deposit leaving pillars of rock and ore standing to provide roof support. The mining cycle consists basically of: rock breaking (drilling and blasting); loading; and transporting (hauling and hoisting). The actual methods used by each mine will vary according to the nature of the mineral deposit.

Open pit mining is practically used only in areas where the ore body is close to the surface. The overlying soil and rock are removed and the ore may have to be drilled and blasted, or it may be simply stripped and transported from the site, leaving a hole in the ground after completion of the mining. It is likely that most future production will be from open pits (Department of Environment, Department of Fisheries and Oceans, 1979).

Milling

Milling is the process by which the uranium content in the ore is extracted and concentrated into a substance known as "yellowcake", which is refined elsewhere for the manufacturing of fuel for nuclear reactors.

The uranium ore enters the mill, where it is crushed and ground. Following this, the crushed ore is then subjected to a sequence of chemical treatments to remove the uranium from the ore. Two waste types are produced: solid wastes composed of the residue from the ore, and liquid wastes composed of the water, components leached from the ore and chemicals used in the extraction process. The extracted uranium is dried and packaged for shipment in the form of yellowcake. The two waste types are combined, neutralized with lime or limestone, and released as tailings to the tailings pond.

The tailings ponds are used to separate the solids and liquids in the mill wastes and to provide storage for the solids. Within the pond, the solids settle out and the liquid effluent is decanted to a secondary treatment pond. The effluent stream is treated to remove any radioactive or heavy metal elements, which settle in the secondary treatment basin and the remaining water is discharged to the nearest watercourse, provided that it meets Federal/Provincial effluent standards. Figure 2 illustrates the milling process for uranium ores.

Tailings Composition

The bulk of the radioactivity in the uranium ore is discharged to the waste management areas in the form of radium-226 in the mill tailings. It is estimated that 85% of the radioactivity from the ore is discharged with the tailings (Blakeman, 1979). The actual composition of the tailings depends on the mineralogy of the ore body, and the processes and chemicals used to extract the uranium. Regardless of the method of extraction whether acid or alkaline leaching depending on the nature of the ore, mill tailings slurries contain from 25 to 40% solids. These solids are composed of particles of common rock minerals, and may also contain heavy metals, pyrite, and various proportions and combinations of the remaining radioactive elements (Table 5).

FIGURE 2.
Acid-leach flowsheet (Elliot Lake)

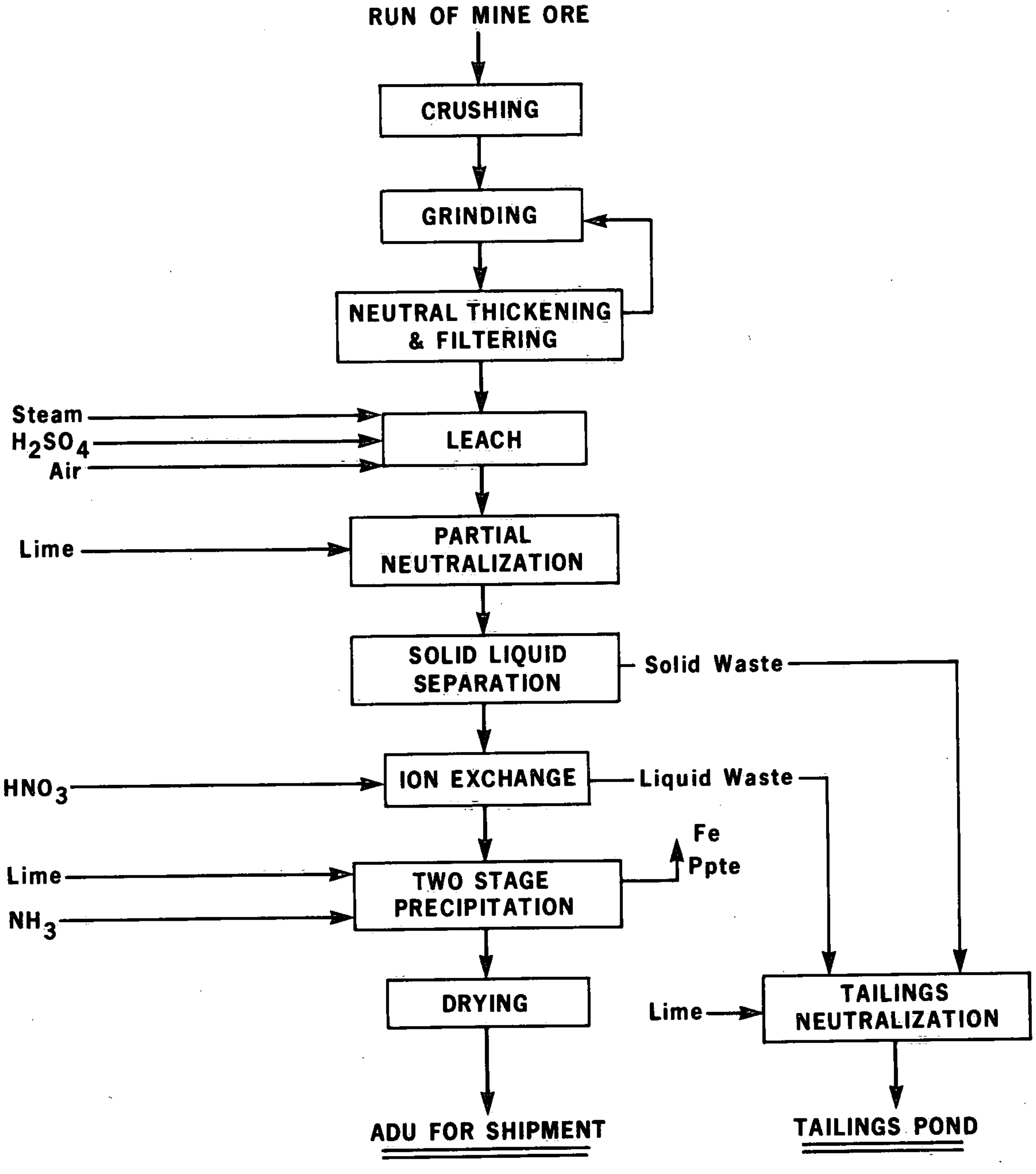


TABLE 5
Important radionuclides in mine/mill tailings

Radionuclide	Half-life (years)	Radiation type
Lead-210	19.4	beta
Radon-222	1.0×10^{2}	alpha
Radium-226	1.6×10^{3}	alpha, gamma
Thorium-230	8.0×10^{4}	alpha
Thorium-232	1.4×10^{10}	alpha
Uranium-238	4.5×10^{9}	alpha
Polonium-210	0.4	alpha
Uranium-234	2.5×10^{5}	alpha
Radium-228	6.7	beta
Uranium-235	7.1×10^{8}	alpha

Source: Muller, 1980.

The concentration of radionuclides in the tailings is 2-3 times greater than that found in the natural environment. Approximately, 98 percent of the radium discharged to the tailings pond is in the solid form, with 2 percent or less of this element being dissolved in the liquid portion. Seventy to eighty percent of the radium in the tailings solids is usually contained in the slimes which consist of very fine sand and clay sized particles. The slimes represent about one-third of the total tailings solids (Blakeman, 1979). The remainder of the tailings is composed of coarser sands. The tailings slimes must be effectively settled from the tailings effluent before it can be treated and discharged into natural receiving waters. The liquid portion of the tailings also contains other wastes, such as process reagents, ammonia, nitrates, and sulphates, which are not specifically treated at the waste management area.

Additional Wastes

The mining and milling processes also create wastes other than the tailings, the greatest volume of which is made up of waste rock from the mining process. The actual amounts of waste rock vary from site to site, being determined by the depth of the ore body, the cut-off grade of the ore, and whether the ore occurs in massive or scattered deposits. The greatest volumes of waste rock are generated by open pit mines where as much 10 t of rock may have to be removed to extract 1 t of ore. This waste rock is disposed of somewhere on the mine site surface (W.B. Blakeman, pers. comm., 1981). It is estimated that 1 t of ore occupies 0.375 m^3, whereas 1 t of broken rock occupies 0.562 m^3 (Department of the Environment and the Department of Fisheries and Oceans, 1979). This phenomenon, known as the "swell factor", increases the amount of land necessary for the disposal of the wastes, thus increasing the size of the affected land area. Waste rock can be a significant problem if it contains pyrite and does not contain minerals that have a natural buffering capacity. It can become acid generating, and its runoff and seepage could contain low levels of radioactivity and dissolved heavy metals. Even waste piles containing inert rock can be sources of airborne dust and suspended sediments in the runoff.

Another type of waste is mine water resulting from the introduction of water into the mines for drilling and dust control, as well as from ground water, rain, and snow. This water is collected in the mine and is normally contaminated by one or more of the following: radioactive elements, dissolved heavy metals, and/or ammonia and nitrates from blasting operations. Because it can contain dissolved uranium, it may be used as a source of mill process water and the uranium recovered. In some cases, however, it is sent directly to the tailings pond.

In addition to the tailings solids and waste water, tailings slurries also contain the reagents used in the process. It is estimated that 80-100 kg of reagents are used for each tonne of ore in an acid leach mill, and 10-12 kg per tonne in an alkaline leach mill (Moffett, 1977). The combined liquid and solid wastes are pumped to the waste management area, wherein most of the reagents degrade naturally.

Production rates

The rates of production of uranium ore depend on the world demand for the refined product. As fossil fuel energy sources are depleted or become economically impractical, the practicability of uranium-based nuclear generated electricity increases. In Canada, growing domestic and export demands have caused existing uranium mines and mills to increase production, and have stimulated the development of new mines in Northern Saskatchewan. Canada produced 7 746 t of refined uranium in 1981, with about 60% coming from Ontario and 40% from Saskatchewan (Canadian Mineral Production, 1982).

Since their first operation in the late 1940s, the uranium mills had produced 90.7 million tonnes of tailings in the period up to 1977 (Advisory Panel on Tailings, Atomic Energy Control Board, 1978). At the 1978 combined production levels of the underground mines (16 145 t per day), and given that every tonne of ore mined results in nearly a tonne of tailings, it is expected that the existing quantity of tailings will have doubled in 10 years (AECB, 1978). In Elliot Lake alone, the largest producing area, it is estimated that within 30-40 years, 1 000 000 000 t of tailings will be deposited (AECB, 1978). As demand increases, lower grade ores may have to be used, hence the waste generated in the milling process marginally increases but large areas of land are still required for disposal of the tailings.

Growth in uranium mining can also bring about increases in the volumes of waste rock to be disposed of and in both mine and surface run-off water, which, as potential sources of radioactive and possibly heavy metal contamination, might have to be collected and treated. However, mill tailings still pose the most significant waste management problem due to the sheer volumes of waste and their longevity of its contained radioactivity.

Disposal of wastes

Existing methods

Several methods for the disposal of uranium mill tailings have been proposed in an effort to create an environmentally acceptable technology that will have long term disposal capabilities. All the currently operating mines in Canada utilize the tailings pond method of solids disposal, combined with barium chloride effluent treatment in ponds or lagoons.

The sites are isolated from human access in order to protect people from radioactivity. Tailings management facilities have been and are being designed and constructed to provide an effective means of treating, containing and storing these wastes until safe permanent disposal techniques are developed. The ponds are used to separate the solid and liquid components of the mill wastes and to provide a storage area for the solids. The tailings disposal facilities have two separate parts, the tailings basin, where solid residue from the mill collects; and the effluent treatment basin, which collects the precipitates from the treated liquid overflow from the tailings basin. It is suggested that there should be 10 ha of tailings basin area for every 1 000 t of tailings discharge produced per day. The actual land utilized for this purpose varies from site to site, but as of 1977, approximately 795 ha of land were covered by tailings (Advisory Panel on Tailings, Atomic Energy Control Board, 1978).

Engineered dams are required to contain the tailings within the basin. They are generally about 20 m high, but it is possible that they will reach heights of 50 m within 30 years (AECB, 1978). The most common type of tailings disposal now used in Canada is the valley impoundment method which makes use of natural land depressions such as swamps, creeks, or lakes as the original basin. Dams are simply raised at the ends of the valley and other low points as required to maintain tailings storage capacity and a sufficient settling pool size.

Because tailings disposal sites are commonly situated in natural depressions, they tend to be in the path of the natural water flow. Rainfall, small streams, and other run-off will collect in the basin, thereby increasing the total flow of water. Major efforts are made to divert as much natural drainage as possible away from the basin and to reduce its natural watershed to a minimal size. Any waters captured in the tailing sites are contaminated and therefore the overflow is treated with barium chloride to remove Ra 226. Once the barium radium sulphate precipitate has settled to form a sludge on the bottom, the water can be released to surface waters, provided it meets with federal Metal Mining Liquid Effluent Regulations and provincial regulatory standards.

As natural depressions are used for the tailings basins, a standard measurement of facility size requirements is not possible. Basin sizes will vary with the length, width and depth of the depressions used, as well as with the tonnage of tailings to be disposed of. All existing Canadian uranium mines utilize the valley impoundment or a modification of it, but new techniques are now being considered as described below.

Alternative methods

In addition to the tailings ponds and effluent lagoons, several other methods have been proposed. These include backfilling the mine, open pit storage, combined waste rock and tailings storage, underwater disposal, and stacking or coning of tailings.

a. Backfilling

In this process, the coarse sands are separated from the finer slimes and used for underground backfill, with the fine slimes being sent to the tailings pond. This method reduces the affected land surface area by reducing the volume of tailings to be disposed of on the land. Wastes backfilled into the mines would consist of coarse tailings, waste rock, and additives such as cement. The radioactivity would have to be of a very low level so as not to contaminate the area in which men are working. If the wastes are placed in an abandoned mine, their effects on the groundwater regime should be monitored. Backfilling has been practiced by Eldorado Nuclear Limited at its Beaverlodge, Saskatchewan mine.

b. Open pit storage

This method has been proposed at an operating mine in Saskatchewan, which will have a worked-out pit reasonably close to the mill. Tailings would probably be placed in the worked-out pit, in a de-watered condition, capped by a material of low permeability and allowed to flood. The significance of this method is that it would reduce the amount of land required to accommodate the tailings. The use of an area previously affected by mine tailings disposal would allow a lake to remain as a natural water body rather than being filled with tailings.

c. Underwater disposal

This method is currently receiving study by both the industry and the regulatory agencies. It would require the discharge of tailings into the bottom of a deep natural lake. There appear to be certain advantages to this method. First, it supports the "out-of-sight-out-of-mind" thinking; the tailings are completely hidden and therefore would have no aesthetic effect on the appearance of the land. Second, the tailings would eventually be covered by sediments brought in through natural processes. Weathering along the tributaries of the lake would contribute sediments which would eventually be deposited on the tailings in the lake. Finally, the low availability of oxygen in water implies that pyrite oxidation and acid formation would be significantly reduced. There are also disadvantages to this method. Very little is known about the potential long-term reactions between the tailings, water and bacteria in an active or inactive lacustrine environment not continually being neutralized by man. In the event that it was environmentally necessary, the recovery of the tailings would be very difficult, if not impossible. Even more important is the possibility that local environments could be threatened or damaged by this disposal method; if the system should fail to perform as predicted, the tailings could contaminate the waters of the entire watershed and, perhaps, reduce the economic, aesthetic and recreational values of substantial adjacent land areas.

d. Stacking or coning

These methods require the placing of tailings solids above water level in a natural basin or dry land disposal site, similar to present containment areas except that fresh dewatered tailings are piled on previously deposited tailings. One Elliot Lake operation is proposing to stack tailings at its existing facility in order to increase its storage capacity to what it will require up to the next century. Coning is also a possible method for increasing existing storage capacity; it refers to the release of thickened tailings from a central point within the basin. This method would not require massive earth fill dams or a large settling pond.

The importance of stacking or coning is its reduction of land effects because of the smaller amount of land utilized to accommodate the tailings. However, the overall height of tailings would increase resulting in potentially greater visual intrusion into the landscape. The actual size of reduction is unknown as this process is not yet in use in Canada.

Impacts

Many types of land uses do not limit their impacts solely to the immediate land area they directly occupy. Mining is one land use that will inevitably have considerable influence on land surrounding an operation. This influence has been referred to as the 'shadow effect' and has been documented by Marshall (1982). Such influences beyond the mine site are both tangible by measurable variables or intangible encompassing more-subtle effects which may be neither visible or immediate. For example, the influence of a transportation infrastructure (roads, railways) serving a mine may be measured by not only the land allocated to transport but also must account for the traffic and associated noise and dust along its route as it may affect those land uses abutting its route. The potential severity of impact is also largely tempered by human perception and by the location of the impact; the perceived impacts may be greater in pristine recreational areas than on zoned commercial/industrial areas. The 'shadow effects' are certainly important and can extend a mine's influence several kilometres into the surrounding territory. Nevertheless, the balance of the forthcoming discussion will focus on the lands directly utilized to serve mine operation and their associated impacts.

Unlike the producers of other mineral commodities, the members of the uranium mining industry are closely regulated at the federal level. The federal agency which has the mandate and authority to licence uranium mining, milling and waste management operations in addition to the other components of the nuclear fuel cycle, is the Atomic Energy Control Board (A.E.C.B.). Because none of the operating or inoperative tailings management sites in Canada can be considered as being permanently 'closed out' in a manner which would not require continuous human intervention to maintain the integrity of the site, the A.E.C.B., in consultation with other federal and provincial regulatory agencies and members of the industry, is developing "Interim Close Out Criteria". These criteria will identify procedures which should be followed and conditions which should be met in closing out existing or future tailings management facilities in order to minimize the need for human intervention to reduce health and environmental risks. This criterion would be in effect until such time as acceptable permanent close out techniques are developed.

In this report, therefore, it is only possible to identify the impacts caused by uranium tailings management sites as they exist today, that is, as temporary storage facilities containing low-level, but long-lived radioactive wastes. Present conditions will exist at these sites until the Interim Close Out Criteria, and ultimately, permanent disposal technologies are developed.

The major concern with respect to uranium tailings is the long-term release of radioactivity present in the tailings. Radium and thorium, because of their slow decay rates, will not have reduced their radioactivity to half the present level for roughly 100 000 years, and even then it will be too high for the tailings to be left in a condition wherein they would be accessible to the general public (Department of the Environment, Department of Fisheries and Oceans, 1980). Present methods of tailings management deal with enormous volumes of tailings over large areas of land. Individual sites may vary in size, ranging up to 160 ha in area or more (James F. MacLaren Limited, 1977), but taken as a cumulative total, they could consume an area considerably larger than the 1977 Canadian total estimate of 795 ha. Currently these lands are devoted to the containment of wastes, with no other uses allowed on these sites. In addition to tailings, in areas where surface mining of uranium is practised, they must contend with extensive volumes of waste rock which require large land areas for disposal.

According to 1977 statistics, approximately 100 million tonnes of tailings had been generated in Canada since the commencement of uranium mining. Elliot Lake, the largest producing area in Canada, accounted for roughly 76 million tonnes of tailings covering approximately 685 ha. Bancroft accommodates 10 million tonnes on 72 ha, and Beaverlodge, Saskatchewan has 6.5 million tonnes on 9 ha of land. Other sites in Saskatchewan, near Lake Athabasca contain 7.5 million tonnes on 29 ha of land (Advisory Panel on Tailings, Atomic Energy Control Board, 1978).

Although the non-radiological properties of the tailings, especially their heavy metal components and the acidic nature of the tailings from some areas, may constitute serious health and environmental hazards, it is the radioactive content that causes greatest concern because of its extreme longevity. Most direct impacts on land or water stem from the seepage of either untreated tailings liquids or the release of suspended solids into the surrounding aquatic environment or the dispersion of airborne particulates from uncovered surfaces of dry tailings ponds on to the nearby land surface.

Water contamination

Both by catastrophic events such as dam failures and by mundane events such as natural erosion, tailings solids may escape from their containment areas and, in doing so, pollute downstream surface waters and groundwater with dissolved and suspended heavy metals, inert solids, and radioactive contaminants.

In the past, water pollution from tailings impoundments was one of the most serious and widespread problems associated with tailings disposal. Current effluent treatment technology is capable of greatly reducing the problem provided that it is constantly practiced. If proper effective treatment methods are not employed to isolate the tailings from air and water in inactive sites, or to treat contaminated seepage and runoff, extensive contamination of water can occur through the leaching of heavy metals and radioactive materials from the tailings by surface run-off, precipitation and groundwater flows. Water pollution may also be caused by chemicals used in uranium processing operations. Radioactivity, acidity, and high ammonia levels can be lethal to an ecosystem, affecting everything from plankton photosynthesis to fish production. The polluted water can, in turn, have widespread consequences throughout the watershed. Downstream of the mine, the value of the water for other uses may be lowered. The proposed disposal of tailings in lake bottoms may warrant additional studies to determine if it could provide a safe means of permanent disposal.

Physical impacts

Impacts on the land result from contact with contaminated water, the blowing of dust particles from the tailings, and the physical presence of the tailings themselves on land which may have other uses. Water contamination can affect soil quality through the loss of organic matter and the absorption of contaminants into the soil. Organic matter may be lost through the leaching of nutritive ions from the soil or from the subsequent salinization of the soil. Wind erosion of dry tailings areas disperses radioactive dust over a wide area; soil or adjacent lands may have increased radiation levels in the top few inches of the soil. Tailings can also create localized climatic effects by altering the natural landscape. The height of tailings management areas may alter wind patterns, aggravating the dusting problems in nearby areas. The actual area of land that is dusted will be dependent on prevailing weather conditions in the region. These wind-blown tailings can change the physical and chemical characteristics of the soil, impairing its capacity to support vegetation. Tailings frequently contain metallic micro-nutrients in amounts sufficient to inhibit or kill plant growth (James F. MacLaren Limited, 1978*b*). Existing vegetation may absorb the contaminants and pass them along the food chain, spreading the effects even farther. In certain areas, soil contamination by tailings could remove land from productive uses such as farming or forestry, and increase the area of affected lands to more than just the land accommodating the tailings.

Other land impacts resulting from mining and milling include the construction of buildings, access roads, and other ancillary facilities. These do have local effects but should have minimal effects over the whole region. Until permanent disposal techniques are developed, the natural areas dedicated to tailings containment may well be lost to future use and become non-productive. Impacts other than those directly related to the tailings are also probable. Once a site is to be closed out, the tailings may have to be covered with some form of fill, meaning that some other area of land would have to be disturbed in order to provide the soil. The amount of land that would be affected in this way is not known because the criteria specifying a depth of cover necessary to effectively close-out a facility have not yet been developed. Similarly, there is no way to determine how much land is disturbed to provide the fill material used in the construction of dams to retain the tailings, as dam sizes and construction methods vary.

Airborne pollutants on land

In addition to ground and water contamination, tailings can also pollute the air. Piles of uncovered tailings generate radon gas from the decaying of Ra 226. This gas is hazardous because it can be inhaled and result in health problems in man. In addition to the gas, all tailings impoundments are a source of dust, particles of which are likely to be radioactive. Large areas of land, exclusive of the tailings impoundments, can be contaminated to levels higher than background radiation (Bearman, 1979). To combat both the gas and the dust releases, tailings may have to be covered by inert material, likely some form of fill.

Aesthetic effects

Conventional tailings impoundments are highly visible. Furthermore, uncovered tailings have the appearance of sand, and impoundments, because of their size, create an undesirable visual intrusion into the landscape. It is not uncommon for a tailings pond to be 160 ha in area. Dams and embankments may also be conspicuous, but this will depend on the location of the impoundment. The re-vegetation of tailings areas can reduce the visual impact, although its main purpose is to stabilize the surface and reduce air and water pollution. From the standpoint of appearance, the best disposal method could be deep water disposal. However, the environmental implications of this method are as yet largely unknown.

In Northern Saskatchewan, similar concerns can be voiced about the large volumes of waste rock extracted in surface mining operations and stored on the land surface.

Land use impacts

Tailings and waste rock disposal areas can compete with other land uses, and may prevent large areas being used for other purposes. The numerous lakes in Northern Ontario, where a number of existing disposal sites are located, have great potential for recreational uses, such as sport fishing, boating or hunting. If active treatment measures are not maintained, water pollution from tailings sites could preclude the recreational use of fairly large watersheds. The nature of uranium tailings requires that tailings areas must remain isolated until the radioactivity of the waste has attained natural background levels.

As but one example, the discussion of potential uranium mine sites in British Columbia poses some important land use questions. Ninety percent of B.C. is mountainous and non-arable, with the remaining 10% accommodating the majority of land uses. The Okanagan Valley contains some potentially mineable uranium reserves, but it is also an important area for wildlife, outdoor recreation, human settlements, and agriculture. The land requirements for mining – roads, railroads, possible towns, as well as the mines and tailings sites themselves – may affect these other uses. In consideration of the longevity of the radioactivity, and the land area required for tailings management facilities, microclimatic conditions in mountainous terrain, and the limited amount of arable land available in B.C., it is probable that any proposals to develop uranium mining operations in this province would encounter significant opposition and require a very thorough environmental assessment.

Rehabilitation or reversibility

The approach to tailings management differs in principle from the management of high-level radioactive wastes from nuclear reactors (discussed elsewhere). In contrast to the search for deep geological disposal sites for high-level waste, which implies an inherent acceptance of responsibility to future generations, there had been no similar concept on which a national plan for tailings could be based. Until recent years there has been an insufficient concern about what would happen after a site is shut down; however, in 1982, the National Uranium Research Program has been initiated to develop long-term disposal techniques.

Emphasis was formerly placed on the treatment of liquid effluents before release with subsequent work on methods of tailings stabilization to reduce effluent quantity or improve quality. However, greater emphasis is now being placed on the stabilization of tailings, with the aim of covering the tailings with vegetation or stabilizing them in other ways. Vegetation would alleviate dusting, erosion, and aesthetic problems, and may reduce seepage by reducing the amount of water entering the tailings. Other methods of stabilization would include chemically stabilizing the tailings in the hope of curtailing seepage and erosion, and capping the entire tailings area with an impervious material, or reducing the radioactive content of the tailings in a milling process that would lessen the radioactivity of the tailings. It is assumed that acceptable methods will be developed for the rehabilitation of the tailings disposal sites to the point that no further human intervention is required.

It is important to stress that because there are no "close-out" or disposal criteria for tailings at present, they are only considered as being in controlled storage. Human intervention is still required, although permanent long-term disposal without human intervention is the ultimate goal. Until such time as a permanent disposal system is developed, the existing situation must be maintained to ensure environmental protection.

HIGH-LEVEL RADIOACTIVE WASTES

The operation of a nuclear reactor generates a certain amount of irradiated fuel more commonly referred to as spent fuel. Whether this spent fuel is discarded in its present form or reprocessed to recover useful constituents, it is designated under the general name of high-level radioactive waste. Over 99% of the radioactivity resulting from the operation of a nuclear generating station is in the spent fuel (AECB, 1981). Of the three types of nuclear wastes, high-level radioactive wastes constitute the greatest potential hazard to the public, and for this reason, must be safely disposed of.

Nature and composition of wastes

Reactor fuel, before being introduced in the reactor core, is composed of uranium oxide pellets produced at a fuel refinery from the yellowcake from the uranium mills. The pellets are placed in zirconium tubes assembled in fuel bundles (Photo 1). Zirconium is relatively immune to radiation damage and interferes very little with the fission process. Each bundle of zirconium fuel rods is welded shut to prevent leakage, after which it is placed in the reactor. After a year to a year-and-a-half inside the reactor, the fuel bundles become spent and must be replaced. When a fuel bundle is removed, it is highly radioactive and produces heat.

The spent fuel contains a wide variety of radionuclides. Some of them decay to half their original level in a relatively short time (the time for a radionuclide to decay to half its original level is called half-life), e.g., iodine-131 has a half-life of eight days and krypton-85, of 10.7 years (see Table 6). Others such as plutonium which have a half-life of 24 400 years, take thousands or even millions of years to decay to insignificant quantities. They will therefore require appropriate isolation from the environment if they are to pose no hazard to humans and other forms of life.

TABLE 6
Important radionuclides in spent CANDU reactor fuel

Radionuclide	Half-life (years)	Major type of radiation
Krypton - 85	10.7	beta, gamma
Strontium - 90	28	beta
Zirconium - 93	1.5×10^6	beta, gamma
Technetium - 99	2.1×10^5	beta, gamma
Iodine - 129	1.7×10^7	beta
Iodine - 131	2.2×10^{-2}	beta, gamma
Cesium - 135	2.0×10^6	beta
Cesium - 137	30	beta, gamma
Neptunium - 237	2.1×10^6	alpha
Plutonium - 239	2.4×10^4	alpha
Plutonium - 240	6.6×10^3	alpha
Plutonium - 241	14.6	beta
Americium - 241	433	alpha
Americium - 243	7.4×10^3	alpha
Spent fuel		alpha, beta, gamma

Source: Muller, 1980.

It is evident that some of these elements will not decay to insignificant quantities before thousands of years.

Production rates

Each CANDU reactor contains about 5 000 fuel bundles. Since the operation of the first

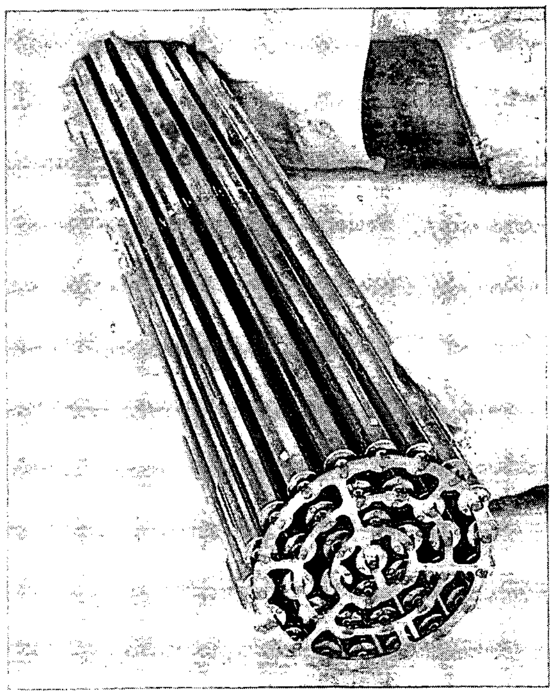


Photo 1. Nuclear fuel bundle.
Chalk River Nuclear Laboratories

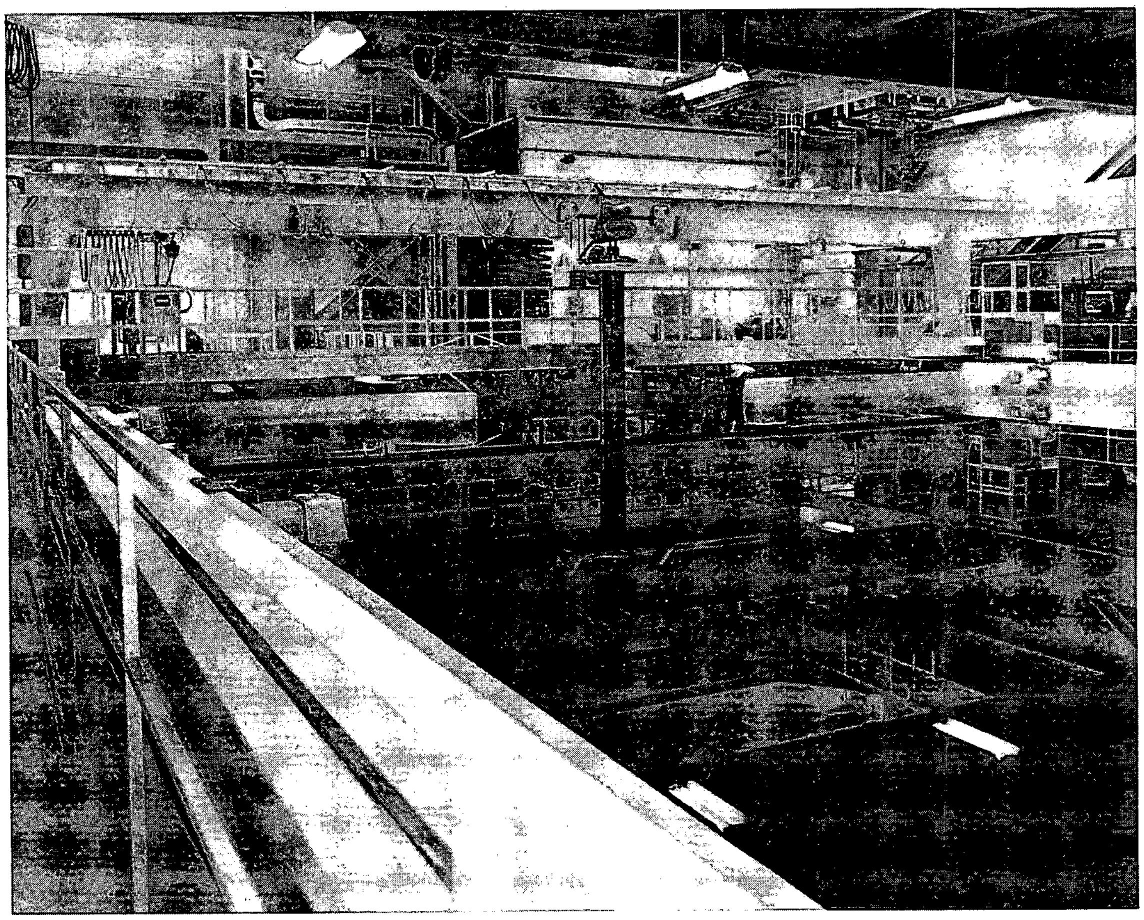


Photo 2. Fuel storage bay, Pickering A.
Ontario Hydro

Canadian reactor in 1948, some 50 000 t of spent fuel had been produced by 1980 (Webb, 1980). Approximately 770 kg of spent fuel is produced every day from the six operating Canadian nuclear power stations (Clugston, 1980). These wastes are in the same physical form as the original fuel, and occupy a volume of 2 m^3 for each tonne of spent fuel (Aikin *et al.*, 1977). If no new reactors were to come into service by the year 2000, the total amount of spent fuel would then be approximately 72 500 t, enough to fill a Canadian football field between the fifteen yard lines to a depth of 45 m (Clugston, 1980). It is more likely, however, that new generating stations will come into service during this period, thus increasing these totals. Existing storage facilities have the capacity to accommodate all the spent fuels produced to the year 2000, but any growth in the industry may severely tax this capacity.

Present storage methods

Spent fuel is currently stored underwater in large tanks known as fuel bays (Photo 2) at the sites of the nuclear generators. Although sizes and shapes vary, fuel bays are generally similar in size and shape to an Olympic-class swimming pool, with a general depth of 8 m (Aikin *et al.*, 1977). The spent fuel bundles are placed in baskets, which are stacked on the bottom of the pool, and are continually cooled by circulating water. In addition, the water acts as a shield against radiation. Water leaving the pool is treated to remove any radioactive elements that may have accumulated by contact with the spent fuel baskets.

Proposed disposal methods

As the quantity of spent fuel produced increases, a permanent method that requires no monitoring for disposal of the high-level wastes is being actively sought. Several methods of permanent disposal have been considered. These include:

a. the placing of the wastes in sealed canisters and leaving them in various designated locations to be monitored for as long as necessary;

b. transporting the wastes in suitable containers to the Antarctic or to Greenland for burial in the great ice sheets;

c. loading the wastes into rockets and firing them into space;

These methods are no longer thought to be feasible. Surface disposal was rejected because future generations would have to continue monitoring the hazardous wastes we have left behind. Moreover, surface disposal would be vulnerable to man-made hazards such as wars. The use of the ice sheets was rejected because the Antarctic is covered by an international treaty which forbids the disposal of nuclear wastes in the Antarctic and neither it nor Greenland is Canadian territory. Canadian glaciers are too small for consideration. The use of rockets was eliminated because of its high cost and the possibility of accidents.

There are currently two options which are receiving consideration throughout the world: disposal of the wastes, suitably contained, either into the sea or into terrestrial geological media.

Canada has opted for the second option, and more specifically, for disposing the wastes in crystalline (hard) rocks. A disposal site is intended to be developed in the Canadian Shield in Ontario to accommodate all high level wastes to be produced up to the year 2050. The method requires the construction of a vault in undisturbed rock in the Shield. The vault would be 500–1 000 m below the surface (Webb, 1980). The high level wastes would then be sealed into containers to trap the radioactivity and placed in the vault. Once the vault is filled, the repository would be backfilled, sealing the containers deep underground (Photo 3).

This system of disposal is favoured for several reasons. Precambrian formations have remained substantially unchanged for millions of years. Sites with sufficiently slow groundwater movement so that radioactive releases will be acceptably low are anticipated to be found. The design of the disposal facility is similar to any conventional mine and the excavation of the repository can be performed with existing mining technology.

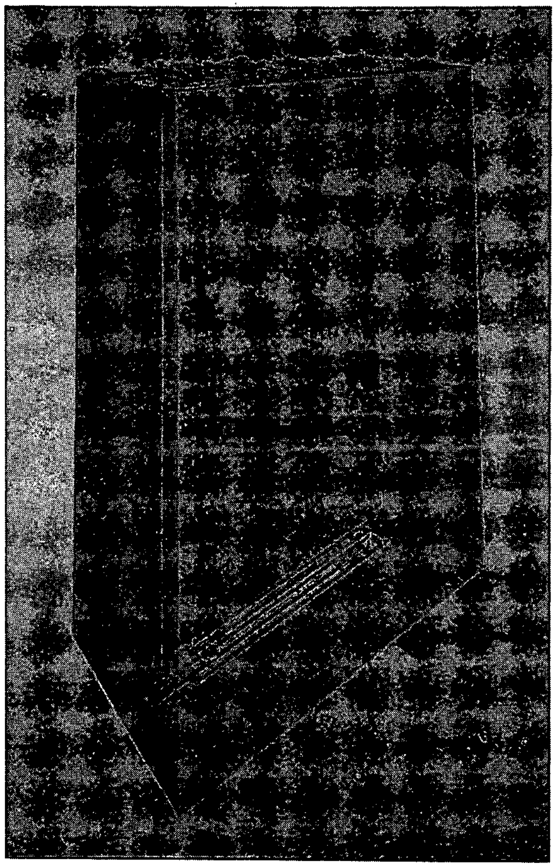


Photo 3. Artist's rendering of high-level waste facility.
Atomic Energy of Canada Limited

Impacts

Existing facilities

The water-filled bays currently used to store high-level wastes affect the land in much the same way as any other man-made building. Their construction takes land away from other uses and compacts the soil due to the weight of the structure itself and the equipment used to build it.

The Bruce storage site is situated on bedrock and organic soils which, according to the Canada Land Inventory (CLI), have no stated value for agriculture. The lands surrounding the site have been assessed as being predominantly class 1 lands for agriculture, meaning there are no significant limitations in their use for crops. The site area has low recreational value except for isolated areas of cottage development on the neighbouring Lake Huron shoreline (DREE, 1970). The 8 km buffer zone around the heavy water production plant at the site ensures that no activities attracting large numbers of people to the area will be allowed within the zone. This AECB policy resulted in the relocation of the existing provincial park outside the buffer zone. Existing agricultural and farm-related residential uses were allowed to remain. Ancillary uses associated with the Bruce plant have begun locating in the site's vicinity. Greenhouses utilizing waste heat pumped from the plant have been established in a neighbouring community. The closing of the plant would affect such ancillary uses, causing either closure or relocation.

The Pickering generating site is in an urban setting, 32 km from Toronto, 20 km from Oshawa, and within 6 km of both the Town of Ajax and the Village of Pickering. The waste storage site is within the project, on land that CLI classifies as being primarily class 1 land for agriculture (ARDA, 1967), and class 1 land for forestry (DOE).

At both Bruce and Pickering, the impacts on the land result from the nuclear generating projects as a whole, not from the existence of the high-level wastes within them. The presence of both plants has removed land from other uses. The sites will remain out of use until such time as the plants shut down, and the radioactivity of the structures is low enough to allow the land to be put to other uses. Surrounding lands are not directly affected by the presence of the disposal sites, but may have been indirectly affected by the energy-related industries and businesses attracted to the Pickering generating station's general area.

Changes in land value and productivity are difficult to measure because much of the affected area has not been in active use. A particular parcel of land may have diminished in agricultural value, but its value for industrial use may have increased. As the storage bays are on the site of the generating stations, they have few aesthetic impacts other than those associated with any building. Reversibility is a possibility once a site has been closed out and any latent radioactivity has decreased to safe levels.

Proposed disposal facilities

The proposed underground disposal sites would have most of its effects below ground, but little lasting impact on the surface itself. Surface impacts would be those of the operations and structures common to any sub-surface mine. The land would first be cleared of vegetation, then the mine facilities would be constructed, associated buildings erected, and finally the mine itself would be dug, with the resulting waste rock piled on the surface. While the disposal site is in operation, the land would be removed from all other uses, and would present a scarred appearance to the surrounding area. However, none of the effects is permanent, as once operations are suspended the site would be backfilled with the waste rock, the buildings removed, and the area re-landscaped, if necessary. The entire process is completely reversible, with reclamation a distinct possibility. The land could be put to any use desired, as the radioactive wastes are assumed to have no significant effect at the surface. No restrictions on the site are foreseen, but it is important to remember that this is entirely conjecture, as no such site has yet been developed. Public perception of the dangers of radioactivity may alter land values or cause the land to fall idle, but the deep burial site will have very few direct land impacts.

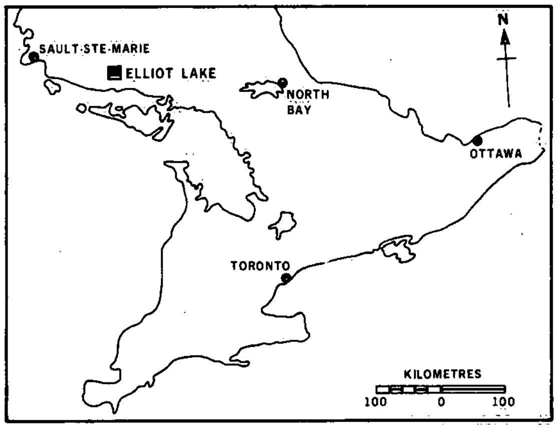
THE CASE STUDY OF ELLIOT LAKE

Introduction

Elliot Lake is currently the largest uranium producing area in Canada. Canadian uranium production in 1981 totalled 4 664 t, the bulk of which was supplied by the operations of Denison Mines Limited and Rio Algom Limited in Elliot Lake (Canadian Mineral Production, 1982). Proposed expansion of these operations ensures that they will continue to be major contributors to the Canadian uranium industry.

Uranium ore was first discovered in the Elliot Lake area in 1953. The demand for uranium for use in atomic weapons created a boom for the area in its early years of operation. In all, 12 mines (11 with accompanying mills) were brought into production by 7 different companies over the 4-year period between 1955 and 1958. In 1954, the Ontario Government decided to plan a local community to serve the mining industry, and by 1959 a town serving over 25 000 people was established close to the southern portion of the main ore body on the eastern shore of Elliot Lake in the District of Algoma (Map 4).

MAP 4.
Location of Elliot Lake



In 1959, the United States Atomic Energy Commission, the chief buyer of the uranium produced in this area, announced that it would not extend its uranium contracts beyond 1962. As a result, most of the mines and mills closed down, with only Denison's and Rio Algom's mines remaining in operation. The population in the town of Elliot Lake subsequently dropped to about 7 000 in the early 1960s. Most of the original operations were then absorbed by Denison Mines Limited and Rio Algom Limited, the only two companies to continue operation from the early 1960s to the present.

In 1974, there was a resurgence in the demand for uranium as an energy source, and both Denison Mines Limited and Rio Algom Limited proposed expansions of their operations. The population of Elliot Lake has now grown to approximately 18 500; current town expansion programs project a population of about 21 000 by 1982. This apparent prosperity is tempered only by the shadow of uncertainty over future foreign uranium contracts.

TABLE 7
Weight of existing tailings
(1 January 1976)

Operating mines (Company)	Disposed tailings (millions of tonnes)
Long Lake (Denison)	37*
Quirke (Rio Algom)	17.2
Non-operating mines (Company)	
Williams Lake (Denison)	
Stanrock (Denison)	5.5
Lacnor (Rio Algom)	2.7
Nordic (Rio Algom)	12
Panel (Rio Algom)	3.3
Pronto (Rio Algom)	2.1
Spanish American (Rio Algom)	0.45
Crotch Lake (Rio Algom)	7.5
Total	87.75

* To the end of 1980.

Source: James F. MacLaren Limited, 1977.

Table 7 indicates the amount of tailings produced by each mine in the Elliot Lake area. An average grade ore contains 0.1% uranium, therefore, for every tonne of ore processed, about 1 kg of uranium is extracted and 999 kg of tailings are produced. To produce the tailings indicated in Table 8, nearly 88 million tonnes of ore was mined and milled.

As of 1981, it is estimated that some 100 million tonnes of tailings have been produced and placed at the disposal sites within the Serpent River Basin (J.K. Chakravatti, pers. comm. 1981). Three of the tailings sites in Table 7 are currently in use: Denison's Long Lake facility and both the Quirke and Panel operations of Rio Algom, representing 67% of the total tailings in the area.

TABLE 8
Tailings disposal areas
(including treatment ponds)

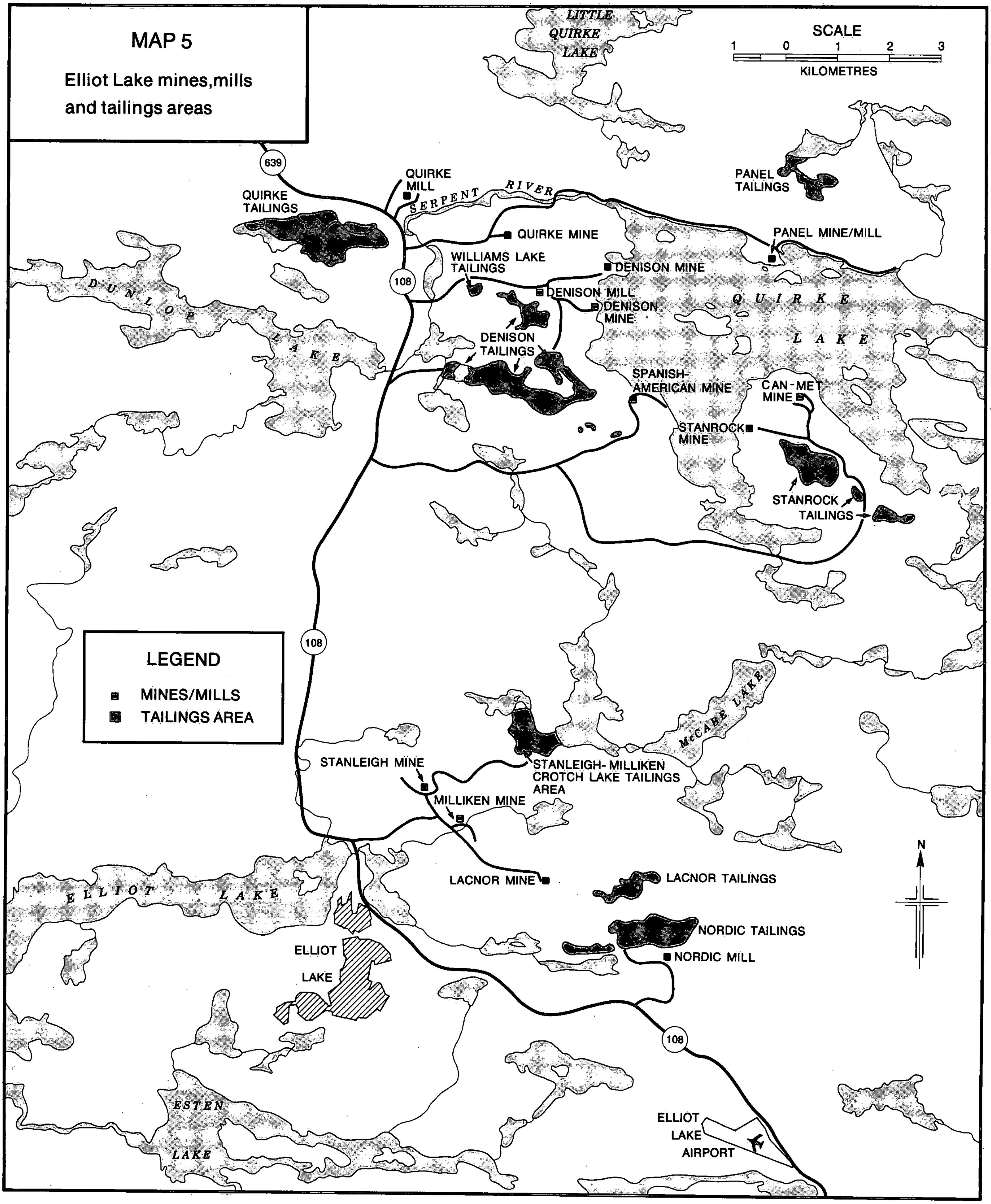
Operating areas	Area (ha)
Denison	75.0
Quirke	160.0
Panel	38.0
Non-operating areas	
Williams Lake	3.0
Stanrock	65.0
Lacnor	24.0
Nordic	102.0
Pronto	47.0*
Spanish American	10.0
Crotch Lake	52.0
Stanleigh	34.0
Total	610.0

* Copper and uranium tailings.

NOTE: Areas are based on averages from three sources: James F. MacLaren Limited, 1977; Dave Murray, pers. comm., 1981; Kalin, M.A., 1981.

Land impacts

The original selection processes for siting tailings ponds were based primarily on operational considerations. The main objective was to find areas that had natural barriers requiring few dams to aid in containment. Lakes and other natural depressions were examined with this in mind. The selected sites were located close to the milling operations in order to reduce transportation costs. In order to protect the town's water supply, the mill's water source, and the health and welfare of the towns people and the workers, the tailings ponds were sited away from the local fresh water supply. All the existing sites were chosen in the mid-1950s; current operations have merely expanded them. Map 5 indicates the locations of the tailings sites in the Elliot Lake region.



MAP 5

Elliot Lake mines, mills and tailings areas

Although waste rock is associated with the mining of uranium ore, because Elliot Lake's mining is an underground operation its disposal is not of prime importance from a land impact perspective. Non-radioactive waste rock can be used as construction material within the mining operation whereas radioactive rock must be placed within the tailings, left underground or placed in designated waste management areas. This case study will emphasize the impacts of the tailings as their prominence and environmental significance is greater.

Sizes of tailings disposal sites

To date, the 100 million tonnes of tailings produced by the eleven mills in the area have been placed at nine main sites and two smaller sites. The Serpent River Basin covers an area of 1 349 km² and discharges into Lake Huron. Statistics are conflicting, but the Elliot Lake tailings areas cover in the range of 610 ha of land, less than 1% of the basin's area. The three operating sites account for 40% of the area occupied by tailings. Table 8 indicates the sizes of the individual tailings areas. All these tailings areas use surface deposition as a means of placement; the sites are generally topographically low areas surrounded by low permeability bedrock ridges.

In most instances, these areas originally contained small lakes or marshes which were subsequently filled with tailings or incorporated into tailings management facilities as settling basins. The tailings areas at Williams Lake, Crotch Lake, Denison, Quirke, Lacnor, Spanish American, Panel, Pronto, and Stanleigh were once lakes, Nordic is sited on a swamp and Stanrock is sited on a ridge. All these areas typically include one or more engineered dams to augment the containment offered by the natural shape of the basin.

The areas buried beneath the tailings were capable of other uses, even though most of the area had been completely undeveloped before uranium mining began. Utilization of the lakes for this purpose has prevented their use for potential recreational resources, fishery sites, forestry production, and sand and gravel extraction. The whole region is capable of supporting various species of wildlife, including deer and moose, making it potentially desirable for hunting.

Former uses of the land were few. Prospectors working in the area had to be flown in as there were no roads into the present Elliot Lake area. In the 1920s and 1930s there had been some extensive logging in the vicinity of the present town site, but now there is only a small industry employing 62 people (James F. MacLaren Limited, 1977).

The lands surrounding the tailings areas are not extensively used because most of the neighbouring lands are leased from the province by the mining companies, who chose to leave them undeveloped. Some recreational uses are evident, however, including fishing, boating, hiking, cross-country skiing, and hunting. There are also areas of potential forestry production which remain unexploited. The remainder of the surrounding land is owned by the Crown, very little of which has been released to the public.

Land-use impacts

It is important to note that the examination of the land impacts of tailings in the Elliot Lake area is based on the status quo. All tailings sites, whether operative or inoperative, are still being maintained as to their environmental stability. It is not appropriate to extrapolate the current situation to some future time where maintenance procedures would be discontinued and assume that the stable environmental conditions that currently exist would remain.

Most land use impacts are of a localized nature, occurring mainly at the sites of the tailings and their neighbouring lands. Many of the impacts that are experienced in the area today are a result of the original disposal methods employed 25 years earlier. Those lakes used as disposal areas were killed originally by the placement of tailings in them. Little or no subsequent damage has been done and seepages are collected, monitored and treated to ensure that surrounding areas do not suffer the same fate. Areas containing tailings now have the appearance of bleached deserts in those areas that have not undergone rehabilitation, and of wet grasslands in those areas that have been re-vegetated. All the land buried beneath the tailings has been permanently removed from its former state.

Other localized impacts are caused by natural actions on the tailings areas. Wind and water play a large role in spreading the radioactivity and acidity found within the tailings to surrounding lands. Wind-borne dust particles have been found to carry radioactive materials to surrounding areas. In the early years of operation, dust storms were common, but changing operating methods have virtually eliminated this problem. Elevated radiation levels have been recorded within 100 m of tailings. Beyond that, radiation readings revert to natural background levels. Dusting tends to occur during two seasons of the year: in the spring, when frost action breaks up the surface of the tailings, and in August and September when long dry spells are often followed by storms which stir up the tailings surface. The re-vegetation of non-operating sites together with the practice of spraying mulched grass and straw on active areas has reduced the amount of dust significantly. As surrounding lands are mainly undeveloped, the land use impact of the dust has been negligible. If radiation levels were found to be significantly high, certain activities may be curtailed should development occur, but a clean-up effort may alleviate the problem.

The seepage of water through faults and fractures in the underlying bedrock and through the retaining dams is another potential source of contamination for neighbouring lands. However, in 25 years, no adverse effects have been detected on the local groundwater system. Such

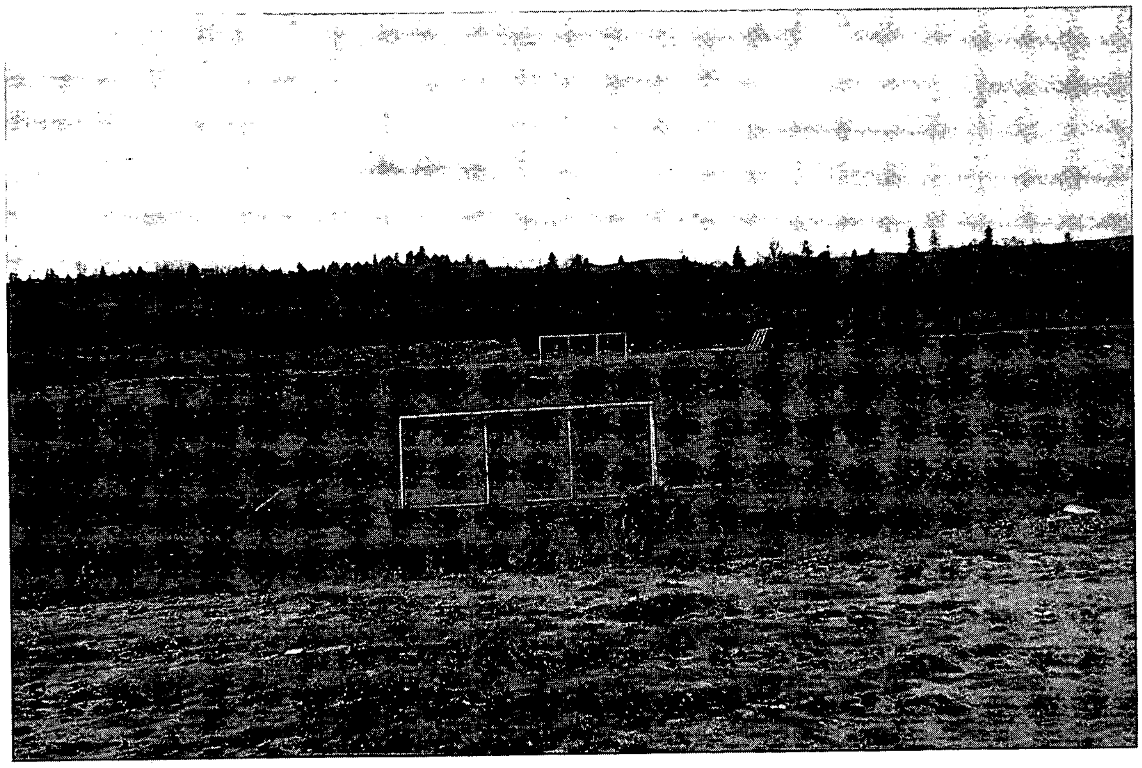


Photo 4. Rehabilitated spill area near the Milliken mine site.
I.G. Redmond

Photo 5. Stanrock tailings impoundment.
I.G. Redmond

seepage may spread contaminants over wider areas but this is, as yet, unknown. Seepage rates seem to be quite slow, indicating that the effect on neighbouring lands may be small. Once again, the fact that neighbouring lands are undeveloped lessens the land use impact of any such contamination. With a high local water table, however, contaminated groundwater can enter the surface water system.

Radon gas emissions are also a problem found in tailings areas, but they have no land use impact on the surrounding lands because these areas are open space and the gas tends to disperse quickly. However, radon gas does decay to radioactive polonium and lead which are deposited on plants and land surfaces.

Land value impacts are found only in areas far removed from the tailings. As most of the land in the immediate vicinity of the tailings areas is either Crown land or held by the mining companies under long term lease, values have not been altered. The tailings are too far removed from exploitable lands to have any real effect, although land along the affected river basin system may decrease in value for recreational uses; some cottages can be found within the basin area. Land value impacts are based on the public's fear of radiation rather than on any physical changes to the land.

The original town was located well away from the tailings areas. The siting of the tailings areas in hollows, swamps, and lakes used land that did not impinge on the town's development or on its future expansion.

The visual impacts associated with the tailings in the Elliot Lake area vary depending on whether or not the site is in operation. Active tailings areas resemble lakes surrounded by deserts, with the sand-like tailings drying out and cracking along the peripheries of the settling basins. Very little vegetation is evident on the tailings, as their acidity is usually too high and they lack nutrients as well as moisture retention capability to support plant growth. Large portions of active areas are covered with mulched grass to hold in moisture and prevent dusting, creating an appearance of a freshly cut field. Non-operating tailings areas that have been re-vegetated appear as grassy fields, the tailings being hidden quite effectively. However, only a small percentage of the inactive tailings in Elliot Lake have been re-vegetated. Lime and fertilizers, too, may be added to the surface of tailings or the tailings may be covered with soil. Regardless, it is not known whether or not follow-up maintenance procedures can ever be discontinued without jeopardizing the rehabilitated tailings environments. Non-rehabilitated areas are similar to active areas in that they resemble deserts. The most visible portions of any tailings site, whether active or inactive, are the dams. These can range up to 10 m in height and are clearly visible from surrounding land.

Future land uses

Short-term uses

People work daily on the tailings areas still in operation at Elliot Lake maintaining the sites and constructing new containment areas. Several other activities have developed on the non-operating tailings areas. Because access is free to all those who trespass and venture out on the tailings, and no warning signs are posted to ward the public off, tailings areas have been used for overnight camping, racing areas for dune buggies and dirt bikes, and cross-country skiing areas. The Nordic tailings area has a rifle range established by a club from the town. In addition, this site was once used as a temporary

Photo 6. Work on tailings.
I.G. Redmond

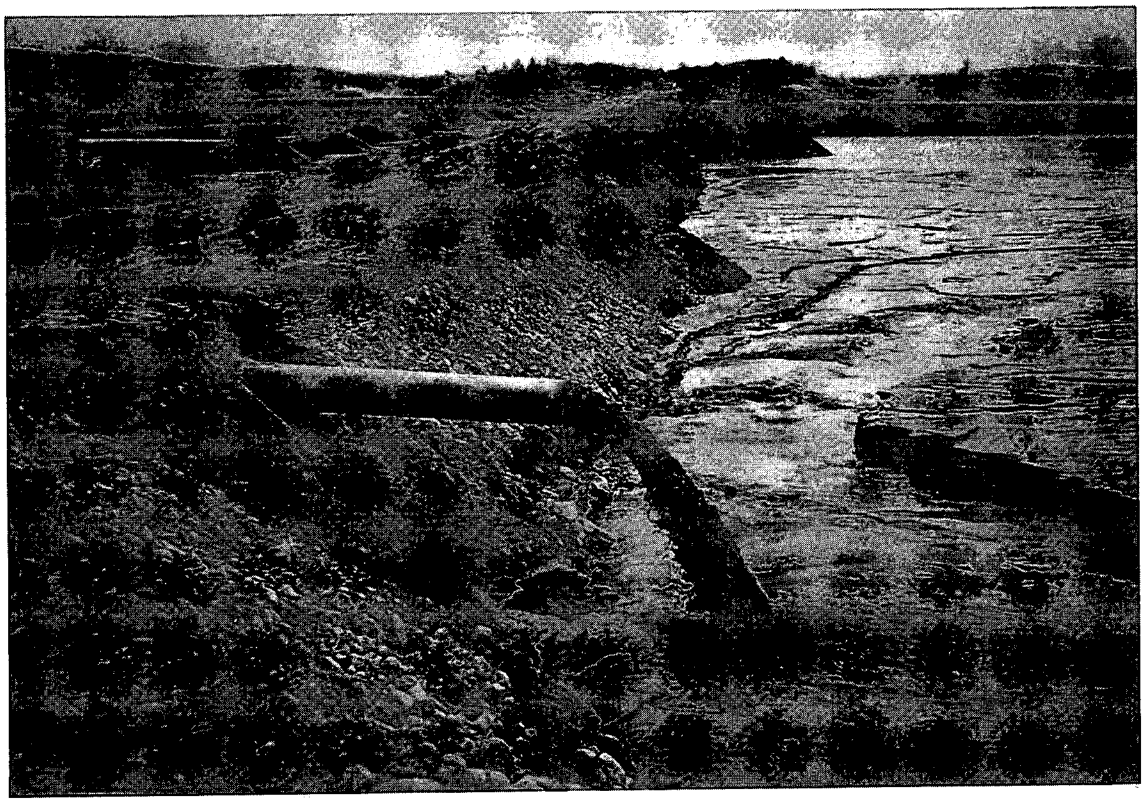


Photo 7. Tailings.
I.G. Redmond

airport while the local airport was under repair. None of these uses, however, entail any permanent structures. Studies are being carried out to determine if an inactive site, such as the Nordic one, could serve as a sanitary landfill site for the town of Elliot Lake.

A tailings spill area near the Milliken mine site has been dredged, cleaned up, re-vegetated, and landscaped to provide for two baseball diamonds, a soccer field, and a horse riding park. To apply such a method to an entire tailings area would probably be impracticable.

Long-term uses

The radioactive nature of the tailings is recognized, and it is therefore generally accepted that no permanent buildings will be permitted on a tailings area. No long-term land use decisions have been made, but several ideas have been suggested.

Those who view the radioactivity as a minor problem see the tailings areas being used for productive purposes. In the early years of operation, tailings had been used for road building and parking lot construction, because of their sand-like composition, but uses of this nature are now frowned on. Reforestation of the tailings for timber production has been suggested. The potential agricultural use of the tailings, once a layer of top-soil has been established, may be substantial. If deemed economically viable, and this appears unlikely, any crop capable of being grown in the Elliot Lake climatic region could be grown on the tailings. The possibility of contaminant uptake into the vegetation would have to be carefully studied before such a program could be attempted. Even if it proved successful, such productive uses may be prohibited by the Atomic Energy Control Board. In addition, the public's concern about radiation would also have to be overcome before any productive uses would be fully accepted.

In the short term the storage of tailings with continued maintenance and effluent treatment will ensure environmental protection. Eventually, however, the resolution of the question of storage versus the actual disposal of tailings will clarify questions of future land uses. It is only at that point in time that more meaningful statements of long term impact on land use can be formulated for Elliot Lake as well as for all other uranium tailings sites across Canada. Formal mine close-out procedures will begin to provide a clearer definition of the long-term land repercussions.

GLOSSARY OF TERMS

Backfill:	Rock or other waste material used to fill and support the walls of a mine.
Background radiation:	Radiation in the human environment from naturally occurring radioactive elements and cosmic radiation.
Barren solution:	The solution in the uranium milling process that has passed through the ion exchange column and thus is "barren" of uranium.
Curie:	The unit used in measuring radioactivity, equal to the quantity of any radioactive material in which the number of disintegrations per second is 3.7 X 10^{10}.
Disposal:	Confinement of radioactive waste in such a way that its separation from the biosphere is expected to be permanent, with no need for further surveillance.
Fission:	The splitting of a heavy nucleus into two approximately equal parts, accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously, but is usually caused by nuclear absorption of gamma rays, neutrons, or other particles.
Fuel cycle:	The complete series of steps required for supplying fuel for nuclear reactors. It includes mining, refining, the fabrication of fuel, its use in the reactor, and the management of spent fuel and radioactive wastes.
Groundwater:	Water that exists or flows below the earth's surface.
Half-life:	The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form.
High-level wastes:	Spent reactor fuel.
Igneous rock:	Rocks formed by solidification of molten material.
Leaching:	A chemical process used in milling for the extraction of valuable minerals from ore; also the natural process by which groundwaters dissolve minerals, thus leaving the rock with a smaller proportion of some of the minerals than it contained originally.
Low-level waste:	Solid radioactive waste consisting of contaminated machinery, gloves, aprons, tissues, paper, etc.
Radioactive waste:	Any material containing or contaminated with radionuclides in concentrations greater than would be considered acceptable for uncontrolled use or release, and for which there is no foreseen use.
Radioactive waste management:	All handling, storage, and disposal operations carried out on radioactive waste.
Radionuclide:	Any nucleus that undergoes radioactive decay.
Reactor core:	That part of a nuclear reactor containing the nuclear fuel.
Spent fuel:	Irradiated reactor fuel that has been removed from the reactor core.
Storage:	Temporary or interim confinement of radioactive wastes, in the expectation that a disposal method will be developed.
Tailings:	Material rejected from a mill after the recoverable valuable minerals have been extracted.
Uraninite:	A uranium mineral carrying a high percentage of uranium oxide.
Waste management site:	The area intended to accept the radioactive waste management facilities. If the waste management area is located within the site of some other nuclear facility, it comprises that area set aside for the management of radioactive uses.
Waste rock:	Barren rock in a mine, or at least material that is too low in grade to be of economic value.
Yellowcake:	The final product of a uranium mill, a semi-refined uranium concentrate extracted from raw uranium ore.

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SANITARY LANDFILLS

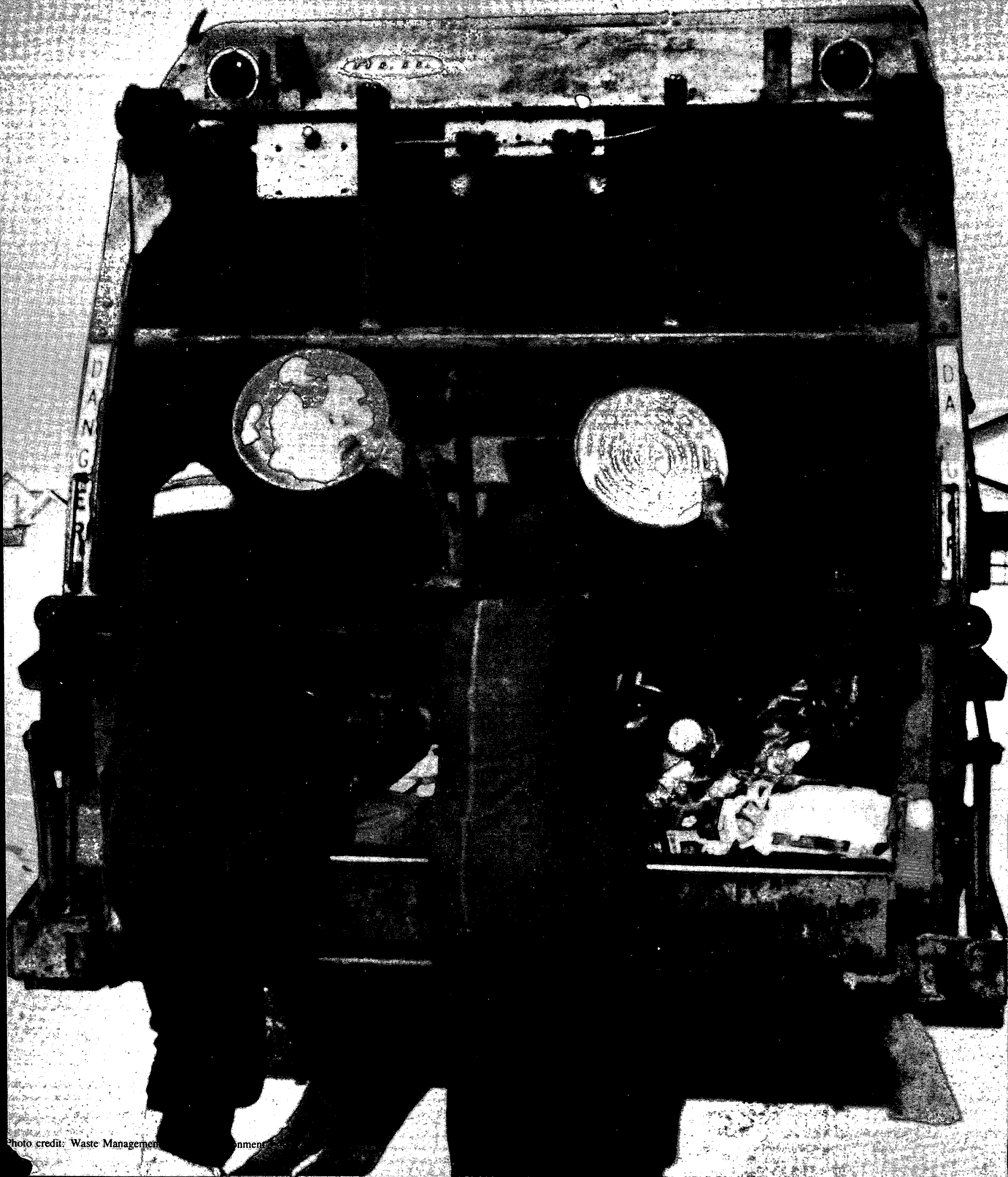

Photo credit: Waste Managemen [illegible] onment

SANITARY LANDFILLS AND THEIR IMPACT ON LAND

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INTRODUCTION

Waste management is much more than just 'getting the garbage to the curb'; yet for most Canadians once the garbage truck rounds the corner the waste magically disappears. Seldom does the average individual ask "where does it go from here?" In fact, the collection stage is only the first step in the disposal of unwanted goods. Where do the wastes go?

In the past, as well as today, man has used various means to dispose of wastes; he has burned them and discharged the products of this process into the atmosphere, buried them in the ground, and used the waters and oceans as sewers. Although the equipment used for the collection and handling of wastes has become more sophisticated over the years, the land still remains the most common receptacle for wastes.

This chapter of the report will focus on one specific method for the disposal of wastes on land: the sanitary landfill. It will look at sanitary landfills from coast to coast to see how Canadians site, operate, and rehabilitate them and will consider the effects of such actions on the land resource.

The precise technical definition of sanitary landfill operations has been stated as:

> "*A method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary*" (Environment Canada, 1977*a*).

This technical explanation originated with the American Society of Civil Engineers in the 1950s, has received worldwide acceptance, and is the operational definition used in this report. It is important to recognize that to be considered a sanitary landfill, a layer of earth must be applied at least at the conclusion of each day's operations. This small but significant qualification should be kept in mind throughout the remainder of this section of text.

To appreciate the stresses that sanitary landfills exert on land, it is important to see where and how they fit into the stress on land study. The contents of a sanitary landfill are predominantly solid wastes. These wastes are substances remaining from society's activities for which no perceived use or value is attached at the time of disposal. Yet perceptions do change; - some wastes of yesterday constitute a resource today. Used newspapers, metals, and glass are three common contemporary examples of such changing perceptions. Nevertheless, sanitary landfills are a collection of discarded products that are buried. Burying remedies the waste problem because wastes are biodegradable and decompose to their basic elements through natural bacterial processes.

Landfilling has land-use repercussions in that it prevents a particular parcel of land from being used for some other purpose; however, sanitary landfills are only a transitional land use. Apart from the constructional nature of the activity it can affect surrounding land uses and users. Sanitary landfills introduce additives to the land by concentrating large volumes of waste or residuals in a single location.

In time these wastes or their residuals have changed in nature and in volume, making the whole disposal process increasingly complex. Prior to the 20th century, garbage originated from natural products, such as cotton and food, which could be dealt with quite easily by nature's biological processes. Today, society's wastes have changed and some break down at a much slower rate or not at all. Plastics and other petroleum-based products, synthetic materials, glass, aluminum, rubber, corrosion-resistant coatings for metals, and other complex materials constitute a measurable part of our garbage.

As the nature of the wastes changed over time, so did the various methods of waste disposal. Until about 1500 A.D. garbage was simply dumped, sometimes on land and sometimes in the water, conveniently close to where it was generated. The "out of sight, out of mind" philosophy, which is still operating today, can be traced back at least to ancient Rome. A sign posted there read: "Take your rubbish further or you will be fined". During the Middle Ages, fire was used as a means of disposing of wastes; it was not uncommon to see a series of dumps burning just outside the castle or city walls. These types of disposal were far from ideal and wastes and garbage were a breeding ground for disease. In fact, the spread of the plague can be attributed in part to these practices.

A chronology of some of the changes that took place in waste disposal is shown in Figure 1. A number of factors contributed to changing the

Photo 1. This garbage dump at the Toronto waterfront in 1922 illustrates the waste disposal technique and philosophy that existed at that time.
PA-84921/Public Archives Canada

methods of waste disposal. Decomposing wastes were a medium for transmission of disease. The increasing volumes and the potentially harmful characteristics of wastes changed the problem from an individual to a collective concern; this was a key change of attitude. Finally, certain detrimental environmental effects of improper waste disposal were recognized and regarded as socially undesirable and unacceptable.

FIGURE 1.

Milestones in waste disposal

1559: first irrigation system for sewage established in Prussia
1856: first collection of refuse at public expense in the United States
1859: Royal Commission on Sewage Disposal in England recommends application of town sewage on land to avoid river pollution
1874: first garbage incinerator in England
1916: first sanitary landfill established in England
1930s: U.S. cities experiment in compacting garbage before burial
1940s: garbage compaction practised
1950s: first sanitary landfill in Canada

In Canada, the first sanitary landfill was established in the late 1950s in the Metropolitan Toronto area. In the 1960s, many Canadian cities began using this technique. The principal reason for adopting the sanitary landfill was that it was a significant improvement on the open dump yet relatively inexpensive. Also the health problems posed by smoke from the burning of refuse and by vector migration were controlled. Most municipal wastes could be disposed of in this manner and the operation could be carried out relatively quickly.

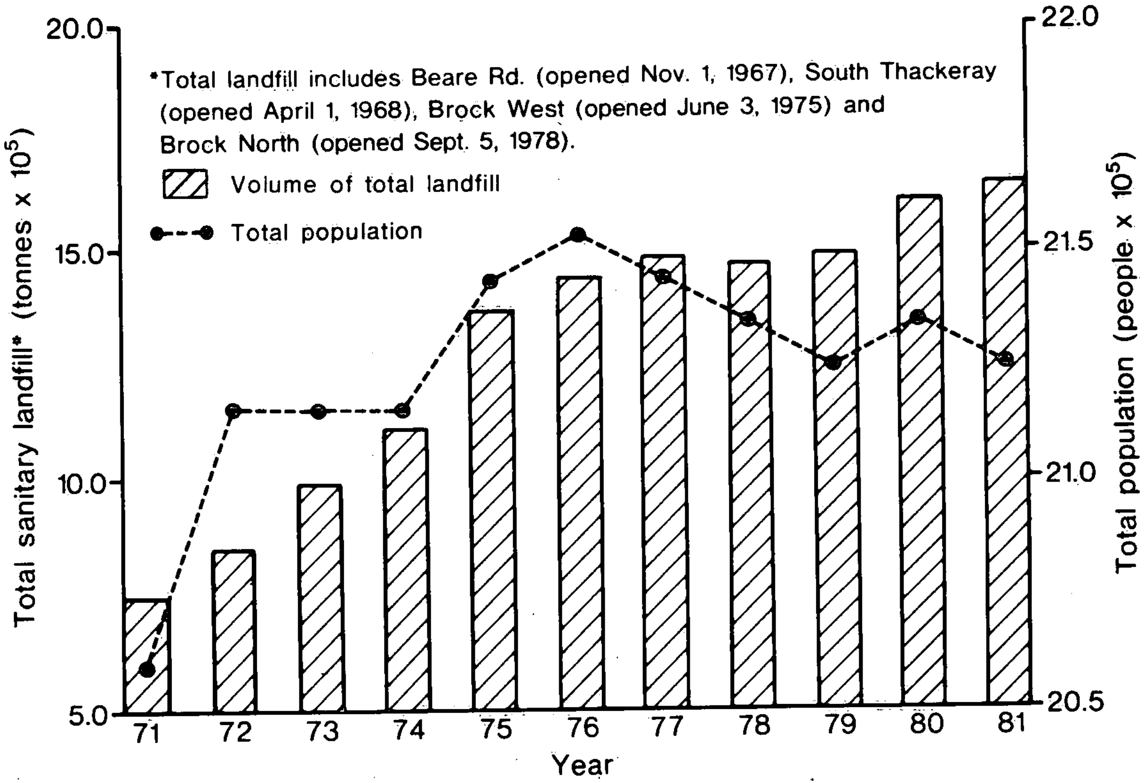
How is land stressed?

The volume of waste being generated is continually increasing. As an example, the increases in wastes and in population over the last decade in Toronto are shown in Figure 2. It is not only how many people live in Toronto but how much garbage Torontonians are throwing out that poses land-use planning problems.

The ideal land areas needed for waste burial are becoming increasingly difficult to acquire. All forms of organized settlement in Canada, from the smallest village to the largest city, generate wastes which require land area for burial. Such sites cannot be too distant from the point of generation. The size of such landfills may vary from a few hectares to as much as 150 ha. Consequently, in and close to the many populated centres there are often competing forces for land for waste disposal and other urban uses.

FIGURE 2.

Metropolitan Toronto: sanitary landfill and total population 1971-1981



Source: The Municipality of Metropolitan Toronto 1982. Metropolitan Works Department, Toronto, Ontario.

Land, air, and water pollutants are generated with the burial of a variable mix of biodegradable and non-biodegradable products. As the process of decomposition begins, water percolates through the buried decomposing or soluble wastes and forms leachates. These are often highly contaminated with metals, bacteria, and salts, which in turn can pollute surrounding surface waters, groundwaters, and land areas if not properly controlled. Decomposing organic wastes also generate methane gas, which can be explosive in certain concentrations. Certain wastes may also contain components of hazardous materials whose presence may have long-term harmful effects on the land.

There are also certain land-use incompatibilities associated with sanitary landfills. Buffer zones may be required to separate them from adjoining land uses. For example, landfills are required to maintain a certain distance from food processing or serving establishments, hospitals, and cemeteries. The past mismanagement of dumps and some supposed sanitary landfills continues to cause many residential property owners to oppose any plans to site a sanitary landfill adjacent to or in the vicinity of their neighbourhood.

Perception, too, plays a large role in the issue of land-use compatibility; landfills fall into the category of "locally undesirable land uses" or LULUs (Popper, 1981). Concerns arise from the publicity given certain sites, where problems of odour, noise, aesthetics, and excess traffic have occurred as a result of either the size of the operation or improper management and thus have affected property values and use.

Industrial activities tend to be the most compatible land-use neighbours of landfills. Sanitary landfills serving urban needs are frequently found in rural surroundings, as the search for waste disposal sites moves farther out from the centre of generation. Because of the low intensity of rural land use and the small population directly affected, landfills in such locations are often perceived as being more compatible. Furthermore, the countryside can be an area where large blocks of land are available for purchase at relatively low cost.

The lifespan of a sanitary landfill is another stress on land. Although sanitary landfill operations may have ceased and the land surface rehabilitated, the contents of the landfill may linger for a century or more beneath the surface. Some wastes may take hundreds of years to decompose whereas the surface may have had a series of land uses planned and implemented. Once a sanitary landfill is filled to capacity and a layer of soil of sufficient depth is spread on the surface, activities such as agriculture, recreation, and even limited construction of buildings may begin, subject to strict control. In contrast, many completed sanitary landfills do not have specific land uses re-established and remain simply as open space. Nevertheless, the physical contents—the garbage—of a sanitary landfill may continue to generate methane gas and leachates, which must be carefully controlled when necessary, over an extended period. The succession of land uses that may occur on the surface must take into account that the contents of a sanitary landfill remain invisible, yet their impact can continue for decades.

Increasing volumes of wastes, competition for land, the growing complexity of materials that constitute day-to-day garbage, the resulting land-use concerns and impacts, and the prolonged periods of degradation required by wastes of increasing durability, means that the activity of sanitary landfilling poses many stresses on the land.

Scale

The sanitary landfill method of disposal is used in all provinces of Canada and is certainly environmentally superior to its predecessor, the open dump. The distribution of sanitary landfills closely parallels that of the population, which is, after all, the garbage generator. Unfortunately, disposal of wastes by sanitary landfilling as defined, is still rarely used.

Sanitary landfills have been identified in all provinces and jurisdiction for them rests directly with the individual provinces. Table 1 provides some national statistics on the occurrence of sanitary landfills based on a survey of the provincial departments responsible for them. The table indicates the wide range of sizes of sanitary landfills, from 2 000 m^2 to 163 ha, that exists throughout the country. There is also some variation in the number of sanitary landfills per province: Prince Edward Island records two whereas Quebec reports 56. This variation arises not only from the differences in waste operations in each province, but also from the size of the province, its population, and the provincial definition of what constitutes a sanitary landfill. Sanitary landfills are not the only method of waste disposal currently practised; dumps, modified landfills, and secure landfills are among the other burial methods of waste disposal in use. (A section at the end of this chapter deals with the special circumstances of waste disposal encountered in Canada's North, principally the Yukon and Northwest Territories.)

TABLE 1.

Some national statistics on sanitary landfills

Province/Territory	Number of existing sanitary landfills	Size range (ha)	Total area occupied by sanitary landfills (ha)
British Columbia	20	N/A	N/A
Alberta	14	N/A	N/A
Saskatchewan	10	N/A	N/A
Manitoba	8	1.0 to 163	550
Ontario	N/A*	0.2 to 100	N/A
Quebec	56	0.6 to 55	730
New Brunswick	13	4.0 to 20	120
Nova Scotia	5	12.0 to 146	325
Prince Edward Island	2	16.0 to 24	40
Newfoundland	15	2.0 to 40	190
Northwest Territories	+		
Yukon	+		

N/A - Not available.

* Because the definition of sanitary landfill in the Province of Ontario differs from that of this study, the figures are unavailable.

+ Conditions do not favour such operations.

Source: The provincial departments responsible for sanitary landfills.

Research indicates that figures on waste generation have never been compiled on a national basis. Some approximations of the quantities of wastes can be made and give some measure of the size of the problem. The quantity of municipal garbage in 1970 was estimated at 15 million tonnes annually (Environment Canada, 1976). This means every Canadian contributed about 2 kg of garbage daily or 717 kg annually. The generation of waste can range from as little as 0.3 kg to as much as 3 kg per capita (K. Childs, personal communication, 1981). A recent survey indicates rates of waste generation in Ontario (Table 2). All this waste has potentially a very large land impact. Webber in 1973 stated: "The city of Toronto produces about 1.5 million tons [1.4 million tonnes] of waste per year...[and it] would cover a 100-acre [40-ha] farm to a depth of ten feet [3 m]." In many centres throughout Canada sanitary landfills are the recipients of this waste. Because the compacted wastes in sanitary landfills are covered by soil, at a ratio of 1 part soil to 4 parts garbage, 4 m of garbage would now grow to nearly 5 m with the addition of soil cover.

A close correlation has been observed (Geoff and Rogers, 1973*b*) between a nation's standard of living and the amount of solid waste it generates. This correlation also reflects the 'disposable society' that has arisen in the most industrialized nations; everything from cars to containers has a planned obsolescence or is dis-

TABLE 2.

Average waste generation per person for 38 Ontario municipalities in 1980*

Population	Number of municipalities	Average waste generation per person (kg)
> 250 000	8	1.04
100 000 - 250 000	8	1.09
50 000 - 100 000	8	0.95
25 000 - 50 000	8	0.95
< 25 000	6	0.86

* Based on sample survey for residential and light commercial solid wastes only.

Source: Hare, 1982.

TABLE 3.
Selected advantages and disadvantages of sanitary landfills

	Advantages	Disadvantages
Political	Once in operation or successfully completed and rehabilitated to a popular land use such as recreation, the entire process can be an example of excellent planning.	Sites outside cities are usually within a different political or governmental jurisdiction thereby requiring co-operation and planning across political boundaries. The matter often becomes politically contentious and a major issue in city, municipal, or provincial elections. Political considerations may over-ride environmental or engineering factors. Research necessary to satisfy governmental requirements is often time-consuming and sometimes considerable delays may be experienced before installation becomes operational. Improperly operated facilities may return to haunt politicians.
Social	Sanitary waste disposal is a necessary and desirable service for a community. Reduction of rodents and flies due to sanitary procedures improves public health.	Individuals exhibit "not in my backyard" syndrome. Public opposition, justified or not, can effectively delay site selection process or may even force a better site, from an environmental point of view, to be rejected in favour of a more publicly acceptable site. Public's lack of technical knowledge and its misconception that sanitary landfills are open dumps contribute to fears, confusion, and sometimes opposition. Health concerns may be transferred from wider urban scene to landfill site and vicinity.
Operational	May be operated in most temperate climates. Greatest flexibility to accommodate peak loads, varying quantities, and different collection schedules Can be brought into operation in relatively short period because it does not require construction of major infrastructure. Can receive most types of solid wastes, thus eliminating the need for separate collections by collection vehicles. Operation can be terminated quickly.	Winter operations in some climates pose difficulties. Sanitary landfills can not be operated in areas of continuous permafrost. Initial steps of official and public approval, engineering and planning operations can be very time-consuming and can delay operational start.
Economic	Most economical method of sanitary waste disposal, given the availability of appropriate land within reasonable haul distance. Economical even for smaller communities Initial capital investment is low compared to other waste disposal techniques. Can be completed or terminated, without a great capital loss in land or equipment; land may be rehabilitated to other uses and equipment can be used for a variety of other municipal operations. Minimum capital investment required for permanent structures.	More expensive than operating open dumps. Transfer operation costs may be high if distance between sources of garbage and sanitary landfill is great. Prevention of groundwater pollution from leachate and control of methane gas may be expensive. Costs are increasing with increases in population, consumption of consumer goods, complexity of wastes, land costs, collection and transportation costs, etc.
Environmental		
Aesthetic	Centralized sanitary waste disposal site greatly improves aesthetics in entire urban or service area, improving environment around homes, businesses, and industries Properly designed and operated sanitary landfills have minimal problems with odour, noise, dust, blowing litter, vectors, and birds. Through use of berms and other landscape barriers, sanitary landfills can be operated less obtrusively than incinerators and open dumps.	Transfer of aesthetic concerns from entire urban or service area to landfill site and vicinity. Odours, noise, dust, blowing litter, vectors, and birds are major problems at improperly operated sites and may still be nuisances at well-run sites. Non-natural landscape during operation and occasionally after completion.

TABLE 3. (*continued*)
Selected advantages and disadvantages of sanitary landfills

	Advantages	Disadvantages
	Completed and rehabilitated sites can be an aesthetic asset to community.	During site preparation and operation there may be disruption or total removal of natural vegetation. Landfill gases can impair or destroy trees and other vegetation after completion of landfill.
		Abandoned and unrehabilitated sanitary landfill sites are eyesores.
Pollution	Properly managed sanitary landfills incorporate special engineering techniques, as required, to control methane gas and leachate. Both land and groundwater can thus be protected from contamination.	Leachate and methane gas are concerns at all sites; their environmental impact can range from nil (if properly controlled) to serious.
	Properly sited, designed, and operated landfills minimize air, water, and land pollution.	
	Sanitary landfilling is a single-process/complete waste disposal method that does not require subsequent rehandling of wastes, as do incineration or composting.	
Wildlife	Unlike dumps, which attract animals such as bears, sanitary landfills minimize animal-man confrontations.	Forced relocation of native animal and bird life in area because of disruption of habitat and watercourses, landscape alteration, and noise.
		Poorly operated facilities may attract certain species such as bears, seagulls, and rats.
		Habitat may be destroyed by uncontained pollutants.
Other Land Aspects	Sanitary landfills require less land than dumps because refuse is compacted.	Sites require sizable and increasing amounts of land.
	Permit the reclamation and subsequent re-use of submarginal lands or lands that were undesirable because of their previous condition (strip mines, gravel pits, and quarries, ravines, or just poor land).	Sites compete with other urban requirements for land, often close to or within urban communities.
	When rehabilitated, former sanitary landfills can have a variety of uses, including recreational (parks, ski hills, playing fields, golf courses, etc.) and in some cases storage or parking.	Possible threats from leachate, methane gas, and land settlement restrict ultimate uses of sites and surrounding land uses.
	Land values of surrounding parcels are largely unaffected during operation.	Land-use impacts on surrounding land can be far-reaching, as in the case of locating an airport.
	Land values of surrounding land are often enhanced if completed site is rehabilitated to recreation.	Public perceptions and fears of negative impact on land values are widespread and are occasionally fulfilled.

posed of after a single use. Labour costs are high, therefore most frequently it is cheaper to throw away articles rather than repair them. This, of course, generates the input to, and the need for, sanitary landfills. Even with better resource use, including some recycling or incineration processes, there remains a need for residue disposal, this can readily be met by the sanitary landfill.

Advantages and disadvantages

Sanitary landfill is a recommended method of waste disposal from the standpoints of health, environment, economics, and engineering. Across Canada, community, municipal, and provincial policies and practices are moving away from open dumps to regional sanitary landfills. Nevertheless, enthusiasm and support for this technique are tempered by questions about pollution, land-use concerns, and individual rights in specific cases. The advantages and disadvantages of sanitary landfills have been well documented (Flockton, 1971; Glysson *et al.*, 1972; Baum and Parker, 1973*b*; Stearns and Ross, 1973; Pavoni *et al.*, 1975; Rimberg, 1975; Reindl, 1977*b*; Stone, 1977). These are summarized in Table 3.

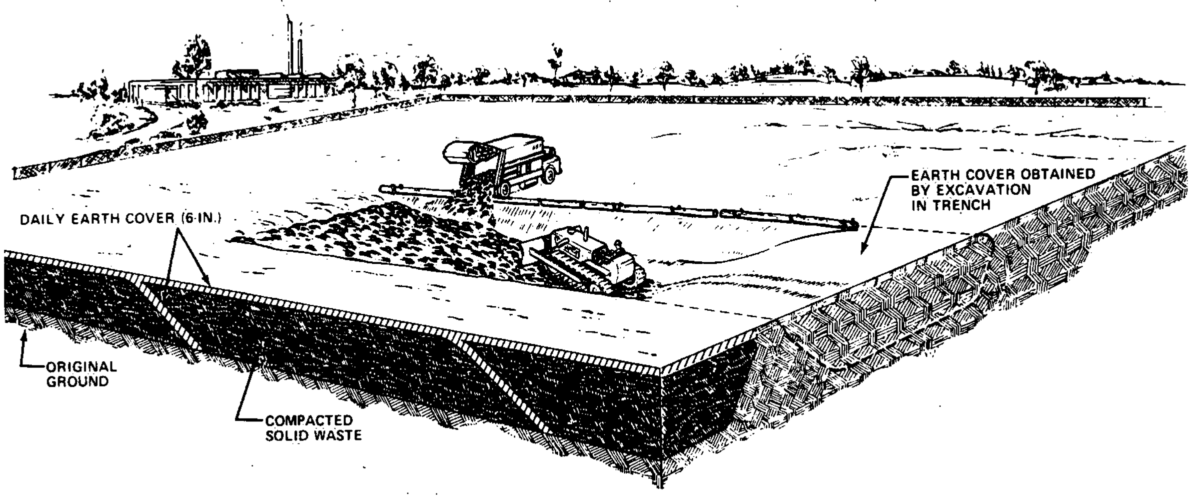
Types of sanitary landfilling

There are two basic types of sanitary landfilling, trench and area. Any other technique, including the popular ramp, is a variation of these two methods.

> The trench method: *"In the trench method of sanitary landfilling, a long narrow excavation is made in the earth and the soil removed from this excavation is stockpiled. Wastes are then deposited at one end of the excavation on a sloped end of the trench. The refuse is spread on a rather shallow inclination (usually about 3 horizontal to 1 vertical), and is then compacted by the placement/compaction equipment used at the site. At the end of the day's operation, the compacted layers of refuse are covered with a layer of soil taken from the stockpile of material removed in the original excavation. When the entire trench has been filled with refuse, a thicker final cover layer is placed over the completed deposit of refuse"* (Pavoni *et al.*, 1975).

This technique is most appropriate where the geology is suitable, permitting deep excavations, where there is a deep layer of impermeable clay beneath, and where there is a deep layer of suitable cover soil. The trench method is most suitable in areas of flat or very gently rolling topog-

FIGURE 3.
The trench method



Courtesy of: United States Environmental Protection Agency.

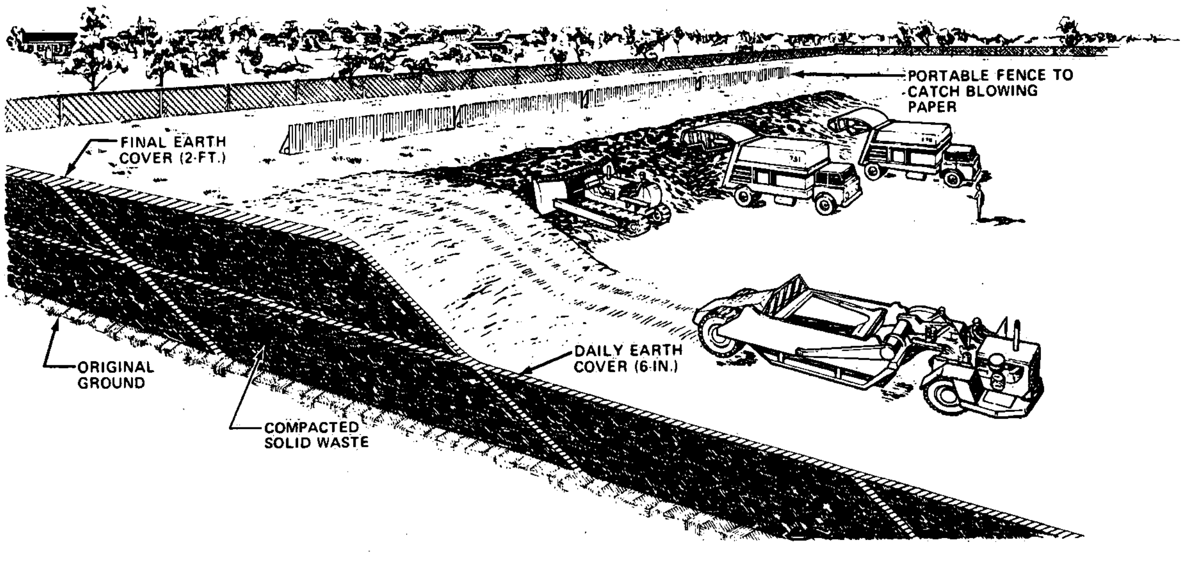
raphy and is excellent for smaller landfill operations (Figure 3).

This trench method has a number of advantages, one of which is that surplus soil excavated from the trenches may be stockpiled for later use, particularly if the area method is to be used on top of the completed trench-fill site. Problems of blowing litter are minimized if placement of the refuse is made at the end of the trench and spread rather than dumping it over the side.

> <u>The area method</u>: *"In the area method of sanitary landfilling, in contrast to the trench method, refuse is dumped on an undisturbed existing ground surface; the only prior operation in the area-method landfill may be surface removal of top soil and highly organic material (humus) suitable for final cover. After the refuse is dumped from collection and transportation vehicles, it is spread over the ground surface in a uniform layer and then compacted to a higher density. The compacted layer of refuse is covered with soil at the end of an operational day or when the deposition area is filled. When the final layer of refuse has been placed and the entire site is filled, a final cover layer of greater thickness is placed over the completed fill"* (Pavoni *et al.*, 1975).

The area method (Figure 4) is employed even where the groundwater table is at or near the ground surface, precluding deep excavation for refuse burial. It is usually employed where the terrain is irregular and is particularly useful where natural or man-made depressions are to be used for landfill. The area method can also be employed on sites that have been previously filled and levelled using the trench method. The main disadvantages are that cover material must usually be trucked in from other locations and that extra care is required to control litter, dust, and vectors over the larger working face.

FIGURE 4.
The area method



Courtesy of: United States Environmental Protection Agency.

> <u>The ramp method</u>: *"The ramp method is a hybrid technique combining features of both trench and area methods of landfilling. Before refuse deposition is begun, a small excavation is made in front of the proposed face on an existing slope. The soil removed in this excavation is stockpiled nearby. Refuse is then deposited on the face of the slope, spread and compacted by standard landfilling equipment, and then covered with the soil which had been stockpiled from the preceding excavation. This process is repeated again and again at the face of the newly created slopes so that a succession of slopes are produced in a line across the landfill site. Because of this successive technique, the ramp method has also been called the 'progressive slope' method"* (Pavoni *et al.*, 1975).

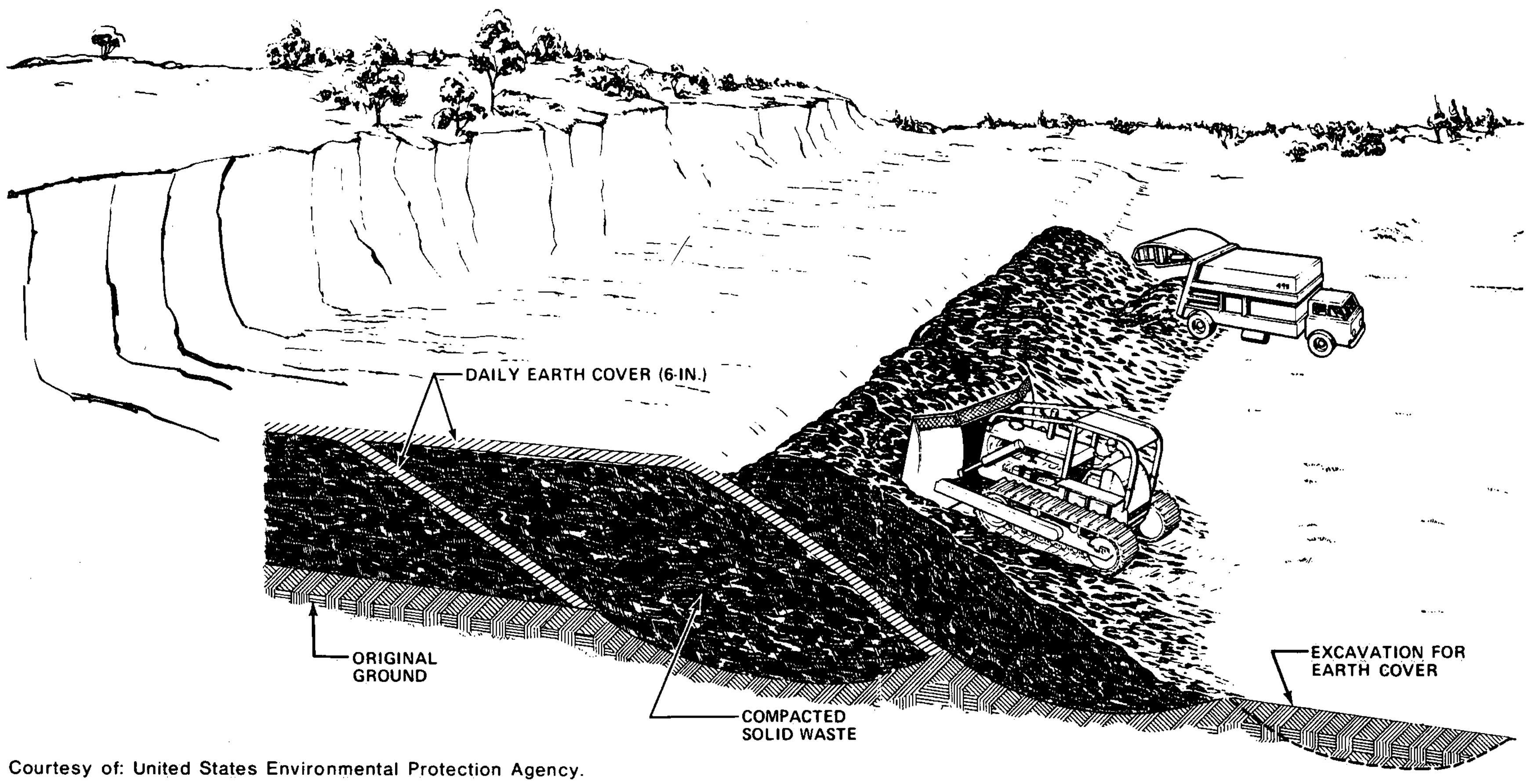
This variation is the most common combination of the two basic methods (Figure 5). One great advantage is that the excavation made in front of the working space provides not only the depression for refuse deposit but also the cover material. It is generally more economical than the area method as it requires no transportation of cover material and allows for a certain amount of excavation below the original ground level (Hagerty *et al.*, 1973).

Legislation

Jurisdiction over sanitary landfill siting, operation, management, and closure rests with the provinces. Provincial legislation specifically enables certain departments to oversee sanitary landfills. Table 4 itemizes legislation on sanitary landfills in a comparative form. All provinces except Prince Edward Island have legislation that controls waste disposal practices; frequently, however, sanitary landfills are only one method of waste disposal specified in the legislation. In the majority of provinces the respective departments of environment serve as the agency responsible. In Prince Edward Island, where no formal legislation exists, the Department of Community Affairs is responsible. In Saskatchewan the provincial Department of Health is the responsible agency, although advice on sanitary landfills is still obtained from the Department of Environment. A similar situation exists in Alberta where the departments of Health and Environment work in close co-operation. It is not only the land impacts associated with waste disposal that are of concern but also environmental deterioration and its repercussions on human well-being.

In those provinces with established legislation, permission to site, establish, and operate a

FIGURE 5.
The ramp method



Courtesy of: United States Environmental Protection Agency.

waste disposal facility, including sanitary landfills, must be formally secured in writing from the department responsible. This form of 'permit system' establishes a means of assessing environmental factors and stopping operations if prescribed operating conditions are violated. Frequently, mutual agreement is reached between the province and the operator of a site on the specific conditions to be maintained, but conditions can ultimately be dictated by the provincial department responsible.

Associated with the provincial acts are guidelines and regulations. Their purpose is to set out the siting, establishment, and operating details; however, these guidelines and regulations are not uniform in content nor are they mandatory, or uniformly enforced. Close examination of the land aspects in Table 4 indicates the variation in standards. For example, although all provinces recognize buffer zones to separate the sanitary landfill site from all adjacent land uses, for aesthetic or environmental reasons or for containment of contaminents within the site boundaries, such zones vary in width. For example, distance to the nearest dwelling varies from 402 m in Manitoba, to 800 m in Nova Scotia, and 1 600 m in Newfoundland. The dimensions of buffer zones are not specified in the regulations of many provinces.

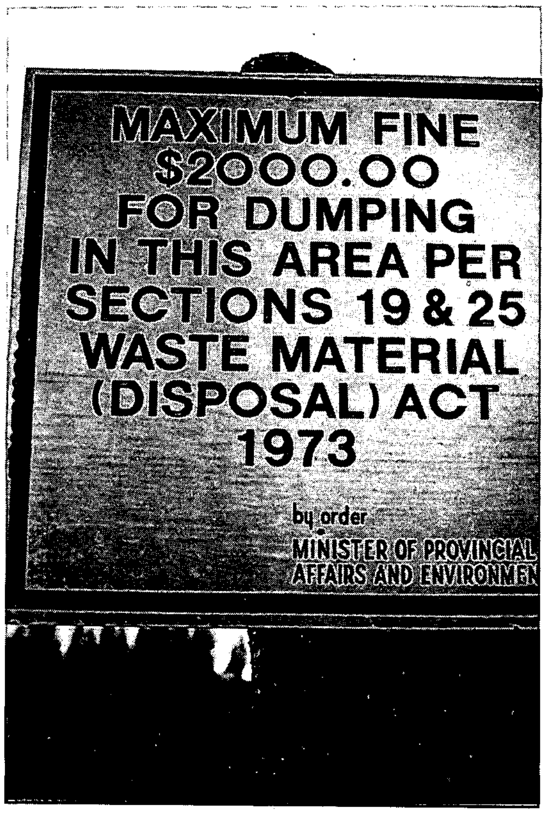


Photo 2. As seen in this sign in Newfoundland, provincial legislation may specify fines for dumping or other inappropriate waste disposal activities.
Waste Mangement Branch, Environment Canada

LAND IMPACTS OF SANITARY LANDFILLS

Direct land impacts

"There is no question that the operation of a sanitary landfill significantly affects the environment" (Stearns and Ross, 1973). In view of this statement, it is surprising to learn that so little research has been done on the land-impact aspect of such facilities. It is understandable that the technical and engineering aspects are more advanced because of the primary concern for long-term health and safety. In the past, however, land resource issues received scant attention. Fortunately, today's sanitary landfill projects frequently incorporate an impact study as part of the site selection, design, operation, and rehabilitation processes, thus helping to minimize potential land impacts.

Landscape alteration

> *"During the active life of the landfill, land forms are constantly changing. Vegetation is removed and roadways are constructed...In all cases, the overall appearance and drainage characteristics in the vicinity of the fill are altered significantly"* (Stearns and Ross, 1973).

TABLE 4.
Provincial legislation relating to sanitary landfills

Province	Applicable Act(s) and date enacted	Departments responsible	Type of approval
British Columbia	Waste Management Act c. 1982	Ministry of Environment, Waste Management Branch	'Permit system'; approval from Director of Waste Management or Regional Waste Manager
Alberta	Public Health Act 1980; 1972 with amendments	Provincial Board of Health assistance from Department of Environment	'Permit system'; from Provincial Board of Health
Saskatchewan	Public Health Act R.S.S. 1978, Chapter P-37	Department of Health	'Permit system'; final approval from Minister of Health and approval from Minister of Environment who ensures water pollution control measures are adequate
Manitoba	Clean Environment Act 1972	Manitoba Environment	Approval from the Department
Ontario	Environmental Protection Act 1980	Ministry of the Environment	'Permit system'; approval from Director, Environmental Approvals and Project Engineering Branch
Quebec	Environment Quality Act 1972	Environnement Québec, Service de la Protection de l'environnement (Environment Quebec, Environmental Protection Service)	'Permit system'; from Director, Environmental Protection Service
New Brunswick	Clean Environment Act 1973	Department of the Environment	'Permit system'; from Minister of Environment
Nova Scotia	Environmental Protection Act 1973	Department of Environment	Approval from the Minister
Prince Edward Island	None	Department of Community Affairs	As local circumstances dictate
Newfoundland	Waste Material (Disposal) Act 1973; with 1976 amendments	Department of Environment and Department of Municipal Affairs	'Permit system'; approval from Waste Disposal Committee

Source: Data obtained from the provinces.

	Land aspects specifically recognized in guidelines or regulations					
Specific regulations or guidelines	Buffer zones	Soil suitability	Compatibility of land use	Geologic factors	Transport	Ground and surface waters
Pollution control objectives for chemical and petroleum industries; mining, smelting, and related industries; forest products industry; food processing; agricultural and other miscellaneous industries; municipal waste discharges	Yes	Yes				Yes
Design and operating standards (1972)	Yes	Yes	Yes	Yes	Yes	Yes
Waste Management Regulations, 1972	Yes	Yes	Yes	Yes	Yes	Yes
Regulation 208/76	Yes	Yes	Yes	Yes	Yes	Yes
Guidelines for the establishment, operation, management, maintenance, and closure of landfilling sites Chapter 86 Part V of the Environmental Protection Act and Regulation 309 (formerly Reg. 824) state the regulations on waste management	Yes	Yes	Yes	Yes	Yes	Yes
Solid waste management regulations	Yes	Yes	Yes		Yes	Yes
Guidelines for land disposal of solid wastes	Yes	Yes	Yes	Yes	Yes	Yes
Regulation 51(f) of Environmental Protection Act	Yes	Yes	Yes	Yes	Yes	Yes
In-house site selection guidelines	Yes	Yes	Yes	Yes	Yes	Yes
Construction and operation stipulations outlined by each certificate approval	Yes	Yes		Yes		Yes

Photo 3. The removal of vegetation and topsoil in preparation of a sanitary landfill site is an obvious landscape alteration. Even after completion of the sanitary landfill, the terrain may be noticeably different from the surrounding area.
Waste Management Branch, Environment Canada

The nature of the land impact will depend on the original topography and on the technique of filling (trench, ramp or area) selected for the site. In areas of irregular topography, the area method may be employed. If so, the filling of the depressions will result in the conversion of a rolling landscape to a flat one. The trench method may produce extensive excavations or hills where none existed previously. In either case, the natural terrain is altered, affecting not only the runoff, drainage, and erosion but also the aesthetic character.

Not only can the contouring of the landscape change but also the vegetation cover may be drastically altered. In establishing a landfill facility, preparation includes clearing trees, diverting watercourses, removing and storing cover material, and pre-grading for the construction of roads, work areas, buildings, and ditches. Such drastic landscape alteration can seriously affect the local flora. "Virtually all vegetation is destroyed during filling operations. Also, methane gas may migrate laterally to the surrounding areas outside the fill boundary itself. Presence of landfill gases in the rootzone can impair the growth of certain trees and other foliage" (Stearns and Ross, 1973). The local fauna are also affected as a consequence of total removal, damage or change of vegetation during landfill development, operation and completion.

> *"Any animal life in the fill area is forced to relocate or is killed, since forage and living areas are eventually covered with waste and earth. Also, the noise caused by heavy equipment operation and collection vehicle traffic can disrupt animal habitats for miles around. This noise is particularly bothersome to mammals and birds. In addition, leachates entering natural waters may endanger any fish present. During filling operations, non-native animals may be attracted by the garbage content of solid waste. For example, rats, flies, and seagulls are sometimes encountered, even when proper landfilling techniques are employed. These animals may displace native species that remain in the area"* (Stearns and Ross, 1973).

What happens when the facility reaches the end of its lifespan? Until very recently, little if any attention was paid to the rehabilitation, maintenance, and end use of a site. Many sites were left without proper soil cover, vegetation, or seeding. Slumping, settling, and erosion often allowed the site to become an eyesore. Such situations caused not only health and safety concerns but also environmental and aesthetic problems. Often, even if they were rehabilitated, the sites appeared to be out of place in the surrounding environment; ravines had been filled, landscapes were levelled, or hills appeared in the middle of flat terrain. At the start of operations, little thought was given to the final appearance of the site. Today, there is evidence that planning for rehabilitation and end use of the site is an integral part of the project.

In summary, a landfill facility is dynamic; the landscape is always changing as the processes of excavation and filling continue over what may be a period of 20 years or more. The sights, sounds, and smells introduced as a result of the landfill operations and the ultimate alteration of the terrain and vegetation can be considerable.

Land use

Throughout the stages of siting, operation, and rehabilitation, sanitary landfills influence land uses in many ways. The nature and extent of the impact will vary with and depend on the location of the site and whether the facility is operating or closed. There are also different impacts on the site itself and in the surrounding area. Just as the location of a new disposal facility is affected by existing land uses, the new disposal site effects certain impacts on existing and future land uses.

The establishment of a sanitary landfill requires at least the temporary cessation of the existing land use on the site. In urban centres, the displaced uses may be permanent dwellings, trailer parks, commercial businesses, industry, institutions, recreation, or agriculture. In the rural–urban fringe and rural locales, the former uses are more likely to have been agriculture, forestry, recreation, idle land, or some of the service industries that traditionally locate in these areas. It is significant that although much has been written on how land uses affect the siting of waste disposal facilities, no studies were found that examined the repercussions of displacing land uses for landfill sites.

Similarly, scant information exists on how sanitary landfills influence land uses in the adjacent areas. From the literature available and the opinions elicited, a few general observations may be made. Landfill facilities are seldom sited in the heart of urban centres because of the scarcity of land, higher land costs, greater degree of existing development, existing zoning and land-use plans, and the potential of greater opposition.

Photo 4. Several provinces prefer to locate sanitary landfills in rural, forested areas. As in this example from New Brunswick, a treed buffer zone helps isolate the site from any adjacent land uses.
Waste Management Branch, Environment Canada

In the urban periphery, a variety of land uses may be affected, and to different degrees. It is unlikely that existing heavy industry will be significantly affected. The movement of heavy equipment, as well as the dust, waste handling, and noise that may occur at landfill sites, can be likened to operations at industrial locations. However, most other land uses in the suburban areas are more sensitive to sanitary landfill siting. Residential and many commercial land uses are more susceptible to impacts from waste disposal facilities. Owners and proprietors are likely to be concerned about the possibility of declining land values and deteriorating landscape appearance. Such concerns may cause the departure of some residents or commercial operations near the site and discourage other users from moving into the vicinity. Thus, the desirability and value of any adjacent parcel of land may be reduced. However, the impacts are seldom strong enough to cause a wholesale changeover of neighbours, although some land uses may be affected.

In rural locations, where the neighbouring land is idle, is not zoned for future development, or has low capability for other uses, it is likely that a disposal facility would have less discernible impacts on adjacent land uses. However, the situation may be different in rural areas that have agricultural, forestry, recreation, wildlife, or residential uses. On current evidence, there is no significant impact on surrounding forestry or agricultural uses, assuming that proper landfill operations eliminate leachate and methane hazards. But groundwater contamination by leachate, and the subsequent pollution of well water or surface water, could be detrimental to both farm operations and rural residents. Enjoyment of outdoor recreation areas may be affected by noise, odour, or other undesirable consequences of landfill operations. Natural habitat, hence wildlife, may also be affected by waste disposal facilities.

It is a common belief that land-use impacts from landfill operations are greater in urban than in rural areas, but measurable proof is hard to find. It may be a question of perception that the impacts in rural areas are viewed as less significant. Perhaps urban residents believe that impacts are greater in their neighbourhood and less in other people's communities. Rural residents often strenuously object to their landscape being used as a recipient of urban wastes, while urban dwellers feel that the "empty" rural countryside is a natural site for garbage.

How can land-use impacts be minimized? Both provinces and municipalities attempt to address this. In New Brunswick's case, sites are located in remote rural areas, with low population densities, or on forested or unused land parcels where no existing or proposed development is planned. In Newfoundland, disposal sites are located on Crown land whenever possible. In Saskatchewan, most municipalities have been able to acquire 'waste' lands never utilized for agricultural production. In Quebec, sanitary landfills are usually established in rural or cottage areas. If the selected site is in an agricultural zone (as stipulated in the Act to Preserve Agricultural Land), an application must be filed with the Commission de la protection du territoire agricole (farmland protection commission) to de-zone the plots affected. Officials in the Province believe that because of certain stipulations in the Act, including siting constraints, buffers, and design requirements, negative impacts on adjacent lands are minimized.

Another means of reducing land-use impacts is to specify minimum distances between land uses. For example, Alberta requires a distance of 457 m between landfill sites and hospitals, dwellings, or food establishments. With regard to distance of a sanitary landfill from the right of way of any public road, New Brunswick requires 150 m for a screened site or 300 m or more if the site is open.

As one method of reducing land-use impacts and pollution problems, most provinces have guidelines or criteria that must be considered in evaluating potential landfill sites. For example, in Prince Edward Island general guidelines are used in-house to help evaluate selected landfill sites. Each factor of the guidelines is usually rated on a scale of 0–10 points, with the higher score indicating the better sites. Possible impacts on land use are the subject of several factors, such as "groundwater pollution potential", "public acceptability", "isolation from noise, dust, and odor" and "surface water pollution hazard". Even more specific are the two factors of compatibility and desirability taken from Prince Edward Island's guidelines.

1) Compatibility of Operating Site with Present Land Use

Site has class 2 or 3* soil and is being used for solid waste disposal	10
Site has class 2 or 3 soil and is lying dormant	9
Site has class 4 or 5 soil and is lying dormant	7
Site has class 4 or 5 soil and is being used agriculturally	5
Site is less than 1,000 feet [305 m] from houses	3
Site is within one mile [1.6 km] of a recreation area	1
Site has class 2 or 3 soil and is being used for agricultural purposes	0
Actual site is presently under housing	0
Site is within one mile [1.6 km] of airport runway	0

2) Desirability of Improving Present Land Use

Site is presently a disposal site or pit which could be improved	10
Site is presently abandoned and is lying dormant	9
Site is presently a recreational area or of similar use to a community	5
Site is within one mile [1.6 km] of an airport	1
Site is presently being cultivated for farm use	0

(Prince Edward Island, n.d.)

* The Canada Land Inventory, a classification system of soil capability for agricultural use, groups mineral soils into seven classes, according to their potentialities and limitations for agricultural use. The first three classes are considered capable of sustained production of common cultivated crops, the fourth is marginal for sustained arable culture, the fifth is capable of use only for permanent pasture and hay, the sixth is capable for use only for wild pasture, and the seventh is for soils and land types (including rock outcrop and small bodies of water) considered incapable of use for arable agriculture or permanent pasture (Environment Canada, 1972*b*).

Nevertheless, when all factors are considered, active farmland may yet be selected for a sanitary landfill. The St. Eleanor's (Summerside) landfill was previously the site of agriculture (field crops) and a shale pit. Generally speaking, agricultural land uses continue to surround the disposal site. The pit was used for bulk storage and the farmland has provided cover material for the landfill operation. One field was lost from agricultural use. Otherwise farm operations have not been significantly affected.

Land value

The impact of sanitary landfills on land value varies with many factors, among which are: 1) ownership and location of the site, 2) perception of surrounding land users, and 3) rehabilitation.

1) Site ownership and location

Sanitary landfills fulfill a public need to dispose of wastes and as such the acquisition of sites is subject to unique market forces. If they can be accommodated on publicly owned Crown lands their effect on land values is minimal, as they occupy land not normally available on the open market. However, if privately owned lands are involved, a different situation results. The price of privately held land often rises when public use of it is in prospect. Private landowners recognize that there is often pressure on the responsible agency to secure a site to end a period of uncertainty, or to satisfy an urgent need for a new disposal facility. They are also aware that there may be no appropriate alternative sites available and that government money is financing the project.

In effect, a captive market exists and vendors will usually obtain a higher price for the land than they would under normal market circumstances. Land is normally priced according to its most profitable alternative use.

2) Perception of surrounding land users

Much of the opposition to establishing new landfills arises from concern over the impact on land surrounding the site. "The public is usually apprehensive about possible health, nuisance and safety problems, and whether or not property values in the immediate neighborhood will depreciate" (Graff and Rogers, 1973*a*). Whether or not sanitary landfills actually exert a negative impact on land values, there is a fear of negative impact, particularly among residential landowners. It is significant that on this important subject there are currently no figures or reports available that document changes in land value or productivity as a result of locating a sanitary landfill. The concern over the depreciation of land values is reflected in the considerable opposition that greets any proposal for a landfill site. Although the community's need for disposal facilities is recognized by everyone, the individual's response is likely to be "not in my backyard". The same fear of decline in land values does not seem to affect industrial users for whom land values may not change with the development of a landfill site.

There also appears to be some discrepancy between the general public's perception and the views of technical or professional experts. Officials across Canada were split in their opinions of the impact of sanitary landfills on surrounding land values. Officials in New Brunswick, where most sanitary landfills are located in isolated areas of unused or forested land, see no marked effect on surrounding land values. In Ontario, Manitoba, and Newfoundland it is

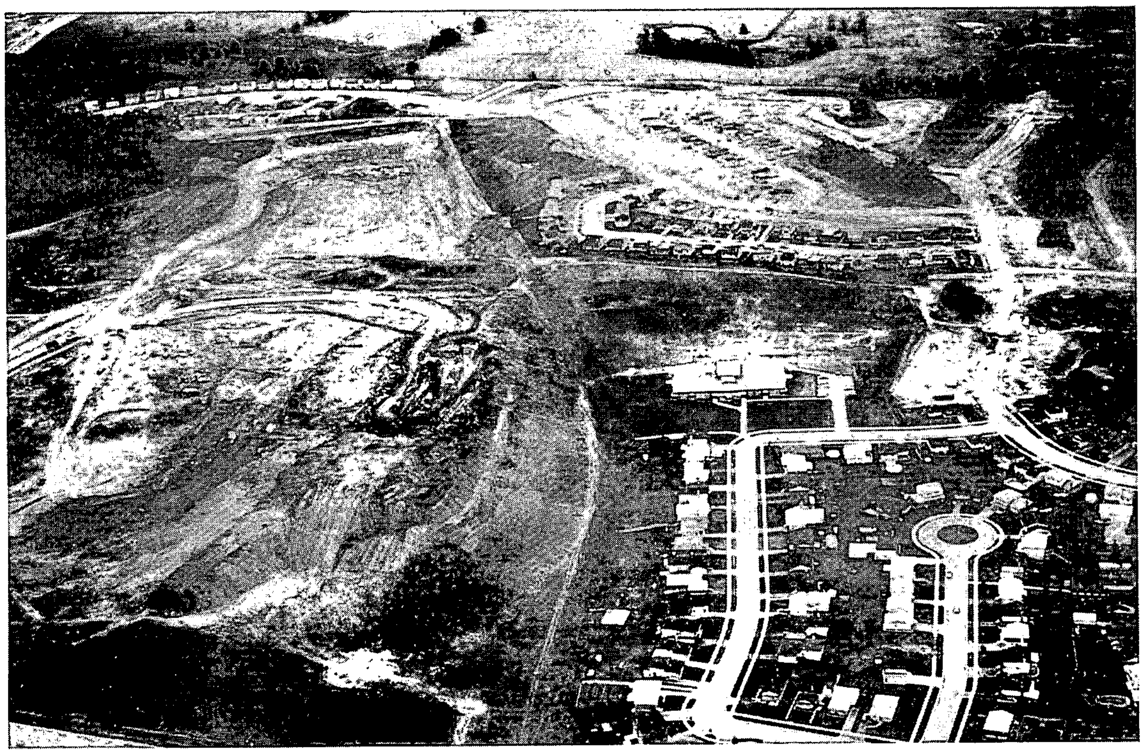


Photo 5. When a sanitary landfill is located near residential areas, people are naturally concerned with the possible impact on property values and aesthetics.In general, if the site is rehabilitated to recreational use, the value of surrounding residential properties will be increased and the community as a whole will benefit from the additional green space.
Waste Management Branch, Environment Canada

thought that sanitary landfills, no matter how well they are operated, exercise a downward pressure on values of surrounding lands, particularly on those in residential use, because of nuisance factors, possible odour and blowing litter, potential leachate or methane gas problems, and a site's appearance i.e. aesthetics. There may also be a decline in value as a result of the restrictions placed on surrounding land uses, although this does not necessarily apply to industrial land values. In Saskatchewan, one of the major economic impacts of a sanitary landfill has been the perceived depreciation of land values on and around the site, even though no evidence was available to support this perception.

In Prince Edward Island there appears to be little or no influence on land value. At the St. Eleanor's site, which is surrounded by agriculture, there has been little if any influence on land use, value, or productivity. The only complaint encountered relates to birds, which are attracted to the sanitary landfill, and then damage the grain crop on the adjacent fields. Litter is also an occasional problem. The East Royalty (Charlottetown) landfill site also seems to have had little effect; land surrounding it has not lost value for urban, particularly residential, use. The houses built adjacent (as close as 90 m) to the site have been assessed at fair market value with no discernible influence from the landfill. The medium-value housing prices are consistent with other urban Charlottetown properties ($60 000 for a duplex in 1982). The developer obviously took into account the presence of the landfill site and proceeded with the development.

3) Rehabilitation

> *"For local residents who may be inconvenienced while landfilling operations are in progress, there is generally some compensation in the form of improved land values throughout the area once the landfill is completed. Since most completed sites have built-in limitations, they are best reserved for open-space usage—which is perhaps the most precious type of usage in heavily populated areas"* (Glysson *et al.*, 1972).

A critical stage is reached when a sanitary landfill comes to the end of its lifespan. Land values of both the site and the surrounding area are influenced by rehabilitation and final use. "Land values increase when the filled land is used for recreational or industrial purposes" (Goodings, 1974). "Often the land increases in value appreciably" (American Public Works Association, 1970).

Increases in land value following rehabilitation depend on a site's final use. In general, recreational end use enhances surrounding residential land values.

> *"The public is usually concerned with health, nuisance, and safety aspects of an operation in the neighborhood and is apprehensive that an unsanitary operation will depreciate the value of local property. An exemplary operation will gain public support and will enhance the value of surrounding property if it provides land useful to the home owner or is landscaped and used for a park or recreational facility"* (American Public Works Association, 1970).

It is also true that a site rehabilitated to industrial use could have a higher land value than the same site rehabilitated to residential use. If the sanitary landfill has been located in an abandoned gravel pit, as some are, it is easily seen that land values will increase if and when full rehabilitation is completed. Where low-lying areas require filling, landfills may enhance land values (Jacobs and Biswas, 1972). A properly rehabilitated site may be more valuable than it was originally.

All 10 provinces now require rehabilitation of landfill sites, which may range from a top cover of soil with no planned revegetation to complete rehabilitation for a specified end use. The recognition that proper "completion" of a sanitary landfill includes rehabilitation has been a significant step toward meeting the public's concerns for appearance, minimizing land-use problems, and maintaining property values.

Allied consequences

There are two potential by-products of sanitary landfills which, if not acknowledged and properly controlled, may have serious environmental impacts on land, air, and water. These are leachate and methane gas. The severity of these two hazards, both within the site and on the area surrounding it, varies across Canada as a result of different climate, soil, topography, hydrogeology, elevation, composition of the refuse disposed, style of operation, quantity of refuse, location, etc. Both by-products can migrate from the site to adjacent land areas and as a consequence, affect the use of those lands. Certain standard engineering techniques may be employed to control these hazards.

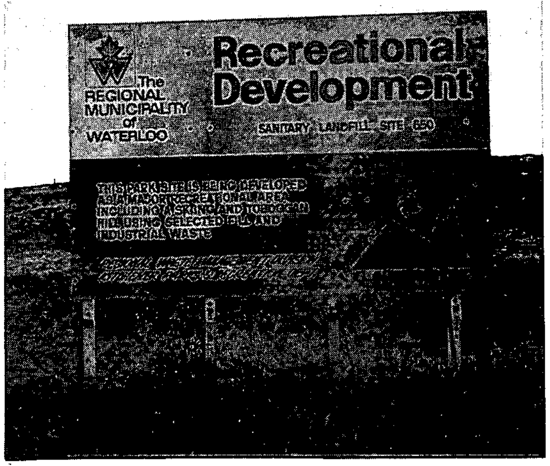


Photo 6. In Kitchener, Ontario this sanitary landfill was rehabilitated to a recreational development that included a ski and toboggan hill. Knowing the end-use of the site in advance is of assistance in the final contouring of terrain and planting of vegetation.
Waste Management Branch, Environment Canada

Leachate

Leachate is the liquid product of decomposition of the organic components. It is also produced when water enters the landfill site and percolates through the material contained within it. All sanitary landfill sites produce leachate but qualities and quantities vary from site to site. Water is introduced by direct precipitation, groundwater invasion, and surface seepage or runoff from the surrounding land. As surface or groundwater moves through the landfill, it dissolves soluble components of the refuse and picks up suspended solid matter and microbial waste products. These "suspended and dissolved solids in the migrating water transform it from a harmless fluid to a leachate which has all of the characteristics of a strong industrial wastewater..." (Pavoni *et al.*, 1975). As the leachate moves down gradient, the concentration of contaminants is attenuated by natural processes. The landfill will absorb moisture, from whatever sources, until it approaches the saturation level (Mooij, 1976), at which point the landfill will discharge liquid in the form of leachate. The composition of the leachate depends on the composition of the refuse. Decomposing refuse produces methane, carbon dioxide, water, organic acids, nitrates, chlorides, calcium, sulphides of iron, ammonia, manganese, hydrogen, etc. Ground and surface waters can become grossly contaminated by leachate, thereby affecting the water for drinking, irrigation, recreation, wildlife, fish, and other uses.

Studies indicate that leachate does migrate into adjacent soils; the greatest problem is in estimating the extent of contaminant migration. If necessary, leachate migration can be prevented by containment within the site followed by treatment, or by water table modification, but these can be expensive processes. Before a control system can be selected and designed, the factors affecting the leachate characteristics must be identified and monitored at the site. The major factor affecting quality and quantity of leachate is the amount of moisture infiltrating the site.

Control of water infiltration can be accomplished by some of the following actions: effective application of cover material, which when compacted is nearly impervious to water; grading of surface cover to prevent ponding; digging of ditches to increase and direct surface drainage and runoff to locations away from fill; and the use of vegetative cover to reduce erosion and enhance runoff and evapotranspiration. However, vegetation over a landfill can also reduce runoff causing greater infiltration thus increasing leachate generation potential. Leachate contamination of groundwater can be controlled by collection, using buried tiles, cut-off trenches, french drains, specially designed collection areas or wells, and pumping facilities. Such collection systems may be located under, around, or hydrologically downstream from the site. Treatment can be required if uncontrolled releases of leachate would have a detrimental effect on groundwater quality. Monitoring is necessary to allow enough time for a contingency plan to be put into effect before any serious contamination occurs. Well points are commonly used for monitoring and are located at various points along the edge of the site. The leachate may be treated at a sewage treatment plant after discharge to a sanitary sewer. If this is not practicable because of the availability or the leachate characteristics, it must be collected and treated on site. However, collection followed by treatment of leachate is not usually economically feasible and other solutions such as recirculation or clay liners are more often employed.

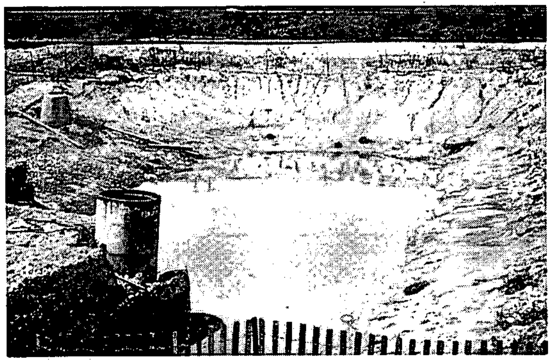


Photo 7. This photo shows a leachate collection pond with no on-site treatment.
Waste Management Branch, Environment Canada

Leachate characteristics may also be controlled by restricting the types of wastes deposited at the landfill site. A large portion of ordinary municipal waste decomposes to form contaminants that may migrate from the landfill site to the surrounding environment (Pavoni *et al.*, 1975). "A considerable portion of municipal refuse landfill leachate strength may be attributable to the textiles, rubber, leather, wood, paper and cardboard present in municipal refuse" (Mooij, 1976). Unless designed to accept them, sanitary landfills should not accept hazardous wastes because the leachate may then contain toxic chemicals. If these chemicals enter the groundwater, they could be injurious to human health.

Control over the type of wastes deposited and control of water infiltration may be sometimes impractical and can be only partial solutions. Where there is high risk to the surrounding environment it may be necessary "to provide impervious liners in the bottom and sides of the landfill site and to collect any migrating fluids and prevent their exit from the landfill site into the surrounding environment ... The collected fluid may be removed from the landfill site and transferred to a wastewater treatment plant wherein it can be rendered innocuous" (Pavoni *et al.*, 1975). Such carefully selected preventive measures could include the use of clay or plastic liners and leachate collection, recirculation, and treatment facilities.

The problem of leachate production should be considered during the site selection process. Ideally, sanitary landfills should be located so as to avoid direct groundwater or surface water contact. Certain bedrock formations such as fractured limestone should be avoided, as should areas where till (fine-grain) soil is either limited in depth or nonexistent. The proximity of wells, springs and open watercourses should also be considered.

Methane

Methane gas is one by-product of the decomposition of organic wastes in a sanitary landfill. The control of this potential problem should be given consideration at the time of siting and designing the landfill. Furthermore, potential hazards posed by methane gas are some of the factors considered when determining or restricting the end use of landfill sites.

"The quantity and quality of gas released from a landfill is determined by the nature of the decomposition process involved and the physical and chemical properties of the material" (Ecologistics Limited *et al.*, 1980). Also the amount of methane gas generated is proportional to the volume of wastes. In sanitary landfills the decomposition of wastes progresses through several stages. During the initial period when oxygen is present the decomposition is aerobic; considerable heat is generated, the principal gas produced is carbon dioxide, and the supply of oxygen is reduced. As the oxygen supply is depleted, the organic decomposition becomes anaerobic and the principal gases generated are methane, carbon dioxide, and hydrogen sulphide (Stone, 1977; Pavoni *et al.*, 1975). Hydrogen sulphide gas is primarily responsible for the odour problems associated with sanitary landfills. During the final stage of decomposition, methane could account for as much as 50% or more of all gas produced. Methane production will begin from within a few months to many years after the wastes are landfilled. "Total methane production depends on wastes composition, but, theoretically, about six and one-half cubic feet of methane gas can be produced from each pound of refuse [about 400 L of methane from 1 kg of refuse]" (Reindl, 1977*b*). Landfilling of putrescible wastes will produce methane gas for up to 100 years after disposal (Anon., 1979*a*).

What are the hazards created by the presence of methane gas? Methane is highly combustible; it can pose a serious fire or explosion hazard where it is allowed to accumulate to concentrations of 5–15% by volume in the atmosphere (Ontario Ministry of the Environment, 1981*a*, 1981*b*; Stone, 1977; Flower *et al.*, 1977). In the presence of a differential in pressure, methane could diffuse through porous materials. "... the more permeable a medium, the easier it is for the methane to migrate through that medium. For example, unsaturated granular media such as sand and gravel will offer little resistance to methane, while saturated dense media such as wet clay, will act as a barrier" (Ontario Ministry of the Environment, 1981*b*). Under certain conditions, methane gas produced in landfill areas will migrate into structures, utility trenches, and sewers. "Explosions can result as a consequence of gas accumulation, and the effects are, of course, detrimental to all types of development. Automobile ignitions, or various activities undertaken at ground level may trigger explosions. In addition, underground services, particularly hydro conduits, must be carefully designed to prevent methane collection" (Ontario Ministry of the Environment, 1981*d*).

Experience with this potentially dangerous hazard varies across Canada. Officials in Prince Edward Island state that methane has not been a problem; it appears that the gas moves slowly upward through the sandy loam fill, and does not migrate horizontally. Newfoundland and New Brunswick have no recorded cases of methane gas build-up in past or current sanitary landfills. Methane gas build-up has been assessed as somewhat of a problem in British Columbia; however, most sites are fairly remote and are simply covered and left unused. In addition, nuisance problems with hydrogen sulphide gases have occurred as a result of plaster and drywall scrap being buried in wet low-lying sites.

Other provinces such as Manitoba, Ontario, and Saskatchewan have reported problems with methane. In Manitoba, one recorded case of methane gas build-up was in the St. Boniface area of the City of Winnipeg. A number of industrial and commercial buildings located on or close to former landfill sites were evacuated because of the methane gas concentrations. The City decided to purchase these buildings and pay compensation to the owners for relocation. Measures of this type can be avoided if buildings are not allowed on or close to former landfill sites.

In Ontario, problems due to methane gas migration have been encountered in London, Mississauga, Ottawa, Hamilton, Oshawa, and Whitby and in all cases remedial actions have been taken either on site or on adjacent land areas. Because of the many implications of methane gas production, the Ontario Ministry of the Environment is currently studying methane gas production, migration, interception, and monitoring at landfill sites.

Methane and other landfill gases such as carbon dioxide have serious detrimental effects on vegetation, either by being directly toxic to the plants or by displacing or utilizing oxygen in the root zone causing suffocation (Ontario Ministry of the Environment, 1981*d*; Flower *et al.*, 1977).

> *"Prior to the 1960's many landfills were frequently operated as open-burning dumps. While this caused air pollution and vector control problems at the time of their operation, the end result was that most of the material left in the landfill was non-biodegradable. This meant that there was much less ultimate settlement of the landfill and much less or practically no development of anaerobic gases after the landfill was closed. The modern landfill does not permit open burning; therefore, it provides much more food for microorganisms. It is these microorganisms which generate the gases, mainly carbon dioxide and methane, which present problems for growing vegetation"* (Flower et al., 1977).

High concentrations of methane, carbon dioxide, and other gases in the root zone of plants can be toxic to vegetation. "In any case, we associate the presence of persistent high concentrations of combustible gases in the soil atmosphere with poor health and eventual demise of vegetation" (Flower *et al.*, 1977).

One of the most disconcerting characteristics of methane is its ability to diffuse readily. The mechanics of gas movement through refuse and soil are extremely complicated but generally gas tends to migrate from the landfill, through the refuse and soil, over a path of least resistance (Reindl, 1977*c*).

> *"As a general rule, the distance that methane will migrate in fine-grained materials such as clays (unsaturated) is a matter of feet while in coarse-grained materials such as gravels, (unsaturated) the distance travelled can be hundreds of feet.*
>
> *The lateral migration of methane is encouraged where the cover material is less permeable than the underlying material. Lateral migration should be at a maximum during winter months and also during early spring when soils at the ground surface are either covered by a snow and ice seal or are saturated with meltwater. Under these conditions, the natural venting of methane through the surface is impeded causing some additional gas pressure in the landfilled area. This forces the methane to migrate a greater distance laterally into the adjacent materials. Lateral migration is especially pronounced where there is a sequence of beds which contrast greatly in permeability"* (Ontario Ministry of the Environment, 1981*b*).
>
> *"Many landfills are being built into the ground to depths greater than 50 ft [15 m]. This extensive depth of refuse coupled with the high compaction and daily cover can result in high gas pressures building up within the landfills, at times greater than 5 pounds per square inch [approx. 35 kPa]. These gases travel out of the landfill via the easiest route. This can result in the landfill gases traveling beneath the ground laterally from the landfill. Land adjacent to former sand and gravel pits is particularly receptive to this migration. The landfill gases may migrate to areas where they can cause poor health and/or death of vegetation. They can also migrate into buildings where they may cause fires and/or explosions. Landfills in former sand and gravel pits are particularly noted for having problems with the external migration of landfill generated gases into the surrounding soils. This is in most cases due to the high porosity of adjacent soils and their lack of resistance to the movement of these gases. We have also observed that when the mixtures of adjacent soils are horizontal layers of sand and gravel interspersed with clay layers, the distance of migration may be the greatest, because the clay layers tend to prevent the vertical movement and venting of the gases from the soil. Freezing of the ground surface and extensive rainy weather also seem to contribute to the increased lateral migration of these gases"* (Flower *et al.*, 1977).

Consequently, potential problems with structures and vegetation exist not only on former or existing sanitary landfill sites, but frequently in areas adjacent to such sites. In cases documented by Flower *et al.*, lateral migration of landfill gases has exceeded 250 m and has affected agricultural crops and housing on surrounding land.

How is methane controlled? Depending on whether the quantity of methane or its rate of generation is to be reduced or increased (for use as an energy source), the methods of control differ. In some cases a buffer area is left around the landfill site to allow natural venting, thereby dispersing the gas and preventing it from migrating through the subsurface materials to adjacent property. Other designs control the migration, exit, and disposal of methane by intercepting the gas or venting it to the atmosphere by constructing systems which range from passive to sophisticated active systems. These systems include: 1) trenches filled with material of high permeability such as sand or gravel; 2) open trenches; 3) barrier trenches of material with low permeability such as clay or plastic sheeting; 4) venting pipes or gas wells with or without exhaust fans; or 5) any combination of the above (Ontario Ministry of the Environment, 1981*a*, 1981*b*).

It is also necessary to monitor methane gas concentrations and pressures at the sites to estab-

Photo 8. Methane gas proved to be a problem at one Kitchener, Ontario sanitary landfill.These methane gas vents were installed on site to control and disperse the gas.This is particularly important if there are structures nearby.
Waste Management Branch, Environment Canada

lish pressure gradients around the landfilled areas and thus determine the direction of flow.

When it established a youth centre on land that was previously a sanitary landfill site, the town of Milton, Ontario took precautions by constructing a cut-off trench 600 mm wide filled with clear stone; and a 100 mm perforated header pipe was placed in the stone and vented through three vertical stacks.

Kitchener, Ontario, experienced many problems with methane gas from landfills. "In 1968 the City of Kitchener passed a by-law that future development within 200 feet [61 m] of landfill sites would have to include the trapping and venting of weeping tile and the use of epoxy paint for floor and wall cracks if necessary" (Anon., 1979*a*). That city has spent hundreds of thousands of dollars on methane gas venting systems and the monitoring of homes and soil surrounding one landfill site.

It is possible to minimize methane production by regulating wastes deposited on site so that during the decomposition phase only certain gaseous by-products are produced. Anaerobic decomposition can be prevented by adding oxygen so that only carbon dioxide will be produced. However, operators must be careful not to cause fires within the fill.

Clay barriers (liners and covers) and venting and burning systems are the most common approaches to methane control. Clay covers aid in the prevention of moisture infiltration. Careful site selection, the use of appropriate cover material, and efficient operations can also reduce the methane hazard.

A number of measures can be taken to minimize impacts on vegetation, including proper fertilization, soil amendments, irrigation, removing the landfill gas from the vegetation area, the use of tolerant plant species, and suitable planting techniques (Flower *et al.*, 1977).

The methane gas hazard is one of the principal reasons for the existence of buffer areas or separation distances that are specified in provincial guidelines or legislation. Important considerations are the subsequent use to be made of former landfill sites and the set-back distance prescribed for buildings located adjacent to such sites.

Methane gas recovery

Despite the fact that methane gas can be hazardous for adjacent land users if not properly controlled, it can also be tapped as an energy source for those same land users. "Utilizing landfill gas as a source of energy is attractive due to the large concentration of methane (50 percent) present during the latter phases of decomposition, rising energy prices..." (Reindl, 1977*c*).

In Canada, Ontario seems to have taken the lead in investigating the energy potential of methane gas. For example, the methane gas produced at the Kitchener landfill site is now being recovered and used in the kiln operations in boilers at a nearby plant.

In 1978 a project was initiated at the St. Thomas Collection Services Limited landfill site to evaluate and demonstrate the physical and economic feasibility of gas recovery and utilization technology. The project commenced for a 3-year period and was funded by Environment Canada, Ontario Ministry of the Environment, and Energy Ontario. The system installed at this site pumped landfill gas from a well installed within the landfill and used the gas to heat an on-site greenhouse. "A conventional forced air gas furnace was utilized with minor modifications to heat the greenhouse over the winter of 1979. Both tomato plants and bedding plants were grown in the greenhouse, commencing in February 1979" (Conestoga-Rovers & Associates, 1979).

This landfill site is divided into two sections. Section 1, occupying 5.7 ha, was in operation from approximately 1949 to 1967 and has a depth of 6.1–9.2 m. Section 2, 9.7 ha, was in operation from 1967 to 1978 and has an average depth of refuse of 12.2 m. The gas recovery and utilization facilities were located in Section 2.

The greenhouse was constructed adjacent to the pump on the landfill site because there was no non-filled land nearby. It was selected as the most feasible method for demonstrating the utility of the landfill gas because of its high heat requirements and relatively low capital cost. The project results indicated that recovering and utilizing landfill gas in an unprocessed state is feasible both technically and economically. The possibility of recovery of landfill-generated gas in the Canadian climate is significant, particularly during the winter months when the demand for energy is highest. Greenhouse heating is not the only possible use for this gas.

> *"Alternative uses can be classified according to the degree of treatment the raw landfill gas receives before it is used.*
>
> *Raw landfill gas can be burned directly in conventional natural gas equipment and as such can be used as a replacement for natural gas, provided that compensation is made for the lower heating value and the corrosive nature of the gas. Such uses could easily and economically include: grain dryers, apartment heating, warehouse and industrial heating and possibly even heavy industrial furnaces and boilers. These uses would be restricted to an area close to the landfill as the cost of a special pipeline would quickly consume the economic advantage. . . .*
>
> *Landfill gas can be "cleaned" to remove moisture,* CO_2 *and trace contaminants to*

> *obtain relatively clean gas that approaches the quality of pipeline natural gas and can be injected directly into existing pipelines"* (Conestoga-Rovers & Associates, 1979).

The cost of such treatment is high and not economically feasible in Canada at present. In the United States, however, it is being done commercially at large landfills.

> *"Landfill gas may also be purified and liquefied to provide a fuel for automobiles and trucks. The process is undeveloped at this time but the technology is available. . . .*
>
> *Small power-plants on locations remote from existing transmission lines may however, prove economically viable when the cost of installing transmission facilities is included in an economic analysis"* (Conestoga-Rovers & Associates, 1979).

A study currently underway in Toronto is examining the physical, technical, and economic feasibility of using the methane gas produced from the Beare Road sanitary landfill site to heat the Metro Toronto Zoo, a sizable greenhouse, and a ski chalet. The first phase of this study, examining the economic feasibility of using the methane gas, was completed in 1982.

Despite the fact that methane gas produced at sanitary landfills is a potential energy source, it remains a significant environmental hazard. The control of methane gas must be considered during the siting, design, operation, and rehabilitation stages of any sanitary landfill; the health and safety of citizens must be assured and environmental impact must be minimized.

Social considerations: human perception

Compared with the physical context, the social environment is exceedingly difficult to study and define. Yet social factors may over-rule decisions made by both politicians and technicians. Given its potential influence on decision-making, public response to the issue of landfilling must be taken into account.

Visual and aesthetic concerns

To the average Canadian, a sanitary landfill conjures up an image of a smelly, dusty, noisy, unsightly dump marked by open fires, infested by disease-carrying rats, and home to a host of other scavengers. For a variety of reasons, public opposition is one of the most influential factors in siting many sanitary landfills. Public acceptance or public opposition are critical elements in the site selection process and whose significance is clearly recognized in textbooks and handbooks on waste disposal.

Photo 9. Burning of garbage in dumps contributes to public apprehension of sanitary landfills.
Waste Management Branch, Environment Canada

> *"Public acceptance should be a constant key consideration both during and after the site-selection process. A site with minimal potential for public opposition, all other things being equal, should be chosen over a site generating considerable local controversy"* (Stone, 1977).
>
> *"It's not certain whether there are ever any landfills selected, designed and built without some public outcry"* (Reindl, 1977*d*).

The negative attitude toward sanitary landfills is a result of several factors: the public's lack of specific knowledge concerning waste disposal practices combined with their confusion and concern about the subject; the generally poor record of past sanitary landfill operations; and the lack of attention paid to aesthetics by planners and operators.

"The fear in the minds of people regarding any waste processing and disposal activity near their neighborhood is due to their association of such activity with a dump" (General Electric Company, 1975). On learning that a sanitary landfill is to be located in their neighbourhood, some people panic, assuming that it is to be a dump. Conversely, disposal sites, including dumps, are often erroneously referred to as sanitary landfills. Dumps are frequently operated without regard to appearance or pollution prevention. Most people are unaware of the strict siting, design, and operational engineering guidelines that differentiate a properly operated sanitary landfill from such dumps. Few people are aware of the variety of land-based waste disposal facilities outlined below.

> *"A dump is an uncovered land disposal site where solid and/or liquid wastes are deposited with little or no regard for pollution control or aesthetics. Open burning, scavengers, and disease-carrying organisms are problems associated with dumps.*
>
> *A landfill is a land disposal site located without regard to possible effects on water resources, in which the waste is covered intermittently with a layer of earth to minimize scavenger, aesthetic, disease, and air pollution problems.*
>
> *A sanitary landfill, however, uses an engineered method of disposing of solid wastes on land to minimize environmental hazards. The waste is spread in thin layers, compacted to the smallest practical volume, and cover material is applied and compacted at the end of each operating day. [A modified sanitary landfill may deviate from this definition by not applying cover material daily.]*
>
> *Finally, a secured landfill is a land disposal site that allows no hydraulic correction, segregates the waste from the environment using containers etc., has restricted access and is continuously monitored.*
>
> *The first ... [four] types of disposal sites are intended to accept primarily municipal*

> *and commercial wastes, may or may not accept sewage sludge, and may accept hazardous wastes with or without the knowledge of the site operator....*" (James, 1977).

The second factor contributing to the negative public response is the generally poor record of some waste disposal operations in the past. Some so-called sanitary landfills were not operated according to the accepted engineering standards. Operating sanitary landfills were occasionally allowed to deteriorate without due regard to pollution prevention or impact on surrounding land and land users. The failure to meet prescribed engineering standards in these instances has added to the general public's fear of having any disposal facility in their vicinity.

The third factor is the lack of attention paid by landfill planners and operators to the effects of the site on human perceptions.

> *"The public, it seems, never wants a landfill near where they live. After all, most people believe that fills have litter, pollute the ground water, have rats and odors, are accessed by noisy trucks that also impair the safety of the streets, reduce property values, and much worse"* (Reindl, 1977*d*).

To the public, such issues are of obvious concern. However, planners, engineers, and other technical experts involved in siting or operating sanitary landfills commonly refer to potential impacts as "nuisances". There is "... strong public aversion to the potential nuisances associated with any kind of wastes disposal, including traffic, odors, noise, air and water pollution, litter and general unsightliness ..." (Graff and Rogers, 1973*a*).

Failure to assess the importance of these "nuisances" has caused much of the opposition, especially in residential areas. There is evidently considerable difference of opinion with respect to the significance of the impacts of sanitary landfills on human perceptions. Although there is some validity to both views, it has been the gap between these opinions that has caused serious problems. This is particularly evident in locating sites for new facilities. On a number of occasions the most suitable site from a physical and environmental standpoint has been rejected because of public opposition and the accompanying pressure exerted through the political system. As a result, a less environmentally suitable but more socially acceptable site has sometimes been selected. It is ironic that fears about possible aesthetic or other kinds of infringement or damage to an individual's property will result in the choice of a site that may cause greater pollution or greater expense to the community.

It is little wonder that the following observation was made:

> *"The industry will continue to have difficulty in establishing landfill sites even though they are shown to be technically satisfactory. The problem is only 50 percent technical. The other 50 percent is in the soft, mushy world of social perceptions – political inputs and other factors"* (Anon., 1978*c*).

Despite recognition of the significance of these social considerations, only minimal research has been undertaken.

Let us now look briefly at the specific topics that constitute these aesthetic factors. They include litter, odour, noise, air quality, and vectors.

Litter. "Blowing paper wastes was the operating problem most commonly mentioned in a survey of landfill practices by the American Society of Civil Engineers" (Graff and Rogers, 1973*a*). Perhaps more than any other factor, blowing litter exemplifies the visual concerns many people have about landfills. Blowing paper is unsightly; should it escape the site, the neighbourhood's attractiveness may be reduced for both residents and potential home buyers. First impressions are important and blowing refuse will not enhance neighbourhood appearance or value.

Odour. Odour is a "nuisance" that is most commonly associated with waste disposal sites. The extent to which it affects surrounding areas depends on the type of wastes deposited, temperature and wind conditions, and the level of care exercised in the landfill operation. Properly operated sites will minimize this problem. However, where organic protein constitutes a large portion of the waste; when high temperatures, inversions, or prevailing winds combine to broadcast the odours; and where disposal operations are lax, odour can extend well beyond the immediate vicinity of the landfill site. Complaints would be a natural outcome of such conditions, particularly from residential, commercial, and recreational users.

Noise. Collection and transport of refuse from the source to the landfill site and the operation of the site itself necessitate the use of heavy trucks, compactors, and earth-moving equipment. "... truck noise is both downright annoying and can impair hearing if the noise level is excessive and sustained. The noise problem is particularly acute if residential areas are situated near access roads" (Stearns and Ross, 1973). Although noise problems are most acute on-site, the intrusion of truck or landfill operation noises into surrounding residential, commercial, or recreational areas can disturb people who live or work nearby. The impact would be less significant in an area already supporting heavy industry or extraction activities.

Once a sanitary landfill is in operation, the increased volume of traffic has a significant impact on the surrounding land uses. It increases the noise level, increases the volume of total traffic for the area, and requires an effective road maintenance program.

Air quality. Dust is a common problem along access routes and around the landfill site, particularly when soil and cover material are fine-grained, during dry or windy periods, or in dry climates. Dust can reduce visibility in the area, create a nuisance for many residential activities (hanging laundry out to dry, washing cars and windows, painting), and prevent the enjoyment of outdoor activities. Because of increased truck traffic and the use of heavy equipment, the associated exhaust emissions may adversely affect the air quality along access routes and at the site.

Vectors. Vector—"an animal or insect which transmits infectious disease from one person or animal to another by biting the skin or by depositing infectious material on the skin, food or on another object" (Environment Canada, 1978). Flies, mosquitoes, rats, and birds are the major vectors associated with land disposal of wastes. It is the control of these vectors, and the obvious public health benefits, that distinguishes properly operated sanitary landfills from landfills and dumps. Some vectors, such as flies or rats, may be brought to the site with the waste. All vectors may be attracted to the site if it is not properly operated. Birds, particularly seagulls, pose more than a health hazard; they are a serious hazard to airport traffic (Solman, 1973; McNeil *et al.*, 1973).

Addressing visual and aesthetic concerns

What can be done to minimize the undesirable aesthetic impacts of sanitary landfills? A number of means may be employed at the siting, design, or operational stages. The site selection process itself offers opportunities to address social concerns. Potential sites should be evaluated for their compatibility with existing land uses and future land-use planning. Adverse effects on residential neighbourhoods, which are particularly sensitive to impact from sanitary landfills, may be minimized by locating the landfill some distance from, or out of sight of, housing areas. Sites located in areas either already supporting or planned for heavy industry or mineral extraction could be more acceptable.

The design of a landfill can minimize unsightliness in the surrounding environment by careful planning of the site. For example, a berm or embankment of earth can effectively isolate the landfill operation, and when planted with grass and shrubs can be an attractive landscape feature that helps screen sight and baffle sound. A curved entrance drive with attractive landscaping is another design feature.

Many of the complaints caused by noise, poor air quality, litter, odour, and vectors can be

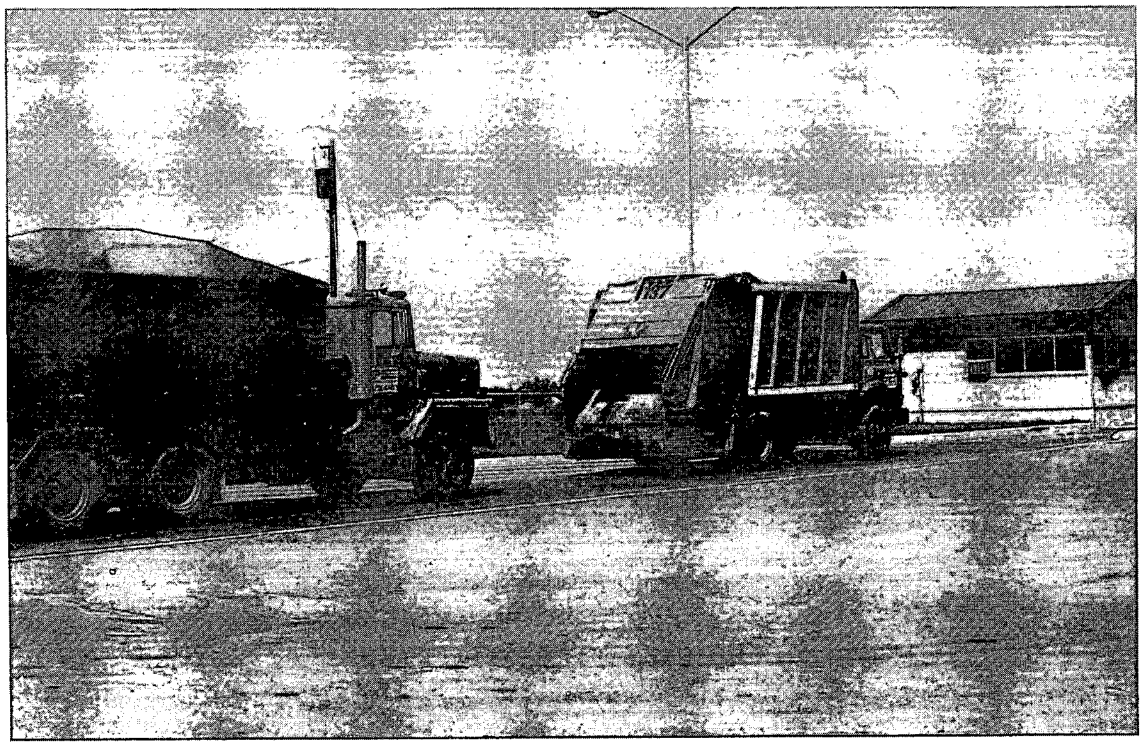


Photo 10. A paved entrance and use of covered trucks improve operations at a sanitary landfill in Ottawa, Ontario.
Lands Directorate, Environment Canada

effectively reduced by actions taken during the operating stage. For example, concern about noise from landfill operations can be reduced by restricting operations to reasonable daytime hours. Complaints about noise, dust, and emissions from trucks can be addressed by routing traffic to avoid residential, recreational, and even commercial areas, and by scheduling site operations so that trucks are not operating in the early or late hours of the day. Access roads can be improved by a program of dampening or by paving.

An effective litter control program should include not only design features such as berms, fences, shelterbelts, or shrubbery but also an operational program of manual or mechanized pick-up of refuse. Trucks should be covered to prevent blowing paper, both along the route and at the site.

If the working face is not excessively large, and the refuse is adequately compacted and covered with soil at the end of each operating day, odour problems can be reduced. Covering the refuse tends to reduce odours resulting from the decomposition of organic material or due to the strong aroma of any one particular waste.

The basic method of vector control is by a combination of refuse compaction and immediate cover of refuse in the landfill. A well-compacted 15-cm cover of soil applied to the refuse face at the end of each operating day will limit vector problems. Flies have difficulty emerging through 15 cm of compacted soil. Rat problems can be eliminated if compaction and cover remove easy access to food and eliminate habitats. This also applies to other animals which might be attracted to waste as a food source, (stray cats or dogs, bears etc.). Mosquitoes can be reduced by preventing standing water. Birds present a problem because they are noisy, messy, carry germs, and difficult to discourage at a site. Yet it is particularly important that birds be discouraged from the area; attempts include using small working faces, daily soil cover, and other techniques such as noises or predators. Birds are less likely to remain at waste disposal sites that are frequently and effectively covered, thereby offering less opportunity for scavenging.

Concern for the maintenance of aesthetic quality is reflected in all provincial legislation and guidelines. For example, all provinces make provision for buffer zones to allow camouflaging of the site and to provide a separation from other uses or to provide space for on-site contaminant controls. In British Columbia, the permit may specify a berm or screen for adjacent land uses, if warranted. Ontario's regulations require an on-site buffer area around the landfilled area and state that the site must be adequately screened from public view. The Environment Quality Act in Quebec makes provision for camouflaging with a fence, a line of evergreens, a slope, a topographical feature, or some other natural screen so that the site cannot be seen from a public road or any building or park open to the public. In these examples, the design feature can also be an effective method of reducing problems of noise, blowing litter, odour, and land-use conflicts.

In other provinces visual quality is achieved through the siting process. In New Brunswick there is a conscious decision to locate sanitary landfills in more isolated areas. Perhaps, because of the more remote sites, government officials believe that the visual impact is minimal. Sanitary landfills have not been the subject of complaints from local residents; environmen-

Photo 11. Birds that congregate at open dumps pose health/aesthetic problems and create serious hazards to aviation.Sanitary landfills, with daily cover are a vast improvement in waste disposal.
Waste Management Branch, Environment Canada

tal concern is focused on groundwater quality rather than on land pollution or unsightliness. Similarly, many sanitary landfills in Newfoundland are relatively remote and for this reason the aesthetic impacts are unknown or not documented.

The sites in Prince Edward Island have aroused no serious complaints except for occasional incidents of loose paper on surrounding farmland at the St. Eleanor's site. In fact, the East Royalty site in Charlottetown is in close proximity to housing but has not been the subject of complaints. In Nova Scotia, attempts are made to locate landfills in visually remote areas, ideally within a wooded area making the site invisible from passing traffic. In any event, the site will be disguised so as to be least obtrusive to the public. Vegetation around a landfill, taking the form of a mature coniferous and deciduous mix, is desirable. The tree screen will act as a visual barrier for the landfill operation, as well as an effective wind buffer to control blowing paper. In addition, good vegetation tends to secure an area against erosion and aids in lowering the water table through transpiration. Ideally, completed sites are revegetated for reasons of erosion control and aesthetics.

To summarize, although aesthetics have been neglected in the past, it is imperative to pay adequate attention to such considerations at all stages of site selection, design, operation, and rehabilitation. Because approval of sanitary landfilling in general, and specific sites in particular, depends largely on public acceptance, it is obvious that "making a landfill site aesthetically pleasing is largely cosmetic, but hardly frivolous" (Reindl, 1977*b*).

Rehabilitation and end use

One of the most significant stages in the sanitary landfill cycle is rehabilitation and end use. There are two reasons why this stage is so important. The first is because the site actually undergoes a physical change from one land use to another and this change may have repercussions on the site itself and the adjacent land uses. Second, rehabilitation is one stage that has a profound impact on the public's perception of the whole sanitary landfill process.

Once sanitary landfill sites are completed and rehabilitated they may be used for a variety of purposes including parkland, golf courses, hiking trails, ski hills, baseball diamonds, toboggan runs, etc. These are tangible examples of favourable end uses, which might assist in changing attitudes and perceptions towards sanitary landfills from negative to positive. Former landfill sites that have been rehabilitated and are being used for such purposes, are viewed more favourably by the public. The public perceives that there has been an increase in both the social and monetary values of the site.

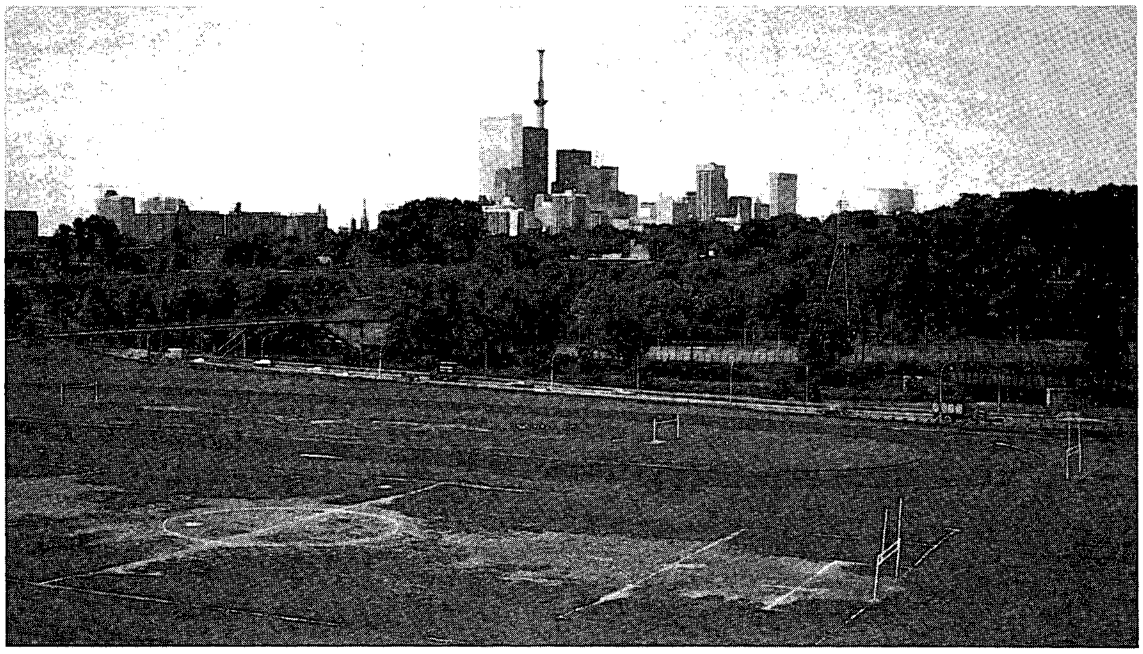


Photo 12. This rehabilitated waste disposal site in Metropolitan Toronto is now being used for recreational activities.
Waste Management Branch, Environment Canada

In most cases the site becomes an asset to the community, providing much needed additional open space. It is because of these positive benefits of rehabilitation that "the projected use is generally one of the strong selling points in convincing the public that it should accept a sanitary landfill in a certain area" (Mantell, 1975). Another potentially positive aspect of sanitary landfills is that the improvement of some low-lying property by filling can be an economic advantage. For example, "many cities have turned mosquito producing pestholes into play areas, athletic fields, and parks. Others have used completed sanitary fills to extend airport runways or as sites for industrial buildings" (American Public Works Association, 1970). A well rehabilitated site can yield both economic and social benefits whereas poor use of a site can lead to serious environmental problems (Pavoni *et al.*, 1975).

Before any sanitary landfill can be rehabilitated, all the physical attributes of the particular site must be examined. These will affect the rates of settlement and gas generation, which in turn will determine the future use of the site. Information on the climatic and topographic conditions at the site, the landfill design, and the characteristics and types of materials deposited is required. The time required for complete decomposition of the organic material in a fill will vary depending upon many factors, particularly climatic conditions. In addition, the many different types of materials deposited are all decomposing or oxidizing at varying rates throughout the site. During decomposition the landfill surface begins to settle, the amount of settlement varying according to the types of waste present. However, settlement is also determined by:

> *"... the volume of the cover used in relation to the volume of waste, and the density achieved by compaction. The larger the quantity of cover material placed and the greater the density obtained, the less settlement should take place. When settlement occurs, the surface must be resloped and graded to maintain good drainage and to keep surface-cover cracks from developing. If wide cracks develop, the waste is exposed to rats and flies, water infiltrates, and the gases escape. Settlement also causes problems to structures on landfills and utilities or structures within landfills. Potential settlement, therefore, must be considered in the design of any facility built on or within a landfill"* (Mantell, 1975).
>
> *"Recorded settlements of fill materials have varied from approximately 2 to 40 percent. A rule of thumb for estimating this is that fill settlements are likely to be at least 20 percent of the initial height of the fill"* (Hagerty *et al.*, 1973).

In addition to settlement, other necessary considerations during the planning of the end use of a site are the methane gas levels and the amount of leachate contamination. Methane gas build-up can pose serious safety problems and limitations for buildings and houses constructed on a former landfill site. In fact, construction of buildings is infrequent and prohibited in most cases unless special monitoring devices are in place prior to any construction. For structures that are built on former sites, "... any foundation elements such as piles or piers which are inserted through the refuse must be designed to withstand the corrosive effects of both gases and leachate" (Hagerty *et al.*, 1973).

Another consideration in planning the end use of a site is the type of vegetation cover to be

Photo 13. The final soil cover should provide a good basis for re-vegetation and should be contoured to prevent ponding.Grasses and shrubs reduce soil erosion and enhance the visual quality of the rehabilitated site.
Waste Management Branch, Environment Canada

established. First the fill surface has to be protected from wind and water erosion, then the cover material has to be graded to prevent water from accumulating and entering the fill. If the cover material has limited depth, only shallow-rooted vegetation such as rooted grass, flowers, and shrubs will grow. The accumulation of gases in the root zone must be considered as it can stunt growth or even kill vegetation.

> *"In order to overcome these obstacles a moist, fertile cover soil of sufficient thickness must be used in conjunction with a gas venting system. Choice of the vegetation to be used as cover in the area will depend upon the climate of the landfill site, the soil used as final cover material, and the allowable depth of the root system above the top of the final refuse cell. Any type of vegetation which requires irrigation should obviously be disregarded for planting on a completed fill surface.*
>
> *Similar considerations must be kept in mind when a completed landfill site is to be used for agricultural purposes. Here too, gases generated in the decomposing refuse may interfere with the growth of plants in the overlying soil unless venting for these gases is provided"* (Hagerty *et al.*, 1973).

The amount of cover material required for a site to be rehabilitated for agricultural use varies from 0.6 to 3 m, depending on the type of soil, the crop to be raised, and the climate of the area. Landfill sites that are used for recreational purposes usually require only 0.6 m of top soil.

Experience with rehabilitating landfill sites for agricultural and construction purposes is more widespread in the United States than it is in Canada. Experience of landfill rehabilitation in Canada is mostly for recreational uses; there are only a few instances where construction has occurred.

In Canada, when a sanitary landfill site is completed—reaching its maximum capacity for garbage—rehabilitation starts with two basic steps. First, a final compacted layer of at least 0.6 m of cover material is placed over the entire site; second, the site is revegetated. The manner in which these steps are undertaken varies from province to province.

For example, in Manitoba regulation 208/76 stipulates the specific rehabilitation process required at waste disposal grounds: "... upon termination of use of an active area in excess of 0.4 hectares (1 acre), or upon closure of the waste disposal ground, a final cover of earth compacted to a thickness of at least 0.6 m (2 ft.) shall be applied to the surface of the active area and the area shall be so graded as to minimize the ponding of water on the surface."

Prince Edward Island takes the process a step further, specifying not only 0.5–0.6 m of top soil, rough grading, terracing, and leaving a seeded or grassed landscape but also the final gradients, in the order of 2:1 to 3:1.

Once a site is reseeded, the decision on whether it is to be left as open space or used for some other purpose is made by the municipality in most cases or by the private owner.

Aside from open space, the predominant end use for a sanitary landfill site in Canada is recreation. However, Alberta, and Manitoba both intend to rehabilitate former landfill sites to agricultural as well as recreational uses.

In Alberta the end-use decision is documented in the engineer's design report prepared before the site is developed. Alberta Environment supervises the rehabilitation process to ensure that the site is reclaimed as specified in the contract between itself and the operator. Most sanitary landfill sites in Alberta are intended to be returned to their original land use, although none have yet reached that stage.

None of the provinces has regulations requiring a specific type of end use, although some do prohibit certain end uses. Ontario will not normally consider residential or other sensitive types of development on any former sanitary landfill site, and does not encourage such development on lands adjacent to the site. Section 45 of the Ontario Environmental Protection Act states that no use may be made of lands used for waste disposal purposes (this includes the landfilled area and on-site lands set aside for gas and leachate control) within 25 years after it has ceased to be so used, unless the proposed use receives approval of the Minister. Requests for such ministerial approval are made through a regional office, where their feasibility is reviewed. The Minister is unlikely to approve a request unless the local municipality is prepared to provide the necessary monitoring and remedial measures. Some transient or minor uses that the Minister may approve are cattle grazing, road crossings, and the installation of hydro poles (Ontario Ministry of the Environment, 1981*d*), but most of the sites that have received approval before expiry of the 25-year period have been rehabilitated for recreation.

In 1981 the Ontario Ministry of the Environment, recognizing the potential hazards from migrating gases generated from waste decomposing within a landfill site, prepared interim guidelines for the use of land adjacent to or on completed landfilled areas. The guidelines were prepared to assist the Ministry's regional staff in making decisions on further use of the sites and on control of development on adjacent areas. The guidelines discuss the problem of methane gas production, the methods necessary for eradication of the problem, the size and need for an on-site buffer area around a landfill area to protect any development from migrating gases, the use of land on landfilled areas, and the need for methane gas detection and monitoring systems. Ontario is currently conducting a comprehensive study on gas migration, which will form the basis of the final guidelines to be drafted.

Manitoba will not encourage building of any type on a former landfill site unless special provisions such as gas-probes and positive venting systems are made. Legislation to enforce this is being considered. The City of Winnipeg does not allow any buildings on former landfills.

As of 1982 neither Prince Edward Island nor Nova Scotia has completed sanitary landfill sites. However, in Prince Edward Island, as part of a seven-party agreement that included municipalities, the provincial government, and the private developer, the possibilities for end uses on the Charlottetown site are now being studied. As this site will be completed in 1984, it is expected that more residential development will take place adjacent to the site and that additional recreational facilities, such as a marina or yacht club, will be constructed along the coast. In 1982 several areas of final site completion were commenced. Concrete rip rap was placed along the leading edge of the bulk area, which has defined the north side of Wrights Creek. The Department of Forestry has developed a management plan in which the present natural buffer zones are being upgraded and new buffer zones are being constructed and seeded with various types of seedlings. The completed landfill area has received an additional 0.6 m of top cover and has been hydroseeded. The grassed area is approximately 8 ha which will be maintained under the site operational contract.

An interesting situation exists in Newfoundland at one previous sanitary landfill site known as the Wishingwell site. A major subdivision was built around and on parts of the old Wishingwell site. It now contains a sports complex and a

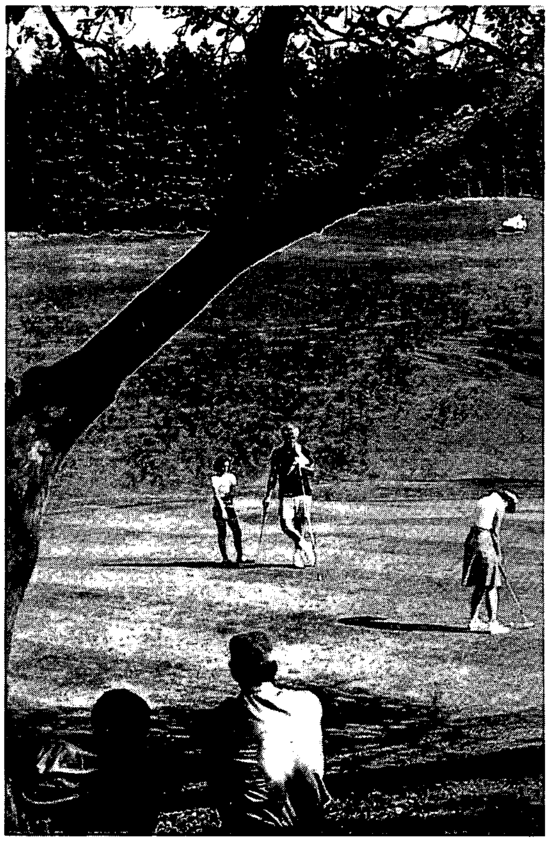


Photo 14. A golf course is an excellent end-use for a rehabilitated sanitary landfill.
Parks Canada

federal taxation centre. Structures have undergone extensive design testing and are protected by methane gas vents. As many as six to seven reclaimed sites across the province have been turned into sports complexes and recreational sites.

In Ontario some of the former sanitary landfill sites are used as golf courses, parks, drive-in theatres, or, once covered with the final layer of topsoil and revegetated, left in a natural state. For example, at Milton, a former 8-ha landfill site, with an average fill depth of around 7 m, is today a park with baseball diamonds, a soccer field, and a youth centre. In 1968 Kitchener embarked on an imaginative park and recreational design for a finished landfill site, which included a 33.5-m high ski hill covering 16 ha with two 244-m runs and a toboggan slide. Landfilling assisted in the construction of "Mount Blackstrap," a ski hill which was used in the 1971 Winter Games, located 32 km outside of the city of Saskatoon. Regina's previous landfill site is now a community park. One completed site in New Brunswick has already been used for recreational purposes including tennis courts and soccer fields.

On the west coast, in the city of Vancouver, a dump was converted to a sanitary landfill, which was closed and then rehabilitated to active recreational use. Its final cover was 4.6 m, much greater than the 0.6 m stipulated, and was graded to form a scenic landscape. The site contains a general purpose playing field, tennis courts, arboretum and nursery, play areas, walking trails, bridle paths, and an 18-hole golf course. Some 600 to 700 condominium houses are within a 1.6-km radius of the landfill.

Although few completed sanitary landfills are later used for industrial purposes, there are a few examples. One municipal sanitary landfill site (previously a gravel pit) located near Brandon, Manitoba was closed in 1979. Nearby industries are currently making use of the site for disposal of building debris. In fact, the final grade of the completed sanitary landfill site is being established through the deposit of these rubble or demolition-type wastes. In New Brunswick one privately owned landfill site was developed within an industrial park. In future, when the site is completed, it may be rehabilitated for industrial use such as a parking lot or possibly a structure that will not have an underground foundation or basement.

Landfill sites located away from urban areas are usually left as open space, with only the final soil cover and some reseeding; there is often no demand for their immediate use. Within and on the periphery of urban areas, however, the demand for land is much greater so that the rehabilitation of a sanitary landfill is a necessity for environmental, economic, social and political reasons. A well-rehabilitated site offers a community a wide range of opportunities for an end use that will be beneficial for local residents and users.

The benefits obtained from the rehabilitation of former landfill sites affect not only the actual site areas but also the surrounding land uses, enhancing their value. As a result, people's attitudes toward a sanitary landfill site are changing; it is no longer regarded as a permanent scar on the landscape but is viewed as an interim land use with the potential to be used for community amenities in the near future.

Even though a sanitary landfill is an interim land use, the social and environmental concerns associated with its operation are real and must be addressed. These concerns, of leachate contamination, methane gas build-up, noise, odours, and other nuisances, must be considered long before the site is in operation. To eliminate or control such problems certain steps can be taken during the siting, design, and planning stages. These considerations will be discussed in the following sections.

CONSIDERATIONS IN SITING A SANITARY LANDFILL

A number of specific factors are considered before the location or site for a sanitary landfill is even proposed. Such factors include elements of both the physical and social environments. Aspects of topography, climate, hydrology, cover material, and geology determine the suitability of the physical environment to accommodate a sanitary landfill. Many of these aspects of the physical environment are readily quantified and can be objectively measured. In contrast, society's attitudes and perceptions are much more difficult to quantify.

Physical considerations

Topography

Topography is one of the most significant factors because it affects the type of disposal technique, the potential for pollution, the financial cost of ensuring minimal environmental impact, site capacity, drainage requirements, site access, and final use. "If necessary, a sanitary landfill may be constructed on almost any topographic landform; however, while landfilling is an easily adaptable disposal operation, certain topographies are much more suitable than others for the deposition of wastes" (Pavoni *et al.*, 1975). As mentioned previously, flat areas with with sufficient soil cover are most suitable for the trench method. In more irregular topography the area method is more appropriate. Both the area and ramp techniques are suitable for rolling and irregular topography.

"Some topographies generally have low pollution potential while others may require considerable care and expense to keep them environmentally safe" (Goodings, 1974). Topography governs whether a site is susceptible to flooding and will determine whether additional drainage features will be required. Topography can also influence the path that leachate travels. Surface water contamination can result from either flooding or subsurface discharge of leachate and costs of pollution control rise accordingly. As a general rule, flood plains or other depressions that permit surface water accumulation should be avoided for both pollution and economic reasons.

Preferred topographies include flat upland areas, dry gullies and ravines, and dry strip mines (Fischer and Woodford, 1973*a*). Steep slopes should generally be avoided as they may increase the difficulty of operating a site and hinder accessibility. Abandoned or exhausted sand or gravel pits or excavated quarries may be used only if complete environmental data are available for the site. Proper surface and subsurface drainage measures should be incorporated into the site development together with other pollution control measures. Landfilling has taken place in swamps, tidal flats, and marsh lands. Landfilling in these environments should only be undertaken with a detailed environmental impact assessment, adequate design, effective site management, and continuous control of monitoring systems.

Topography also partly determines the nature of rehabilitation and final use. Landscaping and grading should blend with the surrounding topography.

Climate

> *"The climate of the landfill location area will have an important influence on the landfilling operation. Since it is necessary to prevent, as much as possible, the contact of surface water with the deposited refuse, it is necessary to consider the amount, frequency, intensity, and duration of precipitation to be expected at the landfilling site. Likewise, since blowing paper and litter can be a significant nuisance at a landfill site, some consideration must be given to the velocity and direction of the local prevailing winds. Temperature ranges in the area for the proposed landfill are also important because of difficulties associated with the excavation and handling of frozen ground"* (Pavoni *et al.*, 1975).

The intensity of odours, blowing dust, and soil erosion are also determined by local characteristics of temperature, winds, precipitation, and evapotranspiration. In combination, these characteristics will determine whether blowing snow, rain, or ice may hamper traffic and operations at the site during particularly cold or wet conditions. "Local climate conditions may eliminate some sites, require unusual techniques of operation at others, or rule out landfills as the disposal method entirely under extreme conditions" (American Public Works Association, 1970).

Hydrology

Many of the potential ground and surface water pollution problems may be avoided if sites are thoroughly examined. "... adequate hydrological [hydrogeological] investigations of a site will include gathering of data on surface drainage (rainfall characteristics, infiltration rates, evapotranspiration rates, storage capacity) and data on groundwater characteristics and quality (groundwater table location, direction and flow rate of groundwater, location of groundwater wells, water quality in aquifers)" (Hagerty *et al.*, 1973).

It is these characteristics that help determine whether the migration of contaminants, including leachate, will pose a problem. Site selection, design, and operation should all be undertaken with the objective of minimizing the amount of surface water infiltrating the landfill by eliminating inflow of off-site drainage into the site, suitable surface grading, use of appropriate soil cover, and installation of required surface drainage features. It is also essential to either avoid or minimize contact between the groundwater and deposited wastes. If contact is unavoidable, control measures should be implemented either by limiting the type of wastes, or by the use of mechanisms designed to manage the groundwater or the contaminated liquids leaving the site. This is accomplished either by raising the wastes above the groundwater table if the intervening soils can contain leachate, or by the addition of an impermeable barrier, such as a clay or plastic liner, between the fill and groundwater.

Cover material

Because cover material is required for a variety of purposes essential to the proper operation of a sanitary landfill, it too is an important siting factor. Soil cover can modify the rate of water infiltration into decomposing wastes, prevent emergence of vectors such as rats and flies, control movement of gases and odours, reduce blowing paper and other litter, decrease fire hazard, and provide a suitable base for vegetation cover during rehabilitation. To address all these tasks, a significant supply of soil is required. For a properly operated sanitary landfill the amounts of daily cover material required alone is generally about 1 part of soil to 4 parts of compacted refuse.

For each of the requirements for soil, quality is as important as quantity, if not more so. Each requirement may need different soil characteristics. Gravel may impede large vectors such as rats but does nothing to inhibit smaller ones, such as flies, or the migration of gases. When saturated, fine particulate material such as silts and clays provide low permeability to gas, water, and vectors, but in dry hot weather large cracks develop which permit easy movement. When wet or frozen, clay can be difficult to work with and provides a very poor surface for truck traffic. Clay is also a poor soil base for revegetation. Pure sand is readily permeable, subject to wind erosion, and is not ideal for vegetation growth. When all needs are considered, therefore, the ideal soil is a sandy loam. The larger particles provide strength, the finer particles will be more impervious to movements of gas, water, and vectors. The combination also provides a good working surface, a material that is easily managable, and a good basis for effective revegetation and control of litter, water, and gas (Hagerty *et al.*, 1973; American Public Works Association, 1970; Pavoni *et al.*, 1975).

The availability of such cover material, either on the site or within a short transportation distance, will make the technical operations more effective and enhance the economic viability of a site. Where suitable material exists on site, its excavation may provide additional space for waste disposal. However, in certain regions of Canada the soils available either on-site or within reasonable haul distance may not even approach the "ideal" requirement. In these cases, changes in operating conditions and the final end use of the site can usually accommodate any deficiency.

Geology

> *"The overall geologic setting of the landfill site will be important to the operation. The presence of a large «thick» layer of suitable cover soil over deep bedrock is an ideal situation for sanitary landfill operation. The characteristics of the bedrock are also important in that certain types of rock are more pervious and therefore contain large quantities of rapidly-moving groundwater, offering significant possibilities of water pollution. Other types of rock (for example, shale) are typically very slowly pervious and groundwater moves very slowly and in only small quantities through such materials. The characteristics of the underlying bedrock are also important in that certain types of rock are more susceptible to chemical action, and may deteriorate rapidly under the attack of leachate produced in a sanitary landfill. Finally, geologic features such as active faults, landslides, or subsidence areas obviously will have detrimental effects upon a sanitary landfill"* (Pavoni *et al.*, 1975).

In general, sites that have thick deposits of relatively impermeable material, such as glacial till, lake silts and clays, residual soils, and windblown silts (loess) offer greater natural protection of groundwater than more highly permeable formations of sand or gravel (Fischer and Woodford, 1973*a*). Sites with porous or fractured material such as sandstone or limestone will not effectively prevent the movement of groundwater or leachate.

Land requirement

Physical properties are not the only criteria used in the selection of sanitary landfill sites. There are also criteria concerned with land area requirements for the landfill, location and accessibility of the site, availability of land, and the compatibility between sanitary landfill operations, existing land uses, and ecosystems. The land requirement is dependent on a number of factors including certain social and demographic characteristics, economic conditions, quantity and characteristics of wastes, desired lifespan of landfill site, degree to which refuse can be compacted, site configuration, and disposal technique selected.

Location and accessibility. It is desirable to locate a disposal facility as close as possible to where the waste is generated. This will minimize the haul distance and, as a consequence, costs for collection and transfer will be lower (Pavoni *et al.*, 1975). It is estimated that in the

Photo 15. Sanitary landfills must compete with residential, commercial, transportation, and other land uses for any available property. Furthermore, landfills are considered "undesirable neighbours" by many urban land users.
NFB-PHOTOTHÈQUE-ONF

past, 80% of the total expenditure on solid waste management was on the collection of refuse, not on disposal. Competition from other urban uses for such logistically and financially advantageous central locations is intense, and as a consequence, land prices rise. The present energy situation increases the incentive for all users, including landfill operators, to seek a central location.

Accessibility is a critical factor. Whether sites are located close to urban centres or in rural areas, it is important to minimize both the travel distance and time by ensuring locations near major highways. All routes should be capable of carrying heavy truck traffic by virtue of both capacity and load limits in all weather conditions. Utilization of access routes that avoid residential and commercial areas will reduce complaints about noise, dust, and traffic congestion.

Availability of land and compatibility with other land uses. As land parcels in urban and suburban areas become more scarce and more expensive, locations further from the sources of waste have to be considered. For obvious reasons locations in existing residential areas or in areas zoned for residential use are difficult to obtain for waste disposal sites. Land zoned for industrial or some commercial uses is more likely to be acceptable for landfill sites. A land parcel within the city, currently under development, zoned for industrial use, and not already surrounded by existing development, can be an ideal choice from a logistical point of view.

The suburban areas of metropolitan centres may offer more opportunities for siting landfills but there can be considerable public opposition. "... suburban residents generally are resentful and enthusiastically resist any attempts to bring urban refuse to the suburban area for disposal" (Hagerty *et al.*, 1973).

If not too distant, the rural areas adjacent to urban centres may also furnish potential sites. Opposition from other land users may be less because of both lower population and lower population density. Although some rural land uses may not be sensitive to the impacts of landfill activities, agriculture and recreation are susceptible to the hazards of poorly sited and/or poorly maintained landfills. Residents of rural communities increasingly resent receiving urban wastes. Furthermore, transportaton costs may prohibit the selection of an otherwise acceptable rural site.

Landfill sites may also be subject to specific restrictions vis-à-vis other land uses.

> *"Land-use plans and planning goals are established by the appropriate local and regional agencies; they, obviously, must be consulted as the preliminary step in site selection. A local or regional master plan, for instance, may preclude the use of an otherwise technically suitable site. Present and future zoning of adjacent land must be considered in determining the suitability of a site for receiving waste and its ultimate use. For example, the proximity of present or future airports is a matter of concern since birds may be attracted to an operating landfill and thus endanger low-flying aircraft"* (Stone, 1977).

Transport Canada (1981) recommends that sites for sanitary landfill or refuse disposal facilities should not be located within 8 km of the centre of an airport.

> *"Another environmentally related aspect of landfill development is to avoid locating the facility in an area where fragile ecosystems or other valuable resources are disturbed. These areas may include the habitat of endangered plant and animal species, virgin timber land, wilderness areas, nesting areas, wildlife corridors, unique physical features, and historical or archeological sites. The development of a landfill in one of these areas may result in a detrimental impact which from an overall viewpoint outweighs the benefits of a successfully operated landfill. Decisions relating to these areas are usually very subjective and controversial. When at all possible, these areas should be avoided for consideration as potential landfill sites"* (Reindl, 1981*e*).

Selection of a landfill site must take account of all the potential effects on the natural environment. The Canadian public has become more aware of the need to preserve ecological quality and diversity.

With all of the above constraints, it is not surprising that "the most significant problem associated with the continuing disposal of solid wastes in sanitary landfills is the decreasing availability of sites suitable for such disposal operations" (Pavoni *et al.*, 1975).

Steps in establishing a sanitary landfill

Factors to be considered

Before the difficult and time-consuming process of selecting a new sanitary landfill site is initiated, several factors must be examined. First, there must be a clear and documented need for a new landfill site, in the immediate or foreseeable future. Second, the area that can be serviced by the landfill must be clearly described. Third, there must be an inventory or thorough knowledge of the quantity, types, and sources of wastes to be dealt with. Based on the current and projected population to be served and on the quantity and types of wastes to be handled, an estimate can be made of the landfill's expected lifespan and capacity. Lastly, the potential end uses of the site and its relationship to existing land uses and future planning should be considered.

1) Site selection process

Because of the complexity of the criteria that determine the choice of a landfill site, the importance and long-term significance of a thorough site selection process cannot be overemphasized. There are three major steps in site selection: identification of potential sites, evaluation of these sites, and selection of the recommended site (Reindl, 1981*e*).

Some of the main considerations in identifying potential sites and in making a final recommendation are listed below:

Principal factors used in identifying landfill sites:

1. Physical
    - topography
    - quality, quantity, and type of soil
    - depth of groundwater table
    - geology
    - climate and microclimate
2. Services
    - road access
    - distance to sewers, water sources, etc.
    - electricity
3. Legal
    - ownership
    - existing or proposed zoning
    - site-specific constraints
    - municipal/provincial guidelines
    - municipal/provincial regulations
    - municipal/provincial approval procedures
4. Social
    - public attitudes and perceptions
    - political attitudes

5. Economic
  - land acquisition expenses
  - site preparation costs
  - landfill operating costs
  - collection and transportation costs
  - rehabilitation and long-term maintenance expenses
  - value of ultimate land use

6. Land
  - availability of land of suitable quality/quantity
  - land uses on site and in surrounding area
  - potential impact on land use, value, and capability
  - potential of land-use conflict
  - final end use of landfill site

The process of selecting the final site, usually from among several acceptable ones, is handled differently according to the province and agency concerned (Sexsmith *et al.*, 1974). Final selection may employ a variety of rating techniques. Numerical ranking or weighting may be assigned to each criterion in order to arrive at the final rating. Another method is to list and evaluate the advantages and disadvantages of potential sites. Regardless of how it is achieved, the final recommendation is then prepared for the planning and design stage.

2) Site planning and design

> *"Often the site selected for sanitary landfill development will have certain characteristics that are less than ideal. In the design of a sanitary landfill, engineering techniques are used to overcome existing site limitations and to meet established criteria or goals. In actuality it is difficult to separate design from site selection.*
>
> *Site design begins early in the site selection process. Each site examined has different characteristics which suggest an appropriate landfill design. One site may be best operated as an area fill, another as a trench operation. Some sites may provide a suitable environment for natural attenuation of leachate, while others may require clay or artificial liners in combination with leachate collection systems. The ease with which a landfill design can be implemented is one factor in site selection since ease of implementation will affect costs and operational methods"* (Reindl, 1981*f*).

Reindl documented the five steps that constitute the design process: establish goals and objectives, identify design basis, prepare alternative designs, evaluate alternatives and select best design, and develop detailed design specifications.

3) Approval

Regulations controlling waste disposal vary from province to province, but convention or legislation require that plans for sanitary landfills require appropriate agency review and approval prior to construction. Application for approval is submitted by the proponent of the landfill site, which may be a private owner, municipality, or provincial government agency. During the review, the plan's acceptability is judged according to provincially established regulations or guidelines, which frequently stipulate the format of the submission as well as specify the background information that must accompany the plans. Most provinces operate on a permit or approval type system which requires that a formal document be secured from the responsible agency. The conditions of the permit, although outlined in broad terms in regulations or guidelines, may still reflect the unique conditions of the individual site and are often negotiated and agreed to by all parties. The agency responsible may unilaterally insist on compliance with certain standards for the siting and operating of the sanitary landfill.

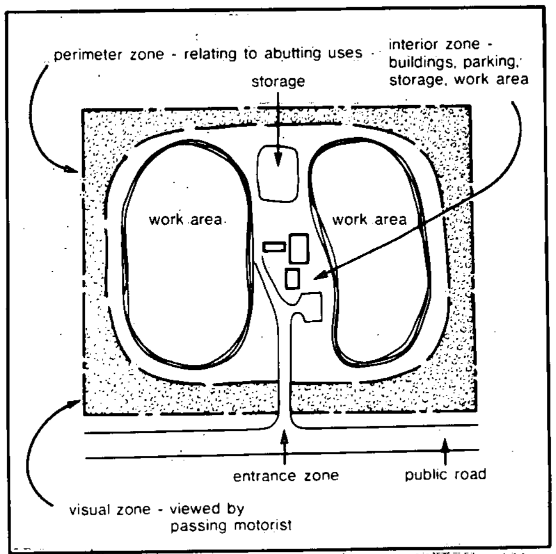
Whereas the site selection and design processes are undertaken by planners, engineers, and other technical experts, the approval of any site can involve a host of non-technical decision makers. In addition to the normal approval procedures that may exist in any province, politicians, the public, and interest groups can and do influence whether or not a sanitary landfill site actually goes into service. In most provinces, the minister responsible may over-ride any boards, panels, agencies, or other official decision makers and grant or deny approval for a particular site. Similarly, public opposition may be strong enough to cause an approved site to be rejected. More than once the best environmental site has been rejected because of public opposition, in favour of a site which is environmentally less suitable but politically more acceptable.

4) Site preparation

Based on the approved detailed site design, the site must be prepared to permit efficient operation. Site preparation includes: land clearing; pre-grading of site; construction of roads connecting public roads to the site; construction of any permanent buildings or, more commonly, the delivery of temporary structures; erection of required fencing; construction of berms; connection of utilities; excavation of drainage ditches or the addition of culverts; and preparation of signs, parking areas, and weigh scales (Mantell, 1975).

Having progressed through the various procedures to the point of operation, what does the final site look like? Figure 6 shows a typical design for a sanitary landfill.

FIGURE 6
Design of a sanitary landfill



With permission adapted from: Solid Wastes Management Journal 1977.

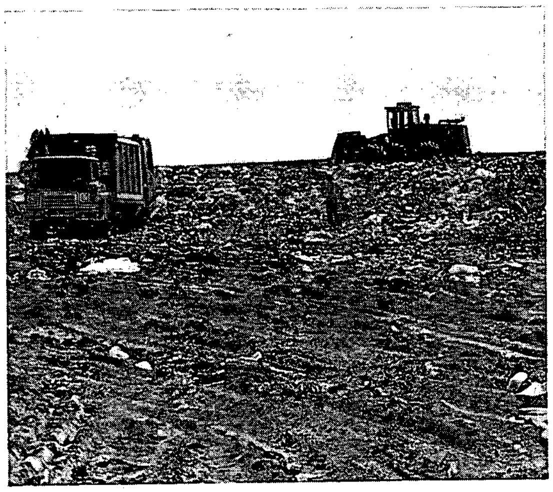


Photo 16. This photo shows some typical activities in the work area of a sanitary landfill in Ottawa, Ontario.
Lands Directorate, Environment Canada

Summary

Disposal of garbage is indeed a complex procedure. It begins with the recognition of the need for a disposal facility, continues with an evaluation of techniques and potential sites, proceeds to the selection phase, followed by development and operation of the facility, and concludes with the rehabilitation of the land to another use.

Many Canadian communities encounter problems concerning waste management, particularly disposal. These centres will be faced with the question of "where can it go?" The question can in part be answered by consideration of technical, environmental, economic, and legal factors. However, decisions cannot be based solely on such objective factors; social and political influences will frequently play a significant role in the decision-making process.

There are many different ways of resolving this dilemma. Three case studies involving 3 different areas have been chosen not only to illustrate various approaches but also to highlight different aspects of the waste disposal problem. The City of Winnipeg provides an example of an innovative approach to resolving the need for both waste disposal and recreation facilities. The Keele Valley case study focuses on the approval procedure required for a large sanitary landfill project north of Toronto. The Highway 101 case study highlights the struggle of Halifax–Dartmouth to find an acceptable site for their urban wastes. A concluding section entitled "Waste disposal in the North" describes the special methods of garbage disposal employed in northern Canada.

CASE STUDIES

Winnipeg's Kil-Cona Park: A unique approach

"The need for a new solid waste disposal facility in the Northeast area of the City of Winnipeg and the desire to locate a major regional park in the same area presented the opportunity for a unique park-sanitary landfill development. By mutual agreement, the Parks and Protection Division and the Waterworks, Waste and Disposal Division of the City of Winnipeg have proceeded with the co-operative planning of the combined facility" (City of Winnipeg, 1975).

The Northeast Park plan in the City of Winnipeg is an interesting example of how foresight, co-operation, and creative planning can produce an imaginative approach to the need for both sanitary landfill and recreation facilities. The following dialogue highlights the main features of the plan.

Q Briefly, what is included in the Kil-Cona Park Plan?

A* The Plan includes:

1) the purchase of land totalling about 180 ha, within the City of Winnipeg,
2) the establishment of a landfill site to dispose of approximately 3.2 million tonnes of refuse, for an estimated life of 12 years,
3) the post-landfill development of a regional park facility for year-round active and passive sports.

Q What were the objectives of this Plan?

A The objectives of the Plan were a combination of effective and economical disposal of refuse, long-term planning and establishment of park facilities, and public involvement throughout all phases of the plan.

Q What is unique about this approach?

A Several interesting features of the Plan are:

1) intensive public involvement throughout the development of the Plan,
2) establishment of a landfill site in close proximity to existing residential development,
3) the incorporation of an extensive lake system into the recreation complex.

Q What is the physical setting?

A The site is 180 ha in size and is located in the northeast quadrant of the City of Winnipeg. It is bounded by two residential and two regional streets. The landfill portion consists of about 80 ha and has a 300-m buffer all around, with plantings of trees and shrubs for screening.

Q What was the impetus for this idea?

A The urgent need for a new landfill site in the northeast quadrant of the City, together with the plan to locate a major regional park in the same area presented the opportunity for a unique park-sanitary landfill development. By mutual agreement, the Parks and Protection Department and the Waterworks, Waste and Disposal Department of the City of Winnipeg proceeded with the co-operative planning of the facility.

(Following the unification of some 13 cities and municipalities in 1971, the Parks and Recreation Department became the sole department responsible for all parks and recreation for the City of Winnipeg. In 1971, the Census Metropolitan Area had a population of 540 000 persons. By 1981, the Winnipeg CMA population had reached 565 000. In this same amalgamation, the Waterworks, Waste and Disposal Department became the regional planning authority of the new City, for water, pollution control, land drainage, and solid waste disposal.)

Q Could you describe the chronology of events and players involved in the Plan?

A With the inception of the new City of Winnipeg in 1971, solid waste disposal for the total City was examined. It was found that sites were becoming inadequate for current operational and environmental standards. Thus small sites were phased out and the City converted to a 3-site operation. Following reviews of alternative disposal methods, economics dictated a continuation of landfill disposal. Since a dearth of capacity existed in the eastern sector of the City, location studies began for a site to satisfy that need. Key considerations were:

- public acceptance regarding location, appearance, health, and traffic,
- minimum relocation or disruption to existing development,
- freedom from pollution to surface and groundwater,
- minimum ecological damage,
- sufficient land area,
- minimum engineering and operational problems,
- compatibility with planning and future land use,
- economics.

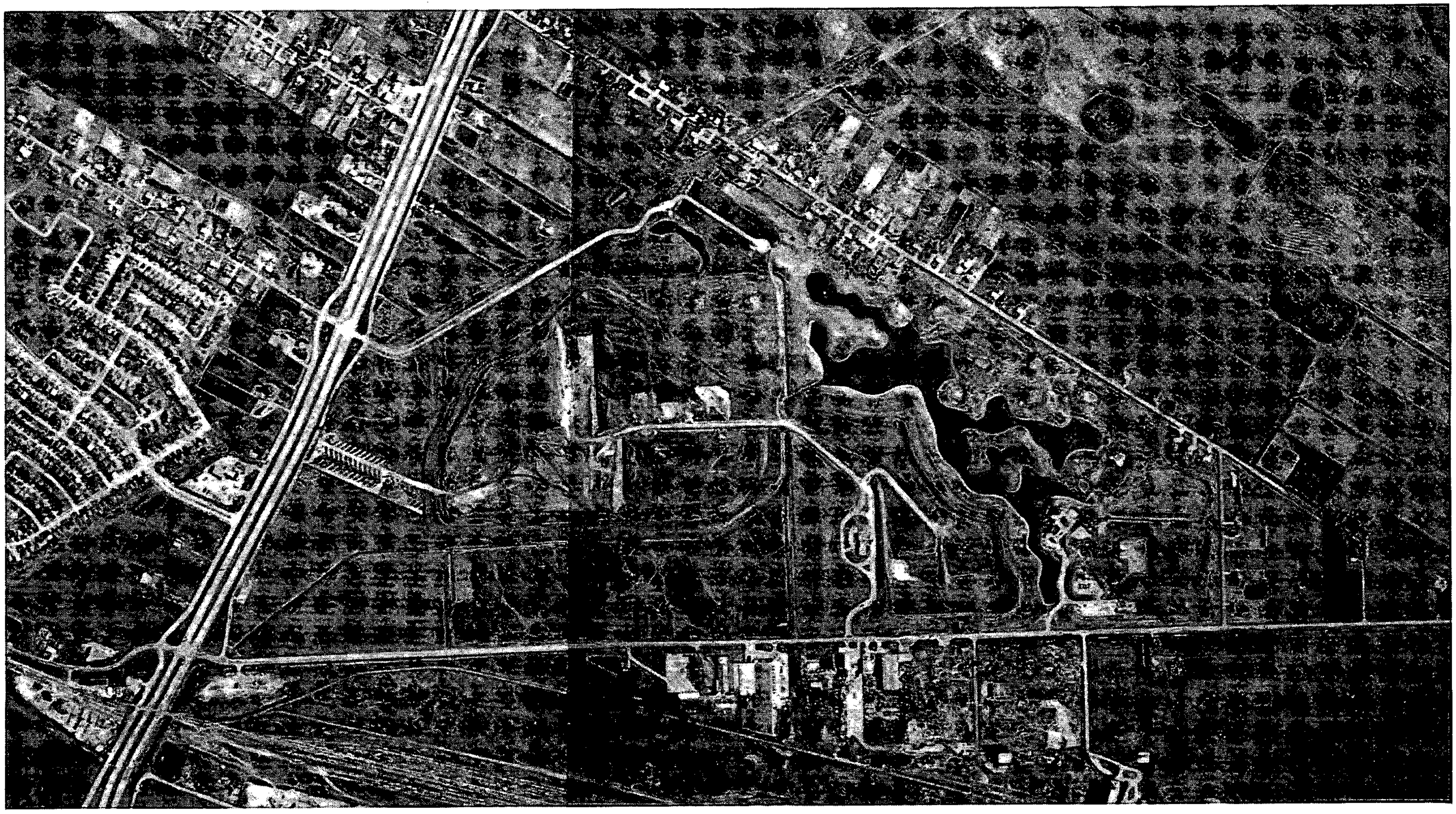
At that same time, the Parks and Recreation Department was beginning to acquire land for a regional park in this quadrant. Potential sites were evaluated on the basis of the above criteria and a joint site was selected. Other successful sites throughout North America were consequently researched.

Extensive surface and sub-surface research was carried out to ensure environmental safety. Discussions were held with all relevant City departments, commercial haulers, citizen groups, and many interested individuals. Once a suitable site was chosen, proceedings were initiated to purchase the property by offers of compensation, and ultimately to a last resort of expropriation. The offers of compensation were determined by doing a land survey appraisal (plus 10%). Once the land had been accumulated a public hearing was held. Prior to the hearing, a public hearing announcement was advertised in the local papers with a questionnaire consisting of 16 items to solicit the opinions of all concerned citizens with regard to the planning of the proposed park/sanitary landfill. The hearings were held before the Clean Environment Commission of the Government of Manitoba and following the hearing of all evidence, the Commission established an Order governing the control and implementation of the Plan. Numerous other public hearings were held to keep the citizens updated and to hear their complaints. As of 1982, the operation is into its fifth year and public meetings are still held, with a minimum of one per year.

During the progressive development of the landfill, coincident park development has occurred, starting with buffer planting. A par-three, nine-hole golf course was started immediately. At the same time, a 12-ha artificial lake was begun as the first stage of the "fishing village" theme. Playgrounds, tennis courts, lawn bowling, and sports fields are currently under construction. This will be followed by hiking trails, ski and toboggan hills, children's playing areas, canoe and paddle boat facilities, and an aquatic environment conducive to supporting native waterfowl. The final product will be a complete year-round regional recreational park, bordered by a well-developed residential district.

Photo 17a. This 1974 aerial photo of the area clearly depicts the ideal site for the Kil-Cona landfill – regional park project in Winnipeg. ▲
Northway Survey Corporation Limited

Photo 17b. This 1982 aerial photo shows that the residences to the north and east were screened from the landfilling operation by a 9-hole golf course and a tree nursery. Sanitary landfilling and park development are progressing simultaneously. Industry to the south has been upgraded and residential development to the west has grown significantly. ▼
Northway Survey Corporation Limited



Q What objections were raised and what steps were taken to overcome them?

A Objections raised by residents and other persons with environmental concerns were:

- odours caused by the many different refuse types,
- pests, litter, and other nuisances,
- methane gas from decomposition of refuse.

The public's impression of landfill sites was one of infested dumps and blights on the landscape. This was largely as a result of the presence of sub-standard garbage dumps. Much energy was expended in changing this impression.

To overcome objections, numerous meetings were held with interested parties, using all available films and reports on properly operated landfill sites. This was complemented with information on proposed plans to combat the objections.

Q What land uses previously occupied the site?

A Prior to the Plan, most of the land was undeveloped. The north and east limits of the site had strip residential development. The core of the site was leased for agricultural purposes, mainly cereal crops. The south edge was bordered by older homes. The west limit contained a mobile home village and golf driving range. Most of the land was zoned agricultural with limited residential and industrial zoning.

As a result of the Plan, all private property was purchased, including nine homes. It is not known where the homeowners relocated. All of the trailers were bought and auctioned off. The owner of the village was reimbursed for his property.

Q What land uses surrounded the site?

A Most of the surrounding lands were privately owned. Lands to the south were largely agricultural, again mostly cereal crops, with light and heavy industry just south of the southern limit of the site (furniture manufacturing, auto wrecking). Agricultural land occupied most of the area to the east and north of the site. Residentially-zoned and developed strips of land occurred to the north and east. Since the plan, the industry to the south has been upgraded and residential development has grown in the north and west. Following completion of the Plan, the development pattern currently operating will continue and perhaps accelerate.

Q Has the Kil-Cona Park development had any impact on land values?

A At the present time, the market value of the lands surrounding the landfill site has increased at the same rate as other areas of the City. We have no evidence that land prices have been depressed or improved by the implementation of the park/landfill (no actual costs or studies have been collected). Since the plan provided for a wide buffer (0.3 km), the construction activity was well removed from residential construction and homes, and it is likely that land values were not affected during the process of implementation. Although it is premature to confirm, it is expected that when the plan is completed, land values of surrounding property would increase beyond the regional rate. [The Environmental Impact Study (City of Winnipeg, 1975) stated that "experience with similar operations of this nature elsewhere in Canada and North America has shown that residential property values are enhanced, especially those properties immediately adjacent to the development."]

Q What steps were taken to reduce the aesthetic impact of the operations?

A Prior to landfill operations, earthen berms were built which virtually shielded the landfill operation from view. Furthermore, fences were constructed on these berms to contain wind-blown debris. Also, the buffer zone referred to earlier, provided a 0.3-km separation of landfill activities and homes.

The first park function was buffer planting, especially adjacent to existing residential areas to the north. This further shielded the activities.

The only intermittent problems are of blowing paper and the presence of land gulls. Under unusual wind conditions some paper will escape from the site. This is retrieved by City forces within 1 or 2 days. Gulls are an inherent part of landfill sites and cause a nuisance by their presence and the faeces they leave. No successful means exist to rid the site of gulls. However, the complaints were nominal.

There were also complaints of rats emanating from the landfill site. However, the City has since retained a local firm for pest control on a continuing basis and their investigation indicated that the rats originated from other areas. The refuse at the site is covered daily.

Q In terms of rehabilitation, what restrictions are there, and what activities are planned for the end use?

A In general, the uses of rehabilitated areas are limited only in the sense that buildings are not allowed on the areas because of potential methane gas problems. A further complication may be the settlement that can occur during the natural compaction of the refuse. These areas would therefore be mostly used as sports fields.

This site will have facilities for all field sports as well as lawn bowling and tennis courts. The nine-hole golf course is now complete. There will also be hiking and cross-country skiing trails, and toboggan runs. The large lake area will allow canoeing and paddle boats, and perhaps fishing. There will also be passive nature areas including natural habitat for native birds.

Q Could such a plan be duplicated elsewhere in Manitoba?

A It is unknown whether other such projects might occur in Manitoba. The feasibility of such a project depends somewhat on its size and on the size of the service area. Small communities with small service areas may not realize the advantages as would a large community, where haul costs for refuse are a significant part of the economic viability.

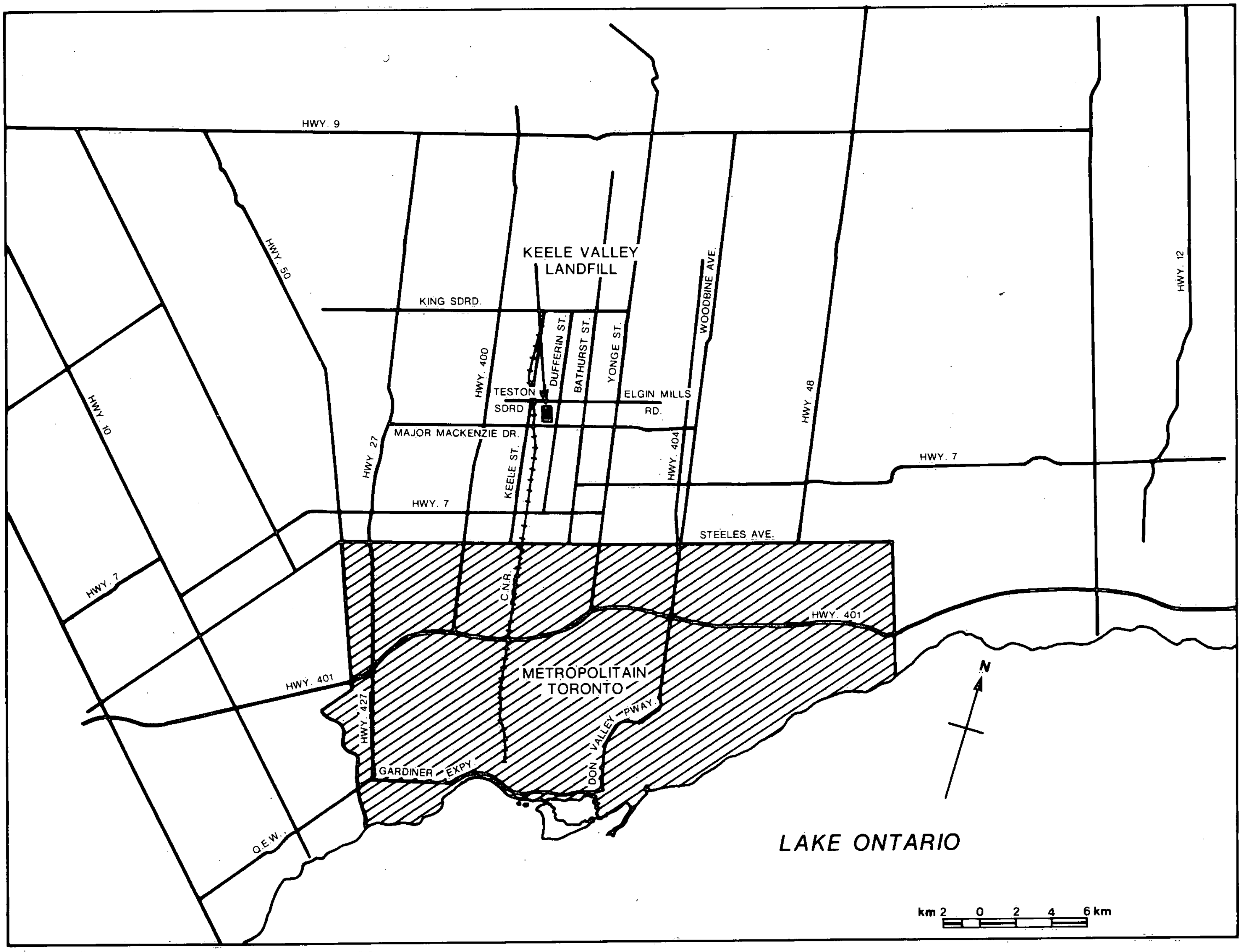
This approach is justified from the economic aspect because optimum refuse disposal is realized when the disposal is as near the centre of the service area as possible. The social aspects alone would not necessarily justify such a plan. Even under the best of circumstances there will be some disruption to the neighbourhood. On the other hand, the experience probably made the participating residents realize that by becoming involved in a project from the beginning they can actually have an impact on the direction and shaping of a large government project. With preplanned controls and monitoring, such a plan can be environmentally entirely successful. In this case, for example, the subsurface conditions were almost ideal and perhaps among the best in Winnipeg.

Q Are there any other benefits to be gained from the Kil-Cona Park Plan?

A This site has the potential for producing large amounts of methane gas. An assessment will probably be made in the near future on quantities and quality, which may result in its extraction. The main facilities buildings of the sports complex could be readily converted to methane use and this may be a step towards making the sports complex energy self-sufficient. Methane could also be used for park lighting and greenhouse use in the winter months.

A* E.H. Klassen, P. Eng., Manager of Engineering, Works and Operations Division, Waterworks, Waste, and Disposal Department, City of Winnipeg.

MAP 1.
Keele Valley landfill site location



Source: Waste Management of Canada, Inc. 1980.

Keele Valley sanitary landfill site case study

Introduction

No one wants a sanitary landfill in their backyard and the citizens of Maple, Ontario, were no exception. They vehemently opposed the proposal that a sanitary landfill be located in their area. They voiced their concerns for health, safety, and environmental protection to government officials and site owners and operators. The final outcome was not a complete halt to the project as the citizens had hoped, but the site was to undergo development as a sanitary landfill with the proviso that it must adhere to strict environmental conditions. Before a certificate of approval would be issued by the Ontario Ministry of the Environment permitting operation, special controls and procedures would have to be instituted.

The Keele Valley landfill site, better known as the Maple landfill site, is situated 10 km north of the Metro Toronto boundary, in the town of Vaughan, 1.5 km north and east of the community of Maple. "The site is bounded on the north by Teston Sideroad; and the east by a woodlot, the Honey Pot ski complex and agricultural land; on the south by an aggregate extraction area; and on the west by agricultural and industrial lands" (Waste Management of Canada, Inc., 1980).

Specific land users along the periphery of the site include: lumber and building supply companies, cement block enterprises, aggregate extraction activities, a ready-mix plant, light and heavy industries, a fisheries research centre, equestrian club, steel fabricating plant, farms, some private residences, and commercial activities.

Originally the site was forested and was later cleared and used for agricultural purposes. Because it is situated within a kame moraine, the area began to be used for extensive sand and gravel operations in 1908. Over time, the continuous extraction of aggregate material created deep pits covering several hundred hectares. The pits typically have steep sloping sides and minimal vegetation and are subject to extensive wind erosion. Currently, it is thought that by the establishment and operation of a sanitary landfill these open pits can eventually be rehabilitated for open space recreational use.

This particular site has made political history. The first application to obtain a certificate of approval to operate a sanitary landfill was submitted in 1973 and for over 9 years it has been involved in the political process. Gaining final approval for operation of the site has been fraught with difficulties. As of spring 1983, the site was still awaiting final approval for a start to be made on the landfill operation.

The environmental problems that such a large landfill site could encounter have been major concerns of the Ontario Ministry of Environment and the adjacent citizens of Maple. In the process of gaining approval for development and operation of the site, the owner, Waste Management of Canada, Inc. hired consultants who established that engineering methods could be used to control environmental problems such as methane gas and groundwater contamination.

This case study is intended to demonstrate the kinds of environmental considerations associated with establishing and operating a sanitary landfill site and the substantial amount of time the approval process can take.

Historical background

In 1967 this area was first identified as a potential waste disposal site in a report prepared for the Municipality of Metropolitan Toronto. At that time the two consulting firms of James F. MacLaren Ltd. of Toronto and Black and Veatch of Kansas City recommended that Metro acquire the site for waste disposal sometime between 1976 and 1986.

> *"In January, 1968, Metro Council approved an application to the town of Vaughan for the right to use the Maple Site for landfill and budgeted $1.5 million for acquisition and preliminary development of the site. Negotiations for acquisition were not completed. A report by Metro's works department said the climate at that time was favourable to waste recycling, with the Ontario Ministry of the Environment predicting that by 1985 almost 85% of urban waste would be recycled"* (Globe and Mail, Sept. 2, 1981, p. 5).

Then in 1973 the five separate companies that owned the pit areas decided they would apply to use the area for landfilling purposes. The interests of the five landowners were represented by two companies, Superior Sand Gravel and Supplies Ltd. and Crawford Allied Industries Ltd. These two companies hired separate consultants to design the disposal sites and had different attorneys represent them during public hearings. The two applicants had different design concepts and control strategies.

> *"The primary constraint on design of the disposal sites was protection of groundwater. The pit formed part of the recharge area for a major aquifer. Locally, removal of surficial till soils and creation of the pits had resulted in substantially increased recharge to the acquifer. It was essential that groundwater quality and quantity be preserved"* (Poland, 1981).

Superior Sand Gravel and Supplies Ltd. made application in August 1973 to operate a waste disposal facility on 157 ha owned by J. Cheffero Sand and Gravel Ltd., Disposal Services Ltd., and Superior. Then Crawford Allied Industries Ltd. applied in March 1976 to operate a disposal facility on an area of 71 ha owned by Crawford, and Downtown Sand and Gravel Ltd.

Further complicating the application for two independent landfill proposals was the existence of one completed and two active waste disposal sites already in the area proposed for landfilling and of these, two were degrading the groundwater quality. Despite the fact that the two applications were totally separate in design, the Ministry of the Environment decided that because of their proximity they should be reviewed concurrently in a single Environmental Assessment Hearing. These hearings spanned the period between July 1976 and November 1977. In a report dated April 5, 1978, the Ministry denied both applications for the following reasons:

—the technical information presented to the board was inadequate;

—the applicants shared a 2 135-m common boundary; groundwater protection techniques proposed by the applicants were incompatible and neither could be monitored independently. There was already a problem of groundwater contamination from former waste disposal sites located to the north of the proposed site, and the presence of this contamination might interfere with verification of the performance of any additional disposal operations; and

—the predicted site life and capacity was thought to be excessive in light of anticipated developments in resource recovery from waste.

Finally, there was no agreement reached with the municipality regarding the provision of necessary site services (Poland, 1981).

Following this negative decision, the principals of Crawford Allied Industries Ltd. and Downtown Sand and Gravel Ltd. abandoned the project. Superior Sand Gravel and Supplies Ltd. purchased their interests and, in conjunction with Waste Management of Canada, Inc., decided to appeal the decision. The proposal was modified specifically to address the reasons given for refusal of the permits:

- "a single control strategy would be used for groundwater protection over the entire site. Waste Management of Canada, Inc. would be the sole operator of the landfill and all property to be landfilled was owned or controlled by Superior;
- purge wells would be constructed to arrest the flow of contaminants from the existing disposal sites;
- an agreement was reached with the municipality for construction and funding of site services;
- the disposal area was downsized to decrease the projected site life" (Poland, 1981).

A multidisciplinary team of consultants and research experts was assembled to evaluate the work to date and improve the technical quality of the proposal. By the time the appeal hearing was completed, some 21 firms and individuals had participated in the project. Most of the intensive preparatory work focused on the assessment of the proposed clay liner for the landfill and evaluation of the hydrogeologic impact on the site.

Design plans for the Keele Valley landfill indicate it is to function as a "containment" site. A clay till liner of very low permeability will be constructed at the base of the site before landfilling takes place. "This liner will eliminate the movement of gas from the landfill and will limit leachate migration to the point where seepage from the landfill will have a negligible impact on groundwater" (Waste Management of Canada, Inc., 1980). It will also permit control of fluids generated in or passing through the refuse and allow treatment prior to discharge.

> *"The site was also designed to function as a 'wet' landfill. Moisture would be applied to the refuse in order to stimulate microbiological activity and accelerate decomposition of the waste. This was intended to stabilize the landfill during the period of greatest liner reliability ..."* (Poland, 1981).

A commercial-scale gas recovery system would be installed to extract landfill gas for possible use as an energy source or for venting or flaring. The clay liner would serve to contain the gas and then it could be collected and marketed commercially. By this means, landfill gas migration and odours would be controlled in a positive manner.

> *"The appeal hearing began in November, 1978 and ran until January, 1980. On April 1, 1980 a favourable ruling was received from the Appeal Board .... The decison which ordered the Ministry to issue the landfill permit, contained 18 conditions, many of which were innovative and stringent. The decision as a whole was hailed as a mitigated victory by the parties who opposed the landfill"* (Poland, 1981).

From the 18 conditions attached to the permit, 6 were particularly significant and were detailed by the Ministry of the Environment in the issuance of the Provisional Certificate of Approval.

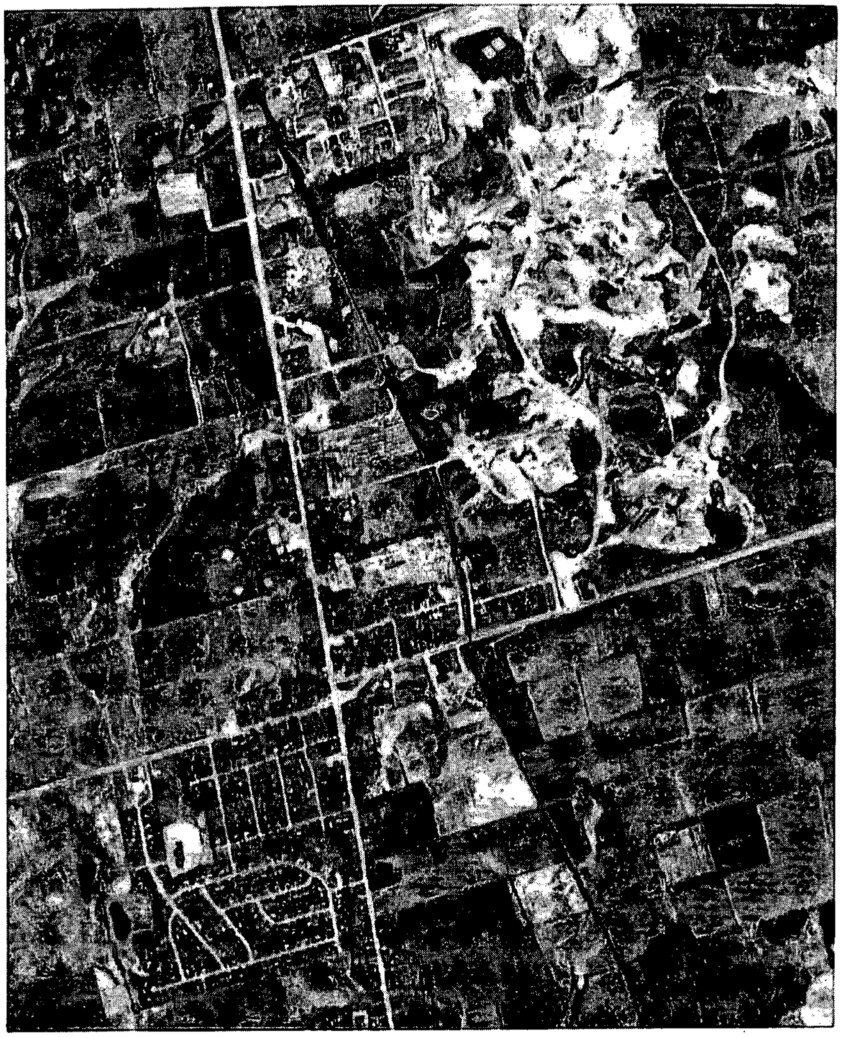
1. Design and completion of a comprehensive environmental inventory to assess the

A

B

Photos 18 a, b, c These three aerial photographs show the proposed Keele Valley landfill site at three different times. Photo 18a shows the site in 1946 with only small sand and gravel pits in operation. The surrounding land was used for agriculture or was forested. The town of Maple occupies the area in the lower lefthand corner of the photo. Photo 18b shows the same area in 1960; the expanding sand and gravel operations have spread onto adjacent farmland and forested areas. The town of Maple was also growing. Photo 18c shows this area in 1981. The sand and gravel pits proposed for the Keele Valley landfill site are now large excavated areas, having overtaken the agricultural and forestry land uses. The town of Maple has increased in size and access roads to the site are well defined.

A10119-21, A17185-149, A25648-59. These aerial photographs © 1946, 1960, 1981 Her Majesty the Queen in Right of Canada, reproduced from the collection of the National Air Photo Library with permission of Energy, Mines and Resources Canada



C

present status of factors such as wildlife or vegetation that might be affected by creation of the landfill. The study was to be conducted prior to landfilling and was to serve as a data base for assessing any future damage claims against the landfill.

2. Correction of groundwater contamination emanating from the existing landfills (north of the proposed site).
3. Construction and in-site performance verification of a clay till liner, 1.2 m in thickness.
4. Designation of a qualified geotechnical engineer to supervise all aspects of liner placement and appointment of an independent "third party" consultant to oversee all liner construction and testing on behalf of the Ministry of the Environment.
5. Preparation and implementation of a program to prohibit hazardous waste entering the site.
6. Disclosure of all technical information and communications with the Ministry to the parties that had opposed the site during the environmental hearings.

Following all the discussions with the Ministry to interpret the Appeal Board order, programs were developed by Waste Management of Canada, Inc. specifically to address the conditions set out by the province (Poland, 1981).

The results of the programs, the engineering studies, and the specifications required to ensure that all 18 conditions would be met, appeared in eight volumes of the Keele Valley Landfill Design Reports, completed December 1980 (see Appendix 1).

The first significant condition to be dealt with was the environmental inventory. A study was conducted addressing: groundwater quality and quantity; surface water quality and quantity; existing landfill gas migration and odours; existing vegetation, vertebrate and invertebrate wildlife, noise, litter, and visual appearance.

> " ... *Aerial photography was conducted over approximately 10 square miles [26 km²] to provide a mosaic of the study area and to be retained for future interpretation in the event of damage claims.*
>
> *An inventory of existing off-site wells was conducted over an area of four square miles [10 km²] to determine well conditions [water] and static levels. In addition, comprehensive water quality analyses were conducted to establish background conditions. This work was conducted at 41 on-site observation points and at some 50 off-site locations. Seven stream flow gauging stations were established within the study area. Flow and water quality were measured at each station once each month for a one year period"* (Poland, 1981).

Probes were to be installed adjacent to the existing landfills to assess the migration of landfill gas. Also, the generation of particulate matter and odours from gases, raw refuse, and exhaust fumes were assessed as to their effect on local air quality. The vegetation was mapped over an area of 10 km² using infrared aerial photography and ground checks, to establish species composition and vegetation stress.

> " ... *Assessment of wildlife species and density was generally confined to the immediate area of the site although bird studies were extended over an area of ten square miles [26 km²] ... Species composition and relative density of aquatic growth was documented at each of the seven stream flow monitoring stations. Invertebrates, fish and amphibians were also studied at each of these locations.*
>
> *Ambient noise conditions were evaluated at ten locations adjacent to the landfill and access routes.*
>
> *Transect surveys and aerial photography were used to establish the present pattern of litter in the vicinity of the landfill.... The environmental inventory involved the services of four consulting firms over a 12-month period at a cost approaching $100,000.00"* (Poland, 1981).

The second area of concern was groundwater rehabilitation. The aquifer exposed in the base of the pits was considered a significant resource which should be protected. Contaminant migration originating from the existing landfills had caused serious degradation of groundwater quality beneath the area of the proposed landfill. The Ministry of the Environment indicated that the existing contamination of the aquifer was excessive, apart from any potential contribution that might ultimately be made by seepage through the liner of the new landfill. Consequently, it was stipulated that purge wells be provided upgradient of the proposed site to prevent further migration of contaminants from the existing landfills.

To address this problem a set of purge wells is to be constructed. Five wells installed at the northern limit of the new landfill are intended to capture all of the flow passing beneath the existing landfills. These wells which are upstream of the new landfill will be operated until such time as the quality of the water meets or exceeds the water quality standards established for the wells downstream of the new landfill. The discharge from the purge wells, when possible, will be applied to the refuse to accelerate the decomposition process; otherwise, it will be discharged to the sanitary sewer. Observation wells will be installed in conjunction with the purge wells to evaluate their performance.

In preparation for the environmental hearings, numerous tests were made to ascertain the suitability of on-site till soils for construction of a landfill liner. The till soil was also evaluated for its shrinkage limits, solubility in leachate, carbolic acid and hydrochloric acid, mineralogy of the fine and coarse fractions, and cation exchange capacity. Tests were conducted using till of differing clay contents. The clay liner is an important element of the site design because it is designed to retain the leachate and methane or carbon dioxide gases produced by the refuse. Then the collection system above the liner will remove the leachate and enable the gases to be either flared or used as a future energy source. Because the landfill liner is the most important element of the proposal, a fully equipped on-site soils laboratory was established and a quality control program was defined. A full-time geotechnical technician responsible for the quality control program was assigned to the site.

In accordance with the Ministry of the Environment's requirements, a soils consultant was retained by the site operator to supervise all aspects of liner construction. In addition, the consultant reviews all reports from the on-site laboratory and performs quality control and audit testing of material properties. An additional soils consultant was retained by the Ministry of the Environment to oversee the work conducted by Waste Management's geotechnical technician and soils consultant. An additional requirement for operation of the landfill was an *in-situ* demonstration of liner impermeability.

A further condition required that only wastes classified as non-hazardous be accepted at the landfill and that all materials deposited at the site be inspected to ensure compliance. New contracts were prepared for all customers who would use the site. The contract included a declaration that the customer would not forward hazardous wastes to the site.

An inventory of waste streams was conducted and a program was defined for sampling and analyses of suspect materials prior to acceptance. A program was developed for the inspection of wastes delivered to the site.

If, and when, final approval is ever given to the Keele Valley site it will be one of the largest landfill sites in North America. The certificate of approval applies to a total area of 375 ha; however, the landfill site itself occupies 99 ha. The site will be able to serve the greater Toronto area, stretching from Etobicoke to Pickering, a distance of 50 km and will accept in excess of 1 000 000 t of garbage annually.

The projected length of operation is 15–20 years, as its capacity is estimated to be 20 million tonnes. Each day, an estimated 500 trucks will unload at the site, averaging one truck a minute entering the gates enroute to the weigh scales. Thus the site will accept approximately 5 000 t of garbage daily and will be in operation 5.5 days per week.

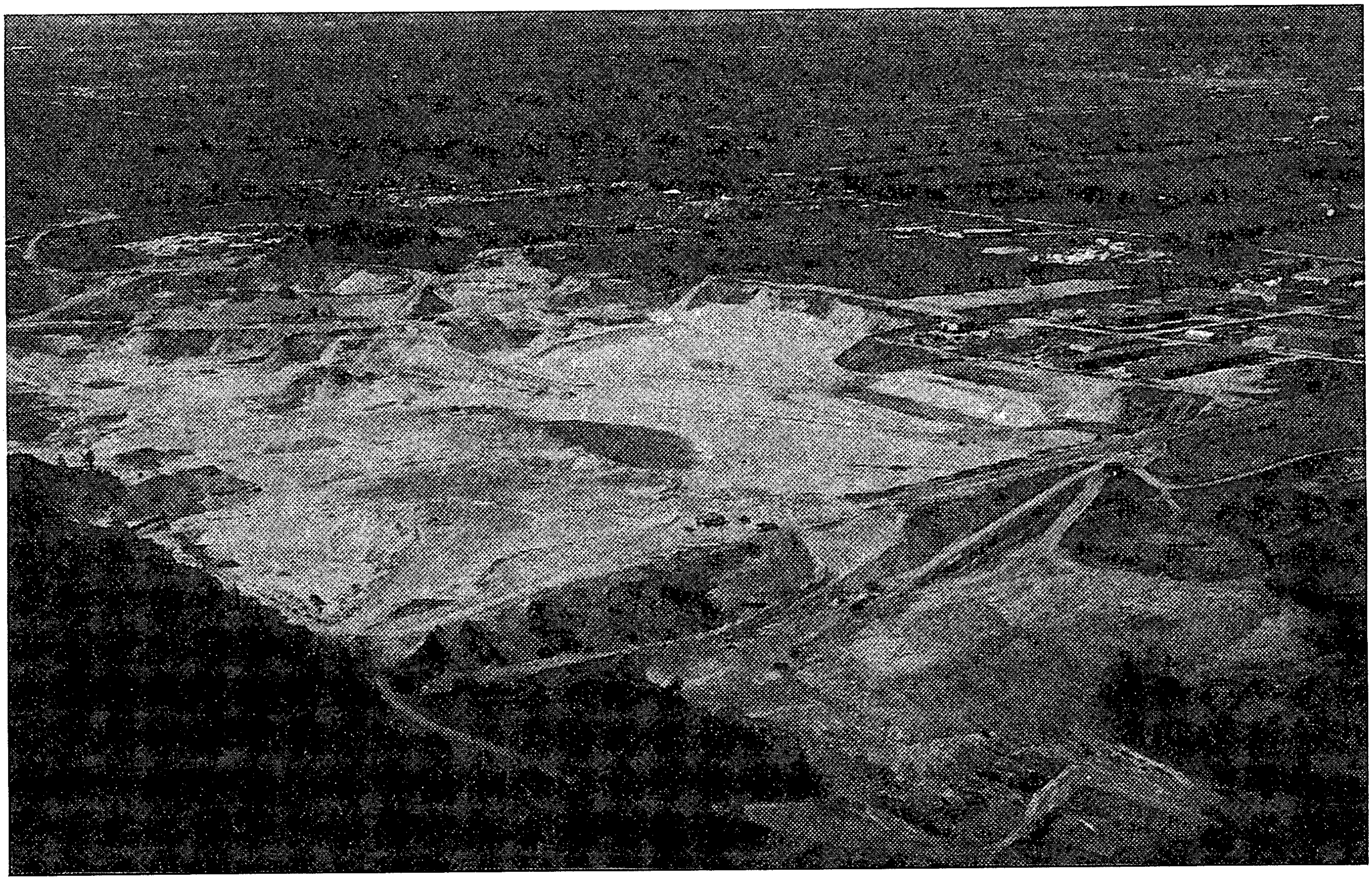


Photo 19. This photo shows the immense size of the proposed Keele Valley landfill site.It has been estimated that this site will hold 20 million tonnes of waste and will serve Metropolitan Toronto.
Waste Management of Canada, Inc., Weston, Ontario

Each day after completion of operation the waste is to be covered with 15–23 cm of sand which will aid in the control of rodents, odours, birds, and other nuisances. The site is divided into four phases, and chainlink fences will be erected on the outer limits of each phase before disposal operations commence. Only when the activities in any one phase are satisfactorily completed, can work begin on another one, thus ensuring orderly progression of development. "Following construction of a section of clay liner and installation of the leachate collection system, refuse placement will be conducted using the ramp method with a maximum lift thickness of 3 m" (Waste Management of Canada, Inc., 1980).

A number of factors must be controlled to minimize the impacts of the sanitary landfill beyond the site. Dust is to be controlled on unsurfaced roads with applications of calcium chloride, oil, or water.

> *"Litter fences will be erected downwind of the disposal face to control blowing paper and debris. A tractor mounted vacuum system will be employed for collection of wind-dispersed litter. Odours emanating from active areas of the landfill will be controlled by placement of cover material and/or moisture application. Nuisance gases will be flared as required to control noxious odours. An exterminator will be contracted to inspect the site on a monthly basis and to undertake any remedial action required for rodent control... In the event that the seasonal gathering of birds at the disposal site poses a nuisance situation, a bird abatement program will be initiated to deter bird congregation"* (Waste Management of Canada, Inc., 1980).

As part of the plan, a separate access route is to be constructed to by-pass the residential development in order to prevent the heavy traffic, noise, odours, or blowing debris from annoying nearby residents. Access to the site will be provided by two routes. Three-quarters of the trucks will enter from the west along the northwest by-pass road and the other quarter will enter from the south using the major arterial highways for access.

The proposed ultimate use of the site is for open passive recreation or parkland with a final vegetation cover. Once the site is completed it will be covered with 1.05 m of soil over which an additional 15 cm of top soil will be laid; the site will then be revegetated with selected grass and trees. The maximum elevation of the site is 305 m above sea level, with a 30 m height above the Teston Sideroad. The final plans for the site include linear ridges similar to the original topography, with a range of slopes of which the steepest is to be four to one. These will include a number of flatter terraces with extended ski runs for the Honey Pot facility and a pedestrian trail system. The site will also contain a drainage control system channelling stormwater runoff to the series of aquifer recharge ponds. In addition to landform provisions, the plans include proposals for long-term revegetation of the site. Coniferous and deciduous trees will be used to provide wind protection for future recreational areas. A mixture of shrubs and trees will be situated along side slopes to provide screening for the visually exposed adjacent lands. A third type of planting consisting of low shrubs and ground covers will be used for edge enhancement to create wildlife habitats and provide a range of colours, textures, shelter, and foods. The final selection of plant species in each group will be made after the technical characteristics of the landfill process such as methane gas recovery, heat generation, and related effects on plant material survival are reviewed (Hough *et al.*, 1980).

The final plans and design of the site are comprehensive and have examined and dealt with all areas of concern in establishing a sanitary landfill: access roads, excess traffic, noise, odours, dust, litter, rodents, vegetation damage, wildlife, ground and surface water contamination, methane gas migration, site servicing, site development, rehabilitation, and end use.

However, following all the studies, reports, and discussions, final approval for operation has, as of March 1983, not been issued by the Ministry of the Environment. Meanwhile, early in September 1981, the Globe and Mail once again had the "Maple" site in the headlines. This time the announcement said that Metro Toronto had begun negotiations to acquire the Keele Valley Site from Superior Sand and Gravel for $38 million. As of March 1983, it is intended that the site be sold to Metro Toronto in May 1983. But this acquisition is not yet finalized, so future operation and ownership of the site are still uncertain. The Keele Valley project had been expected to start in 4 years but by the end of 1982 had consumed 9 years and costs have quadrupled.

In summary, the Keele Valley case study has illustrated the practical complexities of obtaining final approval for establishing an operational sanitary landfill. Because of Keele Valley's immense size, many of its problems have been magnified. Nevertheless, its problems and solutions parallel other situations encountered in the establishment of sanitary landfills, namely:

- sanitary landfills still arouse public controversy,
- negotiations for securing permission to operate sanitary landfills can be lengthy,
- extensive environmental protection controls can be instituted to minimize possible adverse effects of sanitary landfills.

Appendix I

Keele Valley Landfill Design Reports

Volume I:	Executive Summary (Waste Management of Canada, Inc.)
Volume II:	Water Resources (International Water Consultants Ltd., Saskatoon-Barrie-Montreal)
Volume III:	Site Development Report (Conestoga-Rovers & Associates Consulting Engineers, Waterloo, Ontario)
Volume IV:	Geotechnical Aspects of Clay Liner System (Golder Associates, Mississauga, Ontario)
Volume V:	Accelerated Stabilization and Gas Control and Recovery (Emcon Associates)
Volume VI:	Site Servicing (Proctor & Redfern Group Consulting Engineers & Planners)
Volume VII:	Site Finishing (Hough, Stansbury & Michalski Limited)
Volume VIII:	Environmental Baseline Study Design (Ecologistics Limited, Ontario Research Foundation, and Valcoustics Canada Limited)

Highway 101 regional sanitary landfill case study

Introduction

The opening of the Highway 101 regional sanitary landfill in 1977 marked the culmination of a 5-year struggle to locate and develop a sanitary landfill to serve the Halifax–Dartmouth area.

The struggle began in October 1972, when a study commissioned by the Metropolitan Area Planning Committee (MAPC)[1] concluded that "a sanitary landfill will be required and should be readied to accept the total solid waste production of the Halifax–Dartmouth growth area" (Canplan Consultants Ltd., 1972). A review of the existing solid waste disposal systems showed them to be inefficient and environmentally unacceptable. The feasibility of alternate systems such as incineration, recycling, and thermal generation of electricity was examined to determine the most appropriate system for the metro region. It was concluded that although incineration and recycling could provide partial answers to the disposal problem, a landfill would still be required for ash residues and wastes that could not be recycled. The use of solid waste as a source for thermal power generation was given serious consideration. However, the sanitary landfill was given preference because a thermal generation system would require considerable time to become operational and costs would be very high. In addition, private enterprise was encouraged to develop new facilities for recycling paper or other wastes.

It was recognized at the outset that a public information education program would be required to address opposition. However, the extent to which negative public reaction eventually became a limiting factor in the final selection of a site was not anticipated. Public reaction, in fact, became the principal determining force in the siting process.

The situation in 1972

In 1972, the cities of Halifax and Dartmouth operated individual solid waste disposal systems. When possible, the surrounding County of Halifax used the Halifax incinerator on a fee basis. It was estimated in 1972 that the City of Halifax collected and disposed of 135 000 t of garbage on an annual basis. Of this, 82 000 t (60%) was treated by incineration (Canplan Consultants Ltd., 1972). The residue was taken to the Halifax dump site at the north end of the Halifax peninsula. Here, both raw refuse and incinerator residue were deposited in the Bedford Basin as infilling.

The City of Dartmouth also operated an incinerator and a landfill site. Since installation of the incinerator in 1968, it was estimated that 23 000 t of refuse were burnt annually. Rated at 136 t per day, the incinerator was operating three shifts daily for 5 days a week. The residue was distributed over the landfill site along with other forms of dry waste. This landfill was expected to reach capacity within a few years.

In both instances, the incinerator systems were operating at or near capacity. The older Halifax incinerator was in need of extensive repairs and the additional capacity required to serve this county's needs could not be satisfied without embarking on a major repair program. Neither the Halifax nor the Dartmouth incinerator was equipped with adequate air pollution control equipment or waste water treatment facilities. Open dumping at both landfills led to aesthetic and environmental problems. As described in the Canplan report: "With this open dump, the potential for leachates to travel to the basin is high.... Continued use of the Halifax dump will result in leachate production from both the wastes hauled directly to the site... [and] the incinerator residue deposited there." (Canplan Consultants Ltd., 1972). In addition to the environmental and aesthetic problems, the unit cost of disposal was very high.

It was recommended, therefore, that the incinerators be closed down when the sanitary landfill became operational and that the Halifax dump be properly closed. Consideration has been given to removing part of the refuse and replacing it with rock fill to create a stable base for development of the Fairview Cove Container Terminal. Several alternatives have been explored for disposal of the old refuse, one of which is removal to the Highway 101 sanitary landfill site. The consulting firm of Beasy Nicoll Engineering Ltd. (1980) provided further information on this subject.

Site selection process

Based on preliminary investigations, the 1972 Canplan report concluded that the designated Beaverbank–Windsor Junction site (also referred to as the Sackville Landfill) warranted further study. The location of the proposed site is shown on Map 2. Identification of this site resulted from a consideration of: (a) the physical landscape elements—geology, soils, hydrology; (b) accessibility by waste haulage trucks from Halifax–Dartmouth; and (c) the amount of land required.

In November 1973, Canplan Consultants Ltd. were retained by the MAPC to carry out more detailed site investigations. A pre-design report dated November 1974 described work carried out on the engineering design phase of

"Pardon me Sir–but could thou slay another dragon!?"

Barrett Lumber Co. owned the Beaverbank-Windsor Junction site and was instrumental in forcing reconsideration.
Bedford-Sackville News, March 3, 1976

the study. The physical site conditions were well suited to development of a sanitary landfill. A general assessment of soil tests indicated that the area was overlain by material ranging from clay to sandy glacial till, with few boulders; tests to a depth of more than 6 m showed no sign of bedrock. Local surface drainage was controlled by two streams that almost enclosed the site; construction of siltation ponds and preservation of a buffer zone would minimize any problems due to increased siltation.

Strident opposition to development of this site was voiced by private land owners and collectively by the local unincorporated community. Public hearings were held by the Nova Scotia Environmental Control Council, after which approval was granted by the Planning Appeal Board to proceed with site development. All legal impediments were removed and approval was given for rezoning to permit landfill development. The right to expropriate the land was granted.

The provincial government responded to continued opposition by halting action at this stage. By doing so, the Province assumed responsibility for locating a suitable alternative site, now that the Beaverbank site had been effectively abandoned. The Nova Scotia Department of the Environment was directed by the Province to identify possible sites. In April 1975, a five-member committee of Department personnel was established to produce a report on potential sanitary landfill sites for the Metro region. A list of eight sites was drawn up with ratings based on (a) the land area available; (b) watersheds potentially affected; (c) physical characteristics; (d) cultural implications; and (e) economic factors. The site with the highest rating was Jack Lake, located near the Town of Bedford (see Map 2). Title to this site was held by the Nova Scotia Housing Commission. As was the case with the Beaverbank–Windsor Junction site, local residents strongly protested the selection of the proposed site. A cartoon that appeared in a local newspaper effectively illustrates local concerns.

In the fall of 1975 a conceptual plan for the proposed sanitary landfill was presented to a public hearing of the Nova Scotia Environmental Control Council. A well-organized contingent of Bedford-area residents appeared as witnesses at the hearing and expressed unanimous opposition to the proposed Jack Lake site. Use of this site as a sanitary landfill was claimed by opponents to be contrary to existing municipal zoning, to the Regional Development Plan, and to the public's wishes. This position was countered by the argument that the proposed use was only temporary and that the final use would be for passive recreation. Other concerns were expressed about potential problems of rodent and gull control, fire, noise, odour, work stoppages due to labour disputes[2] or inclement weather, and increased traffic. It was also perceived that residential property values would be lowered.

Although there was a lack of technical data, qualified approval of the site was given by both provincial and federal authorities on the basis of environmental considerations.

The Nova Scotia Environmental Control Council recommended in December 1975 that "further consideration of this site for the purposes of sanitary landfill be suspended unless and until formal concurrence and authorization for this land use is secured from the Municipal, Provincial and Federal authorities" (Nova Scotia Environmental Control Council, 1975). The required approval was received and, at the request of MAPC, further study of the physical properties of the site was carried out by Canplan Consultants Ltd. in 1976. In particular, the depth to bedrock, type of overburden, groundwater and surface water conditions, and availability of fill material were evaluated.

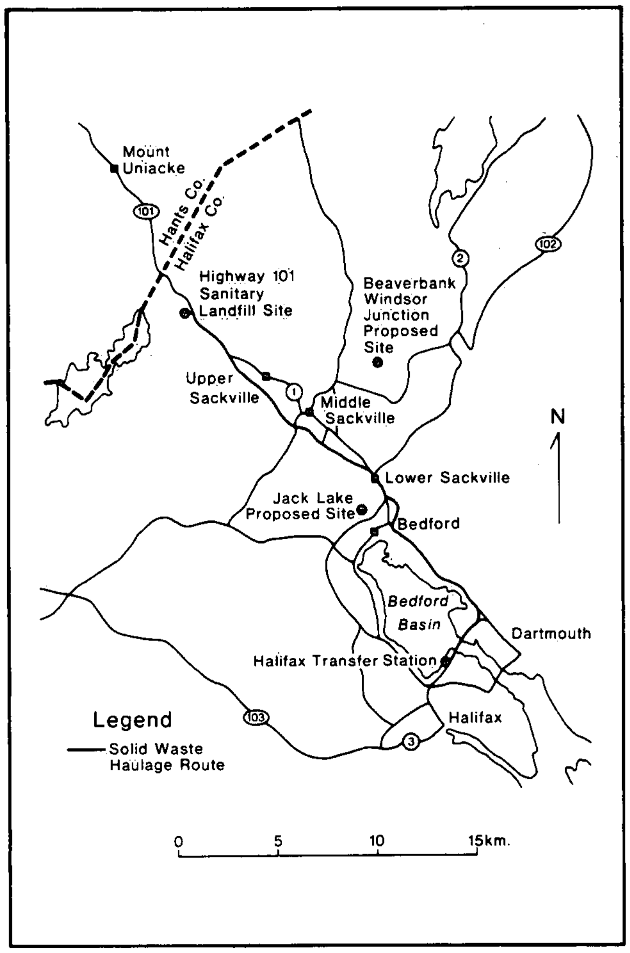
The intense social and political pressure to deny the development continued. Then Central Mortgage and Housing Corporation (CMHC) withdrew its approval to the Nova Scotia Housing Commission for use of the site as a sanitary landfill. This action necessitated consideration of a third site.

By this time, the quest for a suitable landfill site to serve the cities of Halifax–Dartmouth was well known throughout the region. After rejection of the Jack Lake site, a number of offers to sell land to the Province were made by private owners. In 1977 a site close to Highway 101 was purchased by the Province from its private owner for a reasonable price. The land then became Crown-owned and as such it was exempt from zoning by-laws.

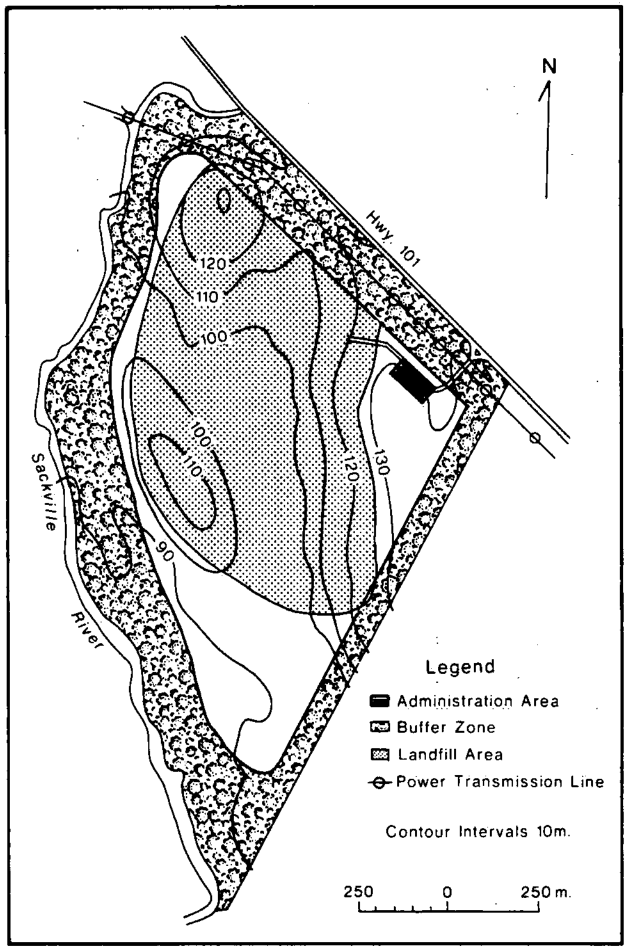
Site description

The Highway 101 site is located between Upper Sackville and Mount Uniacke in Halifax County, 30 km northwest of Halifax. Highway 101 forms the northeastern boundary and the Sackville River borders the site to the west and northwest. The regional sanitary landfill is in a predominantly forested area and has minimal development. It is anticipated that the 144-ha site will meet the needs of the Halifax–Dartmouth growth area and of the greater part of the County of Halifax until 1990. The site, acquired by the Province of Nova Scotia, is now operated by the Province and managed jointly by the Metropolitan Authority of Halifax, Dartmouth, and the Municipality of the County of Halifax.

MAP 2.
Halifax-Dartmouth sanitary landfill-base map

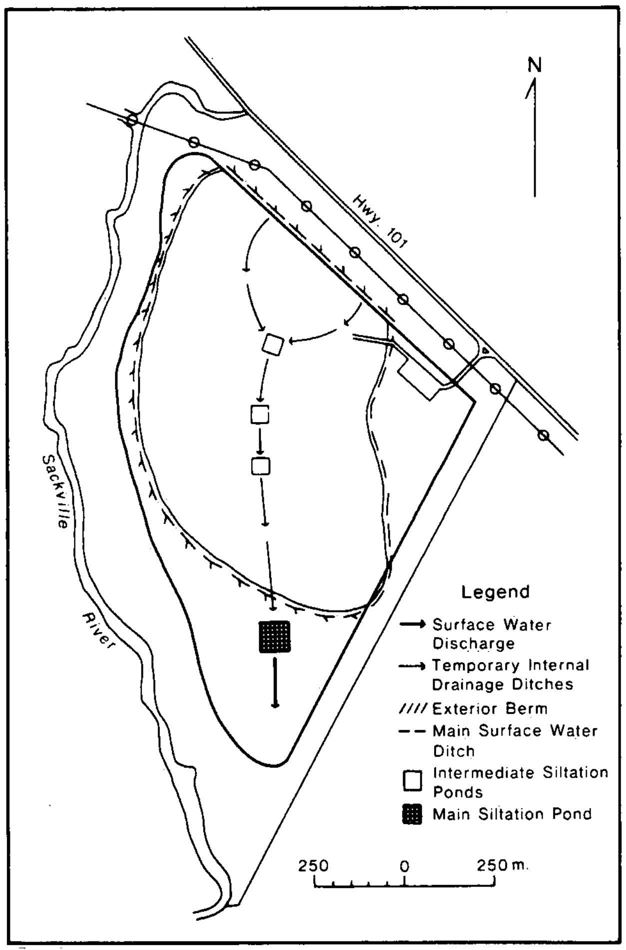


MAP 3.
Highway 101 sanitary landfill-location and activity zones



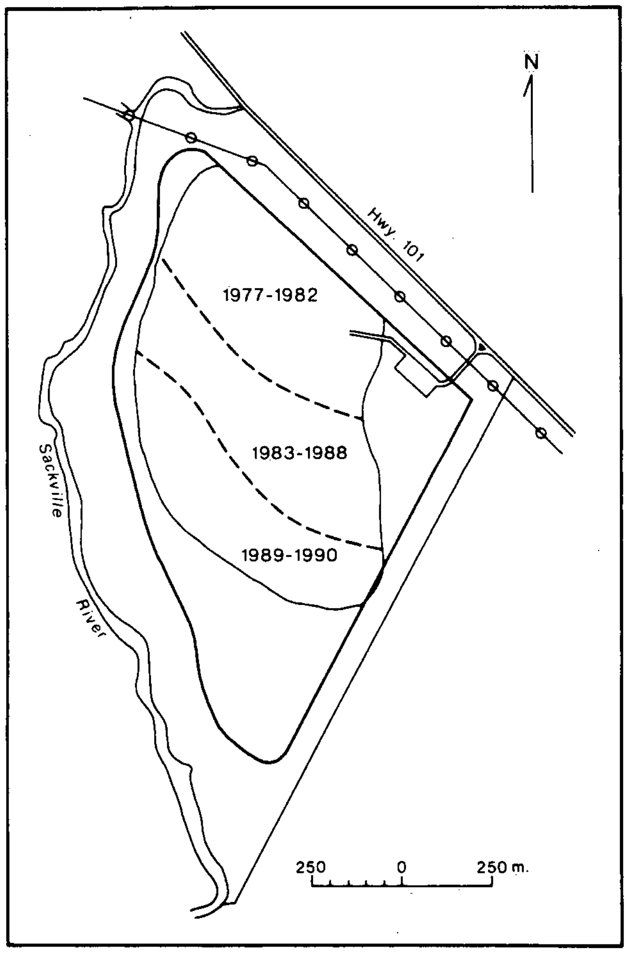
Source: Beasy Nicoll Engineering Ltd., and H.J. Porter and Assoc. Ltd., 1977.

MAP 4.
Surface water control



Source: Beasy Nicoll Engineering Ltd., and H.J. Porter and Assoc. Ltd., 1977.

MAP 5.
Sequence of landfill operations



Source: Beasy Nicoll Engineering Ltd., and H.J. Porter and Assoc. Ltd., 1977.

'A landfill is as different from a dump as a horse is from an airplane!'

- Edmund Morris, October, 1977.

Bedford-Sackville News, November 2, 1977

In July 1977 the consulting firms of Beasy Nicoll Engineering Ltd. and H.J. Porter and Associates Ltd. began preliminary engineering and subsoil investigations of the Highway 101 site. Map 3 shows the boundaries of the site. The site is situated further from the Halifax–Dartmouth metropolitan area and its physical characteristics are less suitable, making it less desirable than the two sites previously considered. The high water table in the peat zone, the relatively shallow covering of an impermeable overburden, and the proximity of the Sackville River compounded engineering problems and greatly increased costs of development and operation. In addition to high development and operation costs at the site, transfer costs could rise considerably because of the additional distance from the Halifax transfer station. Although the site's relatively remote location served to reduce public opposition, it was not totally dissipated. A local residents' committee, initially established to oppose site development, later served as a vehicle for expressing local concerns. Few problems arose and the committee was disbanded after a relatively short time.

Throughout the years of controversy, there was extensive coverage of events in local newspapers. A collage of headlines provides evidence of the strength of opposition.

Physical site characteristics

Geotechnical investigations indicated four distinct geological areas within the site boundaries: two drumlins, rising more than 25 m in elevation above the surrounding area; a bedrock ridge overlain by glacial till; and a low-lying area of peat.

The predominant soils, brown sandy silt and grey silty clay, are generally suitable for use as cover material. The lower permeability of the grey silty clay, compared to the sandy silt, makes it more effective as cover material for the daily cells. Deposits of brown sandy silt found at the surface contain root systems which increase permeability. It has therefore been recommended that this material be retained for use as topsoil in the final grading.

Peat deposits are present in the low-lying area. Before using the site for sanitary landfilling, it was recommended that a 1-m layer of compacted cover material be spread over the peat to reduce permeability and increase the density of the peat. This was seen to be necessary to reduce the risk of groundwater contamination due to migration of contaminants and to increase the bearing capacity for truck traffic.

Graywacke rock (marine deposited sediments, partially sorted) of the Goldenville Formation is found at the site. No evidence of faulting of the bedrock was observed; below a formation depth of about 2 m, groundwater movement is essentially not possible. In the early development of the sanitary landfill, some on-site use was made of the local bedrock as a source of road bed material.

Medium-density coniferous and deciduous forest is the predominant vegetation cover in the vicinity of the site. A small amount of land has been cleared for housing along Highway 1; some timber cutting is carried out in the vicinity. The landfill area has been completely cleared since development of the landfill began. The forest vegetation type shows clearly on the aerial photographs taken in 1975 and 1981. The forest cover provides an effective natural buffer zone that has been maintained entirely around the site (indicated on Map 3).

Prior to development, surface runoff drained directly into the Sackville River. A system of ditches and berms has been created to direct the surface flow into siltation ponds within the site (see Map 4) where most of the suspended solids are settled out.

The groundwater table was determined to be at or near the surface in the low-lying peat zone and 1 m below the surface in the drumlins. The original areas of discharge were either into the Sackville River or the peat zone. Contamination of groundwater was of prime concern in site development. Additional fine-textured impermeable till was required to reduce contaminant migration and percolation. A leachate collection system was installed to intercept leachate before it could migrate and aeration ponds were constructed to treat it before discharging it to the receiving environment.

Climatic factors are an important consideration in site operations. Operating problems at this site have been encountered due to moisture, freezing temperatures and the freeze-thaw cycle, and wind. For example, it is more difficult to achieve an evenly placed and compacted layer of fill when the material is frozen. Another problem related to the use of frozen material is that the high moisture content in the cover causes it to move readily downslope and


LANDFILL PETITION STARTS

Waste of prime land

United approach on landfill site urged

Sackville landfill no solution--Barrett

Sackville landfill project

"There go the people" – so Regan follows

DUMP..-THE VERY LATEST PLANS

Dump Fight Goes On

Residents seek meeting on Jack Lake site

soil erosion losses may be significant. Occasionally, unseasonably warm rains occur during the winter months, thawing the ground surface. Excess moisture can also hinder movement of the tractor trailers and heavy equipment. Before the waste is covered, windy conditions may cause some litter to be blown about; climatic statistics show there is sufficient wind throughout the year to cause this to happen. Wind speeds are a little higher during the winter.

Site operation and management

As previously mentioned, the Highway 101 sanitary landfill site, owned and operated by the Province, is managed jointly by the Metropolitan Authority of Halifax, Dartmouth, and the Municipality of the County of Halifax.[3] On-site operations are directed by a Site Supervisor who in turn reports to the Manager of Waste Management responsible for the total waste management system. Other components of the system include the Halifax transfer station and the haulage system.

Garbage from residential and commercial sources is brought to the transfer station and packed into enclosed tractor trailers for transport to the landfill. It is expected that the site should meet the area's needs for 12 years, given the projected volume increases from 195 500 t in 1978 to 319 100 t in 1990 (Beasy Nicoll Engineering Ltd. and H.J. Porter & Associates Ltd., 1977).

The cost of land purchase was met by the Province and costs of development and equipment of the landfill were shared equally by the Province and DREE. Financial assistance from DREE was in the form of a grant. The provincial contribution was in the form of a loan to be repaid by the Metropolitan Authority over a period of 5 years. Funding assistance by senior levels of government was conditional on use of the site as a demonstration project providing information to other municipalities. Operating expenses of the solid waste system are met by the user municipalities. Each municipality is billed according to the number of tonnes of solid waste that are disposed. In 1981 the cost of disposal (capital and operating) was $9.70/t.


Photo 20. Construction of daily waste cells, June 30, 1981.Fly ash from the Tuft's Cove Thermal Power Station is being unloaded for this, a special permit from the Nova Scotia Department of the Environment was required.
E. Kienholz, Lands Directorate, Atlantic Region

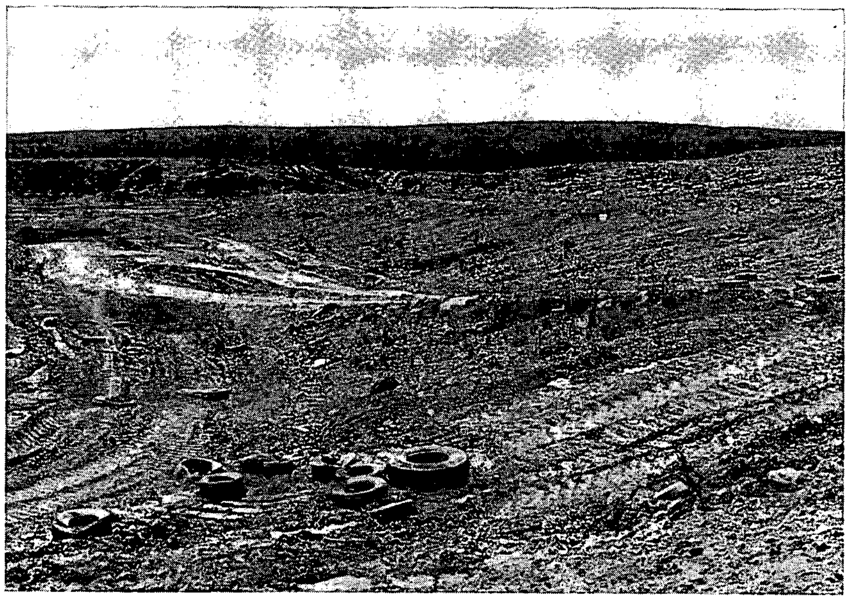


Photo 21. Initial landfill unit - semi-completed, June 30, 1981.The burial of tires has presented some problems to the operators.
E. Kienholz, Lands Directorate, Atlantic Region

Site operations

As shown on Map 3, approximately 40% of the total site area will actually be used for solid waste disposal. Contours in this portion will be raised by 25 m, with the final elevation being no higher than 125 m above sea level. A buffer zone, varying in width from 75 m on the south to at least 125 m along the river, has been retained around the entire site. This will protect the quality of surface water entering the Sackville River and reduce the visual impact of the landfill site. A site administration centre with offices, weigh scales, and machinery repair facilities has been constructed. The remaining portion of the site is used primarily for treatment facilities for surface run-off and leachate, and for access roads.

Prior to depositing any waste, the landfill area was cleared and the site now operates as an area-fill. Controls and collection features for surface run-off, leachate, and methane gas must also be constructed. The ground surface is to be graded and compacted, except in the peat zone, to improve impermeability. A minimum of 1 m of fill is to be placed over the peat and where bedrock is at or near the surface. Disposal areas for the winter and wet periods are prepared in advance.

Although most of the refuse is transported by haulage vehicles (enclosed tractor trailers) from the Halifax transfer site, periodically industry and commercial enterprises contribute a significant volume. Each day the solid waste is compacted and covered with fill, which then constitutes one cell.

The sequence of landfill operations over time is indicated on Map 5. The initial strategy is to complete the landfill face along the boundary parallel to Highway 101 first. This would then act as a secondary screen for future operations. The top layer of cover material will be at least 1 m in depth; topsoil will be spread over this and grading carried out. Because the final use of the site has not yet been determined, it has been difficult to plan the landscaping of completed units.

Safety and security features are incorporated into the site operations. Precautions are taken to prevent and control fires; access is restricted to specific times; generally the public is not permitted beyond the administration area; and the entire site is bounded by a security fence.

Environmental protection

Protection of the surface and groundwater is a primary concern of site operation and management. As noted earlier, a system of berms and drainage ditches directs surface run-off to siltation ponds. A minor problem has been experienced with erosion of fill on the bare slopes of the first completed landfill unit. This has had the effect of increasing sediment loads in the siltation ponds and permits seepage of leachate from the lower slopes. The problem was not seen to be serious enough to warrant the undertaking of remedial measures such as seeding which will occur when the final grading has been carried out.

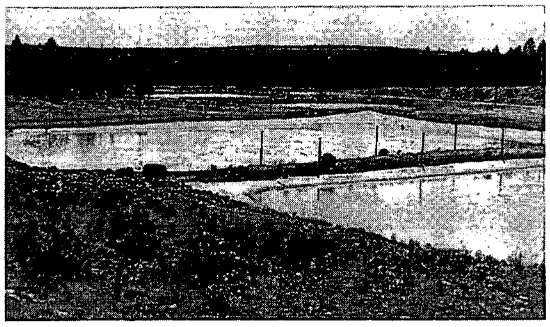


Photo 22. Leachate treatment lagoons, June 30, 1981.Leachate treatment ponds are in the foreground and siltation ponds are in the background.
E. Kienholz, Lands Directorate, Atlantic Region

Prevention of groundwater contamination due to the migration of contaminants including leachate, is partly accomplished by site preparations designed to reduce permeability and the application of a daily layer of cover material. In addition, the following features have been constructed: (a) a major underground drainage system beneath the landfill area; (b) a collection drain around the downstream perimeter of the landfill under the toe of the side slopes; (c) an aerated lagoon with controlled discharge; and (d) a system of monitoring wells throughout the site. Map 6 illustrates the leachate collection and treatment system.

Prior to the spring of 1981, the leachate produced did not warrant operation of the treatment facility. Operation of the treatment ponds in the spring of 1981, had shown that aeration effectively reduces the biological oxygen demand of the leachate. It was thought that follow-up treatment procedures, such as spraying the leachate back on to the landfill could be used if necessary. However, since then a leachate problem has developed. As of March 1983, the leachate produced was too great for the present system to manage. Therefore the leachate control system is being redesigned in order to control leachate migration.

Although the leachate treatment facility will be required for some time after the end of the operational life of the landfill, the need for the siltation ponds could rapidly diminish once seeding and revegetation have been undertaken. In 1982, 12 ha were reseeded, including some of the fill areas and the completed cells. A testing program was carried out in late 1977 and early 1978 to determine background information regarding the chemical and bacteriological characteristics of surface water, domestic wells, and on-site monitoring wells. Comparisons of these data can be made with future results to determine whether contamination is occurring. Re-testing of the on-site monitoring wells in 1979 gave no indication of leachate contamination.[4] A further test by the Nova Scotia Department of Health in 1982 showed no contamination of domestic water wells in the area. The monitoring program will continue during and after the operational life of the sanitary landfill for as long as leachate is being produced in any significant amount.

As solid waste decomposes, methane gas is generated. To intercept the gas a venting system is installed within the landfill area and around the perimeter (Map 7). A program has been established to use the methane gas for heating on-site facilities. A grant was provided for this purpose by DREE and the Nova Scotia Department of Mines and Energy. As part of the program to utilize rather than waste the gas, the peripheral vents will be sealed off. However, as of March 1983, there was insufficient methane gas produced to generate heat, but the site is still being monitored.

Nuisances such as pests and blowing paper, which are frequently encountered at open dumps, are not as serious a problem because of the control measures implemented at this site. Rodents are less likely to inhabit the sanitary landfill site because of the daily cover of earth. A rodent control program, which includes baiting, deals with any rats that may be brought into the site along with the solid waste.[5] Seagulls, however, do present something of a nuisance. Initially they are attracted to the site as it is a source of food and offers warmth and shelter. Then they rapidly become accustomed to the activities at the site including the presence of machinery. For a variety of reasons including weather conditions, they frequent the site in large numbers. Concern has also been expressed that a large number of seagulls in the area will pollute domestic surface water supplies in the Pockwock watershed. A similar problem was reported in Saint John, New Brunswick. The windy conditions at the site contribute to the problem of blowing paper. Fences around the periphery catch much of the loose paper and these are cleaned when necessary. Also, covering with soil daily reduces the amount of loose paper.

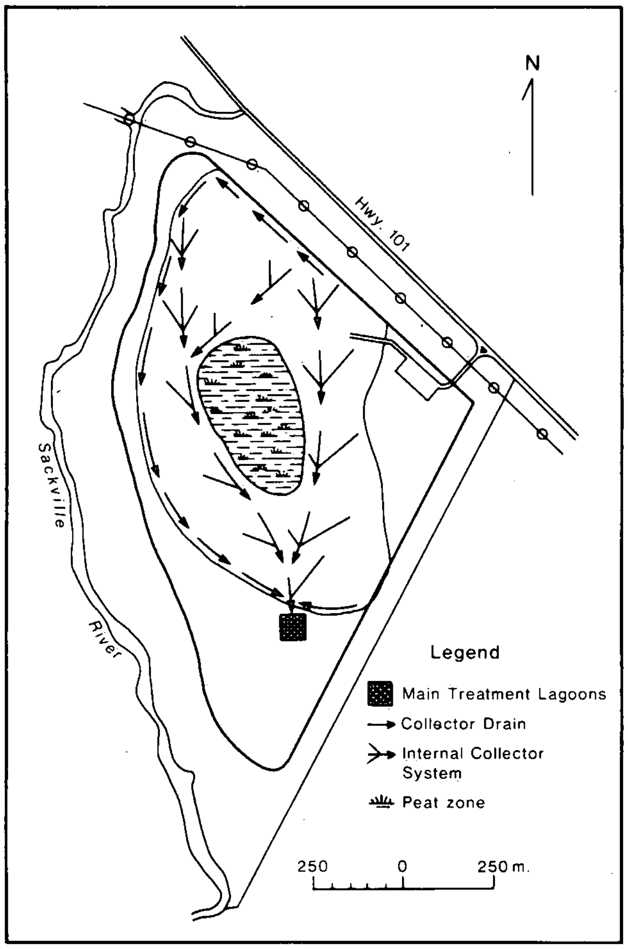
Because of an excessive amount of moisture in the peat zone during the spring and summer of 1981 it was difficult to completely cover the cells each day. It was planned to build up this area as quickly as possible to permit movement of the heavy equipment necessary for complete coverage.

Land use

Land activity

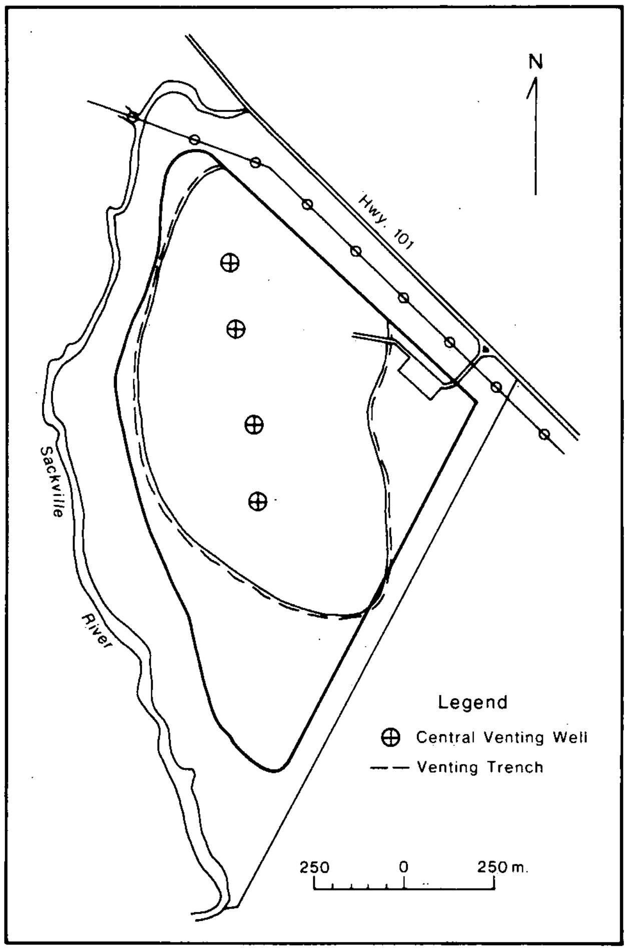
An important advantage of the Highway 101 site is its relatively remote location. The area

MAP 6.
Leachate collection and treatment



Source: Beasy Nicoll Engineering Ltd., and H.J. Porter and Assoc. Ltd., 1977.

MAP 7.
Methane venting system



Source: Beasy Nicoll Engineering Ltd., and H.J. Porter and Assoc. Ltd., 1977.

has generally been one of slow growth. Development in the area is virtually limited to a small number of residential developments along Highway 1 and some recreational cottages adjacent to Springfield Lake. The lack of development is due in part to the distance of this area from the major urban centres, and because municipal zoning discourages urban sprawl within the "green area" of Halifax County.

Several regulations have been set forth in the Regional Development Plan for Halifax–Dartmouth Metropolitan Area to curb ribbon development and rural subdivisions. For instance, with the exception of areas designated for urban development or where infilling is permitted between existing dwellings and commercial or institutional establishments, no subdivision will be approved where the lots are less than 2.02 ha in area. Summer cottages are an exception to this. Infilling within villages and hamlets is restricted to 10 lots in any 1-year period in any development; each lot will be at least 1 350 m^2 and must meet provincial Department of Health regulations for septic tanks or have a central water and sewerage system.

Highway 101, constructed in the mid-1970s, provides an excellent highway connection from the metropolitan area to the vicinity of the site. Paralleling the highway is a power transmission line. Productive woodland is predominant and some timber cutting has occurred in the vicinity. Other uses include quarrying and aggregate extraction, non-productive woodland, marshland, rough pasture, and cleared agricultural land. Prior to 1977, there was little evidence of any active use of what is now the landfill site.[6] The photo mosaics illustrate changes in land use between 1975 and 1981.

Future use

The final use of the landfill site has yet to be identified. It seems probable that the area will be used for recreation; interest has been expressed by the Lake District Recreation Association and the Sackville Chamber of Commerce in developing the site as a public golf course. Other possible uses are as a ski area or as a day-use recreational area. Construction of buildings on the built-up portion of the site area will not be permitted as the fill will not provide a stable base for construction.

Land ownership and value

The site area was purchased by the Province of Nova Scotia in 1977. Much of the adjoining land south of Highway 101 is now held in large parcels by two private companies (construction and gravel business). One of these companies previously owned the site area. Along Highway 1 individual people hold title to most of the small parcels of land.

Information provided by the Assessment Division, Nova Scotia Department of Municipal Affairs (L. Croucher, personal communication, 1981), indicates that there is little evidence to suggest that the presence of the sanitary landfill has had any measurable impact on local property values. In fact, because the municipality discourages urban development and the provision of services, land value has remained low. Prior to 1977 there were so few land sales that it was difficult to determine an average value. Apart from the sale of a few small residential lots, land sales have involved forest land. The area now has little value except for forest resource use and the presence of the landfill has had virtually no effect on transactions of this type.

Public perception of sanitary landfills

It can readily be interpreted from the description of the site selection process that sanitary landfills were not generally viewed by the public as a desirable land use in their neighbourhood. Numerous conflicts can be expected when a proposed site is situated close to a developed area, as was the case with both the proposed

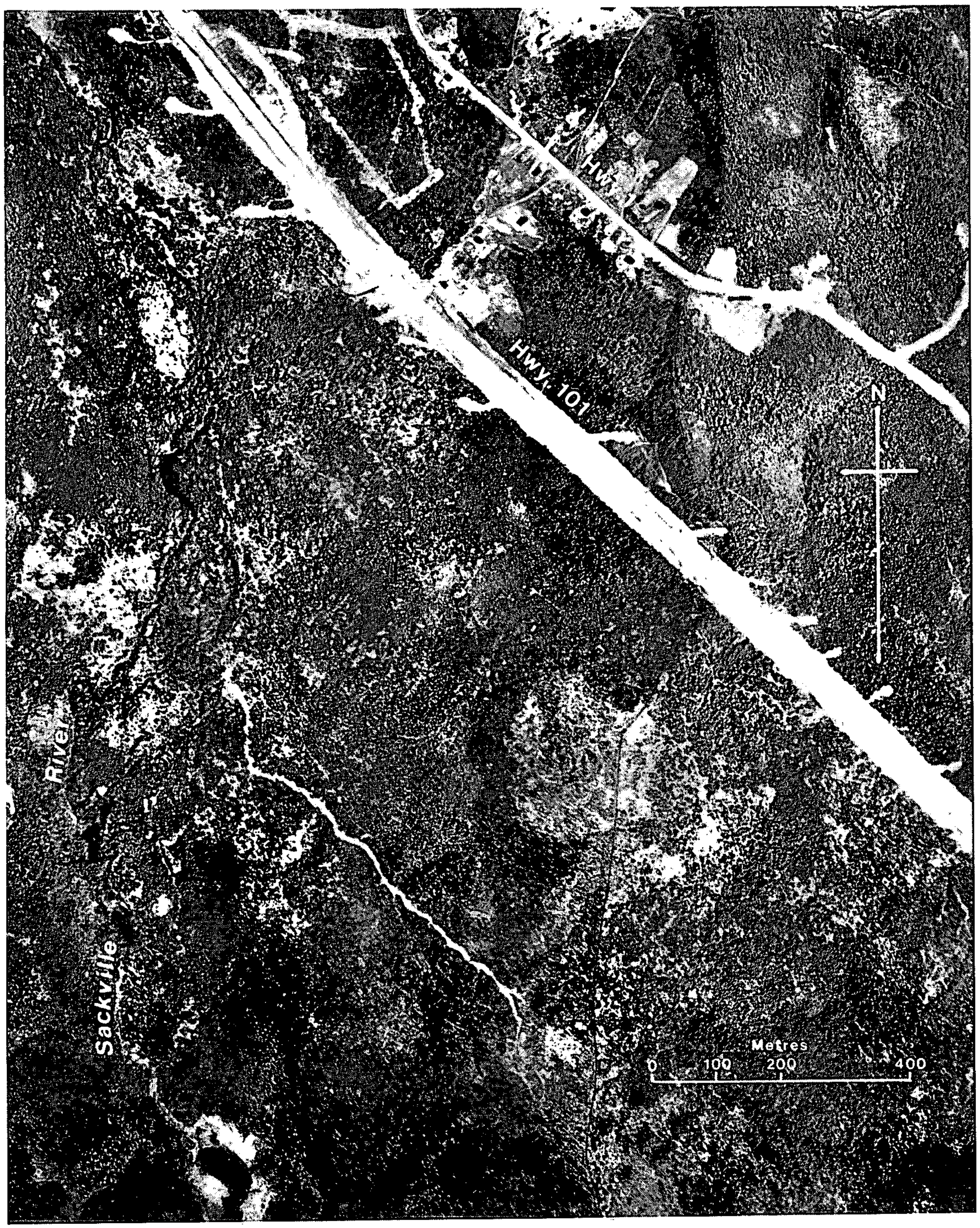


Photo 23. Photo Mosaic - Highway 101 Sanitary Landfill Site, 1974.Minimal development was present in 1974 with a few houses parallel to Hwy. 1.
Maritime Resource Management Service. 1974.Amherst, Nova Scotia

Beaverbank–Windsor Junction and Jack Lake sites. Public opinion and concerns were often and forcefully reflected in articles and letters published in the local newspapers. This negative reaction can be attributed to a combination of factors: (a) conditions at the existing open dump sites were deplorable and, by association, it was feared that the proposed sanitary landfill might exhibit some of the same features; (b) an extensive public education program was carried out but, did not serve to dispel local concerns; (c) detailed technical data were available for the Beaverbank–Windsor Junction site but not for Jack Lake (when there was strong emotional opposition, political considerations became more significant than technical or environmental shortcomings. These could have been alleviated by the infusion of additional funds); and perhaps most significantly, (d) the smaller communities of Bedford and Sackville felt that they were being exploited by the cities of Halifax and Dartmouth.

Because the subject elicited such an emotional response, social and political considerations assumed a greater importance in the final site selection process. To ensure that high environmental standards were met at the Highway 101 site, considerable extra expense was incurred in upgrading the physical properties and the design features of the site. The distance factor also added to the total operating expenses of the whole waste management system.

Summary and conclusion

The Highway 101 sanitary landfill, which now serves as a working model for other municipalities, became operational in late 1977 after 5 years of emotional controversy over selection of a suitable site to meet the waste management needs of the Halifax–Dartmouth area. Locating the site in a relatively remote area reduced public opposition but increased the operating costs of the system as a whole. Because the physical site properties were less well suited than those of the two sites given earlier consideration, additional expenses were also incurred in the early development stages of the site and on a continuing basis for site operation. Environmental considerations such as the possible contamination of the nearby Sackville River and Pockwock watershed by leachates or surface run-off were, in fact, of lesser consequence in site selection. One of the primary concerns was whether or not drumlins were present, from which fill material could be obtained. The decision was a political one, made at a time of near-crisis brought on by the inability of the existing systems to meet the waste disposal needs of the Halifax–Dartmouth area.

Operation of the Highway 101 sanitary landfill has resulted in a few identified environmental and aesthetic problems. Problems that have been encountered include: (a) design of the leachate treatment ponds; (b) soil erosion on bare slopes and consequent seepage of leachate from side slopes; (c) difficulties with operating heavy equipment in the wet areas; (d) disposal of tires; and (e) control of seagulls. However, the on-site methane venting system appears to have minimized any gas-associated environmental problems. Similarly, blowing paper, pests, and odour nuisances have been limited by a daily covering of the waste cells.

Apart from the site itself, land use, value, and ownership patterns have been changed minimally as a result of the landfill operation. The region in which the site is situated was one of slow growth prior to 1977 and there has been little change since that date.

Footnotes

[1] In 1973 the Metropolitan Area Planning Committee became the Metropolitan Area Planning Commission.

[2] Most of the waste from Halifax–Dartmouth is collected, transported to the landfill, and buried by unionized workers; a strike would result in an unsanitary situation compounding problems of odour, litter, and pests.

[3] Before 1978 the Metropolitan Authority was referred to as the Halifax–Dartmouth Regional Authority.

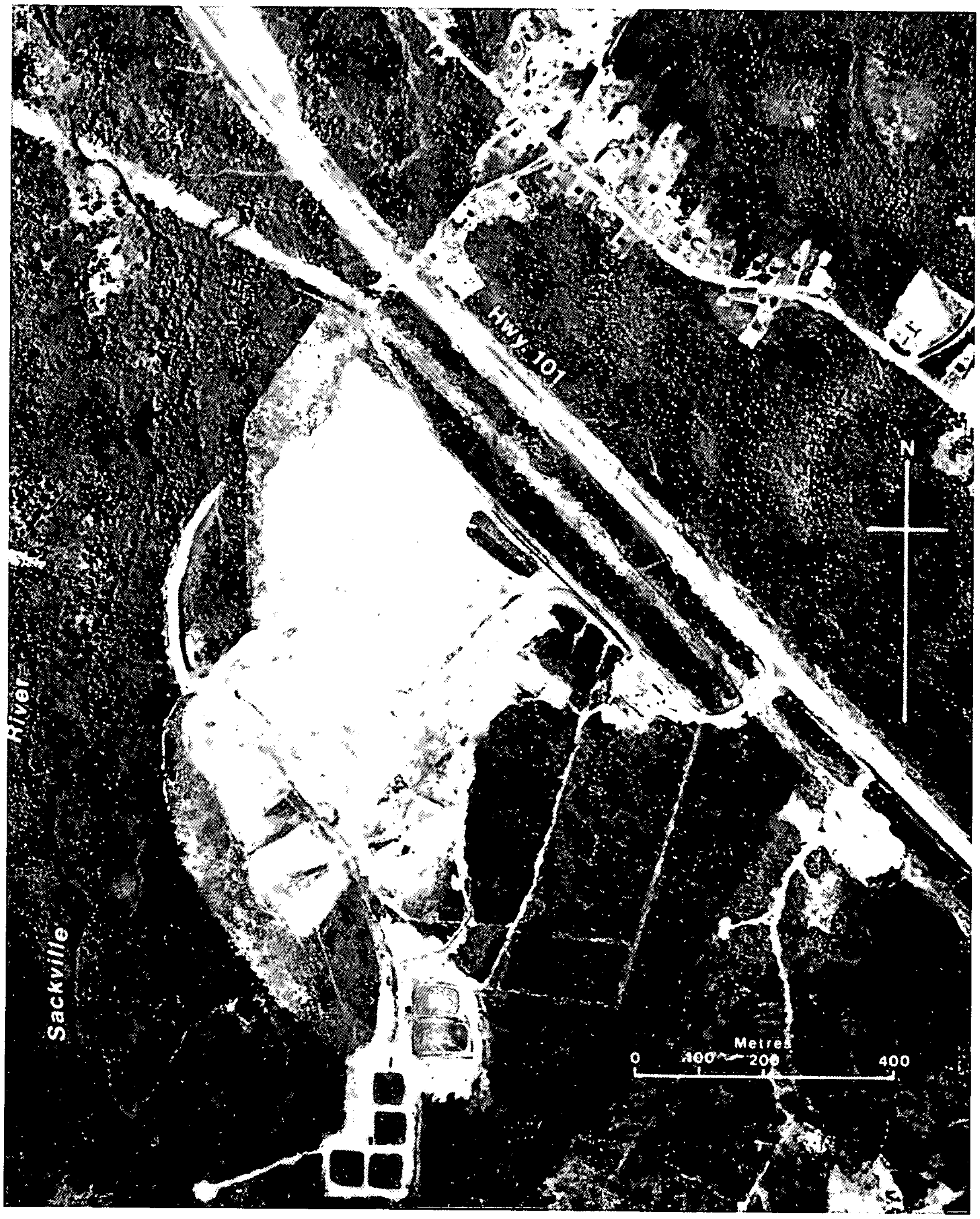


Photo 24. Photo Mosaic - Highway 101 Sanitary Landfill Site, 1981.The waste disposal and treatment areas have been completely cleared since 1974 and access was developed from Hwy. 101 to the administration area.A power transmission line roughly parallels Hwy. 101.The number of houses along Hwy. 1 has increased slightly.Logging has occurred southeast of the site.
Maritime Resource Management Service. 1981.Amherst, Nova Scotia

Footnotes (Continued)

[4] At the time of writing (August 1981) no further test results were available, although it was understood that the Nova Scotia Department of the Environment did plan to carry out testing during the summer.

[5] Since operations commenced in 1977, there has been only one rat sighted at the landfill; no rats have been sighted at the transfer station where a baiting program also exists.

[6] Land-use mapping was carried out by Lands Directorate under the Canada Land Use Monitoring Program using 1976 photography.

WASTE MANAGEMENT IN NORTHERN CANADA

Introduction

In recent years much concern has been expressed about the sensitivity of arctic environments to stresses imposed on them by man. Even a casual inspection of northern Canada will confirm that 40-year-old environmental scars and abandoned junk can still be seen. In more temperate climates, most side effects of man's activities and habits will be eradicated in time by natural forces, but the time scale is much different in the North. This is especially true for waste disposal, an issue that has persisted for decades. Even though the waste disposal situation has improved recently, waste burial in sanitary landfills, as employed in southern Canada, does not occur in the North for economic, climatic, soil, and geological reasons.

Northern waste disposal methods vary due to the nature of the permafrost, year-round temperatures, available soil cover, services, and transportation. No sanitary landfills exist in the North because excessive periods of low temperatures make earth movement almost impossible, daily soil cover is rarely available, and in some regions the ground is permanently frozen. In addition, collection and transport of wastes to designated sites is often difficult and expensive.

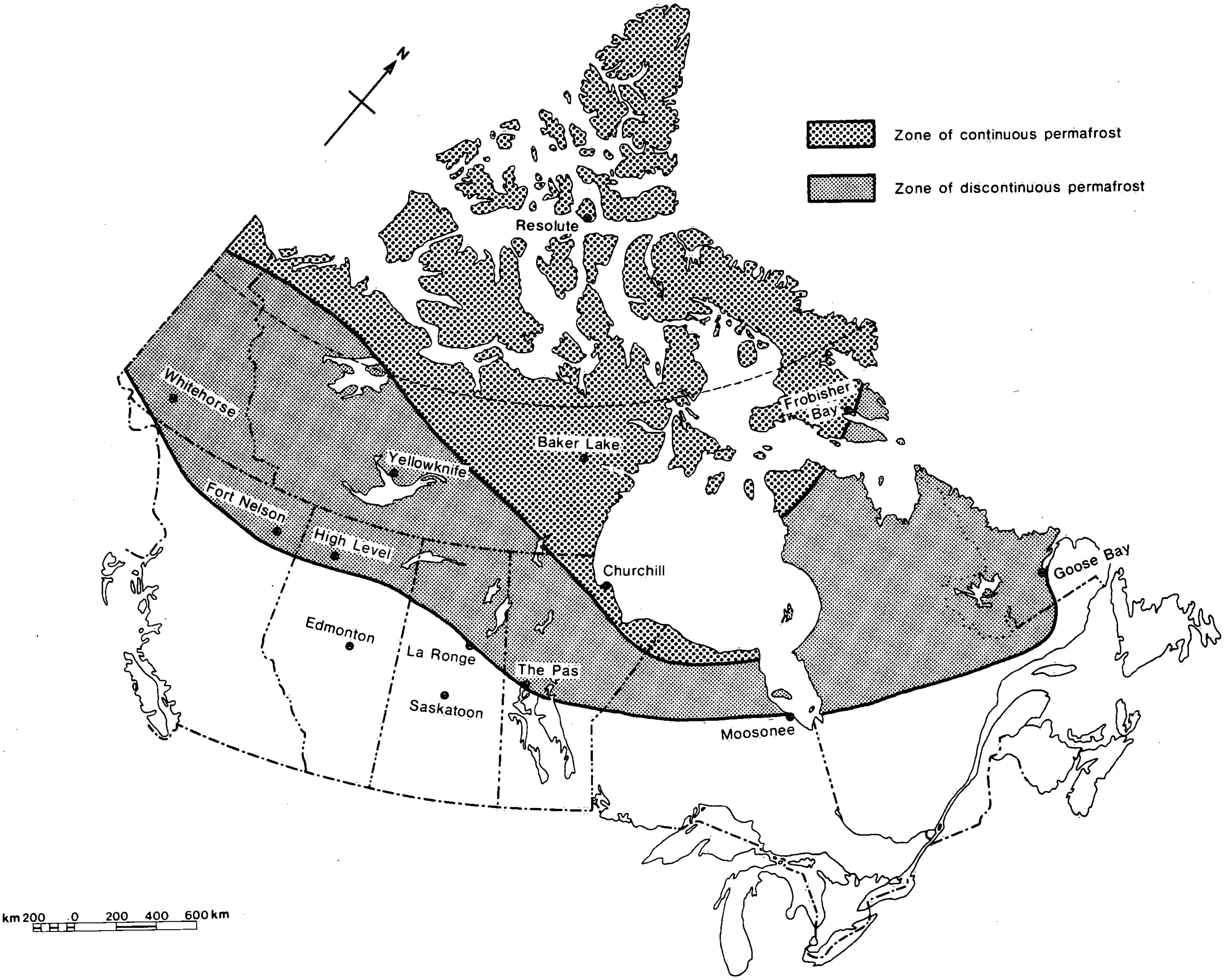
Depending on one's definition, "northern Canada" can represent upwards of one-third the total area of Canada. Yet it is home to less than 0.5% of the country's population. These two facts, combined with the most severe climatic conditions found anywhere in Canada, present major obstacles to proper disposal of wastes.

When one considers that more than 55% of Canadians live in a corridor between Windsor and Quebec City, occupying 2% of the country's area, it should not be surprising that few Canadians have any understanding of a region of their country that is remote from them and somewhat forbidding (Simpson-Lewis *et al.*, 1979). Concepts of social, cultural, and technological life taken for granted by southern Canadians are usually not applicable to the North; the two are very distinct. Therefore, it is essential to understand that there are factors which set the North apart before one can appreciate, or comment on, matters such as waste disposal.

The North defined

Geography and climate have little respect for political boundaries. The political entities of the Yukon Territory and Northwest Territories are commonly regarded as the North, but this is merely an administrative convenience. Northern Canada is regarded by some geographers as that region of the country north of the tree line. Others define the North as the region included in the permafrost zone. As it happens, the region north of the tree line roughly corresponds to the zone of continuous permafrost. South of this is an area where not all the ground is frozen; this is the discontinuous permafrost zone (Brown, 1969). In fact, along the southern

MAP 8.
Extent of permafrost in northern Canada



Adapted from: Permafrost in Canada, Map 1246A, First Edition 1969, Geological Survey of Canada, Energy, Mines and Resources and Division of Building Research, National Research Council of Canada.

fringes of this latter zone, permafrost may be limited to scattered pockets of land of only a few square metres or hectares and may be confined to certain types of terrain. For reasons of climate, culture, population distribution, and common difficulties with permafrost, northern Canada is defined in this discussion as the area included in both permafrost zones (Map 8). Thus, the North includes the Yukon and Northwest Territories and northern portions of every province except for the Maritime Provinces and the island of Newfoundland. This is a region stretching over 4 700 km west to east from the Yukon–Alaska border to the eastern shore of Labrador and at least 3 500 km north to south from the northern tip of Ellesmere Island to The Pas, Manitoba.

Human settlement in the North

Long before Europeans "discovered" North America it was occupied by Asians who crossed from Siberia to Alaska on a land bridge formed during the last Ice Age. Some archeological evidence suggests that humans occupied the Yukon 27 000 years ago. Other discoveries point to the emergence of three cultures in Alaska, 12 000–8 000 years ago, whose descendents form today's Inuit and Indian cultures (Laughlin, 1975; Schledermann, 1981). Indian tribes spread throughout the Yukon and western Northwest Territories, some of whose descendents became Metis by intermarriage with European settlers who arrived much later. Indians found elsewhere in North America are believed to be descended from Asians who crossed the Bering land bridge.

Inuit migrated east from Alaska, reaching Ellesmere Island 4 500–4 300 years ago. Although both Indians and Inuit were hunters of land animals, the latter also took to the sea in pursuit of fish, whales, and other prey. Today, a line drawn from Churchill, Manitoba, to Old Crow in the Yukon roughly divides Indian communities in the west from Inuit on the east.

Except for contact with the occasional explorer, Indians and Inuit had no real contact with Europeans until the mid-1800s. In the Yukon, Hudson's Bay posts were established during this period for purposes of fur trading. Near the end of the century, whalers arrived in the Beaufort Sea. The resulting economy, based on whaling and trapping, flourished until after World War II. A massive influx of people occurred during the gold prospecting period from about 1870 to 1900. This led to the establishment of good transportation and communication systems together with permanent settlements, many of which were and remain associated with mineral and natural resource extraction.

In the area now known as the Northwest Territories, Inuit and Indian alike lived a nomadic way of life governed by the migratory habits of their prey. In the last half of the 19th century, fur trading posts were established in the Mackenzie Valley followed by others in the eastern Arctic during the first 30 years of the 20th century (Lysyk, 1977; Berger, 1977*a*, 1977*b*).

In 1934 gold was discovered on the shores of Yellowknife Bay near the site of what is now the city of Yellowknife. This discovery drew settlers from outside the North; a substantial effort was mounted to explore and extract natural resources and continues to the present day.

Church missions, along with the R.C.M.P. and the Hudson's Bay Company, became the principal administrators of the area until the late 1940s and early 1950s. Inuit and Indians became accustomed to visiting fur trading posts and began to establish camps nearby, which were used as their base of operations during those periods not spent hunting or fishing. In this way, they became accustomed to the availability of schooling and health care so that when subsidized housing was offered to them by government agencies, permanent settlements evolved from the campsites.

Native residents of the northern parts of the Western Provinces and Ontario are predominantly Indian and Metis. Inuit are found in northern Quebec. They, too, have experienced many of the same problems as their northern neighbours and have faced similar cultural conflicts caused by the introduction of a different lifestyle by non-native communities which were established nearby.

Waste disposal

For small bands of nomads, waste disposal is not a problem because campsites often are abandoned before wastes become intolerable or unmanageable. A self-sufficient lifestyle usually includes making good use of whatever materials are at hand, including skins, bones, and other materials that some societies would discard.

Waste disposal in the North did not become a concern until outsiders moved in, bringing their supplies and lifestyles with them. The problem was compounded by the move of native peoples into permanent settlements. Indians and Inuit have undergone a major transition to a new lifestyle including the introduction of technologies and concepts unfamiliar to them. Medical science is an excellent example of this change. Principles of hygiene and sanitation which were taken for granted by southerners were foreign to northern natives. Great strides forward have been taken during the past 20 years. Nevertheless, legacies of the past linger on, particularly in the area of human waste handling and solid waste disposal.

Waste management in the Northwest Territories

Enormous environmental obstacles must be overcome, at great expense, to provide potable water supplies and sewerage systems to remote communities where everything is frozen 7–10 months of the year. This means that residents of many communities still use "honey buckets" for human waste. Large plastic bags (referred to as honey bags) are used for collecting and delivering the waste to a disposal site, which is often the same one used for garbage. Even reaching this disposal site is no mean feat when snowdrifts are up to the roofline, as is common in the Keewatin District (Map 9). Over the years, sewage lagoons and pump-out systems have been introduced as replacements for the honey bag but limited funding has left a substantial number of communities using the old, inadequate systems.

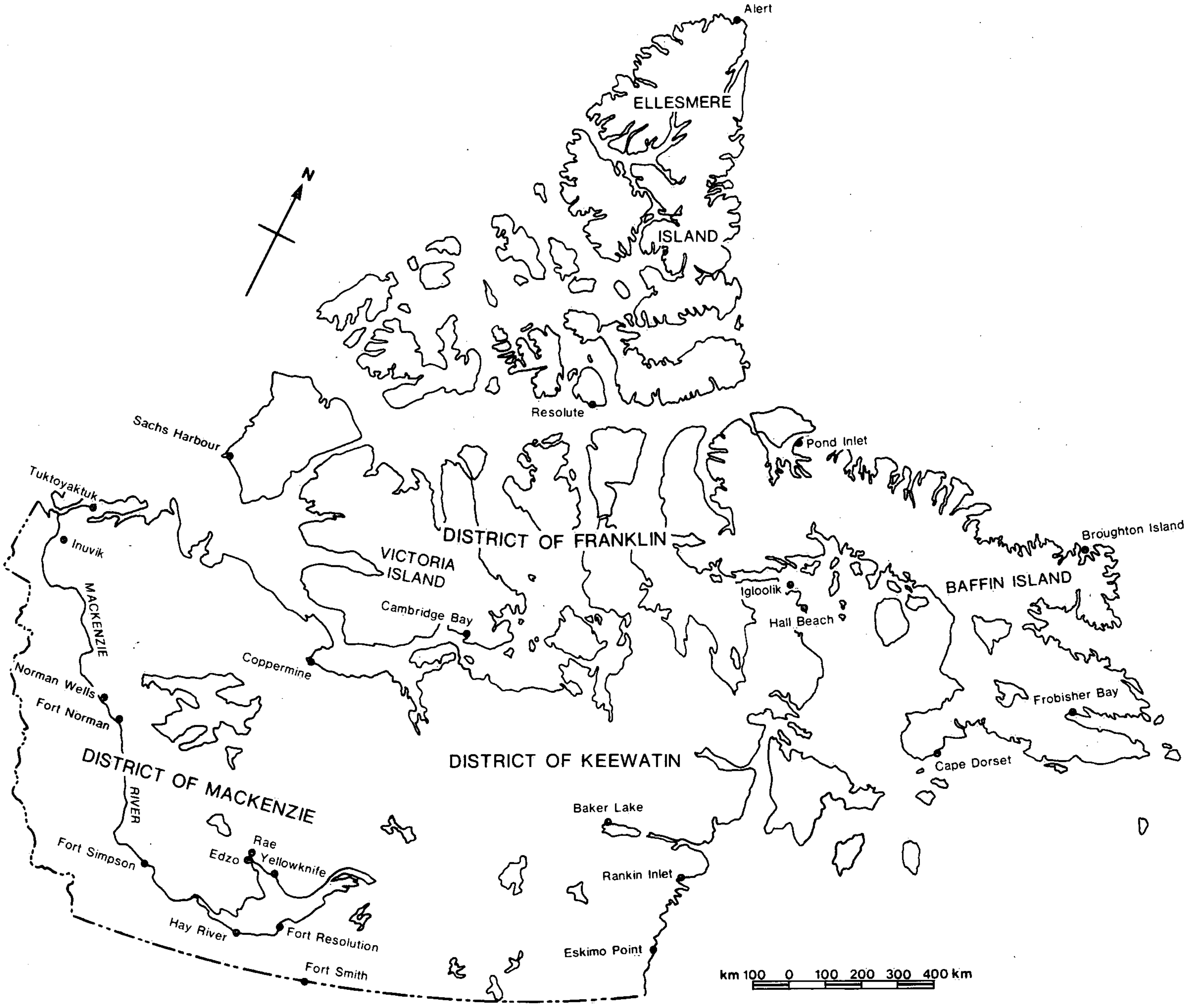
In the Northwest Territories, the subject of solid waste disposal cannot be examined in isolation from bagged sewage because the two are often deposited together at the dump. Bacteria present in both types of waste can survive for very long periods in an arctic environment (Alter, 1972). Thus if wastes can come into contact with surface waters or people, contamination and the spread of disease may result. This is particularly true of enteric, or intestinal, disorders common in arctic regions and other places where sanitary conditions are less than desirable, partly due to local overcrowding. Contamination can occur through the spills or breaks in honey bags. In permafrost conditions, liquids do not percolate into the ground, even when the air temperatures are above freezing. In warm weather the high moisture content of permafrost soils results in ponding which compounds the problem.

Studies conducted in Alaska have shown a long survival period for fecal coliform; one study of an Alaskan river in February indicated survival periods 3–5 times longer than those of more temperate climates (United States Environmental Protection Agency, 1972). Similarly, solid wastes undergo virtually no decomposition under true arctic conditions, leading some investigators to suggest that putrescible wastes should be incinerated and not landfilled. Wastes left exposed in a pit or on top of the ground can soon become windblown litter and are available as food for scavenging birds, pets, and wildlife (Straughn, 1972; Cohen, 1973; Fair, n.d.). Hence soil or snow cover is recommended even though it is recognized that bacterial decompo-

Photo 25. In this northern dump, garbage and bagged sewage are dumped together.
R.C. MacKenzie © Image Communicators-Edmonton, Alberta

MAP 9.

Selected communities in the Northwest Territories



Base map supplied by Energy, Mines and Resources.

sition will not be facilitated by covering as is the case in warmer climates. In many arctic communities rock and gravel are the only cover materials available. In these circumstances there may be encouragement for open burning under "controlled conditions". Controlled conditions include: limiting it to a time where there are no temperature inversions, locating the dump site downwind of the community, and ensuring that an adequate fire break be provided if trees are nearby.

In those communities where honey bags are used for collecting human waste, frequent collection is encouraged. Pick-up service is generally provided according to guidelines that recommend five pick-ups a week, thus avoiding two consecutive non-service days. At the disposal site, bagged sewage should be deposited in pits or areas separate from the solid waste disposal area.

Isolated communities whose economic base is small rely on the Government of the Northwest Territories to finance the provision of municipal services. When compared with similar services in the south, the cost of solid waste collection can be substantially more expensive for the following reasons. Collection can be hampered by extreme cold which can freeze the garbage bags and their contents to the ground. Snow drifts limit access to homes and the disposal site. Mechanical equipment can become inoperative for long periods while waiting for parts and repairs. However, on the positive side, waste collection is labour intensive and creates employment. Where waste collection services are provided, transport vehicles range from open wagons, used in some remote settlements, to conventional garbage collection trucks used in larger communities.

In the past, many residents burned their wastes in barrels in the front yard. This practice continues in some communities but efforts are being taken to encourage burning at the disposal site instead. Even so, severe weather conditions sometimes leave residents with no choice but to continue employing this practice.

Over the years, noticeable improvements have been introduced into waste management systems (Government of Northwest Territories, 1981). For example, in the city of Yellowknife with a population of approximately 10 000, waste collection service is provided using conventional packer trucks. Wastes are deposited in a disposal site which is covered with soil about once a week. All but about 20 homes in the city

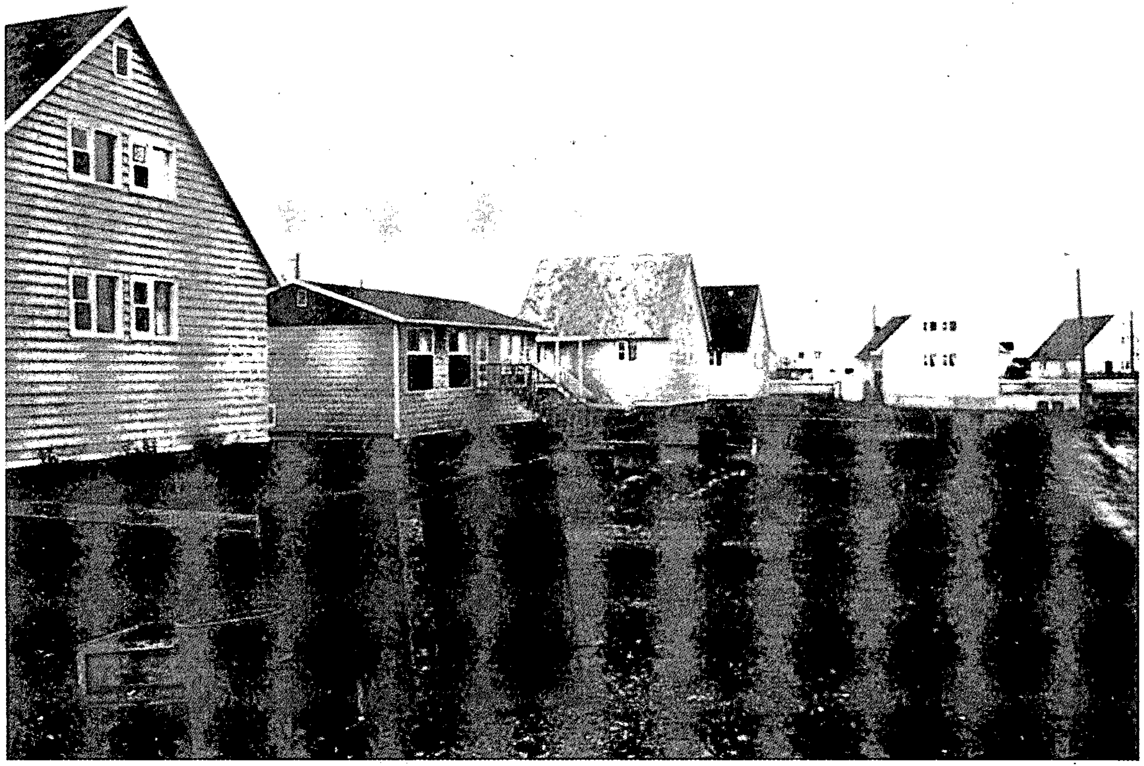


Photo 26. These front yard barrels in Inuvik are used for burning garbage.
R.C. MacKenzie © Image Communicators-Edmonton, Alberta

are provided with a sewer system or a pump-out service. For these few, a facility is located at the disposal site to split open the bags thus exposing the contents to the atmosphere and, in particular, sunlight to facilitate decomposition. This concept has been suggested or tried in other communities as well.

Hay River, with a population of approximately 3 400, uses a deep trench for garbage disposal. When full, the trench is covered with soil. This procedure, or minor variations of it, is being used in other communities in the southern areas of the Northwest Territories.

Inuvik, with a population of approximately 3 000, is limited to above-ground disposal using burning to extend the lifetime of the site. Refuse shredding trials were conducted in Inuvik in the mid-1970s (Forgie, 1976). As might be expected, equipment operating difficulties arose but these were not insurmountable, thus allowing the experiment to demonstrate that shredding under arctic conditions is feasible. Furthermore, shredded waste displayed a measurable increased degree of decomposition even when it was deposited on permafrost.

In other western and central arctic communities, such as Tuktoyaktuk and Coppermine, an above-ground disposal site is used and accepts both garbage and bagged sewage. Wastes are burned at the disposal site and in front yard burning barrels.

At Baker Lake, in the Keewatin District, where extreme cold and severe snow drifting occur, an indoor waste baling operation was proposed but not adopted mainly because of the high cost and complexity of the operation (Stanley Associates Engineering Ltd., 1974).

Frobisher Bay, with a population of approximately 2 700, is situated on a rock outcrop. It has gone through a succession of garbage dumps, none of which was used for a lengthy period; the present one is designated as "temporary". Waste incineration has been suggested for communities in this area, including Pangnirtung, where plans to use a controlled air incinerator have been suspended until more information is obtained on cost effectiveness and operating characteristics. It is possible to design a controlled air incinerator capable of burning both sewage and solid wastes, as was demonstrated by a 1978 Environment Canada study (Zaloum *et al.*, 1978), but unit operating costs ($/tonne) would probably be high owing to the small volume of wastes generated in small communities thus resulting in underutilization of the facility.

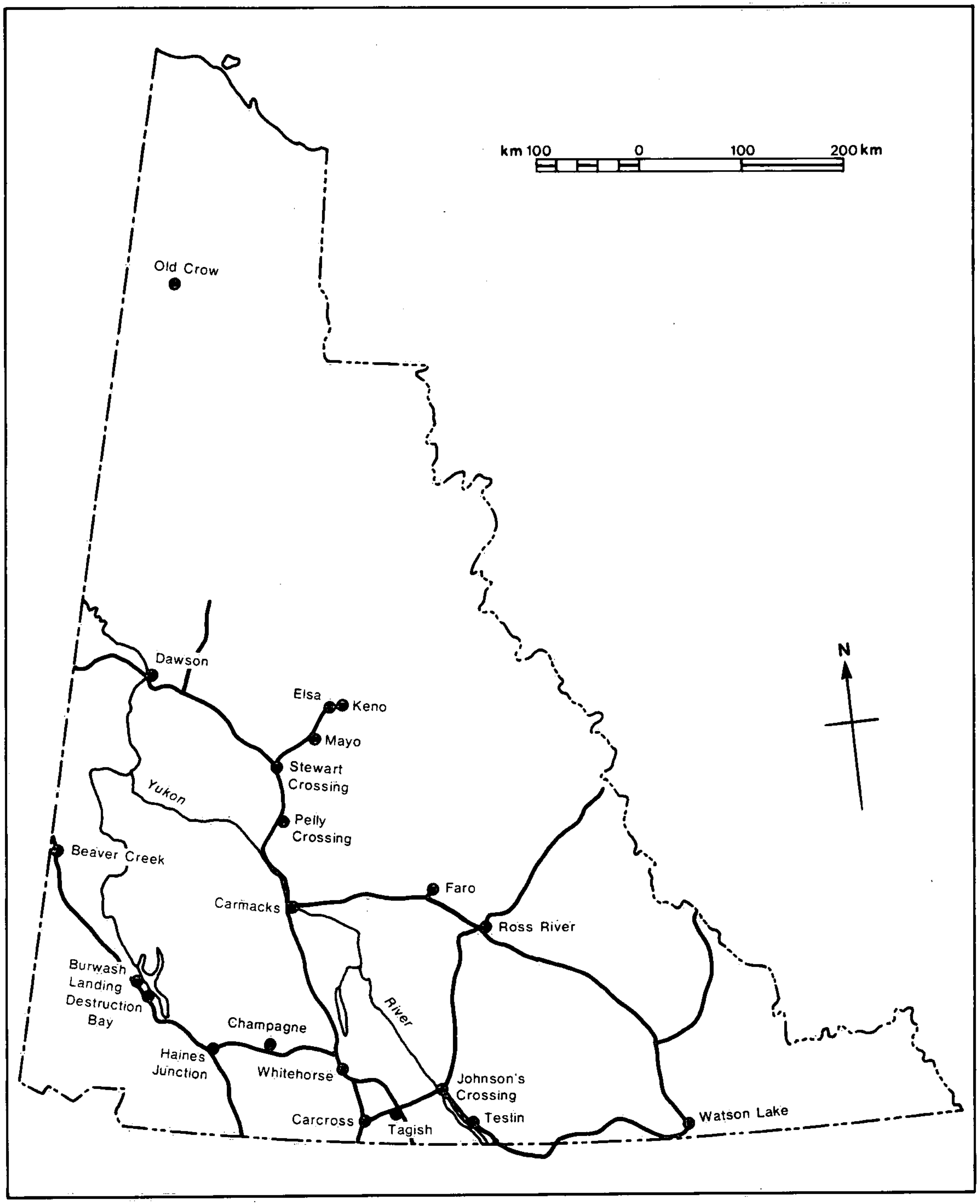
Resolute, on Cornwallis Island, is being developed as a model arctic town, having been planned to incorporate some of the latest cold weather technologies. Solid waste, collected in barrels outside homes, is delivered to a central storage trailer. When the trailer is full it is hauled to the dump and emptied. Loose gravel and rock are the only cover materials available nearby.

Since 1957, the only regulatory control of waste in the Northwest Territories has been provided through the General Sanitation and Public Sewerage Systems Regulations pursuant to the Public Health Ordinance. These are being supplemented by Codes of Good Practice developed by the Northwest Territories Department of Local Government to promote realistic standards of operation. In addition to achieving the operational changes noted earlier, the Codes will be encouraging establishment of separate storage areas for salvageable materials such as metals. This is a particularly annoying problem because materials shipped into the Northwest Territories (and the Yukon) generally never leave. Abandoned machinery, fuel drums, and vehicles are found not only in settlements but at military installations and at some resource exploration sites. Opportunities now exist in the western arctic to stockpile and then remove

Photo 27. Oil drums are abandoned at Baker Lake dump site.
E. Wiken, Environment Canada

MAP 10.

Selected communities in the Yukon



Base map supplied by Energy, Mines and Resources.

some bulky wastes by way of the Dempster Highway. A number of exploration and construction companies now use portable incinerators instead of the less acceptable land disposal practices used in the past.

Waste management in the Yukon

The impact of two major construction projects can still be seen in the Yukon. To prevent isolation and potential invasion of Alaska by Japan during World War II, the Canol Road and pipeline were built to connect the southern Yukon to Imperial Oil's refinery at Norman Wells in the Northwest Territories. Simultaneously, the Alaska Highway was built from Dawson Creek, British Columbia, to Fairbanks, Alaska. Construction equipment used to build both projects and often still in working order was abandoned in the Yukon. So were military vehicles, fuel drums, aircraft, and other supplies. Even though the Canol Pipeline was removed and sold for scrap years ago, the remains of abandoned work camps, supply depots, and pumping stations along the road have been transported to central storage areas. These remains have become tourist attractions particularly for those people interested in the historical significance of the road and the pipeline. Many proposals have been made to remove metal scrap from both the Yukon and the Northwest Territories, but all have foundered due to high transportation costs. Even in the south, scrap materials cannot be transported very far before the costs of doing so exceed the resale value of the material. Nevertheless, various government agencies have promoted drum-crushing programs whereby portable crushers were moved around the territory compressing fuel drums as a precursor to burial or prior to shipment to central holding areas. Efforts are now underway to stockpile all bulky wastes in a similar manner.

Throughout the Yukon, waste handling and disposal practices have been steadily improving over the past few years, although sanitary landfills, employing daily compaction and soil cover, are not found. Continuous permafrost is present in Old Crow (Map 10); elsewhere, most communities use trench-type disposal operations, even though discontinuous permafrost exists in some areas. In addition, the level of sewage treatment and disposal services are relatively higher than they are in the Northwest Territories, thus eliminating the problems caused by co-disposal of garbage and bagged sewage.

Following the release of a 1978 status report on waste disposal, various agencies of the Yukon Government and the federal government agreed to a solid waste management policy that became effective in 1981. A common standard of operation is being sought and this has resulted in the preparation of design and development plans for all disposal sites, including closure of some due to unsuitable location.

The former Whitehorse dump, dating from the 1940s, was one of the more spectacular operations in Canada because wastes had been pushed over a high embankment, occasionally slipping into the Yukon River. Today, this site has undergone rehabilitation to improve its appearance and minimize contamination of the river. The city, with a population of approximately 16 000, is now using an abandoned mine quarry for its waste disposal site.

An embankment dump was also used at Watson Lake for many years but it too has undergone renovation. Now, trench disposal is used at the same location. Open burning is allowed. Occasionally, wastes are compacted and will be covered when the trench is filled. A separate storage area is provided for bulky wastes. This operation is typical of the operating standards being used for the Yukon. Because the Territory is heavily forested and receives little precipitation, special precautions must be taken to prevent forest fires caused by open burning. Wildlife (bear) visits are a concern but are regarded as acceptable risks until more sophisticated methods can be introduced.

Similar to the Northwest Territories, regulatory control is provided by 1962 Rubbish Disposal Regulations of the Public Health Ordinance. Some communities provide control by means of the municipal ordinance.

Photo 28. At this dump near Whitehorse, shown in 1968, wastes that were pushed over the edge fell into the Yukon River below.
Transport Canada

Photo 29. The same Whitehorse dump site, shown in 1982, has been markedly improved by an application of soil cover.
R.C. MacKenzie © Image Communicators-Edmonton, Alberta

Waste management elsewhere in the North

Isolated settlements within the northern areas of provinces usually experience waste handling difficulties similar to those found in southern regions of the two territories, for similar financial, geological, and cultural reasons. Indian reserves on islands in the lake districts of Saskatchewan, Manitoba, and Ontario have only so much land available. Cultural attitudes associated with a hunting and fishing way of life do not place much emphasis on the importance of proper waste disposal. Often, each backyard becomes a waste disposal site.

The fact that wildlife, especially bears, are attracted to garbage is a continual concern. The incidence of polar bears foraging at the Churchill dump has been fully documented. However, even without the dump the bears would be a nuisance for Churchill because it happens to be situated on their migratory route.

Summary

There is a particular urgency to improve waste disposal methods in the North. The harsh climate and rugged physiographic features, and the remoteness of the scattered settlements whose residents are dependent on senior governments for public utilities have combined to create conditions in which it is particularly difficult to manage waste properly.

The text was reviewed by K.A. Childs, Technical Services Branch, Environmental Protection Service, Environment Canada, Ottawa, Ontario.

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AIRPORTS

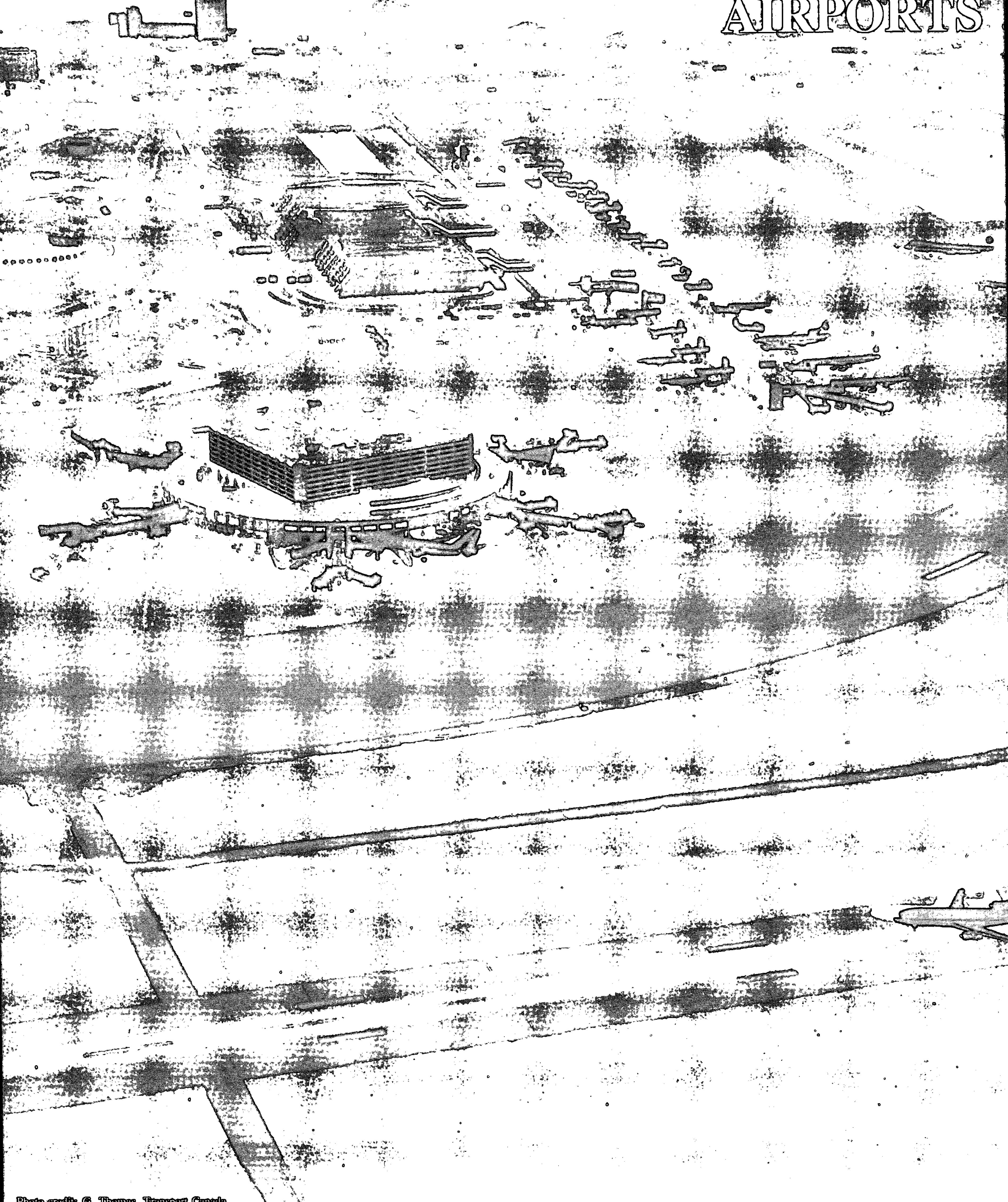

Photo credit: G. Thomas, Transport Canada

LAND STRESSES ASSOCIATED WITH FEDERAL AIRPORT FACILITIES

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FEDERAL AIRPORT DEVELOPMENT AND LAND RESOURCES

Introduction

Definition of stress

The building of an airport called Mirabel was the news of the seventies. Today, in the eighties, the building of Mirabel is still making headlines. It is a sign of the environmentally conscious times we live in that an airport project can remain newsworthy through one decade to the next. Like many other major land-use developments, airports affect people's lives by bringing about changes in their environment, changes that frequently give rise to community protest and public controversy.

An airport's impact on the environment is not contained within its boundaries. The direct impact of airport construction on the land resource occurs on its site, but the effects of airport operations are felt much further afield. And although an airport's influence on its surrounding region is in many ways positive and consistent with aims of economic development, growing community opposition to airport development attests to the kinds of stress airports cause.

There are a number of ways in which airports cause stress on land resources; some are directly identifiable, others arise as indirect effects of airport activity. For example, the construction of new airport facilities at a site will disrupt the existing ecology and directly bring about changes in the physical landscape and patterns of land use. Here, a direct causal relationship can be seen between airport development and land-use changes. It is more difficult to discern a strong causal relationship between airport activities and their indirect impacts, though these impacts are no less pervasive. Airports indirectly stimulate economic activity in their surrounding areas and thereby induce changes in the use, value, and capability of the land resource. This kind of indirect effect is evident where airports have stimulated urban development in rural areas, causing the withdrawal of land from agricultural use and capability.

At a time when many diverse activities are competing for the use of Canada's land resource, our concern about airport-induced land stresses increases. Airports are large land users. Transport Canada, the federal government department responsible for the Canadian Air Transportation Administration (CATA) owns 160, and operates 90, of the 875 licensed airports in Canada. These federal airports comprise all of this country's major international and commercial air transport facilities. Federal land holdings associated with airport facilities embrace as much as 98 765 ha, according to Central Real Property Inventory (CRPI) data for 1981. And, of course, an airport's zone of influence in a region extends far beyond the confines of its site. Table 1 indicates airport land holdings under federal jurisdiction for each of the provinces and northern territories.

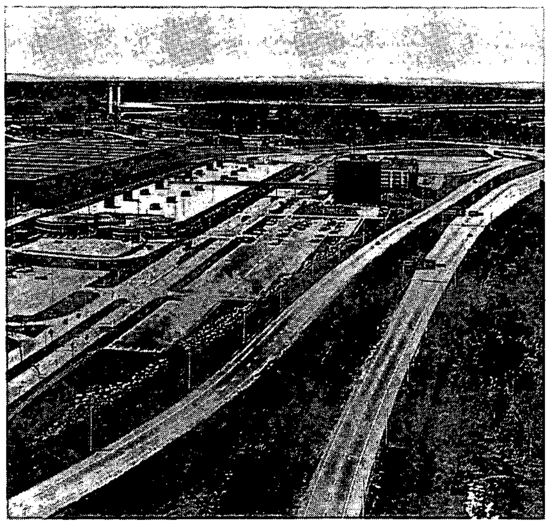


Photo 1. Airports require large amounts of land for a variety of uses including buffer zones, runways, terminals, parking lots, communication facilities, and hangars. Approximately 35 600 ha of land were originally purchased for Mirabel which has an operational area of about 6 920 ha, the largest in Canada.
G. Thomas, Transport Canada

TABLE 1.
Lands used or associated with airport facilities under federal jurisdiction

Province or Territory	hectares
Newfoundland	17 443.4
Prince Edward Island	330.1
Nova Scotia	1 928.4
New Brunswick	3 059.7
Quebec	10 777.4
Ontario	20 014.8
Manitoba	4 876.7
Saskatchewan	2 634.2
Alberta	8 409.5
British Columbia	12 406.3
Yukon	2 074.9
Northwest Territories	14 809.7
Canada Total	98 765.1

Source: Calculated from Central Real Property Inventory (CRPI) Data, 1981.

To investigate the various 'stress on land' issues that relate to federal airport activity it is useful to consider them from two different standpoints. The first, to be examined later in this review, is that of environmental quality and the physical environmental impacts of airports on the land resource. These include land stresses caused by high noise levels in surrounding communities, disruption of the physical environment and ecological systems, environmental hazards, pollution, and loss of desirable landscapes. It should be emphasized that these environmental concerns are to be considered solely in terms of their relation to the stresses on land.

The second standpoint is that of specific land-use issues related to airport activity. The direct impacts of airports on land use include the occupation of a site by airport facilities and related infrastructure, induced land-use restrictions, expropriation, and zoning changes in the immediate vicinity of airports. Indirect effects of airport development that have an impact on land use are: the stimulation of economic activities in a region, stress on local and regional roads as a consequence of increased traffic levels, stress on other surface infrastructure such as hydro and sewage utilities, pressure on local housing markets and land values, and finally, the encouragement of industrial, commercial, and other urban uses of land.

Airport development and infrastructure

At the root of airport-induced stresses on land is the loading of infrastructure on the land resource. Transportation systems superimpose their networks on land, disrupting both the natural environment and existing competing land uses. Moreover, the addition of supporting infrastructure tends to encourage and accelerate the development process in the airport vicinity by attracting activities that can make use of the new services and utilities. In a study of the economic and urbanization effects of airports, the Organisation for Economic Co-operation and Development (OECD) Secretariat observed a distinct "nurturing" impact of airports on their surrounding areas. Airports improve a region's potential for development by providing ready-made services and infrastructure that otherwise might not be available. The building of airports thus leads to the improvement of regional road access and provides other public utilities such as water, hydro power, gas, and sewage services (OECD Secretariat, 1975). According to Young (1974) an airport's supporting infrastructure serves as much more than an integral part of the aviation system; rather, it functions as "adjunctive" to the site, serving to accelerate the development process of a region by providing a focus for economic growth.

Land use, value, and capability

The importance of airport development in determining the use, value, and capability of land resources cannot be underestimated. Canada already faces a scarcity of land suitable for new airport sites or expanded sites. Any proposal to expand existing airports or construct new facilities is apt to be met with opposition stemming from arguments for the 'best' use of basic resources. Competing land users base arguments against airport development on a perceived need for a more efficient and/or equitable use of land. Decisions on building airports require that a balance be maintained between objectives of aviation efficiency and land resource use. In doing so, strategic trade-offs will be made between competitive interests. The OECD Sector Group on the Urban Environment (1975) described the major non-transport considerations of airport decision-making as: regional planning objectives, alternate claims on the use of land, the impact of noise on environmental quality, the effect of airport activity on the local ecological environment, and the public attitudes and reactions of nearby residents.

The degree and significance of airport-induced land stresses can best be assessed by the weight or importance of the above considerations for a particular airport site. For example, building a new airport in a largely rural setting might occasion far greater ecological stress than would expanding airport facilities in a built-up urban area. On the other hand, the expansion of airport facilities in an urbanized region might cause greater conflict between competing users of the land resource than would acquiring a new rural site.

An airport's stress on the surrounding land resource can also be weighed in terms of the region's development policy. A new airport in an under-developed region will have a positive effect on its potential economic growth by attracting aviation-related service industries, spurring employment opportunities in the region, stimulating the building of housing for new employees, and inducing growth of other secondary and tertiary industries and services. This multiplier effect of economic development would indeed be less stressful in a region seeking economic diversification and growth than in a region seeking to discourage further urbanization, or a region having the policy goal of preserving agricultural land (OECD Sector Group on the Urban Environment, 1975). For example, one of the justifications for selecting the Pickering site over the other possible sites for the proposed second Toronto International Airport was that it complied with the Toronto Centred Region Plan objective of directing future growth of the city in a north-easterly direction (Marriot and Cook, 1975; Canada, Airport Inquiry Commission, 1974).

Overview of federal airport activities and land management

Mirabel, located 64 km northwest of Montreal, is what is called a "third generation" international airport (OECD Sector Group on the Urban Environment, 1975). The selection of the rather remote site for Mirabel illustrates a significant airport locational problem that began showing itself in Canada by the end of the 1960s. Before then neither the site selection process nor airport planning were so complicated.

The first phase of large-scale airport building in Canada occurred after 1936 when Parliament passed the Department of Transport Act. The new Department of Transport took over aviation responsibilities from the Civil Aviation Branch of the Department of National Defence, assuming that department's construction of the first landing strips embodying the Trans-Canada Airway (Pendakur, 1974). It was not until the years of World War II that modern airports, as we would recognize them, began to appear across the country. Grassed landing strips gave way to military airports equipped with paved runways, radio communication systems, meteorological facilities, fuel tanks, terminal buildings, lighting, and air traffic control facilities (Pendakur, 1974). Many of these early military airports, such as the Sea Island Airport at Vancouver, reverted to civil control after the war, thereafter becoming international airports (Transport Canada, 1981*a*). The growth of these and other new airports during the 1950s and 1960s constituted the second generation of federal airport building in Canada. Small-scale airport facilities were added to and sites were expanded in response to changing aircraft technology and commercial demand for aviation. Airports were able to grow more or less unimpeded by land resource problems. Communities and urban centres were relatively contained; urban sprawl had not yet begun to compete for land resources outside city limits.

In response to changing aircraft technology the 900-m runways of the early years were expanded to 1 370 m by the mid-1940s, then grew beyond 3 000 m during the 1960s. By this time, however, the potential expansion of many urban airports had become severely limited by an increasing scarcity of land, public outcry, and political controversy. For the same reasons, new airport sites have become increasingly difficult to assemble near urban centres.

Today, the same growing urban populations that increase the demand for airport services are those that threaten to curtail airport expansion and new construction. There are two aspects to this problem.

First, there is the physical and spatial dimension of urban growth and form that hinders airport expansion. The rapid urbanization of Canada in recent decades has been accompanied by a movement of people and industry away from the city centre to newly created suburbs. The multiplier effect of economic development in the vicinity of airports is also responsible for spawning residential and service communities. This process of urban encroachment has largely occurred in a haphazard fashion as an evolutionary trend, rather than by plan or design. Inadequate zoning regulations have permitted the surrounding of many Canadian airports by land uses which are, by and large, incompatible with expanding airport operations. At the same time, the demand for commercial air travel has been enhanced as urban centres grow and spread outwards to airport boundaries.

The second way in which urban and suburban populations act to forestall airport development is by challenging airport planners with public opposition to development plans. Widespread public disenchantment with transportation planning decisions has resulted where planners have failed to account for, or mitigate the impacts of transportation developments upon the community. Another reason for public distrust of governmental decisions concerning transportation projects lies in the failure of authorities in the past to include public participation in the planning process (Roads and Transportation Association of Canada, 1977). As a result of such distrust, and growing demonstrations by citizen groups and individuals, the practices of airport planning have broadened in recent years to include public consultation and involvement, as well as the consideration and evaluation of community impacts.

The spatial significance of airport development

What distinguishes airports from other land uses and development projects is the nature of their spatial impact. Because airports are part of a larger transportation system, airport operations have a spatial impact that is significant at different geographical scales. Airports facilitate local, regional, national, and international transportation flows which are spatially significant.

Photo 2. The first heavier-than-air flight in Canada occurred at Baddeck, Nova Scotia in 1909. Since then, the development of an air transportation network has facilitated the movement of goods and people across the country and around the world.
G. Thomas, Transport Canada

In geographical terms, airports function as nodes within a transportation system. Transportation nodes are points of origin or destination in the movement of goods and people from place to place. The paths of flow which connect different transportation nodes to each other, and along which goods and people travel, are known as transport links. For example, highways and roads form transport links between an airport and other major surface transportation nodes such as a bus depot or railway station. Similarly, the flight paths travelled by airplanes between airports are air transport links. Together nodes and their connecting links form transport networks.

Transport networks that connect with major airports are large and spatially complex–they extend beyond regional and national boundaries. In the case of air mail carrier service, for example, the transport network extends to all corners of the earth. It is through their many surface and air transport links that airports serve the national economy by facilitating national and international trade and commerce.

The functional and spatial dimension of transport networks pose a political dilemma for airport planners. On the one hand they are indispensable members of the community, supplying essential transport services and contributing to the well-being of local and national economies; on the other hand they can be incompatible neighbours, generating stress on valuable land resources and inducing negative impacts on the environment. Planning decisions for major airports may have broad political implications since transportation planning is inter-spatial. And because of its inter-spatial dimension transportation planning and management is also inter-jurisdictional. No single government agency or jurisdiction has complete authority over airport development decisions.

The different roles of Canada's federal, provincial, and local governments in reducing airport-induced land stress is significant. In general, it is the mandate of the federal government to manage the planning, development, and operation of all of Canada's major international and commercial airports in a way that minimizes adverse environmental impacts (Transport Canada, 1974*d*; 1980*a*). Provincial and municipal governments also have a major transportation planning role in managing the development and operation of an airport's surface transport network infrastructure, and this includes highway links and the provision of transit services to and from airports. Provincial and local jurisdiction over land resources give these authorities the responsibility, in effect, to manage an airport's induced impact on a region by controlling land uses through zoning laws and regulations, and by providing public utility services to expanding communities (Young, 1974; Neales, 1972; Pendakur, 1974).

Although it is the federal Ministry of Transport that initiates airport development projects for major Canadian airports, its airport planners must secure agreement on matters which concern other jurisdictions. Federal airport planners must try to coordinate their plans with regional transportation and land-use plans in order to reduce conflict and potential land stresses. The choice of the Pickering site for a second Toronto International Airport is a good example of a situation where there was inadequate coordination between the different levels of government responsibile for transportation planning. In the end, the province of Ontario refused to allow the federal government to build an access road from the airport site onto the regional highway system because the highway would not be able to tolerate additional heavy traffic at peak hours of congestion. The doomed airport project could not proceed without this major highway access to the city of Toronto (Stewart, 1979). If the initial site selection process had been coordinated with regional transportation planning, this conflict might have been avoided.

The process of multi-level cooperative planning, as an instrument of conflict resolution, is a recent phenomenon in Canada. As such, it is not yet a well developed process. In fact, there is no common process or machinery of inter-governmental liaison for transportation planning used across the country.

In the case of airport projects, the way in which planning liaison occurs is left up to the initiative of the federal airport authority. At Vancouver International Airport, for example, two approaches have been used in recent years. First, in 1973, an Airport Planning Committee (APC), composed of federal, provincial, regional, and municipal representatives, as well as individuals from local communities, was set up. It was the responsibility of this advisory body to study the extent to which airport plans were compatible with the planning interests of the different levels and agencies of government and with community interests. The information gathered by APC was then used by the Airport Master Plan Project Team in their drafting of a master plan for Vancouver airport development. The second coordination approach initiated by the Vancouver Airport authority was to hold public hearings inviting response to, and criticism of their draft master plan. The suggestions of various governmental bodies, as well as the public, were then used to improve and revise the draft plan. However, neither of the above two processes were designed with the exclusive goal of providing transportation/land-use planning coordination between different jurisdictions. Nor did they provide on-going inter-jurisdictional planning liaison.

The remainder of this paper falls into three sections; the first of these examines specific environmental stresses and land-use issues relating to federal airport development as they have occurred and have been managed in Canada. No attempt is made to rank the importance or significance of the various kinds of stress impacts. An airport's impact varies with its setting and the scale of its activities. The relative importance of any one type of stress impact at or near a particular airport site will necessarily depend on local conditions such as environmental sensitivity, individual and community tolerance of impacts, and community perceptions of stress. Since airport managers report that objections to noise comprise the greatest number of complaints received from airport neighbours, the subject is dealt with at some length. The next section describes the airport planning and management process in the light of environmental protection considerations, and further illustrates management issues with several federal airport case studies. The final section concludes the review, giving an outlook on the future of Canadian airports.

STRESS ON LAND

Environmental quality

The nature of environmental stress

The quality of the physical environment in which we live is important to our health and to our enjoyment of life. At all stages of their development airports threaten to disturb an area's environmental quality: during the initial site survey, during the construction phase, and throughout their operating activities.

There is a great variation in the character, form, and magnitude of potential stress impacts among airport sites. Each airport has its own unique physical setting. The special relationship between airport development and the physical environment at any one site constitutes what Bryan (1975) describes as a "two-directional" interaction. That is, the nature of potential stress impacts at an airport site bears a strong relationship to the nature of the constraints that the site imposes on airport development. Hence the degree or scale of airport-related environmental stress will depend, to a large extent, on the magnitude of environmental limitations or constraints on airport development. This relationship can be seen in the case of runway extension at two very different airport sites such as the Vancouver International Airport and the Regina Airport.

The location of Vancouver's airport in the ecologically fragile Fraser River estuary and delta poses a major constraint to future runway extension or airport expansion. Here, the sensitive ecosystem is highly valued as an important resource base. The Fraser estuary and delta ecosystem supports a multitude of delicate marine and freshwater habitats that comprise a life-supporting productive system in the food chain. It harbours the simplest estuarine species, such as plankton, invertebrates, and plant vegetation, through to complex mammal species. Any airport expansion requiring extensive dredging, landfilling, and dyke construction to reclaim land for runway facilities would be extremely disruptive of the coastal ecosystem. Negative environmental impacts in this area could result in irreparable damage to the physical environment and all the life systems it supports. In turn, the various resource users dependent on the ecosystem would be affected, not least the west coast commercial fisheries and recreational industry. It is clear that the very magnitude or severity of these environmental constraints largely determines the potential impact of airport expansion at this coastal site.

At Regina Airport, where the magnitude of environmental constraints to airport expansion is not so great, runway expansion can proceed without inducing such a degree of negative impacts on the physical environment. The prairie setting of the Regina Airport does not require land reclamation or other disruptive operations such as blasting, filling, or extensive levelling for runway extension. These two sites illustrate the two-directional relationship between the environmental feasibility of airport activities and the magnitude of impacts they impose.

Compounding the magnitude of environmental stress is the significance of an impact in a particular instance. The degree of impact does not necessarily dictate its significance. Consider the above example of two different airport settings. In the prairies the extension of a runway may seriously affect the storm drainage of the site, yet the importance of this impact could well be small if the implications of poor drainage are not perceived as any great problem in the surrounding area. A reverse situation could be found in the estuarine setting of the Vancouver International Airport. There, a small magnitude stress might have grave implications and be of vital importance in relation to the extremely sensitive coastal resources. In other words, an impact of small magnitude in a fragile environment may be of much more significance than an impact of large magnitude in a less sensitive physical environment (Bryan, 1975).

Another distinction between the magnitude and the importance of stress in the physical environment is found in their measurement. In discerning the magnitude of an impact the measurement is usually based on quantifiable facts. The importance or significance of a stress impact, however, is not always readily identifiable and requires an arbitrary and qualitative value judgement (Applied Marine Research Ltd., 1975; Bryan, 1975).

Before taking a closer look at how specific airport development activities induce stress impacts on the various components of the physical environment, it is useful to consider first how impacts vary in form. As was previously mentioned, airport development results in physical stresses that occur in the form of both indirect and direct impacts. In addition, impacts may have long-term or short-term consequences; they may be felt immediately, intermittently, or over a prolonged period. Environmental impacts may also cause irreversible changes in the physical environment. Many land uses compete for the same land resource. Flat, well-drained, and fine-textured soils have a high capability for agriculture. These same soils and landscapes are also desirable for construction of infrastructure such as airports, houses, and industries. By committing an area's physical resources to airport development they are lost to many other uses. Once an airport site and its adjacent area have been developed for air transport and other urban uses they are no longer available for agricultural, recreational, conservational, or forestry use.

Having established a conceptual basis for understanding the relationship between airport development and the physical impacts associated with it, it is now fitting to look more specifically at how particular airport operations induce stresses on the physical land resource.

As mentioned above there are three major stages of airport development: the initial site survey, the construction stage, and airport operation. Each stage comprises a wide range of activities that may have an impact on the physical environment. The physical setting of an airport site itself can be categorized into a large number of environmental components. For the sake of brevity this discussion will concentrate on the broader categories of airport development activities and environmental components. The three stages of airport development are comprised of the following broad categories of activities:

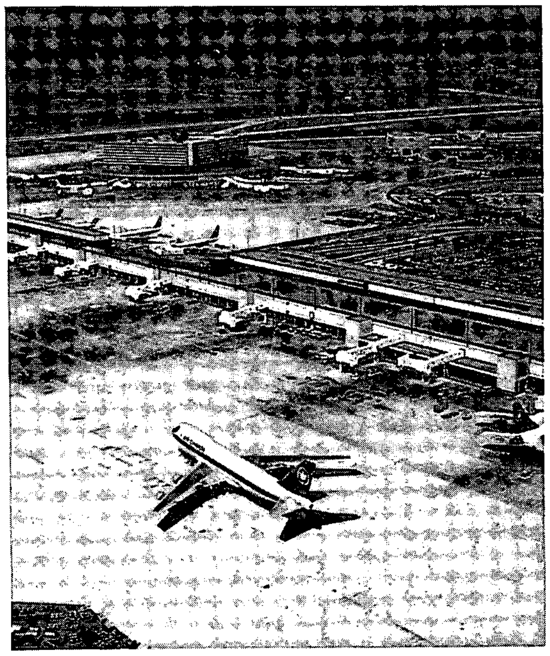


Photo 3. Airports, such as Toronto International Airport, utilize large parcels of flat land that often have high capability for other uses including agriculture. In addition, airports act as a magnet for communication and high-technology businesses and service industries that also require land.
NFB-PHOTOTHEQUE-ONF Photo by George Hunter

Site surveying
—hydrologic survey and drilling
—topographic survey
—soil survey and testing
—surficial and bedrock geological survey and drilling
—marine and aquatic assessment

Construction
—establishment of construction camp and site facilities
—tree cutting and vegetation removal
—ground excavation and rock blasting
—surface stripping and dredging
—surface grading and landfilling
—hauling and vehicular movement
—asphalt paving and concrete foundation laying
—erecting buildings
—sod laying and landscaping
—road building
—building liquid and solid waste disposal systems

Airport operation
—aircraft maintenance and repair
—aircraft movement and engine emissions
—vehicular movement and parking
—de-icing of pavements and runway maintenance including snow removal

—aircraft fuelling
—operation of utilities: boilers, incinerators, sewage, and waste disposal facilities
—storm drainage systems
—fire-fighting and emergency procedures

The major categories of environmental components affected by airport development are:

1) plants, animals, and birds
2) marine and aquatic habitat and species
3) surface and ground water quality and quantity
4) soils, geological formations, and special landscape features
5) air quality

Although not all of the above environmental components comprise what is specifically thought of as land resources, their disruption would lead to repercussive stresses on land by indirectly altering its quality. Land and non-land resources are integral components of the total environment. The following discussion, however, focuses primarily on direct land stresses.

To list all the airport development activities and all the environmental components that they can affect would be a formidable task. Indeed, one assessment of the impact of airport projects on soil and geology lists a total of 140 airport activities and 123 environmental components of soil and geology in a matrix, giving a total of 17 220 possible interactions – impacts or constraints (Bryan, 1975). Similar assessments have been devised for the impact of airport projects on marine and aquatic physical environments (Applied Marine Research Ltd., 1975), and for the plants and animal component of airport environments (Thurlow and Associates, 1975).

Implications of environmental stress

1) Site surveying

The initial survey and sampling of potential airport sites generally does not give rise to land stresses of large magnitude or significance. Usually land survey and testing techniques are carried out at specific stations or installations that cause small magnitude disturbances within their immediate locale.

Perhaps the most disruptive methods of airport site survey are those requiring bore-hole drilling, such as with hydrologic testing and subsurface exploration of bedrock. Still, the impact of bore-hole drilling on hydrology and soils is rarely severe and most certainly would not in itself lead to a change in land use, value, or capability.

Surprisingly enough, it is the use of field transportation vehicles during site survey that causes the greatest stresses on land. Off-road vehicle movement can damage and destroy ground vegetation, which in turn leads to the damage of soils by exposing them to climatic weathering, wind and water erosion. The impact of vehicle movement largely depends on soil type and conditions, the survey time-of-year, and the type of transport conveyance. Potential ground disturbance is of particular significance in the karst landscape of southwestern Alberta and in the thermokarst regions of the arctic and subarctic areas of Canada. Even a small magnitude disturbance of the partially or permanently frozen ground of the north is of great significance. A seemingly harmless summer drive across an area underlain by permafrost can give rise to devastating stress on land: damage and destruction of vegetation, large-scale melting of permafrost ground, soil subsidence and slumping, and excessive soil erosion (Transport Canada, 1977*b*; Bryan, 1975; Thurlow and Associates, 1975). In a physical environment such as this the impact of site surveying could well lead to a change in land capability, use, and value.

2) Airport construction

Of all the different airport development activities it is the construction of airport facilities that causes by far the most direct impacts on the physical land resource. All phases of airport construction operations have potential consequences of stress on land. The most significant direct impact caused by construction activities is land weathering and soil erosion.

The establishment of construction facilities on a site effects the first "gross changes" in physical features of the natural landscape (Transport Canada, 1974*d*). Patterns of land use will have already been disrupted by the land assembly carried out during the airport planning stage that precedes construction. Once having occupied the site, construction crews undertake several operations: access roads, both temporary and permanent, are built; temporary buildings, utilities, and storage areas are installed; sanitary landfills are established; and landscape levelling proceeds. These initial stages of airport site preparation damage, remove, and bury areas of plant and animal habitat. The stripping of vegetation from land surfaces can trigger numerous impacts; soil conditions are rendered unstable and susceptible to erosion, which in turn causes run-off of silt, leachates, and nutrients into water courses after heavy rainfall, thereby reducing water quality (Transport Canada, 1974*c*). Soil exposure by stripping in dry or sandy areas will occasion wind erosion, creating hazards to visibility and to other land users in adjacent areas.

The removal, burial, and erosion of fertile topsoils occur as direct physical impacts of numerous other airport construction operations. Ground excavation, landfilling, vehicle movement, asphalt paving, landscaping, and sod laying are among the major construction activities that cause stress on land by reducing its productive capability. The magnitude and significance of soil erosion at an airport site depend on local soil characteristics and conditions of climate and topography. Whatever the prevailing conditions, erosion remains the most critical and frequent stress on the land resource at airport sites (Environmental Control Consultants, 1977; Applied Marine Research Ltd., 1975; Bryan, 1975; Thurlow and Associates, 1975). Furthermore, the soil erosion hazard has serious implications for other environmental components. The adverse effect on the quality of the ground and surface waters supporting populations of plants, animals, birds, and aquatic life can disrupt all links in the food chain. This kind of interference poses a severe threat to the continued physical productivity and capability of an area, as well as stress on other valuable land uses (Thurlow and Associates, 1975). If the water quality of an area is impaired, so may be its suitability for use by man, be it for agriculture, industry, recreation, domestic requirements or aesthetic enjoyment (J.L. Richards and Associates, 1975).

Photo 4. Stripping vegetation and topsoil to enable airport construction can dramatically affect the ecosystem. Wildlife habitat is lost, soil is more susceptible to erosion, and the appearance of a natural landscape is altered. Transport Canada implements mitigational measures to reduce the impact of construction activities.
Transport Canada

3) Airport operations

When airports reach the operational stage of development the threat of stress on land comes from a different series of activities. Airport operations interfere with the productive capability of the land resource by altering life-sustaining ecosystems. They do this largely by introducing contaminants into the local environment.

The movement of aircraft causes polluting emissions, such as hydrocarbons, carbon monoxide, sulphur, nitrogen oxides, and soot particulates, which have large impacts on the environment. Air pollution adversely affects local vegetation, wildlife, and even water quality (through emission fallout). The physical impact of aircraft movement is one of continuous and long-term stress (Hurtubise *et al.*, 1978; Environmental Control Consultants, 1977).

Production of sulphur and nitrogen oxides may also occur as fallout from airport boilers and incinerators. The impact from these operations, however, occurs intermittently, depending on prevailing conditions of climate (wind, humidity, and temperature).

Surface de-icing, sanding, and silting operations also introduce foreign compounds on to the land resource. The use of urea, glycol, salt, and sand to keep pavements free of ice will have varying effects on vegetation, wildlife, and water quality (Ferguson, 1977; Société multidisciplinaire d'études et de recherches de Montréal, Inc., 1975*a*). Certain de-icing compounds encourage vegetation growth and attract wildlife while others inhibit plant and animal life, impair water quality, and disrupt ecosystems. Aircraft fuelling operations may also be hazardous if large spills result in the contamination of water supplies and damage to local vegetation.

Still more wastes are generated by airport operations: oils, detergents, grease, sediments, solid refuse, sewage, toxic compounds, and foam all enter into the physical environment through aircraft maintenance and repair, runway maintenance, fire-fighting, vehicle movement and parking, and systems of waste disposal (Environmental Control Consultants, 1977). The large-scale production of airport wastes alters the productive capability of local ecosystems and compromises environmental quality (James F. MacLaren Ltd., 1975).

Airport contaminants more distinctly affect the land resource by impairing the quality of soils. Sewage and waste disposal systems introduce nutrients and toxic chemicals into the soil through leachate production. Fire-fighting practices, fuel spills, and the use of urea as a de-icer have a stress impact on soils and geological materials and may cause an imbalance of their nutrient and chemical composition. If not controlled, storm runoff and drainage from paved airport surfaces can cause excessive leaching of soil nutrients to ground waters below (Bryan, 1975; J.L. Richards and Associates Ltd., 1971). The long-term effect of even intermittent contamination of soils may well be irreversible.

Airport impact on the aesthetic environment

Human sentiment places a great deal of importance on the aesthetic quality of the physical environment in which we live. Our quality of life is enhanced by an appreciation of environmental beauty. Just as airports can be menacing to physical land systems, so they may also imperil the aesthetic value of land.

In outlining environmental guidelines for airport planning one group of analysts has defined aesthetic and human interest elements as "those aspects of the environment which have special merit as instances of artistic or natural beauty, those areas which are of value because of their special quality or ambiance, and those sites in a region which are of educational, cultural, historical, or scientific interest" (Société multidisciplinaire d'études et de recherches de Montréal, Inc., 1975*b*). This same group distinguishes the five components of the aesthetic environment as: 1) wilderness areas of woodland, bush, swamp, grassland, mountains, tundra, or other unique habitat; 2) areas of visual quality having landmarks or scenic views; 3) viewing sites and points of lookout; 4) open protected areas such as historical sites, unique physical features, and cultural sites; and 5) restricted access sites such as designated areas of conservation, preservation, archaeological excavation, and special research stations.

It is extremely difficult to measure the value of aesthetic components of the environment because of the inherent subjectivity involved. Perception of aesthetic quality depends on personal value judgements, which are influenced by political, cultural, and socio-economic characteristics of society, as well as temporal factors. Nonetheless, the importance of Canada's aesthetic quality cannot be ignored; Canadians value environmental beauty enough to merit its protection.

Airports affect aesthetic environments during all phases of their development. The impacts vary in the same way as for other environmental components, in importance, significance, degree, and scale. They may be instantaneous and short-lived, intermittent, or continuous and long-term. The significance could be local, or of national concern. Moreover, the aesthetic environment can be affected by both direct and indirect impacts of airport development. The value of land for aesthetic use is highly susceptible to airport-induced changes in the physical environment.

During the construction stage of airport development the threat of physical change or destruction of aesthetic landscapes is most apparent; it may result from the direct takeover of land for airport facilities, or from indirect impacts that alter general land-use patterns in the vicinity of the site (Ecologistics Limited, 1975*b*; Metropolitan Toronto and Region Conservation Authority, 1974).

Pollution (air, water, noise, and visual) from airport operations can also lead to a deterioration of aesthetic resources, rendering them less valuable for certain uses.

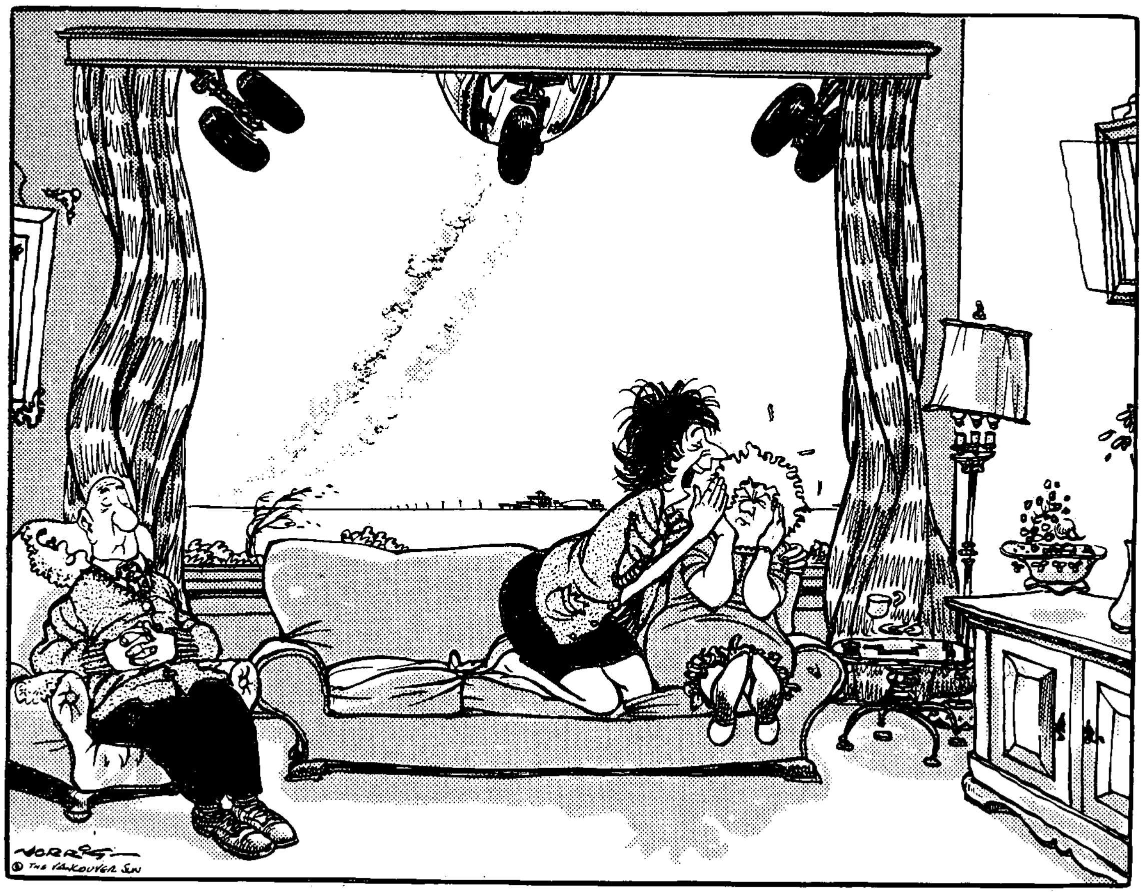
Even the planning stage of airport development can have negative impacts on aesthetic quality. Land speculation and freezes on land sales frequently give rise to the neglect of aesthetic land resources. In expectation of expropriation or future land development projects, private property owners and corporate speculators are less apt to care about the aesthetic upkeep of their land. Once expropriation has been carried out the aesthetic quality of land may continue to be neglected under federal management. The 7 527 ha of prime farmland expropriated for a second Toronto International Airport have grossly deteriorated in aesthetic quality in the years since this project was first announced (Speirs, 1979). In Pickering Township the once scenic countryside is a mess and the farm buildings have fallen into disrepair. It is what Stewart (1979) calls "a ghost countryside, a comfortable wasteland."

Airport noise and land resources

Of the many land stress problems associated with airport operations, aircraft noise is perhaps the most prominent and pressing environmental hazard. Ever since the arrival of commercial jet air traffic in the late 1950s, airport noise has provoked loud and acrimonious public outcry. If people tend to complain more about noise pollution than other common types of urban pollution, it is because they can more readily identify the cause of their discomfort and there is, therefore, a focus for their objections. The source of airport noise pollution is much more easily pinpointed than, for example, the source or sources of city air pollution. Noise pollution is also more readily perceived than other pollutants; noise is immediately apparent in the environment (Hurtubise *et al.*, 1978).

As the aviation industry has grown, so have air traffic demands and airport facilities. Coupled with trends of urban sprawl and community development around airports, the expansion of the aviation sector has made for an ever-increasing airport noise problem. The frequency and magnitude of jet aircraft noise has grown steadily since the early 1960s, affecting increasing numbers of people who live near airports or below flight paths (U.S. National Industrial Pollution Control Council, 1972; Stevenson, 1972; Bauman, 1971).

The tremendous development of the Canadian air transportation industry has greatly increased the number of aircraft movements at federal airports. Aviation statistics compiled by Statistics Canada show a 95.6% increase in aircraft take-offs and landings over the 10-year period from 1967 to 1977. In terms of actual numbers of aircraft movements – take-offs and landings – air traffic controllers at 60 major Transport Canada airports handled a total of 6 487 127 aircraft movements during 1976, as compared to 4 895 376 movements at the 53 federal airports in 1971, and 3 316 740 movements at the 33 major airports in 1967 (Alberta, Environment Council of Alberta, 1979).



"I said . . . we were one of the lucky ones . . . not expropriated for airport expansion."

Norris The Vancouver Sun

Because of the large-scale growth of the Canadian aviation sector, the airport noise problem now constitutes one of the foremost environmental constraints on future airport development across the country. Opportunities for building new airports, and the expansion of existing sites, are time and again limited or stymied by public clamour against airport noise. The widespread community concern about airport noise is twofold. First, there is concern about the adverse effects of noise pollution on people and wildlife; exposure to noise can adversely affect an individual's psychological and physiological health, and disrupt wildlife and other patterns of animal behaviour (Alberta, Environment Council of Alberta, 1979; Harvey *et al.*, 1979; Communauté de travail pour les enquêtes socio-psychologiques sur le bruit des avions, 1974; Stevenson, 1972; U.S. Department of Housing and Urban Development, 1972). The second community concern about airport noise stems from competition for land around airports; certain land uses are not compatible with airport activity. Airport noise may have adverse impacts on some non-aviation land uses, restricting their development or imposing financial costs by reducing the value of land for such use. This is especially so for residential development in the vicinity of airports, which may be indirectly restricted by noise through zoning by-laws imposed in response to it, or may suffer from depreciation as a direct result of noise pollution.

The generation, propagation, and measurement of airport noise

Most simply defined, noise is unwanted sound. According to Alberta's Environment Council (1980*b*), "noise has every characteristic of an environmental pollutant. It affects us in biological, psychological, social, and economic ways." Noise surveys carried out in several Canadian cities indicate that the transportation sector is the main cause of noise pollution annoyance in the country, creating by far the most activity interference for a significant number of Canadians (Environment Canada, 1976*b*).

Aircraft engines are the principal source of airport noise today. The noise generated by aircraft engines generally depends on their power output – the more power, the greater the noise generated. The more powerful, hence noisiest, airplanes are jets: turbojet and turbofan aircraft. The other, quieter classification of aircraft is that of piston and turboprop engine planes (Hauer, 1972). Noise made by piston and turboprop planes mostly results from propeller movement, and to a lesser degree, from engine exhaust. In the days before commercial jet service the noise from propeller planes did not provoke serious objections from local communities. With the introduction of jet aircraft by de Havilland Aircraft in Great Britain and Boeing in the United States, the age of the aircraft noise problem was born (Bauman, 1971).

The year 1958 is historically significant in that it marks the first commercial transatlantic jet flight, the introduction of jet service in Canada, and the first official governmental investigation into the airport noise problem at a Canadian airport, namely Toronto's Malton Airport. Negative community reaction to airport noise thereafter took the form of complaints and law suits in unprecedented numbers (Mary, 1975; McNairn, 1972).

Turbojet engine noise is caused by the turbulent shearing of air by high-velocity exhaust gases. The sound generated by this violent mixing increases with increasing exhaust velocity to a point where shock waves, associated with supersonic aircraft, may occur. Shock waves result when the exhaust velocity exceeds the ambient speed of sound (Alberta, Environment Conservation Authority, 1976; Bauman, 1971).

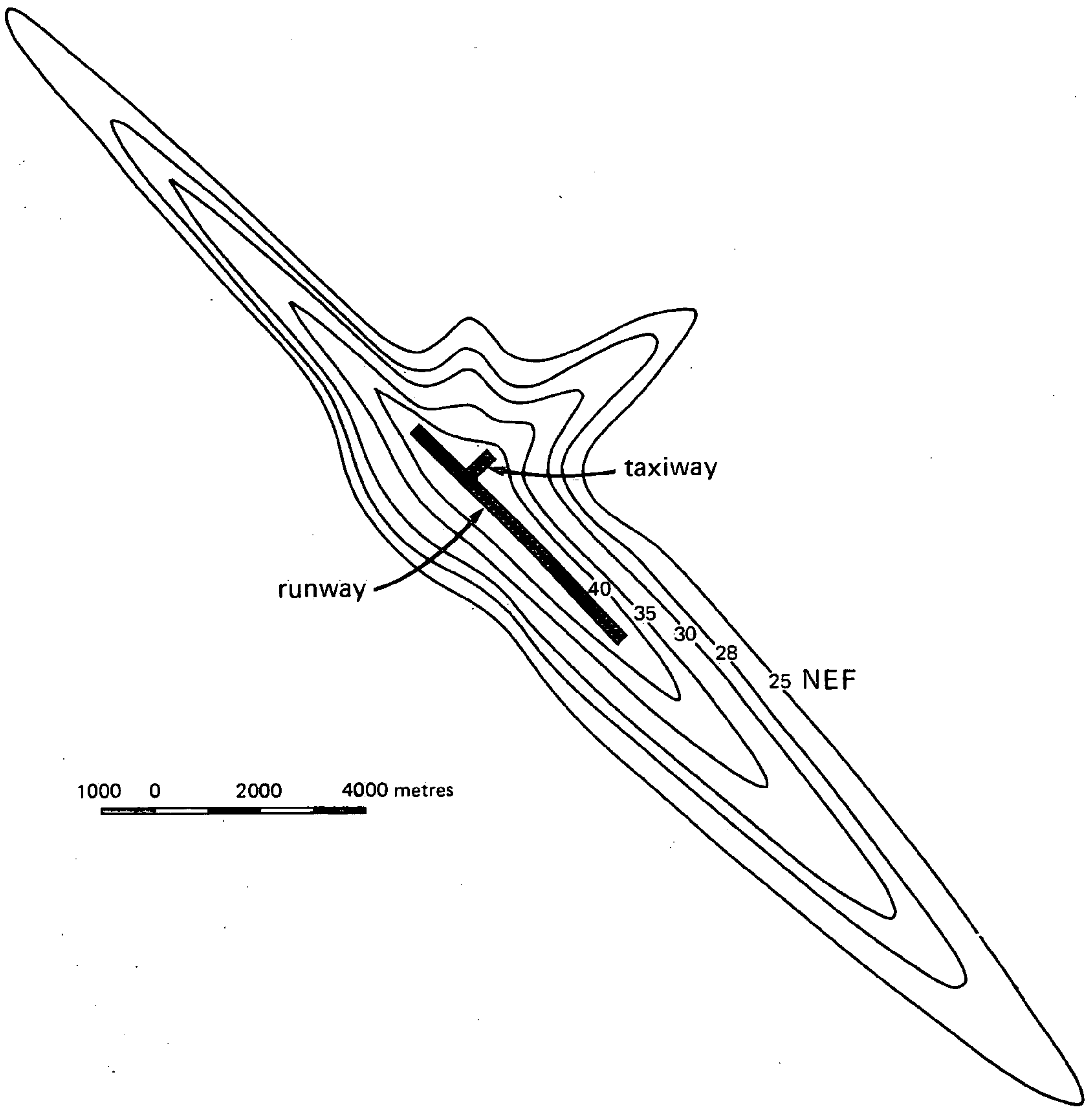
Conventional turbojet aircraft are now being replaced by quieter turbofan commercial jets. Turbofan engines have reduced noise levels owing to their lower exhaust velocities and to a more protracted or diffused mixing between the exhaust jet and surrounding atmosphere (Alberta, Environment Council of Alberta, 1979; Mary, 1975; Hauer, 1972; McNairn, 1972). Unfortunately, the increasing numbers of aircraft movements experienced at major airports tend to offset the technological advances made by quieter aircraft (R.L. Walker and Partners, 1975). Airport vicinities are subject to growing intensities of noise exposure despite the turbofan engine.

The propagation or diffusion of aircraft noise from its source to affected communities is influenced by several factors such as atmospheric conditions of temperature, wind, pressure, and humidity; by the distance sound travels; and by the presence of natural barriers to sound, like woodlands or hilly terrain (Alberta, Environment Council of Alberta, 1979; Hauer, 1972).

Against this brief background to the nature of aircraft noise generation and propagation, the measurement of airport noise and its relation to land use can be better understood. The current means of measuring airport noise in Canada makes use of the noise exposure forecast system (NEF), a technique that reflects aspects of human sensitivity to noise. Because the human activities associated with different land uses are intolerant to certain levels of noise, the NEF system can also be used to determine the compatibility of land uses with airport operations. Measures of NEF provide an index or scale of nuisance based on considerations of perceived decibel levels, time and duration of overhead flights, frequency of sound tones, and number of noise emissions (Hurtubise *et al.*, 1978; Ontario, Ministry of Housing, 1978). The higher the NEF value, the greater is the nuisance for human activity.

FIGURE 1.

Sample NEF contour map for a single runway airport



Calculations of NEF values can be made for any or all point locations in the vicinity of existing airports and can also be predicted for new sites. Such information is best presented in the form of contour maps as illustrated in Figure 1. The preparation of NEF contours, or 'noise footprints', for federal airports is now a standard practice of the Canadian Air Transportation Administration and of Canada Mortgage and Housing Corporation, whose concern is for residential land use near airports (Central Mortgage and Housing Corporation, 1978; Transport Canada, 1978*b*).

The determination of human tolerance for any given numerical quantity of NEF is based on studies of psychological and physiological reaction to noise. The system can be adapted for land-use compatibility guidelines once the adverse effects of given NEF levels of noise on people have been identified. For example, any value in excess of 35 NEF is apt to have negative consequences on the health of individuals exposed to it on a daily basis. It follows that certain land uses, such as residential, park, and institutional developments, would not be compatible in areas exposed to 35 NEF and above. Values of NEF have been listed or charted from both a standpoint of community response (Table 2) and land-use compatibility (Table 3).

Aircraft noise and stress on land

Because most land uses imply some degree of human activity, and human activity is sensitive to noise exposure, it follows that most land uses are likely to be sensitive to noise. It is the very incompatibility of airport noise with certain human activities and their associated land uses that causes conflict and stress on the land resource.

TABLE 2.

Generalized community response predictions for noise exposure

Noise Impact Area	Community Response Prediction
Over 40 NEF	Repeated and vigorous individual complaints are likely. Concerted group and legal action might be expected.
35-40 NEF	Individual complaints may be vigorous. Possible group action and appeals to authorities.
30-35 NEF	Sporadic to repeated individual complaints. Group action is possible.
Below 30 NEF	Sporadic complaints may occur. Noise may interfere occasionally with certain activities of the residents.

Source: Transport Canada, 1978*b*.

According to Harvey *et al.* (1979), Reid (1977), and Crowley (1972), the noise conflict that exists between airports and competing users of land is one of external diseconomy. Airport noise constitutes an external cost to individuals and various competing land uses located in the airport vicinity. The nature of an external diseconomy is to impose costs and adverse effects on different members of society without commensurate benefit, so an inefficient allocation of land resources between competing uses can be expected. The result of the external diseconomy of noise may be that too much of the land resource is allocated to the air transport sector and related uses while too little is allocated to quiet land uses (Reid, 1977). Airport noise can thus be considered as an environmental blight that lowers the economic value of an area for certain uses. However, it should be recognized that for services and industries dependent on aviation the external diseconomy of noise is offset by the advantages an airport location make possible. For example, airport food catering services and hotel industries tolerate airport noise because of the economic benefits they obtain from being close to an airport.

Numerous studies have been undertaken to ascertain the effect of airport noise on adjacent

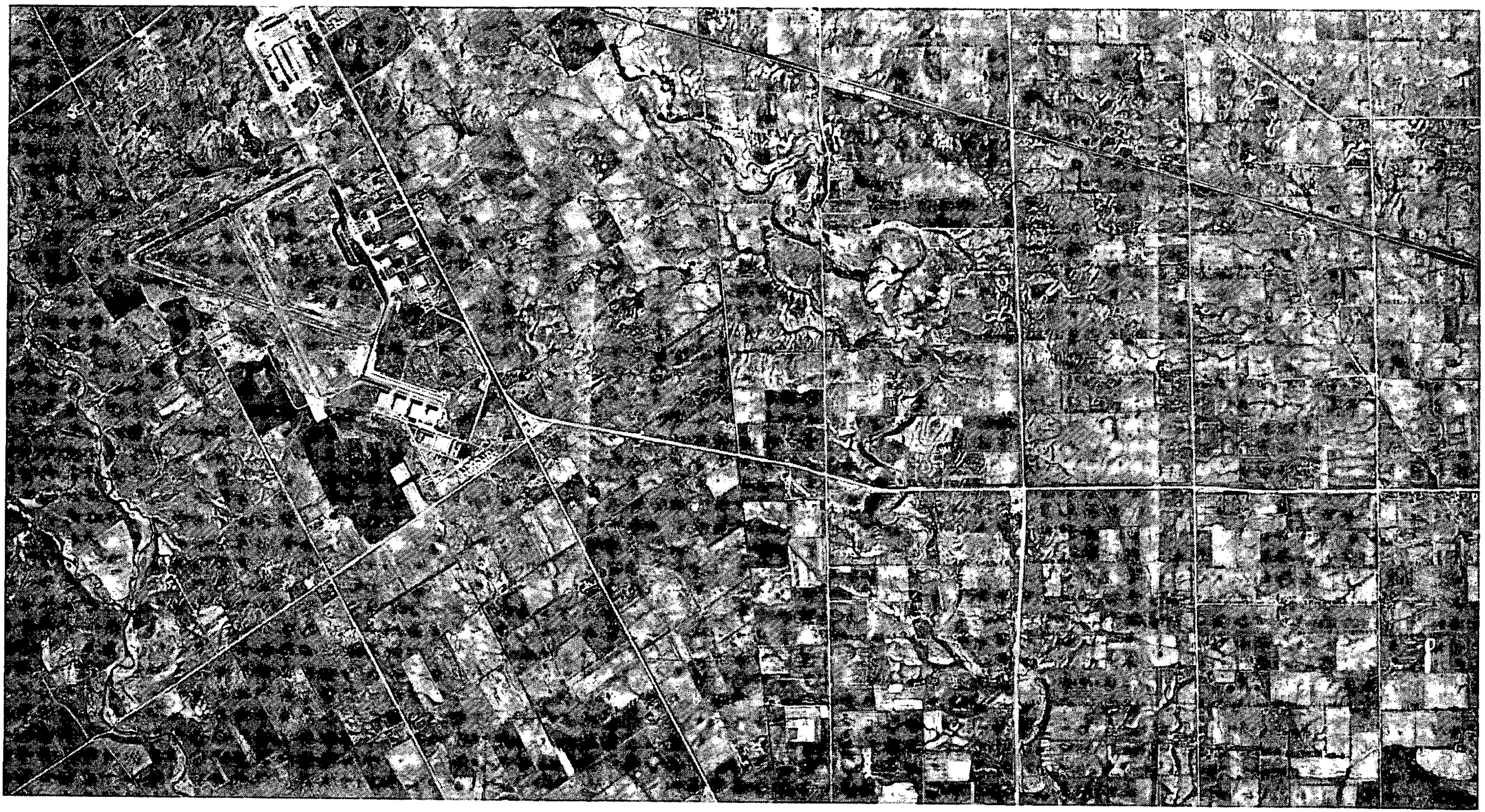
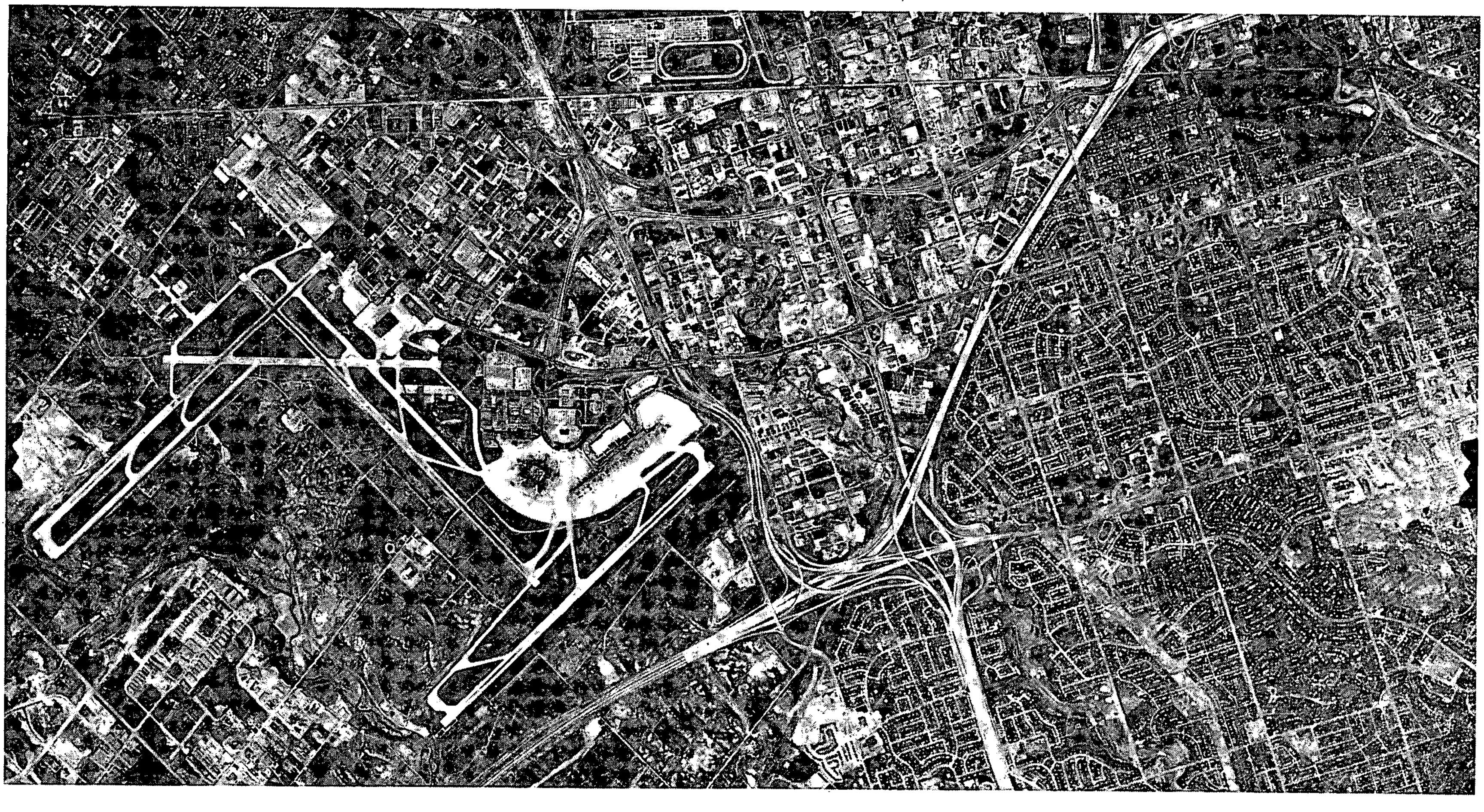


Photo 5. In 1936 it was decided to establish Trans Canada Airlines and to build an airport for Toronto. The Malton site, 567 ha in the centre of a farm area, was selected. Completed in 1938, the airport included one hangar and one of the farm buildings was used as a passenger terminal as well as for communications and weather service. These 1946 air photos show the agricultural nature of the area in which Malton was located. ▲

A9667-37, A9667-40, A9667-43. These aerial photographs © 1946 Her Majesty the Queen in Right of Canada, reproduced from the collection of the National Air Photo Library with permission of Energy, Mines and Resources Canada.

Photo 6. After World War II, increased traffic necessitated a new terminal building and a hangar. During the 1960s and 1970s, the airport continued to grow to meet demands. Meanwhile, Metropolitan Toronto was expanding westward toward the airport. By 1980, urban land uses have surrounded the location and the modern Toronto International Airport dwarfs the original Malton facilities. ▼

A25381-217. This aerial photograph © 1980 Her Majesty the Queen in Right of Canada, reproduced from the collection of the National Air Photo Library with permission of Energy, Mines and Resources Canada.



land values. Most of them have focused on residential property values, with contradictory results. The hypothesis that there exists a definite correlation between aircraft noise and land devaluation has been as much substantiated as disproved in the available literature.

Of the early studies, the research of Walther (1960) into the impact of airport noise on surrounding real estate values is best known. Walther's study, carried out in New York and Chicago, found a negligible difference in land values attributable to airport impact. Subsequent research has largely tended to support Walther's early findings (Mary, 1975). Among such works is Crowley's 1972 study of the Toronto International Airport. Although Crowley arrives at the conclusion that there is no long-term airport noise effect on the value of real estate, he does observe a short-term depreciation of residential land prices during "shock periods" when noisier aircraft are introduced. Crowley further observes that residents sensitive to noise are apt to sell their properties during shock periods of change, allowing people who are indifferent to noise and competing land users to move in. Land values thus recover, although at the expense of noise-sensitive land users. It is important to note that this process has a definite long-term impact on patterns of land use – on what Crowley terms the "econoscape".

Gautrin (1975), one of the few analysts to confirm a small property value depreciation associated with airport noise, also observes the tendency of noise-sensitive people to move away from airport locales. For these residents the true cost of aircraft noise includes not only the loss in property value but also the costs of moving, buying a new home, and the more intangible costs of social stress (Hurtubise *et al.*, 1978; Gautrin, 1975).

One of the more recent studies to find a devaluation of property located close to an airport estimates that Edmonton property values were depreciated by $13 million in 1976 due to aircraft noise levels from Edmonton Municipal Airport exceeding 20 NEF (McMillan *et al.*, 1979). The assessment of this property devaluation costs is based on a 'noise discount factor' in which a percentage loss in property value is assigned to each unit increase of NEF (Alberta, Environment Council of Alberta, 1980*a*). In the study of the Edmonton Municipal Airport it was found that noise discount factors become gradually larger with increasing levels of NEF noise. The devaluation of real estate was found to increase exponentially with NEF noise levels from a discount factor of 0.1% at 20 NEF to 1.8% at 35 NEF. Hence, a house exposed to 35 NEF was assessed as being as much as 8.3% less in value than a residence exposed to 20 NEF.

TABLE 3.
NEF land-use compatibility table

	Noise Exposure Forecast Values			
Land Use	>40	40-35	35-30	<30
Residential				
Detached and semi-detached	–	–	( )	( )
Town houses, garden homes	–	–	( )	( )
Apartment buildings	–	–	( )	( )
Public				
Schools	–	–	( )	( )
Churches	–	–	( )	( )
Hospitals	–	–	( )	( )
Nursing homes	–	–	( )	( )
Auditoriums	–	–	( )	( )
Libraries	–	–	( )	( )
Community centres	–	–	( )	( )
Cemeteries	( )	( )	( )	( )
Municipal Utilities				
Electric generating plants	+	+	+	+
Gas and oil storage	+	+	+	+
Garbage disposal	+	+	+	+
Sewage treatment	+	+	+	+
Water treatment and storage	+	+	+	+
Outdoor Recreational				
Athletic fields	–	( )	( )	+
Stadiums	–	–	( )	+
Outdoor theatres	–	–	–	( )
Horse racetracks	–	( )	( )	+
Auto racetracks	+	+	+	+
Fairgrounds	( )	( )	+	+
Golf courses	+	+	+	+
Beaches and pools	+	+	+	+
Tennis courts	–	( )	+	+
Playgrounds	( )	( )	+	+
Marinas	+	+	+	+
Camping grounds	–	–	–	( )
Parks and picnic areas	–	( )	+	+
Commercial				
Offices	( )	( )	( )	+
Retail sales	( )	( )	+	+
Restaurants	( )	( )	( )	+
Indoor theatres	–	( )	( )	+
Hotels and motels	–	( )	( )	+
Parking lots and gas stations	+	+	+	+
Warehouses	+	+	+	+
Outdoor sales	( )	( )	+	+
Industrial				
Factories and machine shops	( )	( )	+	+
Rail yards and shipyards	+	+	+	+
Cement plants	( )	( )	+	+
Quarries	+	+	+	+
Refineries	( )	( )	+	+
Laboratories	–	( )	+	+
Lumber yards	+	+	+	+
Saw mills	( )	( )	+	+

Using a similar noise discount factor another study undertook to estimate the total annual house devaluation costs to Albertans due to airport noise. By comparing NEF contours with 1976 census information about population and household number, it was estimated that 38 000 Alberta dwellings were exposed to noise exceeding 25 NEF. For these 38 000 households the annual depreciation due to aircraft noise is crudely assessed as between $8 million and $12 million according to conditions of 1976 (Alberta, Environment Council of Alberta, 1980*a*).

These noise discount factor assessments contradict earlier conclusions drawn by Mary (1975) for the same Alberta airport studied by McMillan *et al.*, (1979). Not only did Mary

TABLE 3.
NEF land-use compatibility table (Continued)

Land Use	Noise Exposure Forecast Values >40	40-35	35-30	<30
Transportation				
Highways	+	+	+	+
Railroads	+	+	+	+
Shipping terminals	+	+	+	+
Passenger terminals	( )	+	+	+
Agricultural				
Crop farms	+	+	+	+
Market gardens	+	+	+	+
Plant nurseries	+	+	+	+
Tree farms	+	+	+	+
Livestock pastures	( )	+	+	+
Poultry farms	( )	( )	+	+
Stockyards	( )	+	+	+
Dairy farms	( )	+	+	+
Feed lots	( )	+	+	+
Fur farms	( )	( )	( )	( )

Key:

+ Positive symbol indicates land uses not considered to be adversely affected by aircraft noise.
– Negative symbol indicates land uses considered to be incompatible with aircraft noise.
( ) Parentheses indicate land uses which may be considered compatible in certain situations and under certain conditions.

Source: Adapted from Transport Canada, 1978*b*.

find homeowners to have no reason to fear property depreciation in the vicinity of Edmonton's Municipal Airport, he was able to report that properties in the noise-affected area appreciated in value faster than homes located in quiet neighbourhoods. Mary was thus led to conclude that residential property value can actually be enhanced by proximity to an airport despite the effect of noise. Mary's findings support the position that the cost of noise cannot be translated into a lowered property value because the buoyancy of land markets and housing demand and the number of noise-insensitive residents willing to live near airports tend to offset it (Harvey *et al.*, 1979; Gautrin, 1975; R.L. Walker and Partners, 1975; Canada, Airport Inquiry Commission, 1974; Communauté de travail pour les enquêtes socio-psychologiques sur le bruit des avions, 1974).

Evidently, a cloak of confusion and uncertainty surrounds the question of an airport's noise impact on neighbouring property values. The difficulty of proving a direct correlation between noise and property devaluation has also been experienced in the courts, by private citizens filing law suits against airport operators. Attempts by property owners to win noise damage claims on grounds of trespassing, nuisance, or noise contamination have for the most part been unsuccessful. The majority of common law actions against Canadian airports have been rejected by the courts because of the very difficulty of proving that negligence or disturbance has occurred (Mary, 1975; Bauman, 1971). Furthermore, a quiet environment is not, in effect, a legal right of property owners under the common law system (Reid, 1977).

The more effective actions taken to abate airport noise pollution are those enforced outside the courts by statutory legislation (McNairn, 1972). Governmental regulation of airport noise, and its implications for land use, value, and capability, is discussed presently.

Land-use issues

Urbanization, infrastructure, and regional development

When it came time to build an airport for Toronto in 1937, the rural Malton site was selected over a number of alternatives because "it was believed that this area would remain beyond any built-up section" (Canada, Airport Inquiry Commission, 1974). Since its completion in November 1938, Toronto's Malton Airport has seen the steady growth of an urban landscape all around its boundaries. According to Stewart (1979), "the province had not discouraged – indeed, had promoted – development around the airport...", notwithstanding the will of early airport planners. Today, the Malton site of the Toronto International Airport straddles the highly urbanized municipal boundary between the cities of Toronto and Mississauga; the area has become "built-up".

There are three facets to the encroachment of urban development in airport vicinities. First there is the large-scale rural-to-urban migration of Canadians which has occurred at an astounding pace since the 1940s. This trend, along with natural population growth and the flocking of new immigrants to cities, have occasioned an urban boom across the country and the consequent expansion of cities outwards to the airports that were once located beyond city limits (Isbester *et al.*, 1970).

Second, there are inadequate zoning controls. On the one hand, municipalities on the urban fringe have not always responded to the need for compatible land-use zoning near airports because of the pressures on them to increase their tax base and to make land available for urban population growth (McNairn, 1972). On the other hand, where municipalities have implemented zoning controls around older airports, at the suggestion of concerned airport managers, these controls have become insufficient to deal with expanded airport activity (R.L. Walker and Partners, 1975).

Third, and perhaps the most pervasive influence on patterns of land development in the vicinity of airports, is the airport itself. An airport is at once a catalyst for community growth and urbanization and a magnetic force drawing development towards it (Task Force on Airport Management, 1979). The process is one of recent historical significance whereby local activities – commercial, industrial, and services – were initially spurred by the air transportation industry's demand for a support system (Pendakur, 1972). The availability of relatively cheap suburban land near airports has tended to attract air transport-dependent and aviation-related industries to locations in close proximity. Other industry followed, attracted to the airport environs because of the availability of airport-induced infrastructure, i.e. access roads, public utilities, and service facilities primarily established to serve the airport. These enterprises have boosted local employment opportunities and secondary development arising from the multiplier effect of salary expenditures in the area. Employment opportunities also prompt increased demand for housing near airports, encouraging land speculation and subdivision for residential development. In turn, residential development requires the additional provision of public services such as shopping centres and other commercial establishments, recreational facilities, schools, and hospitals (Isbester *et al.*, 1970). After a while local utilities, such as municipal sewage treatment plants or municipal roads, may become overloaded.

Local infrastructure must then be expanded to meet regional requirements (Transport Canada, 1977*d*; R.L. Walker and Partners, 1975; Pendakur, 1972; Vance, 1972).

Attesting to the attractive force of airports is Bennett's (1980) recent study on The Impact of Toronto International Airport on the Location of Offices. In this paper Bennett demonstrates that businesses are induced to locate near major airports because of convenient access to air transportation, and because the nature of certain businesses dictates their proximal location. Bennett's specific findings for the Toronto International Airport indicate that transportation-based office activities, technical service businesses, and foreign-dominated manufacturers' offices are especially prone to locate close to the airport because of their reliance on air transport. Another interesting finding is that newer offices, those established since 1974, are more likely to locate near Malton Airport (Toronto International). This observation could well indicate that the attraction of airports is stronger than ever for certain enterprises.

Because of their impact on local economies and patterns of land use, airports play a significant role in regional development. Whether or not the economic and land-use impacts are perceived as beneficial to the local community will depend on the extent to which they can be reconciled with regional goals of development (R.L. Walker and Partners, 1975). It is the responsibility of regional authorities to respond to airport-induced constraints against incompatible or uneconomic land uses with opportunities for their replacement by compatible uses. The extent to which regional goals are achieved within this framework will ultimately determine how the airport's impact is perceived by a region. In other words, a community's evaluation of airport-induced amenities and disamenities is influenced by trade-offs between lost opportunities for certain land uses and new opportunities for economic gain.

Although it is impossible to measure exactly how much an airport contributes to a region's economic development or industrial growth, airport planners have attempted to give some description of economic gains in terms of the employment opportunities induced by airport activity (Transport Canada, 1977*d*; Ecologistics Limited, 1975*a*). Local employment brought about as a direct result of airport construction and operations can be readily identified and quantified. Direct employment opportunities generated at airport sites are listed in Table 4. The multiplier effect of airports on economic growth may account for an even greater magnitude of indirect employment opportunities. According to Ecologistics Limited (1975*a*) the number of indirect employment opportunities is thought to range from 1.0 to 2.0 times the number of direct jobs created by airports. In an

TABLE 4.
Activities associated with employment opportunities generated directly by airports

During Airport Construction	During Airport Operations
Site preparation	On-going construction
Road and access system construction	Site maintenance
Service (utility) installation	Aircraft maintenance
Landscaping	Aircraft operations
Physical building construction	Aircraft maintenance and overhaul
	Airline operations
	General aviation activities
	Managerial personnel
	Fuel storage and handling
	Passenger and cargo activities
	Food and other concessions
	Ground transportation

Source: Transport Canada, 1977*d*.

TABLE 5.
Activities associated with employment opportunities generated indirectly by airports

During Airport Construction	During Airport Operations
Construction materials supply	Hotels and motels
Equipment rental	Convention and exposition centres
Consulting services	Food and catering
Product and service supply for airport employees	Rental car agencies
	Manufacture of equipment and material supplies
	Sales of goods and services for airport use e.g. office supplies
	Product and service supply for airport employees
	Ground transportation
	Travel agencies
	Air freight terminals
	Trucking terminals
	Taxi and bus terminals
	Air cargo businesses
	Wholesale distribution centres
	Aircraft and parts manufacturing
	Aircraft repair shops
	Aviation schools
	Airline schools
	Aerial survey companies
	Aviation research and testing laboratories
	Gas stations
	Night clubs
	Banks
	Shopping centres
	Recreation activities
	Textile manufacture
	Clothing manufacture
	Printing and editing offices
	Metallic product supply
	Automobile accessories and services
	Electric material supply
	Chemical product firms

Source: Adapted from Transport Canada, 1977*d*.

employment study of Montreal's Dorval Airport it was found that indirect employment opportunities were approximately twice those of direct employment (Transport Canada, 1977*d*). Another study, reported on by the Task Force on Airport Management (1979), found there to be an indirect job multiplier of 1.5 for every job at the Toronto International Airport site.

An examination of the airport-induced activities that generate indirect employment suggests the type of land-use changes that could be expected to occur locally. The activities listed in Table 5 reveal the sort of developments that have occupied large tracts of land in the vicinity of major airports. At the Toronto International Airport at Malton, the multiplier effect has given rise to what has been called "the phenomenon of the airport strip" (Ecologistics Limited, 1975*a*), comprised of hotels, night clubs, catering businesses, gas stations, trucking terminals, etc. Off the airport strip, in nearby Mississauga, other major land developments reflect the same airport multiplier effect.

Research undertaken a decade ago by Pendakur (1972) for eight major Canadian airports (Halifax, Montreal, Ottawa, Toronto, Winnipeg, Edmonton, Calgary, and Vancouver) found their general influence on adjacent community economies to be beneficial. However, if at one time the benefits of having an airport outweighed the ill-effects and disadvantages, it is now apparent that in some instances the reverse situation has evolved (Young, 1976). Left unchecked, large-scale land development adjacent to airport boundaries has given rise to land-use conflict of great magnitude. Where land-use controls have not from the outset recognized an ultimate level of development, airports are finding themselves hedged in and unable to expand. Land developments once perceived as desirable and compatible by regional authorities and airport managers alike emerge as incompatible in the long-run. Regional economic development gives rise to dynamics of land use where certain uses, such as agriculture or residential land use, will either be eliminated or made to bear disamenity costs due to their inability to compete in the airport region land market, or due to their incompatibility with airport operations. This is the nature of trade-offs between competing land uses in the vicinity of major airports.

Land-use restrictions

Regulatory control of land use and development of land resources in the vicinity of airports is necessary for two reasons. The first is that of ensuring navigational safety from bird hazards, impediments to visibility (smoke, dust, and steam), height obstructions, and electronic interference with navigational aids. The second reason is that of reducing conflicts arising from the health and nuisance aspects of airport noise.

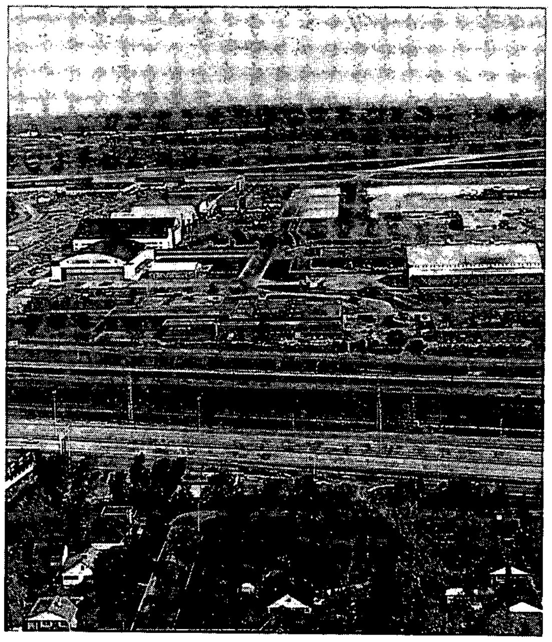


Photo 7. Around some older airports, such as Dorval, residential communities are now next-door-neighbours of airport facilities.
G. Thomas, Transport Canada

Although the Canadian Air Transportation Administration (CATA) seeks to minimize noise conflicts between airports and their neighbours it has no authority to control incompatible land uses. Responsibility for land-use control lies with provincial, municipal, and other regional governments through their authority to implement area master plans, subdivision controls, zoning, and legislation for compatible uses.

Because urban encroachment on airports has frequently been left unrestrained in the past, there are certain limitations to the effectiveness of land-use control devices available today. Land-use controls cannot alleviate the noise problem associated with encroachment after it has been allowed to take place. However, throughout the 1970s there was a notable increase in land-use planning which has effectively prevented further extension of existing incompatible uses and the continued conversion of rural land resources around some airports. It is now standard practice across Canada for provinces to require that area master plans consider land-use incompatibilities on the basis of NEF levels identified by Transport Canada. For instance, in Ontario all land-use proposals near airports must adhere to NEF-compatible land-use guidelines as recommended by CATA in the document Land Use in the Vicinity of Airports (Ontario, Ministry of Housing, 1978). Figure 2 illustrates the type of NEF Land Use Compatibility Table used in Ontario.

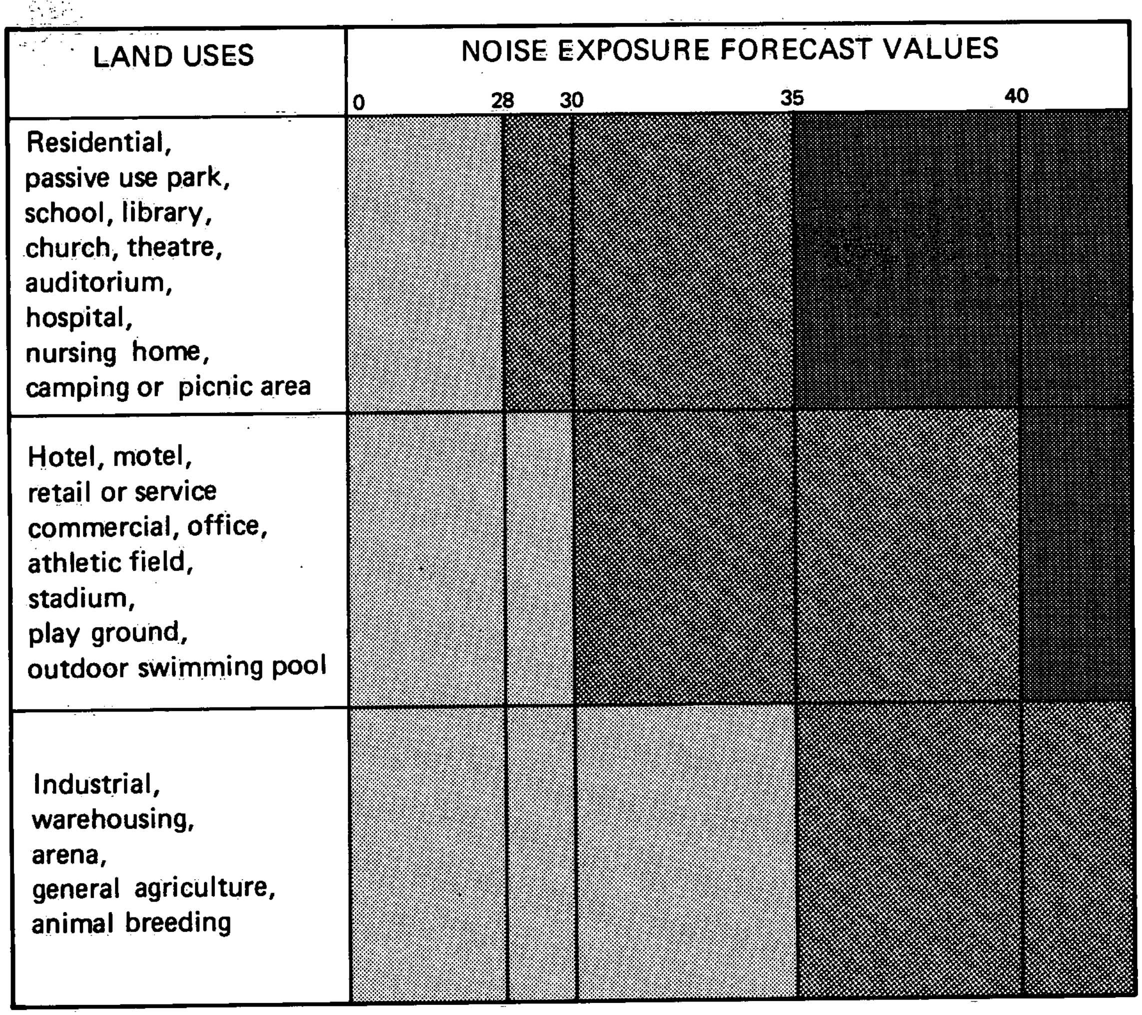
Another safeguard against incompatible land use is provided by Canada Mortgage and Housing Corporation's (CMHC) policy of denying financing for new housing in areas where the NEF level exceeds 35 (Central Mortgage and Housing Corporation, 1978). This residential land-use policy is applied everywhere in Canada.

The most comprehensive provincial legislation governing airport community land use in Canada is that of the "Airport Vicinity Protection Area" regulation enacted by the Province of Alberta in 1975. Based on criteria of NEF levels and operational safety hazards, Alberta has determined boundaries around the Calgary and Edmonton International airports, as well as other municipal airports, which ensure that all new land developments conform to compatible land-use guidelines that zone land uses as permitted, conditionally permitted, or prohibited (Alberta Planning Act Regulation 291/75, 1975). In compliance with CMHC standards, the Alberta Airport Vicinity Protection Area regulations additionally stipulate that all residences constructed within the 25-30 NEF range must be equipped with acoustic insulation and ventilation (Alberta, Environment Council of Alberta, 1980*a*).

Land-use restrictions pose a dilemma in planning for the best use of land resources from the standpoint of regional authorities. This contrasts with the approach of airport managers who wish to ensure the availability of undeveloped adjacent land for future airport expansion requirements. In determining some ultimate level of development near airports, local governments must decide if the most beneficial use of land means the more profitable use in the short-term or long-term preservation of natural, recreational, agricultural, and other open spaces for the livelihood of future generations (Alberta, Environment Conservation Authority, 1975*b*; Martin, 1972; McNairn, 1972).

Although this planning dilemma confronts all jurisdictions having authority over the use of lands in the urban fringe, whether or not an airport is present, it has particular significance in relation to airports where the rate of development and consequential land-use conversion may be rapid. The problem of land-use planning in the vicinity of airports is accentuated by the fact that the very presence of an airport induces a change in the character of land-use demands. By serving as a catalyst for other land developments major airports enhance the value of surrounding land for non-rural uses, thereby reducing agricultural and other open space possibilities. Land speculation occurring in response to observed or anticipated development demands tends to inflate the value of land beyond the reach of agricultural users. Agriculture can thus be rendered uneconomic. Where land markets have already evolved to this point it is extremely difficult for regional authorities to overcome local opposition to proposed subdivision restrictions and zoning for agricultural and open space use (Stewart, 1979; Young, 1974; McNairn, 1972).

FIGURE 2.
NEF land use compatibility table - Ontario



LAND USES	NOISE EXPOSURE FORECAST VALUES				
	0	28	30	35	40
Residential, passive use park, school, library, church, theatre, auditorium, hospital, nursing home, camping or picnic area	░	▒	▒	▓	▓
Hotel, motel, retail or service commercial, office, athletic field, stadium, play ground, outdoor swimming pool	░	░	▒	▒	▓
Industrial, warehousing, arena, general agriculture, animal breeding	░	░	░	▒	▒

░ Clearly acceptable land use

▒ Discretionary range where noise may impose certain restrictions or limitations on land use

▓ Normally unacceptable land use

Source: Ontario Ministry of Housing, 1978.

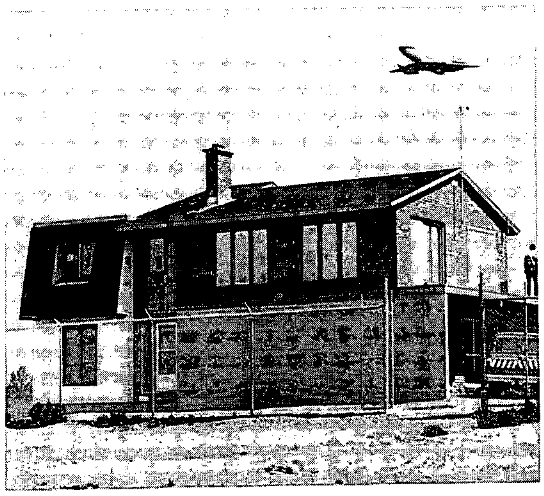


Photo 8. A Department of Transport jet flies low over a unique research house built to determine the best insulating properties for homes constructed near airports. The house was a co-operative project involving the National Research Council, the Central Mortgage and Housing Corporation, and the Department of Transport.
CANAPRESS

AIRPORT PLANNING AND ENVIRONMENTAL PROTECTION

Environmental policy, guidelines, and mitigating measures

CATA and airport environmental protection policy

The Canadian Air Transportation Administration (CATA) states as its basic objective the provision "on a cost-recovery basis and to the maximum practicable extent, safe and efficient facilities and services for the support of aeronautics *consistent with environmental protection* [author's italics] (Transport Canada, 1980*a*). Accordingly, CATA has developed stringent "guidelines" and "standards" of environmental protection for all aspects and procedures of airport activity.

A "standard" of environmental protection is defined as a mandatory instruction, an example being: "Temporary erosion and pollution control measures shall be used to prevent and, if necessary, to correct conditions that occur during construction and as interim protection until completion of permanent measures" (Transport Canada, 1976*a*). Standards of environmental protection also may constitute what is required by law (Transport Canada, 1980*a*).

While standards are general, "guidelines" provide specific instructions on how to achieve environmental protection by outlining development constraints and procedures for controlling potential impacts. An example of a guideline for erosion control is the statement: "Channelling of surface runoff should be accomplished with a minimum of land disturbance. Stream channels should be vegetated or lined to prevent erosion" (Transport Canada, 1980*a*). In addition, guidelines conform to the legislative requirements of federal and provincial departments; for example, guidelines that apply to airport air pollution specify federal air pollution legislation as well as the applicable emission limitations legislated by each of the ten provinces, the Yukon, and Northwest Territories. Where federal and provincial pollution standards differ it is CATA's policy to comply with the stricter legislation (Transport Canada, 1977*a*).

The documentation of CATA's environmental guidelines for airport planning (Transport Canada, 1977*b*, 1977*d*), design (Transport Canada, 1977*c*, 1980*a*), construction (Transport Canada, 1976*a*, 1980*a*), and operations (Transport Canada, 1976*b*, 1977*a*) is comprehensive and necessarily voluminous. Furthermore, because environmental standards are subject to change, e.g. as more information about environmental impacts becomes available, CATA's guidelines are constantly being amended, revised, and added to. Documentation is increased by guidelines drawn up for individual airport projects.

In keeping with its observance of the Environmental Assessment and Review Process (to be discussed presently) CATA has developed a framework for the implementation of environmental protection policy. This framework charts how environmental protection can be achieved at the different stages of airport development.

During the siting, planning, and design stages of airport development the key to environmental protection is found in assessment studies of potential adverse impacts on the physical and social environment. Because these assessments include recommendations on how, from the outset, to mitigate potential adverse effects, the planning and design of airports can be expected to minimize the adverse impacts on the land resource. Similarly, the selection of a particular new airport site from other possible sites ideally represents the least environmentally damaging choice – a choice where negative environmental effects and constraints are least in relation to those found at alternative sites. Such an ideal is hard to attain in actuality in view of the difficulty of predicting and assigning significance to potential impacts.

During airport construction CATA implements environmental protection policy by ensuring that "facilities designed for the protection of the environment are constructed or provided ... " and that "... adequate environmental protection measures (dust, erosion, air and water pollution control) are observed" (Transport Canada, 1980*a*).

Throughout airport operations CATA continues to implement environmental protection policy by adhering to federally and provincially legislated environmental standards and by enforcing "environmentally acceptable operating procedures" (Transport Canada, 1980*a*). The effectiveness of airport procedures in protecting the environment from negative impacts is further assured at this stage by a continuous monitoring system (Transport Canada, 1977*a*). It is important to note, however, that the monitoring program is primarily geared to the testing of air, water, and noise pollution, and does not apply to all CATA airports. The determination of airports to be monitored is based on criteria of aircraft movement number, environmental sensitivity, and amount of contaminants introduced, e.g. chemical runway de-icers (Transport Canada, 1976*b*).

The environmental assessment review process

To allocate land resources among competing uses while at the same time safeguarding environmental quality requires that some kind of decision-making body intervene and reconcile conflicts of interest. Such a regulatory body exists in the Federal Environmental Assessment Review Office (FEARO). By definition, any land development project employing federal funding or federal lands, and all projects initiated by the federal government, are obliged to co-operate with FEARO procedures. Airport projects are therefore bound to the Environmental Assessment and Review Process (EARP) as a consequence of their initiation by CATA or of their use of federal financial assistance.

Several environmental studies and impact statements comprise EARP. The first step of the process consists of a preliminary screening of an airport project by the project initiator. In the case of federal airports the proponent responsible for the preliminary screening will be a CATA regional administration, of which there are six across the country. If, as a result of the screening, there are no foreseeable negative impacts associated with the project, or if anticipated adverse impacts are deemed insignificant, then the project development may proceed without further reference to EARP (Hurtubise *et al.*, 1978). This kind of outcome could be expected with a small airport development such as a terminal building addition. Notwithstanding such an outcome, the project initiator will still be required to prevent or mitigate any adverse environmental impacts identified in the screening statement, and to meet all applicable environmental regulations.

The second step of the EARP consisting of the preparation of an Initial Environmental Evaluation (IEE), is essentially required of all airport projects of environmental significance. For instance, a project for any scale of runway construction must have an IEE (Transport Canada, 1977*d*). The IEE statement gives a general assessment of potential adverse effects of the proposed development and further evaluates whether or not a formal Environmental Impact Statement (EIS), the third stage of EARP proceedings, should be undertaken. It is at this stage of EARP that a detailed study of potential environmental impacts will determine a project's final approval or demise.

For the purposes of the EIS, CATA identifies two environmental categories and their component parts (Transport Canada, 1977*d*):

Physical Environment

Plants and animals

Aquatic life

Ambient air

Ground and surface water

Ambient noise

Special features

Social Environment

Employment and income levels

Community services

Land use

Recreational assets

Human interests

Individual well-being

Once having compared the relative significance of these environmental components for several alternative options of proposed development (or, in the case of airport site selection, the comparison of alternate sites), CATA indicates which development option is preferred. At this point in the EIS comes the large task of identifying in detail potential interactions between the above environmental components and specific disruptive construction and operation activities. The best way to envisage potential interactions is to table them in a matrix, with the environmental components along one axis and the project actions along the other. Tables 6 and 7 illustrate two matrices at differing levels of detail. CATA recommends this method for the determination of potential project impacts and for the identification of suitable measures to minimize environmental consequences (Transport Canada, 1977*d*). The identification of mitigating measures for potential impacts is a major function of the EIS.

Photo 9. Before environmental policies and guidelines were developed, adequate consideration was not given to the impact of airport activities on other land uses. In this 1960s photo, a bulldozer fills in a marsh.
Transport Canada

Another major feature of EARP is the consideration of public attitudes to the development project. Public participation in the environmental assessment of proposed airport projects is an integral part of both the EIS study and its review by FEARO. In keeping with its general policy of facilitating public consultation during all stages of airport planning and operations, CATA attaches much importance to anticipated and observed public concern in determining the significance of potential impacts identified in the EIS. According to CATA, its position is "to maintain its current practice of starting public consultation at the very beginning of CATA project planning regardless of whether the nature of the project does or does not call for an EARP panel" (Transport Canada, 1979).

Further public participation in airport project assessment occurs outside CATA's planning process, during EARP panel proceedings. After CATA's EIS documentation of potential project environmental impacts and mitigating measures has been made available to affected publics, the specially formed EARP panel considers their reaction to the project by way of public hearings and written submissions. CATA defines "affected publics" for consultation as: the air industry; the departments and agencies of federal, provincial, territorial, and municipal governments; the users and beneficiaries of CATA activities; neighbouring communities; the business community; special interest groups; organizations and individuals; foreign governments; international organizations and associations (Transport Canada, 1979).

TABLE 6.
Sample environmental impact matrix - minimum detail

Environmental Components	Airport Project Activities		
	Site Survey Tests	Construction	Operations
Physical Environment			
Plants and animals			
Aquatic life			
Ambient air			
Ground and surface water			
Ambient noise			
Special features			
Social Environment			
Employment and income levels			
Community services			
Land use			
Recreational assets			
Human interests and aesthetics			
Individual well-being			

Sources: Adapted from Société multidisciplinaire d'études et de recherches de Montréal Inc., 1975*d*, and Transport Canada, 1977*d*.

TABLE 7.
Sample environmental impact matrix - average detail

Environmental Components and Subcomponents	Project Action										
	Construction Activities	Tree cutting and stumping	Blasting and excavating	Stripping and dredging	Filling and grading	Hauling	Asphalting operations	Concreting operations	Erecting and finishing buildings	Sodding and landscaping	Waste disposal and clean-up
Land Use											
Residential											
Public											
Commercial											
Industrial											
Municipal utilities											
Outdoor recreational											
Transportation											
Agricultural											
Natural landscapes											
Recreational Assets											
Ski areas											
Beach areas											
Parks											
Golf courses											
Hunting and fishing areas											
Wilderness areas											
Vacation cottage areas											
Other recreational assets											

Sources: Adapted from Transport Canada, 1977*d*.

Following the EARP panel's review of the EIS and consideration of the public's response to it, a final report is prepared by FEARO indicating the panel's recommendation for or against approval of the project. The EARP panel may recommend that the project be allowed to proceed as planned, or that it proceed subject to conditional specifications, or that it be halted in deference to environmental concerns. Conditional specifications may include environmental requirements for the design, construction, and operation of airport facilities, the need for further studies or mitigating measures, or requirements for environmental monitoring of the project. The EARP panel's final report and list of recommendations is then submitted to the Minister of the Environment for a final decision on the project's status.

Airport land-use planning

Aside from the planning considerations of noise impact on land use in the vicinity of airports, CATA identifies four other types of land-use restrictions imposed for operational safety reasons (Transport Canada, 1977*d*). They are:

1) land-use restrictions relating to air navigational safety from bird hazards;
2) restrictions relating to clear visibility – navigational safety from smoke, dust, and steam;
3) building height restrictions safeguarding flight path approach and take-off safety;
4) restrictions governing electronic interference with radio, radar, and other navigational control systems.

Table 8 provides a partial list of land uses that can be restricted or required to change in response to operational safety concerns.

The planning of CATA airports takes into consideration two zones or areas of potential land-use impact: the on-site and the extra-site zones of airport influence. For the development of a new airport site the area within its proposed boundaries is of primary interest. Here the occupation of land and the conversion of ownership is complete. Absolute changes in land use can be expected for all incompatible activities but certain compatible land uses may not be converted, particularly certain types of agricultural use that are permitted on airport sites. Farmland that is purchased or expropriated for the airport proper, or land-banked for noise protection areas, can be leased back to appropriate users. Thus many local farmers at Mirabel sold their land for that airport project and then leased it back again (Stewart, 1979).

In analyzing the impact of an airport project on adjacent land uses CATA generally considers all lands within at least a 20-km radius of the airport centre (Transport Canada, 1977*d*). The

TABLE 8.
Potential land-use incompatibilities

Potential or Existing Land Uses	Operational Safety Concerns			
	Navigational Aids	Height Restrictions	Restrictions to Visibility	Bird Hazards
Residential				
Apartments	×	×		
Commercial				
Offices	×	×		
Hotels and motels	×	×		
Warehouses	×			
Shopping centres	×			
Retailers		×		
Drive-in restaurants				×
Industrial				
Factories	×	×	×	
Machine shops	×			
Shipyards	×		×	×
Refineries	×		×	
Laboratories	×			
Cement plants		×		
Active quarries			×	
Abandoned quarries				×
Saw mills			×	
Food processing plants				×
Institutional and Public				
Churches		×		
Hospitals		×		
Nursing homes		×		
Community centres		×		
Libraries		×		
Auditoriums	×			
Recreational				
Stadiums		×		
Outdoor theatres		×		
Racetracks				×
Parks and picnic areas				×
Fairgrounds				×
Municipal Utilities				
Electrical generating plants	×	×	×	
Garbage disposal and landfills				×
Sewage treatment				×
Water storage				×
Agricultural				
Market gardens and fruit farming				×
Feed lots				×
Fur farms				×
Stockyards and pig farms				×
Sod and seed farms				×
Natural				
Forests		×		
Fish reserves				×
Bird sanctuaries				×
Swampland				×
Flood-prone areas				×
Game preserves				×

Source: Adapted from Transport Canada, 1977*d*.

major categories of land-use studies for impact assessment during the planning process are: residential, public, commercial, industrial, municipal utilities, outdoor recreational, transportation, agricultural, and natural landscapes. In response to the impact that an airport project may have on these adjacent land uses CATA carries out four types of mitigating measures.

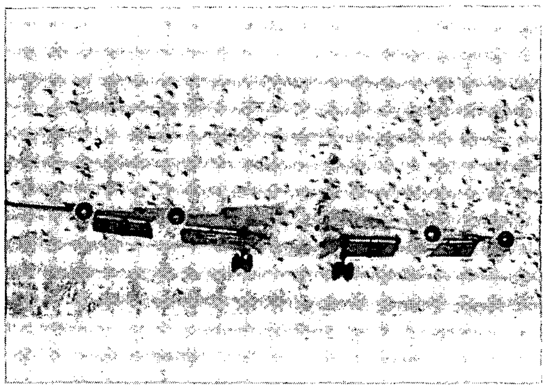


Photo 10. For obvious safety reasons, birds should be restricted near airports. Transport Canada guidelines state that certain land-uses, such as garbage disposal areas that may attract birds, should not be located within 8 km of the centre of an airport.
Transport Canada

The first is that of compensation to the land owner or municipality affected. Compensatory measures include: outright purchase of property or enterprise at market value; financial aid to land users forced to relocate within the region; aid to land users for re-establishment at alternate sites; provision of moving expenses to private property owners; and tax concessions to certain industries and commercial enterprises. The second type, that of regional master planning, zoning, easements, options, and landbanking, comes under the category of land-use control of induced and other incompatible land developments. The third measure is at CATA's direct command – the management or regulation of airport operations and associated activities. An example of this is the restriction of night-time airport operational hours and aircraft movements. The fourth type of mitigating measure is the provision of grants in lieu of taxes to affected municipalities, recompensing them for a loss in tax base or potential tax base, and a loss in land use or potential land use (Transport Canada, 1977*d*).

Airport projects and associated land stresses

Airport expansion: Hamilton and Vancouver

Coincidental with the growth of land developments around airport boundaries is the growth of airport service demands, which necessitate the outward extension of airport boundaries. The conflicting demands on land resources around major airports makes land acquisition and expropriation for their expansion a controversial process. Primarily at issue are the rights of adjacent land users and their concerns about the protection of environmental quality. Airport site expansion poses the threat of increased environmental degradation and increased adverse impacts associated with higher noise levels. When negative environmental and socio-economic effects are perceived as having greater significance than the potential benefits of a proposed expansion, the argument against further airport development can be conclusive. It was this perception that prevented airport site expansion at Montreal's Dorval Airport and Toronto's Malton Airport and led to the alternate development of Mirabel and the planning of Pickering respectively.

The case for or against airport expansion in terms of potential land stresses is ultimately determined by site specific characterisitics of an airport. Hamilton's civic airport at Mount Hope stands out as particularly interesting because of the marked controversy it has stirred over more than a few years.

Exactly ten years less a month elapsed between the time the Hamilton Economic Development Commission first proposed the expansion of the Mount Hope Airport and the time when it was announced that the expansion would proceed. The Commission's submission to the federal Ministry of Transport in January 1971 was to spark a decade of debate between the various groups supporting expansion and those opposed to it (Marron, 1980; Connor Development Services Ltd., 1977). Two very distinct viewpoints emerged during this debate. Those groups in favour of airport expansion based their arguments for development on economic grounds; the City of Hamilton would need expanded airport services and facilities to maintain and stimulate further economic growth, otherwise both airport and city would stagnate (Isbester *et al.*, 1970). Opposing this argument were the objections of numerous anti-airport groups whose concerns were largely environmental. Their objections stemmed primarily from fears of stress on rural land resources, apprehension about the inevitable negative impact of noise on rural communities, and the loss of productive agricultural lands by expropriation. The real need for expanding Mount Hope Airport was also questioned (Federation of Hamilton Environmental Groups, 1971).

By the middle of 1973 the situation had come to a head. At this time it was announced by the Minister of Transport that a study would be undertaken to assess the potential urban, social, economic, and environmental impacts resulting from an expansion of the Mount Hope site, or the development at alternate sites (Connor Development Services Ltd., 1977). Four years of continuous study and public debate culminated in the formation of an EARP panel to examine Transport Canada's airport proposals for the Hamilton area. Three more years of deliberations ensued until the final decision was made to expropriate about 133 ha, comprising 11 farms and 16 residences, for a $50-million expansion of the Mount Hope site (Marron, 1980).

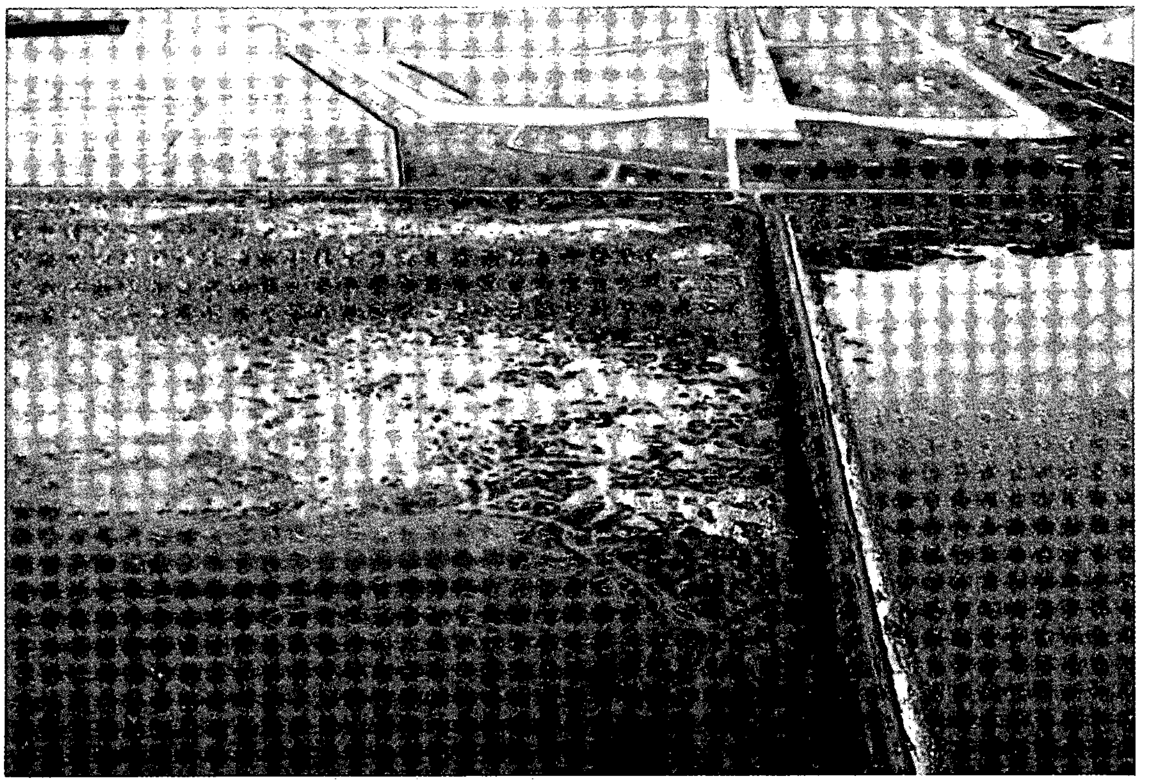


Photo 11. The Sea Island setting of Vancouver International Airport is a sensitive and rich estuarine area. Proposed expansion of the airport raised many land-use concerns, including possible stress on the natural productive capability of the wetlands.

R. McKelvey, Canadian Wildlife Service

The approval for this expansion project was based on the results of comparative assessments of alternate sites; studies that showed that the environmental consequences of expansion would be less stressful than those expected for other new sites. Fewer hectares of agricultural land would be removed from production or otherwise affected by expansion than by construction at a new airport site.

Nonetheless, local rural residents and area municipal authorities alike are justifiably worried about the day in 1985 when the expansion is completed and increased jet traffic makes its noise impact on surrounding land. Notwithstanding the positive economic benefits envisaged by the City of Hamilton and the Region of Hamilton–Wentworth, the rural municipalities are also apprehensive about future development stresses on agricultural land if surplus air traffic is diverted from Toronto International Airport. The extent to which Mount Hope airport will act as a back-up to Malton, by accommodating Toronto region air traffic, remains to be seen.

If the Hamilton case is controversial, Vancouver's airport expansion problems are even more complex. Extending across 1 480 ha of dyked coastal lowlands, the fragile Sea Island setting of Vancouver International Airport is unique. The potential land stresses associated with airport development at other major sites in southern Canada pale in comparison to the impacts of development experienced in this part of the Fraser River Estuary/Delta.

Vancouver International Airport is ranked as Canada's third busiest airport, serving more than six million passengers and handling 70 000 t of cargo a year (Transport Canada, 1981*a*). (According to Transport Canada's 1979-1980 Annual Report (Transport Canada, 1981*c*), Toronto International Airport ranks first with 14 million passengers and 190 000 t of cargo, and Montreal's Dorval and Mirabel airports together rank as second busiest with 8 million passengers and 131 000 t of cargo.) In 1996 the number of passengers and the number of aircraft movements at Vancouver International Airport are expected to be double those of today (Transport Canada, 1980*c*). It is clear, however, that Vancouver's present airfield capacity will not be able to accommodate the projected increases in air traffic. In fact, it has been argued by some that Vancouver's Sea Island airport has passed the point where expansion of its boundaries is essential in terms of operational need. Runway congestion caused the delay of 20% of arriving aircraft, and 30% of departing aircraft in 1980 (Transport Canada, 1980*c*, 1981*a*).

Not surprisingly, proposals to expand the Vancouver International Airport site span three decades – since the first bid for expansion in 1953 (Airport Planning Committee, Vancouver International Airport, 1976).

In anticipation of site expansion, the federal government began purchasing property on Sea Island in the early 1950s. When expansion seemed imminent in 1972, Transport Canada decided to expropriate much of the remaining private property adjacent to the site. Local objections to expropriation resulted in the holding of public hearings under the Expropriation Act to justify the need for expansion. At the same time the Greater Vancouver Regional District (GVRD) Planning Committee, along with various community and interest groups, voiced their concern about the potential environmental impact of airport expansion. In the light of mounting controversy and evident conflicts-of-interest, the federal government established an Airport Planning Committee in the spring of 1973. This committee, composed of federal, provincial, regional, municipal, and local community representatives, was given the task of reviewing the expansion proposal in terms of its compatibility with the planning interests of the various levels of government involved, as well as the concerns of affected communities.

Concurrent with the Airport Planning Committee's establishment, and in co-ordination with it, a Vancouver Airport Master Planning Team was set up by CATA, with the responsibility of producing a master plan for the airport's comprehensive development. Neither of these groups had authority to approve or prohibit the 1971 CATA proposal to expand Vancouver International Airport. Instead, they advised and co-ordinated the documentation of the numerous assessment studies reviewing the potential impact of alternate development schemes. Pending the outcome and recommendations of all assessment studies, Transport Canada withdrew its decision to proceed with the expansion of Vancouver International Airport.

The deliberations of the Airport Planning Committee and its six subcommittees took almost three years. In all, 10 major studies were undertaken to assess the feasibility of an expanded airport site. These studies included:

- an assessment of alternative airport sites;
- an aeronautical noise study of Vancouver International Airport (said to be the most comprehensive investigation of its kind ever carried out at a Canadian airport);
- an environmental impact assessment;
- a study of urban issues;
- a study of social issues;
- a study of air traffic activity forecasts;
- a report on the economic significance of the airport;
- an analysis of traffic demands and capacity of the runway system;
- a report on ground transportation;
- an engineering feasibility study of airport facilities.

The Airport Planning Committee's review of these studies culminated with the publication of their findings in a Final Report in March 1976. Although the CATA committee representatives found there to be "no major detrimental effects" identified in the reports, serious environmental and estuarine land stress issues were brought into focus. The foremost constraint on airport expansion, and thus argument against new runway construction, was found to be the risk of further endangering the natural productive capability of estuarine resources. Runway construction, especially that which would require dredging and landfill operations beyond the present dyked-in area of Sea Island, would threaten the productive and life-sustaining capacity of estuarine wetlands. The continued agricultural capability of Sea Island's prime farmland would also be in jeopardy.

The Fraser River Estuary/Delta has long experienced the stress of competing and conflicting resource users. It has been estimated that past development projects, involving extensive dredging and landfilling as well as dyking for flood control and land reclamation, are responsible for a reduction of as much as 80% in the natural habitat area of the Fraser Estuary/Delta (Environment Canada, 1976*a*). At one-fifth their original extent the estuarine habitat areas have a much reduced capacity to feed juvenile salmon and other fish species, birds, and mammals. Present-day development pressures in this area thus pose grave consequences for the life-sustaining role of the coastal saltmarsh and inter-tidal flats. The potential stress impacts of continued estuarine encroachment could well prove irreversible if left unchecked.

Faced with this kind of evidence, provided by the Airport Planning Committee's investigations, CATA decided to abandon any idea of extending a new runway beyond the existing shore of Sea Island. Instead, it was decided to pursue a proposal to build a third runway within the present dyked area parallel to the existing east-west runway. Because serious adverse impacts could still be expected to result, CATA formally submitted its expansion proposal to EARP in August 1976. Three possible stress impacts were identified as those that necessitated EARP proceedings: the removal of land from agricultural use; a reduction in Sea Island wildlife habitat area; and the environmental impact of increased aircraft noise on wildlife and surrounding residential communities.

Following the formation of a special EARP panel, draft EIS guidelines were drawn up for the Vancouver International Airport expansion proposal. Public hearings were held in September 1977 to receive comments on the draft EIS guideline requirements. After consideration of public comment, as presented at the hearings and submitted to the panel in written form, the EARP panel drew up its final EIS guidelines and issued them to CATA. By now it was July 1978, and it was up to CATA to prepare the required EIS. At this point CATA decided, once again, to temporarily shelve the expansion proposal and to postpone undertaking an EIS while awaiting the release of an airport planning document by the Vancouver Airport Master Plan Project Team. EARP proceedings came to a halt.

The postponement was to last three years. In the meantime, a Draft Airport Master Plan (Transport Canada, 1980*c*) was released for public consideration and comment in October 1980. Here, it was recommended that the Sea Island land area located north of existing airport facilities be reserved for an additional east-west runway. During the four-month period of public consultation that followed the publication of this document, more than 500 people expressed their concerns and views to CATA representatives at eight open forums. Another 318 written comments were received from individuals, various provincial government departments, municipalities, aviation and business interests, and environmental organizations. Then, in December 1981, Transport Canada announced that the Vancouver International Airport Master Plan, having been improved upon in response to public comments and suggestions, would officially be approved. At the same time, it was announced that CATA would pursue two major recommendations made in the Master Plan. First, it was decided to proceed immediately with the renovation and reopening of a disused military airfield at nearby Boundary Bay in order to divert light airplane traffic and general aviation from Vancouver International Airport.

The second recommendation to be pursued was that which recognized the proposed parallel east-west runway as a long-term development option. CATA would now go ahead with the preparation of an Environmental Impact Statement (EIS) and the EARP panel would be reactivated (Vancouver Sun, Dec. 7, 1981, p. 3).

This latest round of EARP proceedings should take years. It is estimated that the preparation of new, revised EIS guidelines by the EARP panel, and the documentation of an EIS by CATA will take at least two years (Richmond Review, Jan. 22, 1982, p. 1). The eventual review of the EIS by the panel, the public, and the federal Minister of the Environment will also be a lengthy process. Public hearings are to be held by the EARP panel in 1984, at the earliest, in order to review all concerns about the potential impact of runway development on the natural environment and surrounding communities. Already more than a decade has elapsed since CATA's 1971 proposal to expand Vancouver international Airport. It seems that the Sea Island runway decision may prove to be the lengthiest and most difficult airport expansion decision ever made.

The Sea Island setting of Vancouver International Airport clearly provides a prime example of circumstances where the magnitude of environmental constraint against development is proportional to the magnitude of potential stress impacts and the magnitude of planning decision-making problems.

A new airport site: Mirabel

Leaving aside the operational and economic problems that have besieged Montreal's Mirabel Airport since its official opening in the autumn of 1975, it can be said that the planning of this "green-field" airport site was an environmental success. At Mirabel the environmental impacts and hazards that result from operations are monitored and controlled, mitigating measures are implemented, and the noise problem does not exist. Simply stated, environmental impacts are not a problem on and around the Mirabel site because of the existence of a large buffer zone between the airfield and neighbouring communities. The use of this land bank is regulated in order to minimize adverse effects on both the social and natural environments (Beinhaker and Choukroun, 1975; Marriot and Cook, 1975; McNairn, 1972).

Nevertheless, in ensuring that adjacent communities were not adversely affected by airport operations the insulation of Mirabel with "noise lands" has resulted in land-use repercussions of a peculiar kind. Apparently too much of this buffer zone land was acquired by expropriation. Thus, in early 1981 it was announced that the federal government had decided to return to private ownership some of the 31 565 ha of mainly agricultural land around Mirabel (Globe and Mail, Feb. 4, 1981, p. 10; Land, 1981).

The reason given for this decision was that there is no longer a need for the federal government to retain full control because the regional zoning of land for agriculture and other compatible uses has been established since the airport was planned, and quieter aircraft technology has been developed since 1969, when the noise lands were acquired.

Although much of the agricultural land has been leased back over the years since its expropriation in 1969, most of the original 800 farm families have now left the region. At the time of writing it had not yet been announced how many hectares would be returned to the private sector. Whatever the amount is, three groups of citizens are likely to be affected: those individuals and families who have left the immediate district; those who have remained as tenants; and those new tenants who moved to the region since the 1969 expropriation. Needless to say, the task of supervising land sales may prove to be a complicated process for the new Crown Corporation established for the purpose. Part of its mandate is consideration of the views of the local residents most directly affected, some of whom may not share the opinion that all original owners be given first refusal to buy back land or obtain long-term leases.

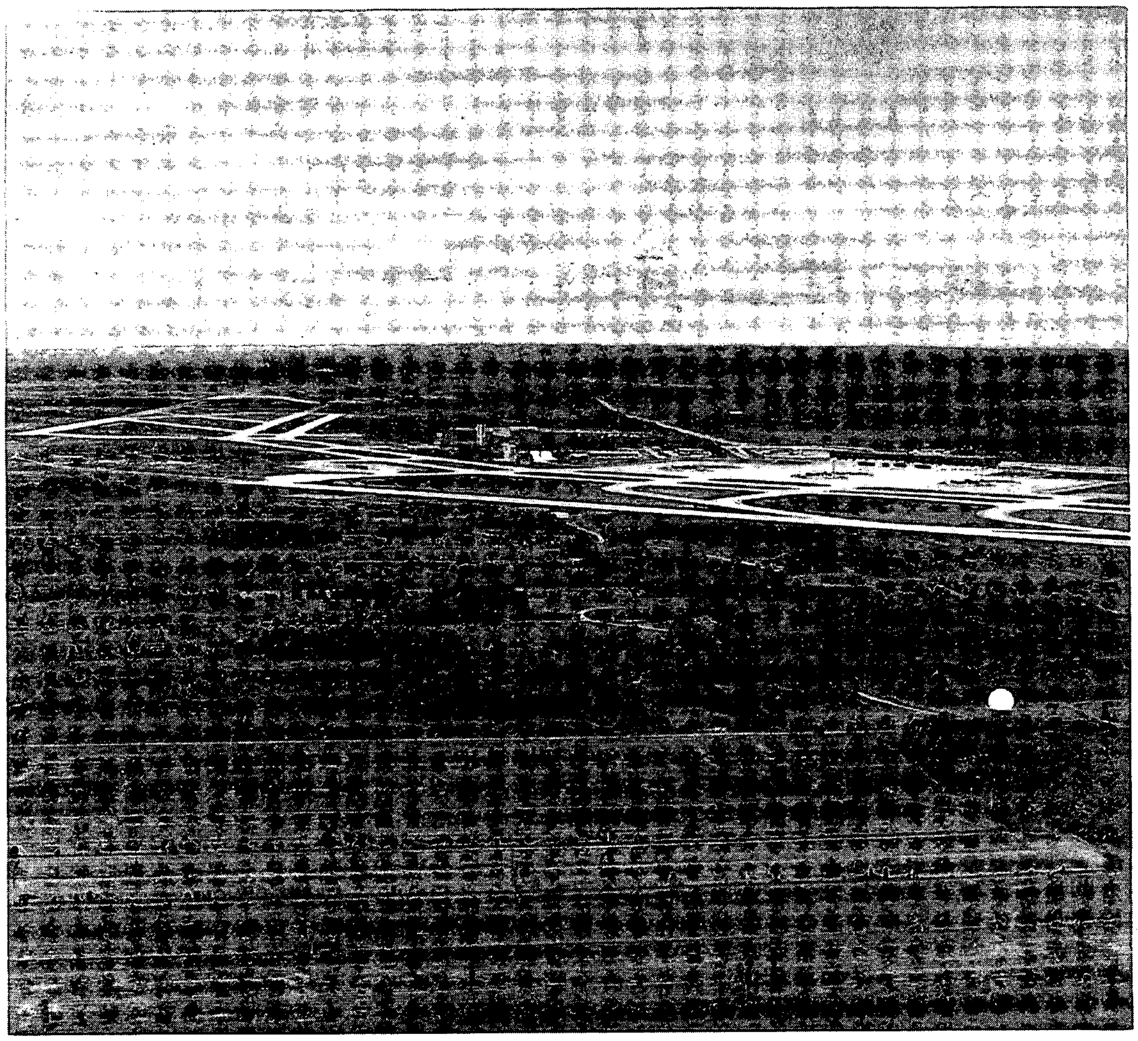


Photo 12. The large buffer zone around Mirabel effectively reduced noise-related problems for neighbouring communities. Some of the agricultural land will be returned to private ownership.
G. Thomas, Transport Canada

An airport project halted: Pickering

Although the second Toronto International Airport project at Pickering was halted on September 25 1975, the land stresses associated with its planning are numerous. The Pickering project had an impact on, and continues to affect, land use, value, and capability. Both land speculation and the conversion of ownership through federal expropriation have been particularly responsible for land stresses at or near the shelved Pickering airport site.

In March 1972 the federal government and the Province of Ontario jointly announced that the Pickering region would be developed for an airport and a satellite urban community. Accompanying this announcement was another which proclaimed a "freeze order" covering certain lands in the region. Although the freeze order on land use tended to stifle any speculative purchasing of the affected lands, a great flurry of corporate land speculation took place on regional land further afield from the frozen areas. As much of the land in the greater Pickering region was already in the hands of speculators because of its proximity to a fast growing urban centre – Toronto – the effect of increased speculative activity was only to inflate the value of regional property. One federal court judge assessed the increase in market value of a certain Pickering property as 30% between the time the federal and provincial development plans were announced and 11 months later, when the land was expropriated (*Capus Developments Ltd. et al.* v. *The Queen*).

Aside from the effect of speculation on land value there was also an impact on land use associated with speculative activities. Speculation for capital gain, along with general competition among users of land in the urban fringe property market, tends to inflate the price of land beyond the reaches of agricultural or other non-urban uses. A case study of land-use dynamics at and around the Pickering site conducted by Martin (1972) revealed that rural-to-urban land conversion trends had already taken a firm hold of land market processes by the time the airport project was announced. Martin's survey of property ownership and sales led him to conclude that widespread speculation in the Pickering region would result in the withdrawal from production of Pickering land, rated as having Class 1 agricultural potential, whether or not an airport was built there. However, it should be noted that the increased speculative activity in areas outside the lands covered by the freeze order did serve to inflate the market value of land beyond what could be afforded by agricultural and other rural users.

The expropriation of property for the Pickering airport site has given rise to several stresses on the area's land resources over the years. According to Stewart (1979) the immediate impact of Pickering expropriations was on surrounding land values: "Once the land seizures began at the federal level, and 35,000 acres [14 170 ha] of prime land was taken off the market, property prices all around began to shoot up, and the displaced Pickering residents could not afford to buy new homes for the amounts they were given for the old." It should be noted that the actual amount of land expropriated by the federal government for the airport was 7 527 ha. Another 10 117 ha were expropriated by the Provincial government for the site of a proposed urban community to be located south of the airport.

Because the Pickering airport has not been built there has not been a significant change in the type of use made of the expropriated land. No longer privately owned by farm families, it continues to be farmed by tenant farmers. The impact of its expropriation, therefore, is on the land-use opportunities foregone. In other words, the removal of 7 527 ha of agricultural land from the market precludes its use for competing activities in the region, i.e. commercial or industrial use. A similar impact results from rural land freezes and agricultural zoning in the vicinity of airports.

The long-term effect of Pickering expropriations may well be on land capability. In the years since the Pickering airport project was halted much of the site's agricultural land has been turned over to corn production. Corn is a cash crop that affords high economic returns per hectare but it is known that over-production of corn in successive years eventually leads to the "mining out" of soil nutrients and erosion of fertile top soils. Concerned residents of the Pickering region thus fear that the expropriated Class 1 agricultural land may lose its high capability for production if corn cropping is not soundly managed and if the land continues to be held in reserve by the federal government (Speirs, 1979).

CONCLUSION

In attempting to show the role of airport development in the determination of land use, value, and capability, several land stress issues have been examined.

First, it has been seen that the relationship between airport sites and their physical environment is one of two-directional interaction in which potential stress impacts bear a strong relationship to the environmental constraints imposed on airport development. Every phase of airport development faces environmental contraints. During the site survey stage of development, potential land stresses are not generally a problem. Only in very fragile and sensitive environmental settings are site survey activities restricted and hampered for reasons of environmental stress. It is during the construction stage of airport development that environmental protection practices are urgently required. Airport site construction is thus guided by stringent measures to minimize the stress impacts that result from gross changes in the physical landscape. The most prevalent and critical land stresses found to be associated with construction are those arising from the soil erosion hazard and the irreversible alteration of physical landscapes. With regard to airport operations it was seen that the introduction of wastes and contaminants into the environment makes it necessary for airports to adhere to certain operational restrictions to prevent degradation of environmental quality and interference with the productive capability of the land resource.

A lengthy discussion of the airport noise problem revealed that the noise impact on competing land uses is one of external diseconomy, resulting in an inefficent allocation of land resources between the air transport sector and quiet uses. The costs of airport noise in terms of land stresses may be manifested in two ways: by restriction to certain developments (imposed with land-use regulation or from a loss in an activity's competitive advantage), and by the financial burden of land devaluation.

The influence of airports on regional development was found to lie with their role as catalysts and attractions of economic benefits. Consequent trade-offs between competing land uses in the vicinity of airports accounts for regional land-use dynamics, whose long-term expression is reflected in patterns of land use.

The jurisdictional responsibility of reducing land stresses associated with airports has been discussed in respect of various levels and agencies of government. In its authority over airport operations CATA must abide by environmental protection policy at all stages of airport development. Provincial and local authorities play a major role in land-use planning and control in the vicinity of airports. And finally, there is the Federal Environmental Assessment Review Office (FEARO), whose task it is to reconcile environmental conflicts arising from the allocation of land resources among competing uses.

In short, an attempt has been made to show how airport development necessitates strategic trade-offs between the goals of air transportation safety, convenience, and efficency on the one hand, and land resource considerations, external to the aviation sector, on the other. Land resource concerns include objectives of regional development, competing claims on land use, adverse impacts of airport noise, and negative effects of airport development on the natural environment.

In view of the magnitude of present-day land stresses associated with airports it seems the airport location problem is here to stay. The scarcity of land suitable for airport expansion and new sites, the problem of airport noise, and the need to protect environmental quality combine to make the future of airport development extremely uncertain. There will always be environmental pressures exerted against the air transport sector's determination to build and expand airports. Although an airport at Pickering may yet be built, it seems likely that mounting environmental and land use constraints will see more and more situations where airport development is thwarted or halted.

Notwithstanding environmental constraints, however, new opportunities are bound to present themselves. Already we have seen a reduction in required noise insulation lands at Mirabel due to the development of quieter aircraft. Just as technological innovation and change has had implications for noise in the vicinity of airports, so may future technological advances lessen certain other conflicts in the areas surrounding airports.

One technological innovation that has been gaining increasing attention because of its potential to reduce airfield congestion is that of STOL (Short Take-off and Landing) aircraft. Because STOL carriers are relatively quiet and pollution-free, and require only short runways for take-off and landing, they are suitable for operation from downtown and alternate airfield sites. It is hoped that the operation of regional STOLports and inter-city STOL services will serve to displace some conventional jet operations from major airports, thereby lessening noise levels and other environmental impacts to a certain extent (Transport Canada, 1978*c*). By alleviating airport congestion, alternate STOLport services may also help curtail the need for new airport facilities and the expansion of larger airports. In the case of Vancouver International Airport, it is possible that the opening of nearby Boundary Bay Airport for use by light aircraft and general aviation will forestall the need to expand its facilities (Richmond Review, Jan. 22, 1982, p. 1).

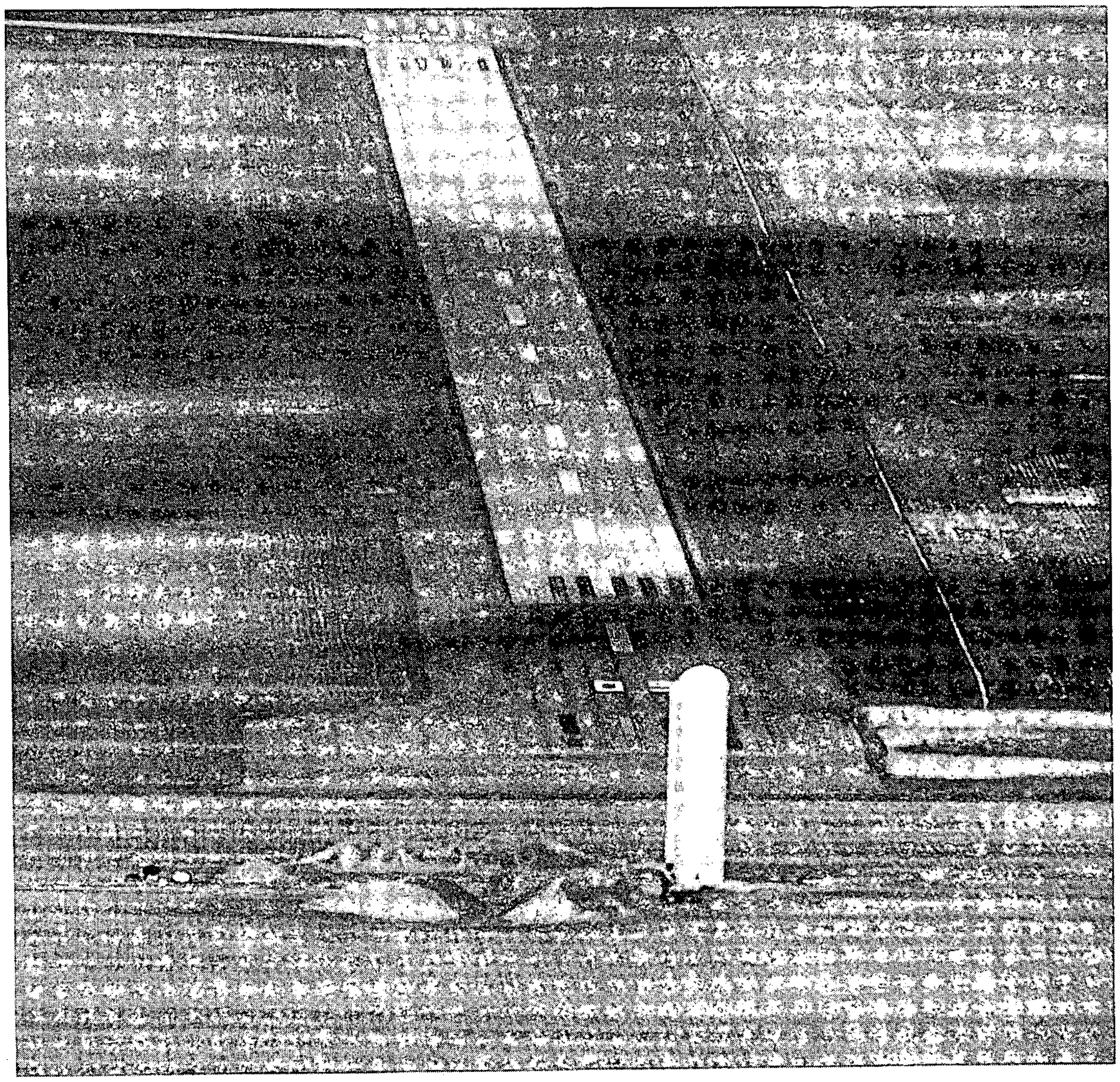


Photo 13. Concerns about land use are not restricted to federal airports. Near the Chatham Municipal Airport a farmer constructed, on his own property, a silo that is 112 m from a runway. It illustrates that different people may have opposing views on land ownership and land use.
George Blumson of the London Free Press

Another partial solution to airfield congestion is also on the horizon – improved traffic control technology, such as Joint Enroute Terminal Systems (JETS); a new and more sophisticated radar tracking system, and the Microwave Landing System (MLS), which is now replacing the use of conventional Instrument Landing Systems (ILS) in Canada (Transport Canada, 1981*c*; Stewart, 1979).

Still other innovations reducing airport stress must come from the non-aviation sector. For instance, rapid inter-city passenger rail service, long overdue in Canada, could do much to take the pressure off congested airports now catering to short-haul distance travel. The Federation of Hamilton Environmental Groups (1971) argued over a decade ago that an upgrading of surface transport systems would solve Hamilton's transport needs and relieve the pressure to expand Mount Hope Airport.

There is a great challenge for future airport planning and operation if land stresses at and around airport sites are to be kept in check. The key to wise management of land resources in the vicinity of airports must be found in a strategy of comprehensive and integrated planning for transportation and the environment. Serious consideration must be given to the kinds of trade-offs allowed to take place between economic benefits and environmental quality. Complicated as it may prove to be, only such a comprehensive approach can mitigate against airport land stresses and ensure the best use of land resources in the proximity of airports.

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OIL SPILLS: COASTAL AND INLAND

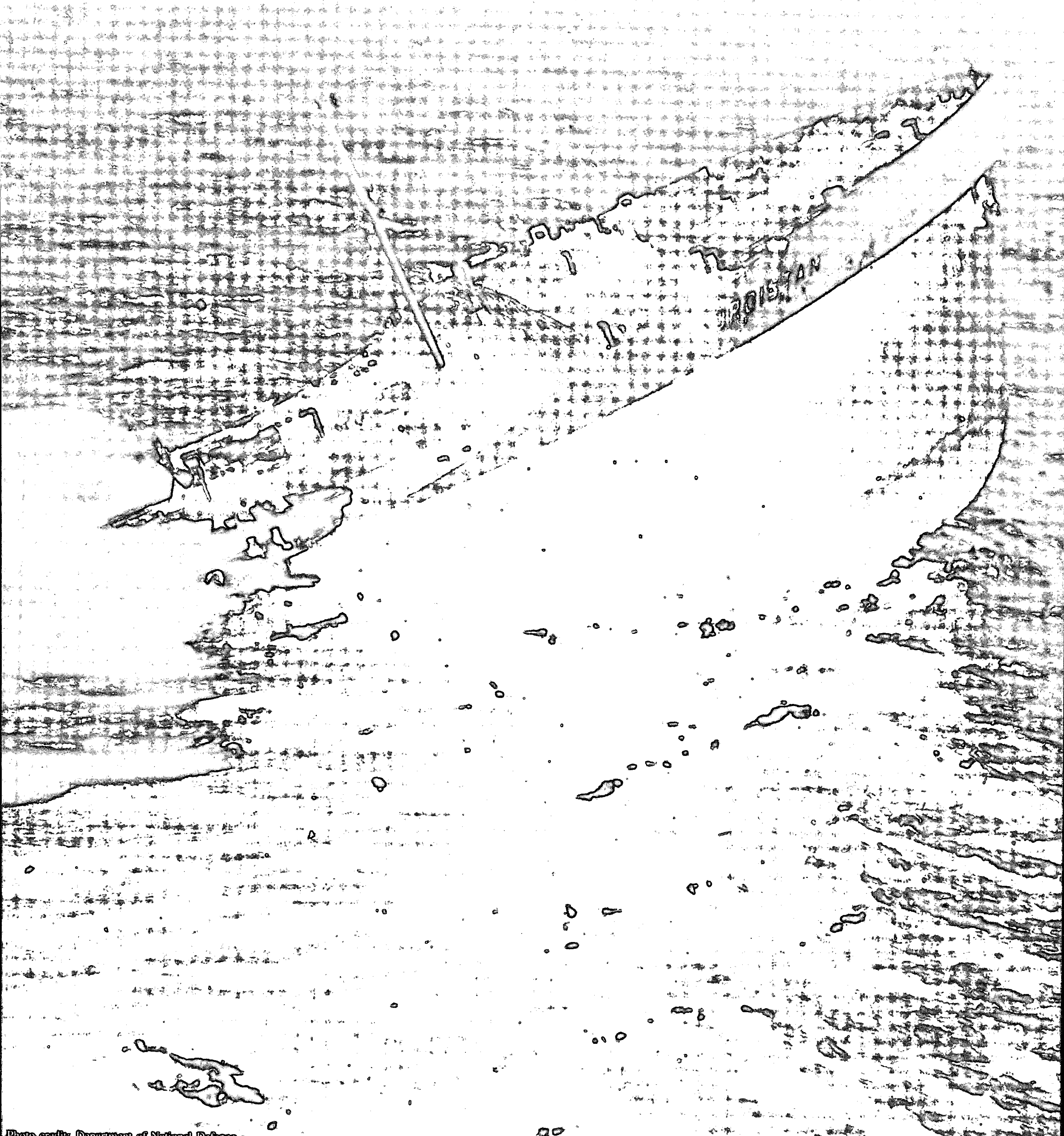

Photo credit: Department of National Defence

OIL SPILLS: COASTAL AND INLAND

COASTAL OIL SPILLS AND THEIR IMPACT ON LAND

Edward H. Owens*

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INTRODUCTION

Sources of spilled oil and causes of spills

Oil spills can occur during any one of the many phases of hydrocarbon exploration, extraction, transportation, or storage in a variety of ways, from well blowouts to marine terminal accidents or tanker collision. The largest and most dramatic oil spills that affect the coast are associated with either blowouts or shipping accidents; smaller spills happen all the time, but are usually not reported or do not receive media attention. During the 5 years from 1974 to 1978, 462 marine oil spills were reported to Environment Canada. No estimates are available on the number of other small spills that went unreported.

The character of an oil spill varies considerably, depending on the type of oil that is spilled. For example, the fate and persistence of aviation gas is very different from that of a bunker oil or a heavy crude, owing to the differences in chemical composition from the refining process. Because of the variations in both type and volume of spilled oils, and the wide range of marine and coastal environments in which a spill can take place, every spill is unique. The only common denominators are the effects that the hydrocarbons may have on coastal ecosystems and the methods that are used to mitigate the adverse effects of the spill.

Oil spills result primarily from man's industrial activities (Photo 1). The accidents that are most likely to occur during the exploration and extraction phases result from blowouts. In recent years, major blowouts have occurred in the Gulf of Mexico (IXTOC 1—3.1 million barrels*), the Gulf of Guinea (FUNIWA 5—200 000 barrels), and in the Arabian Gulf (HASBAH 6—80 000 barrels). However, natural seeps or spills have also been recorded in many parts of the world, including one at Scott Inlet on the northeast coast of Baffin Island, Northwest Territories (Loncarevic and Falconer, 1977; Levy, 1981).

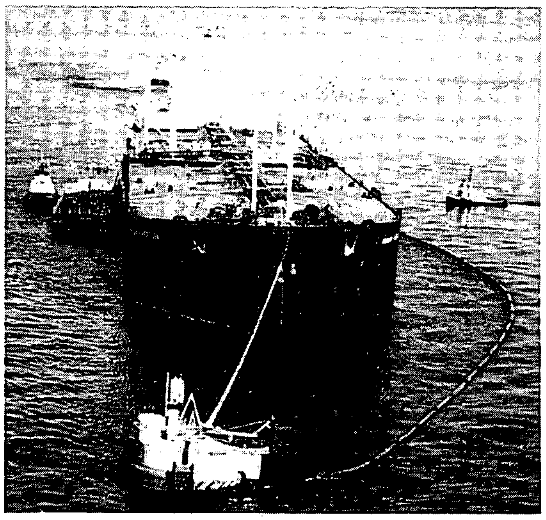

Photo 1. A crude-carrying tanker unloading at an offshore transfer point near Saint John, New Brunswick.
E.H. Owens

The second major source of oil spills is shipping accidents which result from the grounding, sinking, or collision of oil-carrying tankers. The largest spill that has occurred to date in Canadian waters was from the tanker ARROW in 1970. During this spill, approximately 9 000 t of Bunker C fuel oil were discharged into Chedabucto Bay, Nova Scotia. By comparison, the spill from the AMOCO CADIZ on the Brittany coast of France was in the order of 200 000 t of crude oil. Other large spills in Canadian waters caused by shipping accidents include those from the KURDISTAN, NEPCO 140, and the LEE WANG ZIN. Large spills resulting from the accidental discharge of the cargos of oil tankers or of the fuel from other ships are dramatic but relatively infrequent. More common are tank- or bilge-pumping discharges, which occur with almost routine frequency in coastal waters. The volume of oil discharge associated with these pumping operations is generally very small.

Other sources of coastal oil spills include pipeline ruptures and spills from shore-based facilities. The largest pipeline spill that has occurred to date was in the Thistle Field of the North Sea, where approximately 460 000 barrels of crude oil were leaked in 1980. Spills from shore-based facilities can occur during transfer or bunkering operations. Terrestrial spills can sometimes reach the coastal zone, as was the case in 1970 in Deception Bay, Quebec, when almost 2 000 000 L of diesel and gasoline were spilled on to nearshore ice following the destruction of a tank farm by a slush avalanche (Ramseier *et al.*, 1973).

The main sources of coastal oil spills can therefore be listed as follows:

- blowouts
- ship accidents (grounding, sinking, collision)
- bilge pumping
- transfer accidents
- terrestrial spills

The majority of these spills can be directly or indirectly attributed to human error; less than 25% result from equipment malfunctions (Fingas *et al.*, 1979). The major source of oil pollution in the oceans is from oil that enters directly into the sea from effluent pipelines or from rivers. More significant, however, in terms of stress to coastal ecosystems and of man's use of the coastal zone, are spills that result from the sources listed above. The regular and continuous discharge of oil from the land into the sea produces longer-lasting stresses, which are less damaging to specific sites than are the effects of a spill. Floating oil on the water surface that reaches the shoreline generally has a major impact, due to the high volume of oil and the restricted area of the contamination. Coastal oil spills are, therefore, considered specific events rather than continuous background pollution. Not all spills in the marine environment affect the coastal zone. The spillage from the EKOFISK blowout in the North Sea and the ARGO MERCHANT, off New England, did not reach the adjacent coasts.

The sources and the causes of oil spills are extremely varied. The volume of oil in a spill, as well as the type of oil, and the physical environmental conditions at the time of the incident, vary in every case so that no two spill incidents are alike.

Why are spills of concern?

Oil spills are one of many stresses in the coastal zone; they are a man-made perturbation in the natural environment. Because the size and location of oil spills cannot be predicted, the threat is one that affects all coasts equally.

The accidental introduction of oil into the coastal environment can produce a hazard, a stress, or a perturbation in the natural environment or in man's activities. Some components

* *It is customary mariners' practice that all ships' names appear in capital letters.*

Approximate equivalents are as follows:
1 t (metric ton) oil = 7 to 9 barrels, depending on the specific gravity and type of oil.
= 1.11–1.43 m³ (cubic metres)
= 1 110–1 430 L (litres)

of the spilled oil can be toxic to organisms, or the oil can cause damage to flora and fauna by smothering them. In either case, the stress to the individual organism can have wide implications for the coastal ecosystem. For example, an alteration to the population or distribution of capelin on Atlantic coast beaches can have a significant effect on predators such as cod, and in turn on the coastal fisheries. A disruption of man's normal activities as a result of the effects of oil on recreational, commercial, or subsistence species is usually a primary element in the assessment of potential threats or of impacts from oil spills. Rarely is the presence of oil on the coast or in coastal waters a threat to the safety or health of man.

The main concern associated with oil spills is the interaction between man's activities and use of coastal biological resources. Another major concern is the potential impact that spilled oil may have on rare, endangered, or threatened species. For the public, the aesthetic effect of a coastal oil spill is usually of major importance (Photo 2). The presence of oil on the shoreline is itself not a serious concern, except during major spills, such as that from the AMOCO CADIZ or the TORREY CANYON, where large volumes of oil were washed ashore. In most instances, the oil that reaches the coast does not coat the entire shore. Because shore coverage is uneven, the effects of the spill and the concerns associated with the presence of oil are usually localized.

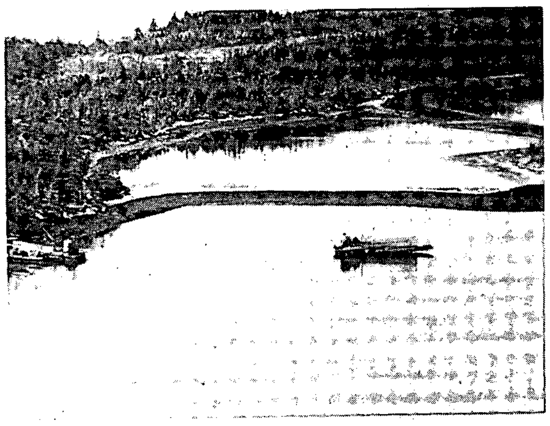

Photo 2. Sheltered pebble–cobble beaches in northern Chedabucto Bay, May 1970. The intertidal sediments are completely covered with a thick (5–10 cm) layer of Bunker C. This oil had immobilized the sediments to produce an asphalt-like beach that had not recovered by August 1973, but that was free of surface oil by mid-summer 1976.
E.H. Owens

The development of organized response to spills

The grounding of the TORREY CANYON in the English Channel in 1967 dramatically changed public perception of the damage that could be caused by marine oil spills. This spill was the first major tanker accident, and resulted in the loss of over 135 000 m^3 of crude oil, most of which became stranded on the adjacent shorelines of southwest England and northwest France. Many coastal oil spills had occurred prior to this accident, but most were relatively small or had gone unnoticed by the public and the media (Campbell *et al.*, 1977). Before 1965, there were no tankers of more than 180 000 t deadweight. By 1975, over 350 tankers in this size range had been constructed and were operating on the oceans of the world. Thus, in a very short time the potential for major spills increased dramatically.

The spill from the wreck of the TORREY CANYON led to the development in Canada of an informal means of responding to spills. Within the Canadian Coast Guard and the Department of Energy, Mines and Resources, steps were taken to develop a loose organization and to acquire items of equipment that could be used in the event of marine spills. This evolutionary process took a dramatic turn in 1970, following the wreck of the tanker ARROW in Chedabucto Bay, Nova Scotia. More than 17 250 m^3 of Bunker C oil were lost during this spill, and much of the oil became stranded on the adjacent shorelines of Cape Breton Island and Nova Scotia. The task force, code named "Operation Oil", established by the federal government to combat this spill recommended in its report to Cabinet that steps be taken to develop an emergency organization capable of immediate response, and to develop an improved technology for the recovery and cleanup of spilled oil (Ministry of Transport, 1970). Shortly thereafter the Department of the Environment was established within which was the Environmental Protection Service. Incorporated in this was the Environmental Emergencies Branch, which includes an Operations Division, a Contingency Planning Division, and a Research and Development Division. The main function of the Branch is to examine the national state of preparedness and to co-ordinate the development of improved technology for dealing with spills. A close liaison exists between the Environmental Emergencies Branch and the Canadian Coast Guard, which has a primary responsibility for marine safety.

The development of response organizations to cope with the problem of coastal marine oil spills can be seen as part of the changing awareness of environmental matters that took place in the mid and late 1960s. The dramatic growth in oil transportation by tankers and the increased size of crude tankers accelerated this development. The problem came into focus with a series of large spills in the late 1960s and early 1970s. Although the TORREY CANYON highlighted the potential damage of major oil spills, it was the wreck of the ARROW in Chedabucto Bay that provided the specific impetus within Canada for the development of a response organization and for improved research and development activities.

The effect and persistence of spilled and stranded oil

Spilled oil is naturally dispersed by physical and biological processes over periods that vary depending on the type of oil, its volume, and environmental conditions. Spilled oil may also be removed and stored by cleanup activities, and, in some cases, may be re-refined for further use. The fate of the spilled oil is dependent on degradation processes which include evaporation, photo-oxidation, dissolution, sinking, and biodegradation. The rate at which degradation takes place is a function of:

- the type of oil
- the volume of oil
- surface area of exposed oil
- ambient temperatures
- mechanical energy levels

Immediately following a spill, lighter fractions of the oil tend to evaporate rapidly, depending on the composition of the oil and on air and water temperatures. Further degradation and dispersion largely depend on the inputs of mechanical energy associated with winds and waves. As levels of mechanical energy increase, so do the rates of dispersion (Owens, 1977). If oil reaches the shoreline, the rate of natural degradation is affected by the actual distribution of the stranded oil, with respect to the zone of wave activity, and its penetration or burial in the coastal sediments. An oil slick that is stranded at the shoreline during periods of

Photo 3. Oil that was stranded on a sand beach in the Straits of Magellan following the METULA spill at a time of very high water levels remains largely unaffected by wave action after 2½ years. The solid arrow indicates the limit of the high spring tides and the open arrow is the normal high-water level.
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spring tides or storm surges would usually be deposited above the limit of normal wave activity, and would therefore not be affected by mechanical energy associated with wave action, except during subsequent high-water levels (Photo 3). This oil would therefore be expected to persist longer than stranded oil deposited in the intertidal zone, which would be subject to continual mechanical energy from waves.

Beach sediments are continually redistributed by wave action, and stranded oil can be rapidly buried and therefore protected from dispersion by waves. Similarly, oil can penetrate into sediments, particularly on pebble or cobble beaches, and remain unaffected by wave action. Wave action can rapidly erode and redistribute sediments and stranded oil. The persistence of oil in the shore zone depends to a large degree on whether a beach undergoes erosion or a build-up of sediments. Erosion usually results from the generation of storm waves by low-pressure systems, whereas deposition or beach build-up takes place during the relatively quiescent periods between storms. On the Pacific Coast of Canada these erosion–deposition cycles coincide with winter–summer changes in wave-energy levels. The most important environmental factors that affect the persistence of stranded oil are the distribution of the oil across the shore zone and the wave-energy levels at the shoreline.

The rate of natural dispersion of oil is dependent primarily on the type of oil and on wave forces. Degradation can be viewed as the dispersion of certain components of the oil. The lighter components rapidly evaporate immediately following exposure of the oil to the atmosphere. The heavier and less volatile components are more slowly weathered, depending on inputs of mechanical energy. Thus, light oils, such as aviation gas or diesel, disperse much more rapidly than heavy crudes or heavy fuel oils. The actual character of the spilled oil changes continuously as the different components of the oil become dispersed. An oil that is relatively light and volatile in character at the source of the spill may become highly viscous and relatively stable after several days on the sea surface. The natural dispersion of spilled oil can be viewed in three stages:

1. Evaporation of the light fractions immediately following exposure of the oil to the atmosphere while on the water surface or at the shoreline. This degradation process is usually significant during the early stages of the spill. The process is most rapid during the first few hours and days, thereafter decreasing rapidly in importance.
2. The physical dispersion of oil on the water surface or stranded at the shoreline by waves is the primary mechanism by which oil is dispersed into the marine environment. For this process to be effective at the shoreline, it is necessary that the oil be stranded within the zone of normal wave activity. The rate at which the physical dispersion of stranded oil takes place is a function of the levels of wave energy during the period immediately following stranding of the oil.
3. Oil that is stranded above the limits of normal wave action or in extremely sheltered low wave-energy environments is dispersed as a result of biological, primarily microbial, processes. These processes are generally very slow and operate over time scales that are measured in years and decades.

Light oils stranded within the zone of wave action on exposed, high-energy coasts would be expected to persist for a very short time, a matter of only days. Oil that becomes stranded in sheltered bays or lagoons at periods of high-water levels, for example during storm surges, would not be subject to physical breakdown processes, and would be expected to persist for years, and in some cases, for decades (Photos 4 and 5). On coasts subject to rapid erosion—greater than 1 m annually—stranded oil would be dispersed as the erosion processes redistribute coastal sediments. This would occur, for example, on sections of the Great Lakes and Beaufort Sea coasts, where annual erosion rates up to 3.0 m have been recorded. By contrast, oil deposited on coasts that are subject to sediment accumulation would probably remain buried for a considerable time. Superimposed on these long-term erosion–deposition patterns are normal cycles of sediment redistribution that take place at time scales in the order of days and months (Owens, 1977). These erosion–deposition cycles are usually associated with variations in wave-energy levels at the shoreline, which produce either onshore–offshore or alongshore transport of sediment.

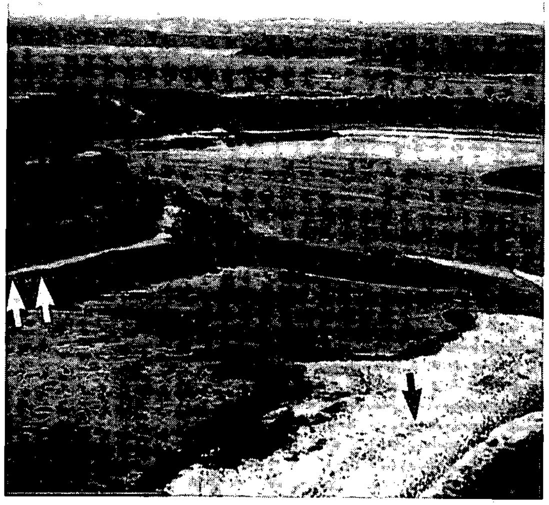

Photo 4. The contrast between the exposed and sheltered beaches, following severe contamination of the pebble–cobble beaches at Black Duck Cove, Nova Scotia, is very evident in this low-tide aerial photograph, taken one month after the oil was washed ashore from the ARROW spill in 1970. Oil originally covered all of the intertidal zone but has been dispersed from the exposed beach, and only traces remain at the high-water mark (located by the arrow). Double arrow indicates lagoon high-water mark (cf Photo 5).
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Photo 5. The intertidal zone at Black Duck Cove lagoon, near Chedabucto Bay, Nova Scotia, 3 years after the shore was oiled. The photograph is directed towards the spit in the lower foreground (cf Photo 4).
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The movement of spilled oil is controlled largely by winds, tides, and currents. Oil in the coastal zone tends to accumulate in sheltered areas, where mechanical (wave) energy levels are lowest, and where the persistence of any stranded oil would be longest.

Arctic and non-arctic spills

Coastal atmospheric and oceanographic processes in Canada are largely controlled by climate. On all coasts, with the exception of British Columbia and southern Nova Scotia, continuous sub-freezing temperatures each year result in the freezing of water or wave spray in the shore zone. The generation of waves on the coast is modified or prevented by the presence of ice on the water surface or in the shore zone itself. The formation of ice is, therefore, a primary control on mechanical (wave) energy levels at the shoreline, and on the physical reworking of stranded oil. Variations in air temperature also affect rates of evaporation of the lighter components of spilled oil. Stranded oil persists longer on coasts subject to low temperatures and the presence of this oil therefore places greater stress on these coastal environments.

The biological character of arctic coasts is generally one of low diversity and low abundance of resident species (Owens and Robilliard, 1981*a*). The scouring action of ice and the exposure to low temperatures for most of the year eliminate all but the hardiest of intertidal species. The presence of ice throughout much of the year reduces the period of biological activity to the open-water season; most of this activity is concentrated on or in the coastal waters rather than at the shoreline itself. There is usually a marked change in the species diversity and abundance between the ice-locked and the open-water season. Biological activity increases during the short ice-free period, and reproduction and feeding are usually concentrated during this period. In arctic environments the recovery potential for some species from major or chronic stresses may be much lower than in non-arctic environments. Many migratory species are restricted in their breeding activity to a few small coastal locations, where the population density is extremely high. As a result of these concentrations, habitat stress could seriously endanger the survival of these species.

The timing of spills in arctic environments is therefore critical. The potential stress placed on both resident and migratory species is heightened, owing to the probability of a longer persistence of stranded oil and to the lower potential for natural recovery for stressed species.

PROFILE

Spill size and high-risk areas

The stress induced by an oil spill in the coastal zone is not a direct function of the size of the spill alone. The biophysical character of the area affected, the time of year, and the physical and chemical properties of the oil are key elements in assessing the potential or actual impact of a spill. However, the size of the spill is a contributing factor to the level of stress imposed on the shoreline, both in terms of the area affected and the local stress level. To date, Canada's coasts have not been subjected to a major oil spill in excess of 100 000 barrels (Table 1). Most spills are relatively small in size, less than 100 barrels, so the effects are usually very localized.

The identification of high-risk areas for coastal oil spills is usually related to the intensity of oil exploration, extraction, transportation, or transfer activities. There is a common assumption that where there are a larger number of ships carrying fuel or extensive fuel transfer facilities, there is a greater likelihood of an accident caused by human error or mechanical failure. At present there are no offshore oil-extraction facilities operating in Canada. Current marine exploration is taking place in the Beaufort Sea, the Arctic Islands, the Labrador Sea, the Grand Banks, the Scotian Shelf, and Lake Erie. In each of these areas the threat of a spill from a blowout exists, although the frequency of this type of event is low when compared with the number of holes that have been drilled in offshore and coastal environments.

TABLE 1.
Comparative size of marine spills

Source	Location	Quantity (barrels)
AMOCO CADIZ	France	1 800 000
ARROW	Nova Scotia	60 000
KURDISTAN	Nova Scotia	57 000
NEPCO 140	St. Lawrence River	8 800

TABLE 2.
Port ranking by number of ship transits (1978)

Port	No. of transits
Vancouver	24 143
New Westminster	6 367
Montreal	5 955
Victoria	4 789
Windsor	3 404
Halifax	3 036
Sarnia	3 018
Thunder Bay	2 816
Nanaimo	2 727
North Sydney	2 688
St. John's	2 326
Powell River	2 325
Campbell River	2 300
Sept-Îles	2 090
Quebec	1 837
Hamilton	1 730
Port Cartier	1 499
Baie Comeau	1 439
Toronto	1 227
Sorel	1 069

Source: Statistics Canada, 1979.

Marine shipping accidents that involve tankers or the discharge of ships' fuels can be considered in terms of traffic density. Table 2 lists the 20 busiest ports in Canada. Clearly, the potential for an accident is greater where the traffic density is greatest. In considering the possibility of a major spill, attention must be given to the volume of crude oil or petroleum products that are transferred by ships. A ranking of ports in terms of the amount of petroleum transferred is given in Table 3.

TABLE 3.
Port ranking by amount of crude/petroleum products transferred (1978)

Port	Mass (t)
Saint John	9 416 401
Halifax	5 951 640
Montreal	5 567 058
Port Hawkesbury*	4 420 251
Sarnia	3 517 708
Quebec	3 015 122
Vancouver	1 368 230
Sept-Îles	751 618
Thunder Bay	505 238
Sault Ste Marie	482 825
Windsor	450 745
Toronto	433 878
Trois Rivières	414 779
Port Alfred	405 064
Hamilton	316 279
Nanaimo	272 742
Sydney	267 176
Victoria	151 405
Campbell River	147 595
Port Colborne	100 830

* Point Tupper refinery now closed, therefore present (1981) annual value is probably less than 900 000 t.

Source: Statistics Canada, 1979.

Risk can be considered, therefore, in terms of either the traffic density or the volume of petroleum carried by ships. A strong regional variation exists between different parts of Canada, in terms of the percentage of petroleum products as a fraction of total cargoes carried (Table 4). The West Coast has by far the largest number of shipping transits, but the majority of these are non-petroleum product cargoes. However, the transport of

TABLE 4.
Cargo handled by Canadian ports, December 1978

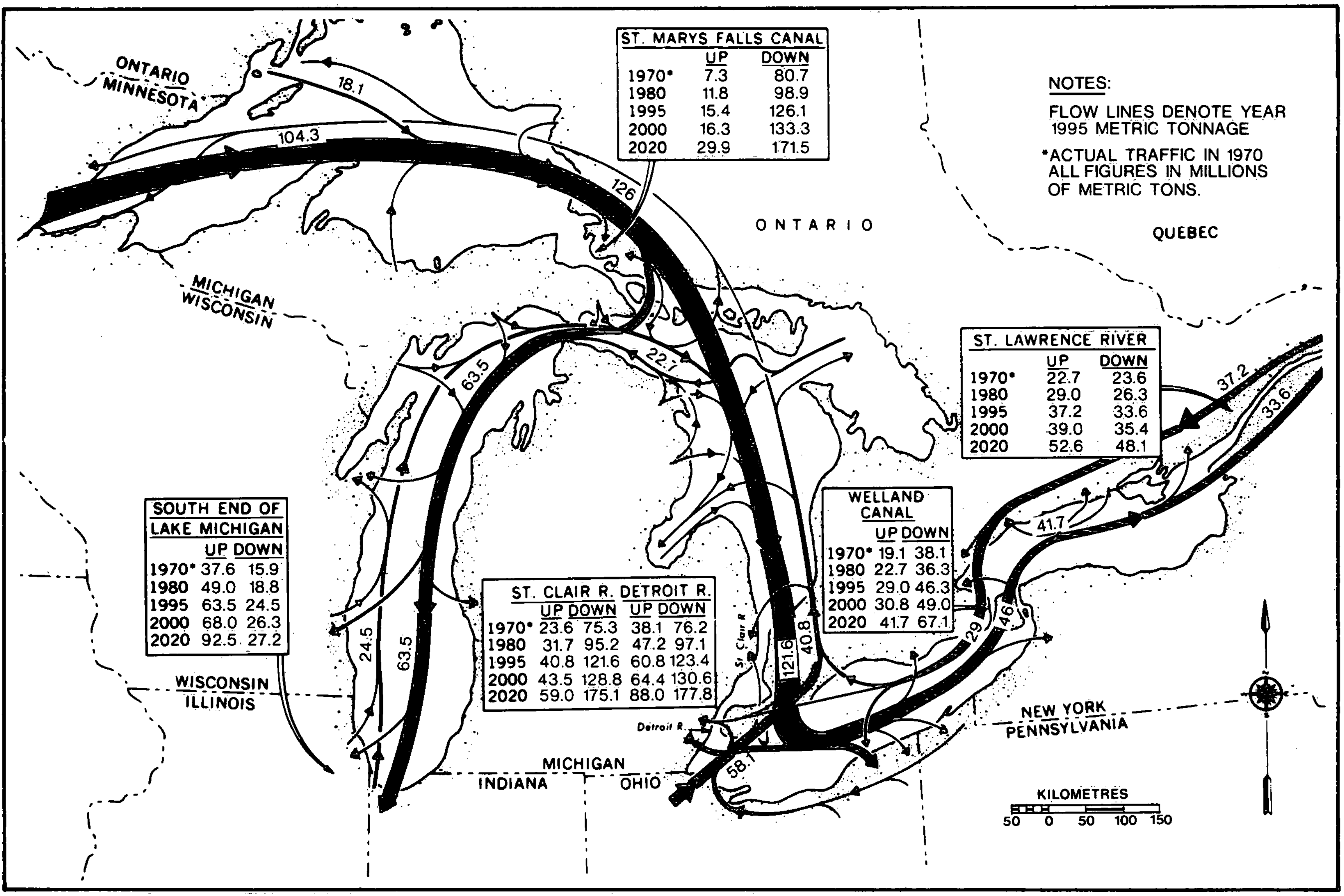
	Atlantic and Arctic	Quebec	Ontario	British Columbia
Total cargo (t)*	7 726 657	10 327 414	7 718 798	5 620 033
Total crude or petroleum and refined products (t)	5 895 333	1 529 393	591 565	265 028

* Total cargo includes crude and refined products.

Source: Statistics Canada, 1979.

MAP 1.

Projected total traffic flow, 1995



ST. MARYS FALLS CANAL

	UP	DOWN
1970*	7.3	80.7
1980	11.8	98.9
1995	15.4	126.1
2000	16.3	133.3
2020	29.9	171.5

NOTES:

FLOW LINES DENOTE YEAR 1995 METRIC TONNAGE

*ACTUAL TRAFFIC IN 1970 ALL FIGURES IN MILLIONS OF METRIC TONS.

ST. LAWRENCE RIVER

	UP	DOWN
1970*	22.7	23.6
1980	29.0	26.3
1995	37.2	33.6
2000	39.0	35.4
2020	52.6	48.1

SOUTH END OF LAKE MICHIGAN

	UP	DOWN
1970*	37.6	15.9
1980	49.0	18.8
1995	63.5	24.5
2000	68.0	26.3
2020	92.5	27.2

WELLAND CANAL

	UP	DOWN
1970*	19.1	38.1
1980	22.7	36.3
1995	29.0	46.3
2000	30.8	49.0
2020	41.7	67.1

	ST. CLAIR R.		DETROIT R.	
	UP	DOWN	UP	DOWN
1970*	23.6	75.3	38.1	76.2
1980	31.7	95.2	47.2	97.1
1995	40.8	121.6	60.8	123.4
2000	43.5	128.8	64.4	130.6
2020	59.0	175.1	88.0	177.8

Source: Adapted from Great Lakes Basin Commission, 1975.

crude and refined products is an important component of the shipping industry in the Atlantic region of Canada. A third element of traffic patterns associated with marine accidents is the character of the water body over which the cargoes are carried. Vancouver and New Westminster are the busiest ports in Canada in terms of the total number of transits, and the adjacent coastal waters are characterized by numerous narrow straits. By contrast, the approaches to Halifax are open ocean with no navigational hazards except within the port area itself. Navigation risks are high, owing to the physical confinement of straits or channels, in:

- Strait of Juan de Fuca and Georgia Strait
- Sault Ste. Marie
- St. Clair River
- Welland Canal
- St. Lawrence River and Seaway

The data on Great Lakes traffic patterns are given in Map 1 and Table 5.

The sensitivity of coasts can be defined in terms of the potential impact of the spill on the biological and human activities of the area. It can be assessed in terms of distribution of high-productivity habitats, of rare, threatened, or endangered species, and of the density of human activity in the coastal zone. The Fraser River and Mackenzie River deltas are prime examples of areas where the impact of an oil spill on the coastal ecosystem could be very severe. By contrast, many sections of the coasts of Labrador or Newfoundland, which are predominantly rocky shores with few marshes or productive habitats, would probably be considered areas of low sensitivity. Where the shore zone is occupied or used by man, the consequences of an oil spill are likely to be serious.

TABLE 5.
Total traffic through man-made channels

Channel	1960	1970 (number of vessels)	1980
Sault Ste. Marie	22 151	12 712	19 200
Welland Canal	7 536	6 768	6 900
St. Lawrence Seaway	6 869	5 936	7 100

Source: Great Lakes Basin Commission, 1975.

Each spill is essentially unique in its character and effect so that to analyse the sensitivity of a shore zone requires the consideration of a number of characteristic variables. The most sensitive sections of Canada's coasts are mainly those that are areas of significant human activities and subject to dense marine traffic.

Size—frequency distribution of spills by amount

Reliable statistics on the location and size of oil spills are limited to the data base available from NATES (National Analysis of Trends in Emergencies System). This system was established in 1972; before the mid-1970s information on individual spills is usually missing, and where available is often sketchy. Many small spills go unreported, so that an analysis of spill frequency and distribution is biased against spills less than 1 t. Table 6, based on the 454 marine spills that were reported to NATES between 1976 and 1980, indicates that the majority of spills (85%) were less than 50 t in size. If all the small spills that were not reported are considered, this percentage would probably be greater.

Between 1970 and 1980, seven major spills (500 t or greater) occurred in Canadian waters: four from tanker accidents, two from other ship accidents, and one from a tank farm (Table 7). All these spills caused extensive oiling of the shore zone except for the LEE WANG ZIN, although the oil from this spill was stranded on the coasts of Alaska. Of the 19 spills listed in Table 7, six are related to tanker accidents, four to spills from onshore facilities, and the remaining nine resulted from other ship accidents. Considering all reported spills (Table 6), it is evident that approximately one-eighth are related to onshore facilities and one-quarter result from tanker accidents; the remainder result from accidents or transfers associated with bulk carriers.

TABLE 6.
Marine spills in Canada, by size and source, that were reported to NATES for the years 1976–1980

Mass (t)	(i)*	(ii)	(iii)	(iv)	Total
0-5	94	139	108	40	381
5-50	13	9	14	10	46
50-500	7	5	5	6	23
> 500	3	1	—	—	4
Unknown	—	—	—	—	10
Total	117	154	127	56	464

* (i) tankers; (ii) bulk carriers discharging their own fuel; (iii) other watercraft discharging their own fuel; (iv) marine terminals.

Source: NATES, unpublished.

TABLE 7.
Partial list of major Canadian spills, 1970–1980

Approx. spill size (t)	Ship/source	Location	Type of spill	Year
10 000	ARROW*	Chedabucto Bay, N.S.	bunker C	1970
7 130	KURDISTAN*	Cabot Strait, N.S.	fuel	1979
1 300	tank farm	Deception Bay, Que.	diesel, gas	1970
1 100	NEPCO 140*	St. Lawrence River	fuel	1976
1 100	LEE WANG ZIN	Dixon Entrance, U.S.A.	fuel oil	1979
840	CANSO LIGHT*	Canso Strait, N.S.	fuel	1979
500	WILLIAM CARSON	Square Island, Nfld.	diesel	1976
400	VANLENE	Barkley Sound, B.C.	bunker B, diesel	1972
387	RICHMOND RED*	Dees Island, B.C.	fuel	1977
331	marine terminal	Gaspé, Que.	fuel	1979
305	marine terminal	Chicoutimi, Que.	fuel	1980
300	CARITA	Cape Breton, N.S.	bunker	1975
250	OSTROV RUSSKIY	Grand Banks	fuel	1978
240	freighter	Burrard Inlet, B.C.	bunker	1973
234	JOHN A. MCDONALD	Beaufort Sea	fuel	1978
230	IMPERIAL ST. CLAIR*	Parry Sound, Ont.	fuel	1976
200	IRISH STARDUST	Alert Bay, B.C.	fuel oil	1973
204	marine terminal	Marystown, Nfld.	fuel	1977
200	SANDINO	Tracy, Que.	fuel oil	1978

* Indicates a tanker spill.

Source: NATES, unpublished and other unlisted sources.

Size—frequency distribution of spills by area

A regional analysis of coastal spills reported to NATES for the 5-year period 1976–1980 indicates the predominance of both onshore and offshore accidents in the Atlantic – St. Lawrence River area (Table 8). This distribution is not too surprising considering the character of the shipping and transportation industry in this region. Crude oil or petroleum products are a major component of the shipping trade, because most petroleum products used in Eastern Canada are imported by sea. By contrast, Ontario and B.C. are supplied by overland transportation systems. In terms of large spills (Table 7), the Atlantic – St. Lawrence River region again has the highest number, two-thirds, of shipping and onshore accidents.

The high number of reported spills for the Quebec region can be attributed, in large measure, to the efficiency of the reporting system, and the high degree of pollution control exercised in the St. Lawrence Seaway and St. Lawrence River. The data for the area are undoubtedly accurate, and probably reflect the true number of spills better than the records for other coastal areas.

Although the high-risk areas, based on traffic density and navigation restrictions, initially appear to be the West Coast and Great Lakes, as discussed in an earlier section, the recorded spill incidents show that the St. Lawrence River and east coast waters have a history of both more frequent and larger spills.

TABLE 8.
Geographical distribution of coastal spills, 1976–1980

Province	Number of spills	Proportion of total spills (%)	Length of coast (%)
British Columbia	44	9.5	10.1
N.W.T. and Yukon	29	6.2	64.4
Labrador	5	1.1	6.0
Newfoundland	33	7.1	5.3
Nova Scotia	43	9.3	3.0
New Brunswick	34	7.3	0.9
Prince Edward Island	5	1.1	0.5
Quebec: Hudson Bay	0	0	3.4
Quebec: Gulf of St. Lawrence	217	46.8	2.0
Ontario: Hudson Bay	0	0	0.5
Ontario: Great Lakes	38	8.2	3.7
Manitoba	0	0	0.3
U.S.A. (St. Lawrence River)	6	1.3	0
Others*	10	2.1	0

* 10 offshore spills on the Pacific and Atlantic coasts did not affect the shoreline.

Source: NATES, unpublished.

TIME

Changes in the potential for stress

The increasing use of petroleum and petroleum products has resulted in an increase in the threat from coastal oil spills. Before 1971, only 10 wells were drilled offshore on the Atlantic coast of Canada, compared to 133 between 1971 and 1980. The pace of exploration in this region and in the Arctic has increased dramatically over the past 5 years. Similarly, the volume of marine traffic and the size of ships carrying crude oil has also increased. Projections of traffic flow for the St. Lawrence River suggest that tonnage has increased by 20% between 1970 and 1981 and that the present level is likely to double by the year 2020 (Great Lakes Basin Commission, 1975). Hence, the potential for stress as a result of oil spills is ever increasing.

Increased marine safety brought about by regulations or by traffic control can alleviate some of the potential threat, but it is unlikely to reverse the general trend. Data on numbers of accidents and spills have only become reliable in the last 5 or 6 years, so that there is no quantitative measure of the changing frequency of coastal spills. The size of ocean-going petroleum tankers has increased dramatically since the mid-1960s (Table 9), so that the potential size of spills from tanker accidents is now much greater. The first major marine spill over 100 000 t was from the TORREY CANYON in 1967. Since that date, the AMOCO CADIZ and the IXTOC I have caused even greater spills. On a global scale, in 1979 alone there were 14 marine accidents that resulted in oil spills of more than 4 500 m^3 each (Oil Spill Intelligence Report, 1980).

Changes in the perception of spill impacts

Industrial development proceeded largely unimpeded by environmental regulations until the 1960s. This situation changed as public awareness of the environment focused on a variety of ecological issues. This awareness developed with the massive oil spills from the TORREY CANYON wreck in Europe and from the Santa Barbara blowout in California, both of which took place in densely populated areas, and both of which received much media attention. Television or film coverage of marine accidents can be dramatic, and lends considerable sensationalism to spills that result from ship collisions or groundings. Daily news coverage of the AMOCO CADIZ spill brought images of that event into almost every home in Europe and North America.

The primary sources of hydrocarbons in the coastal zone are not spills but runoff, the atmosphere, and coastal waste discharges (Table 10). However, oil spills are generally viewed as "disasters" by the public and by environmental groups and therefore receive greater attention. This reaction is largely based on the grim drama of a marine accident and on the visual impact of large volumes of oil on the sea or the shore. Attention is usually focused on the obvious effects, for example on bird kills, so that any major incident assumes the proportions of a severe ecological disaster, whatever the actual long- or short-term environmental stress. Shipwrecks and storms hold a grim fascination that is heightened by the "black tide" that is produced at the shore.

TABLE 10.
Summary of petroleum hydrocarbons introduced into the oceans

Cause	Amount (10^6 t)
Natural seeps	0.6
Offshore production Transportation Coastal refineries	2.413
Atmosphere River/urban runoff Coastal waste discharges	3.1

Source: National Academy of Sciences, 1975.

Despite the public's perception of spills, the most frequent type of accident involves relatively small volumes of oil. The establishment of pollution control regulations and the development of countermeasure training and resources by governments and industry have, in some degree, increased the awareness of spills and their impacts within the industrial sector. These regulatory, training, and response activities do not usually receive much public attention, but have been instrumental in the development of a better level of preparedness for dealing with both large and small spills than existed even 5 years ago.

TABLE 9.
Increase in the size of ocean-going tankers

Year	< 50 000	50 000–200 000 (tonnes deadweight)	> 200 000
1950	308	1	–
1965	274	386	–
1974	293	142	344

Source: Wardley-Smith, 1976.

STRESS ON LAND

Oil-related stress on land

Biological

The stresses on the biological environment are related to the volume of stranded oil, the type of oil, the oceanographic conditions, the time of year, and the biophysical character of the coastal segment affected. It is not possible, therefore, to define simply a level of stress that can be related to all spill situations. Even in the case of the TORREY CANYON, where over 14 000 t of weathered oil and 10 000 t of toxic dispersant were spread over 150 km of coast in western Cornwall, re-colonization of the coastal zone began within weeks of the spill, and the general pre-spill character was re-established in most areas over a 10-year period. Recovery from such major events is slow (Southward and Southward, 1978). The recovery rates of different environments following the stress imposed by an oil spill range from periods of less than a year to greater than 10 years (Thomas, 1977). The initial stress is often severe, with many animals or other organisms being killed by smothering, ingestion, or respiration of the toxic components of the oil. Within the intertidal zone the primary stress usually results from smothering caused by the surface coating of the organisms. Oil that reaches the shore zone is weathered to a certain degree; the lighter hydrocarbon fractions have usually evaporated and toxicity levels are generally not high.

Oil-related stresses are usually greatest in areas of highest biological productivity, for example in estuaries and marshes. These habitats are spawning or nursery areas, where the tolerance level of organisms at various stages of growth can be much lower than in other, more exposed environments. Estuaries and marshes are low-energy environments, in terms of waves and currents, so that the expected persistence of oil is greater than on exposed coasts. The slow dispersal of oil in these habitats means that the organisms are exposed to the stress caused by the spill for a longer time; many of the larval and juvenile forms are particularly susceptible to oil toxicity.

On exposed coasts, that is coasts where there is continuous wave action, population density of intertidal organisms is generally low for sandy or cobble shores but high on rocky substrates. On sediment coasts the low population density is a result of the high levels of mechanical energy that continuously redistribute the sands and cobbles. The most stressful components of petroleum are probably the soluble fractions (National Academy of Sciences, 1975), which are mostly introduced into the coastal zone from land-based spills. Spills at sea weather, and the soluble fractions are dispersed throughout nearshore and ocean waters, and the atmosphere.

A key element in terms of biological stress is the timing of a spill. The presence of toxic components in the shore zone and shore waters, or the smothering action of stranded oil, can have very different effects in the winter months, when many species are dormant, from those during spring growth and spawning periods, when the stress on both the habitat and the organisms can be extremely high. Similarly, the species makeup and population structure of a habitat may change dramatically during the year. A migratory species may utilize a coastal marsh in lower latitudes for only a few days or weeks each year, and may nest and rear their young in an arctic coastal marsh for several weeks during the short summer months. A spill in the breeding areas will have very significant effects on the reproduction of the species. Conversely, a spill when the arctic marsh is not occupied by the migratory waterfowl will clearly have a much lower impact and present less stress to the local ecosystem.

Stress is greatest in environments where the oil spill concentrates in a relatively confined area, such as a marsh or an estuary. In terms of toxicity, stress is greatest from refined oils such as number 2 fuel oil, and in terms of physical smothering, is most severe with viscous crude oils or heavy bunkers such as Bunker C. The same type of oil could also have very different effects on different organisms. For example, marsh plants can survive even after several coatings of a fresh or weathered crude oil, whereas some bird species or sessile organisms may be killed by a single coating. Oil spills have the most severe impact on animals when the oil is ingested or enters the oral chambers. However, oiling does not necessarily incapacitate an animal, and the presence of visible oil on the animals skin does not invariably pose a serious threat to the organism's well being (Photo 6).

Photo 6. Seal partially coated with oil, Sable Island, Nova Scotia.
E.H. Owens

The shorebirds that tend to be most affected by oil spills are waders or those that spend most of their time on the surface of the water and dive to collect their food. In particular, murres, guillemots, razorbills, and diving seaducks are usually those most susceptible to spills on the surface of coastal waters. At the shore zone, waders such as herons may be vulnerable as oil is washed into marshes or intertidal flats, but most shorebirds are unaffected by spills.

Man's activities

The stresses placed on man's activity in the shore zone are largely related to subsistence or commercial enterprises, such as the harvesting of shellfish or commercial fisheries. The other effects of oil spills on man are related to the aesthetic degradation of the physical environment and the inconvenience that tar residues on beaches may cause. Tar balls or layers of oil on beaches can clearly affect the recreational use of the shore zone. Commercial activities associated with recreation, such as restaurants or accommodation facilities, can be severely affected. In some areas the coast itself is a primary local industry, for example the north shore of Prince Edward Island, and a spill there during the early or mid-summer months would have a profound effect on the recreational use of the area and its associated commercial activities.

Nearshore fisheries and the harvesting of shellfish, either for subsistence, recreation, or commercially, can be seriously affected by the presence of large volumes of oil in the shore zone. In addition to the effects that the oil may have on the organisms themselves, it can spoil nets, traps, and other equipment. It is possible to clean this equipment but loss of time is an important factor in assessing the effects of the oil on man's activities.

Oil spills can in some instances pose a threat to human health and safety. In particular, spills of refined distillates could result in fire or explosions or both before the light fractions of the oil evaporate. Water intake for commercial or industrial purposes can also be affected by spills, and would probably have to be curtailed to prevent damage to equipment. Intakes for water-cooling systems, fish plants, or desalination plants are examples of this.

The primary effect of oil spills on human activities is the loss of subsistence resources or commercial activities. The loss of a shellfish area may not initially appear consequential to the economy of an area. However, where one or two families depend commercially on this resource, the effect may be locally severe. Although the habitat and its organisms may recover after several years, their temporary loss will result in a change in the activities of those who previously depended on them.

Comparison with natural perturbations

Coastal-zone species are usually extremely tolerant, owing to the harsh environment in which they live. The immersion and exposure caused by changing tidal water levels, and associated changes in salinity and radiant heating, make the intertidal zone itself a very stressful environment. There are significant daily and seasonal changes in the character of shorelines composed of sediments as a result of the reworking and redistribution of the sediments by wave action. The coastal zone is therefore one of high stress levels, both ecologically and physically. On a global scale and over long periods, oil spills do not pose a permanent threat to the quality of the environment. Desertification, the bio-accumulation of metals, and acid rain are more serious and widespread problems than those associated with oil spills.

Spills can be viewed as detrimental local events from which the environment will recover in time, even though this recovery may take more than a decade. Spills can cause a significant disturbance of the ecosystem and of human activities in an area. Usually, however, the range of stress is well within that of the natural perturbations that might be expected in any area. Mechanical or thermal stresses, for example tsunamis or prolonged hot or dry periods, can result in longer term damage to ecosystems. Although the word "recovery" is usually used rather loosely with regard to oil spills, many studies show that marshlands and estuaries can recover from a single spill in a matter of 2 years or less. As the size of the spill increases, or as the frequency of spills at the same location increases, so the capability of recovery is less and must be expected over longer time periods. Cole (1979) notes that in northwest Europe the effects of the severe winter of 1962–1963 in the North Sea and English Channel were much more serious and widespread, and lasted for much longer, than the changes caused by the pollution from the TORREY CANYON oil spill.

There are no universally accepted or applicable standards by which to measure the effects of either natural or man-made disasters. Political and social values alter with time and with location, so that an assessment of damage done is not necessarily a reflection of the ecological change suffered by the environment.

Cleanup and the stress on land

Biological

The possible effects on biological systems of cleaning up an oil spill have been described by Foget *et al.* (1979) as follows:

- removal of biota with the substrate or as a consequence of cleanup effects
- extension of toxic effects because of cleanup-induced recontamination
- habitat disruption by equipment, technique or personnel
- crushing of organisms with manual methods or heavy machinery
- disturbance of organisms due to noise or activities associated with heavy equipment and/or large numbers of people.

The level of stress imposed on a biological system by a cleanup is largely a function of the initial population density, the types of species present, the total area affected by the cleanup operation, and the seasonal timing.

Certain cleanup techniques, such as high-pressure hoses, steam cleaning, or sandblasting, can remove all existing species from bedrock or hard substrates. Sediment removal from marshes or other vegetated sections of shoreline can also result in severe disruption of the habitat and the physical removal of those species present. Clearly the use of heavy machinery in marshes will have a harmful effect, by crushing the species and by disturbing the habitat itself. In many instances such cleanup operations can result in more damage than was caused by the oil itself, if the appropriate techniques are not employed correctly or if inappropriate techniques are selected for particular locations or shoreline types. In marsh environments, there are suitable alternative approaches that can be

TABLE 11.
Summary of marsh-cleaning techniques

Marsh cleaning techniques	Situations for use of technique	Environmental impact of technique
Low-pressure water flushing	Preferred method: use in small channels; around clumps of plants and trees; on vegetation along channel banks and shorelines.	Minimal impact: some crushing of marsh plants if flushing is done from land.
Sorbents: loose, pads or rolls	Loose sorbents: use in small channels, or pools with low currents. Pads or rolls: use in open shallow pools and on shorelines without debris accumulations.	Loose sorbents are difficult to retrieve and can crush marsh grasses.
Oleophilic endless-rope skimmers	Preferred method: use in open channels or pools with free-floating oil; upstream from containment booms and along marsh shorelines.	Minimal impact.
Vegetation cutting and removal (use only when flushing—will not remove oil from plants)	Hand cutting: on vegetation in small channels. Mechanical cutting: along banks of channels or shorelines.	Damages marsh surface. Foot traffic damages plants.
Burning*	Use in large contaminated areas. Can use if oil will burn. Probably suitable when marsh is in die-back stage.	Considerable air pollution from smoke. Can burn uncontaminated areas.
Soil and vegetation removal	Use when toxic and persistent oils have deeply contaminated substrate.	Major impact: destroys marsh areas. Requires complete subsequent restoration.

* For use on spartina-type (grass-like) marshes only

(after Maiero *et al.*, 1978).

successful in removing the contaminant without severe disruption of the habitat or the ecosystem (Table 11) (Maiero *et al.*, 1978; Cejka, 1975; Vandermeulen and Ross, 1977).

The deployment of equipment and personnel through the dunes should be carefully controlled on coasts where backshore sand dunes have been stabilized by vegetation. Destruction of the dune-grass root system can result in destabilization of entire dune systems through the formation of blowouts caused by wind transportation of the sand-sized sediments. When this happens, access to the shore zone should be carefully controlled to minimize potential damage, and mats or boards should be used where possible to avoid destruction of surface grass-root systems.

The use of chemicals to disperse oil in the shore zone is usually prohibited, as the dispersants, generally applied in relatively large dosages in order to be effective, have often been more toxic than the oil that has been spilled. A concentration of these chemicals in small areas usually results in significant stress and change to the habitat and to the organisms. Although this technique was used in the late 1960s and early 1970s, it is now rarely considered for the treatment of coastal oil spills.

The effects of cleanup operations are generally not significant to the natural environment provided that recommended procedures are followed (e.g. Maiero *et al.*, 1978; Foget *et al.*, 1979), and will generally be a lot less significant than those caused by the oil spill itself, if no major changes in habitat character result from the countermeasures. However, habitat changes in marshes or dunes as a result of the movement of equipment or personnel through the area can cause destruction of the vegetation and irreversible changes to the biophysical environment.

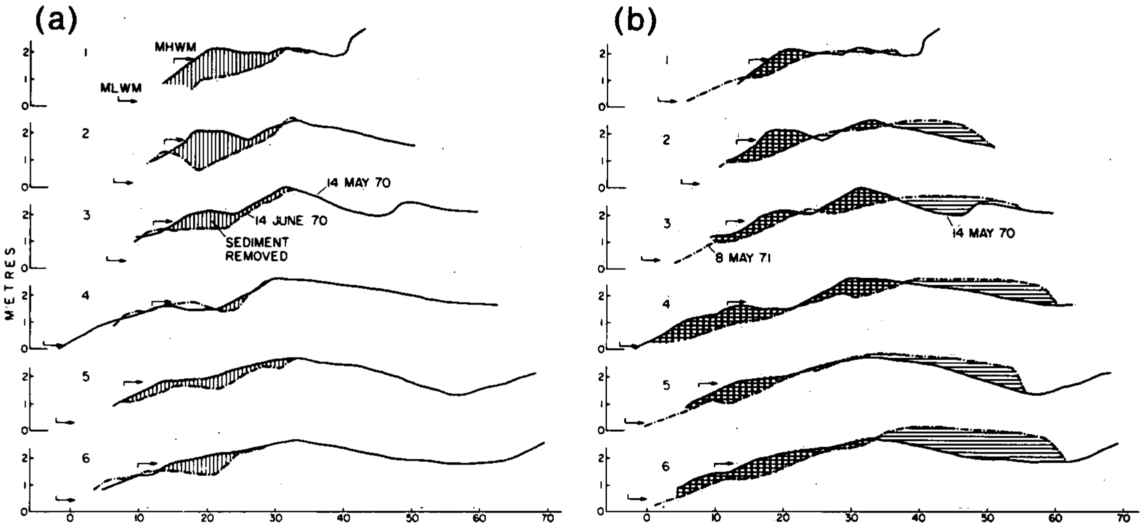
Geological

Shoreline cleanup operations that involve the removal of contaminated sediments and oil can cause damage if large volumes of material are removed from small sections of beach. Such removal often results in landward movement, or retreat, of the beach unless there is a natural replenishment of sediments removed by the cleanup operations. Owens and Drapeau (1973) documented a 20-m beach retreat during the 12 months that followed large-scale removal of oil-contaminated sediments in Chedabucto Bay in 1970 (Figure 1).

Beach erosion is particularly significant in areas that are backed by unstable or unconsolidated cliffs. On this type of shoreline the beach acts as a natural buffer to wave action, and removal of the sediments that constitute this buffer exposes the base of the cliffs to erosion. As a result, accelerated cliff erosion can occur until sufficient material has been eroded from the cliff to renew the protective wedge of beach sediments.

FIGURE 1.

A sequence of profiles across the beach at Indian Cove, Chedabucto Bay, Nova Scotia



The first set of two profiles in (a) are the beach before (14 May 1970) and immediately following (14 June 1970) sediment removal during a cleanup programme. A subsequent survey (b) one year later (8 May 1971) illustrates the retreat of the beach crest. The horizontal shading indicates areas of net sediment gain, the cross-hatching indicates net sediment loss.

MHWM Mean high watermark
MLWM Mean low watermark

Source: Owens and Rashid, 1976.

Man's activities

Spill countermeasures rarely have an adverse effect on man's activities. The cleanup operations require the hiring of personnel and equipment, accommodation rental and other expenses, and an increase of activity in the area affected. The only adverse effect of the cleanup might be the neglect or temporary suspension of other activities. In the event of a major coastal spill at a port, shipping activities may be curtailed or diverted to permit the cleanup to continue unimpeded. The use of booms in rivers, ports, or estuaries is usually avoided if this involves closure of the entire entrance, thereby preventing normal use of the channel.

Following the NEPCO 140 spill in the St. Lawrence River delays to shipping operations cost an estimated $171 500 U.S. (Palm *et al.*, 1979). Forty-two ships were delayed for a total time of 393 hours.

Public perception of the effects of coastal oil spills on man's activities is usually worse than the actual delays or damage that are caused. Inconvenience and loss of recreation activities are usually the most significant effects of a spill rather than actual loss of income or suspension of commercial endeavours. In the NEPCO 140 example, which occurred in mid-summer in a popular recreation area, an estimated 37 400 recreation days were lost by seasonal and permanent residents following the spill—an average of 5.5 days per person for the individuals surveyed (Palm *et al.*, 1979).

Local and logistic support facilities may be taxed beyond their normal capacity for the duration of the cleanup operation, but this would be unlikely to have a serious effect on human activities.

CASE STUDIES

Adverse effects of spills

Physical

The physical effect of oil spills on the land is primarily to coat surficial material and vegetation. This contamination is in most cases limited to the upper intertidal zone. If a spill occurs during periods of storm surges or above-normal water levels, then the oil can be stranded on the higher parts of the shore zone, and occasionally on adjacent backshore environments. The extent of contamination is generally limited to the fringe of land adjacent to the water line (Photo 7). The actual character of the shore zone affected by the spill will vary from site to site because shoreline types vary regionally and locally, depending on geology, sediment supply, and wave action. In Chedabucto Bay, which was affected by the ARROW spill in 1970, 30% of the shore zone was composed of sand or pebble–cobble beaches on exposed coasts. A further 25% comprised low-energy shorelines of poorly sorted sediments, and 25% was made up of either bedrock or boulder coasts.

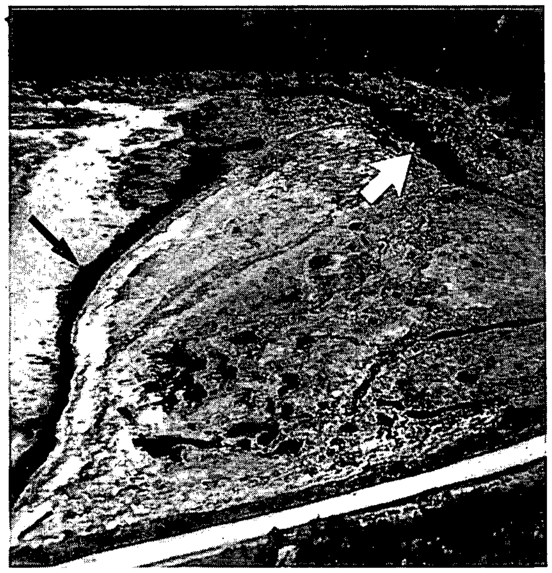


Photo 7. Oil (indicated by the arrows) trapped in a creek and against the marsh edge at high tide, Miguasha, Baie des Chaleurs, October 1974, following the spill from the GOLDEN ROBIN. The spill took place at a period of normal water levels (cf Photo 3).
E.H. Owens

The only significant effect that oil has on the physical environment occurs on beaches of gravel (sand–pebble–cobble) material. In these locations, heavy weathered oils can produce an asphalt pavement (Photo 8). This layer of oil and sediments generally forms in low wave-energy environments where there is insufficient mechanical energy to break up the oil. An asphalt pavement is usually a durable, continuous feature, in which all the surface sediments are immobilized by the presence of the oil. The only effect that the pavement has on shore-zone processes is that the impervious hard layer allows waves to run farther up the beach. Normally, during uprush, some part of the waves will infiltrate into beach sediments, thus slowing down the momentum of the swash. With the loss of this permeation, the landward movement of the swash is enhanced. However, this is rarely important in terms of total shoreline processes. Asphalt pavements, because they form in low-energy environments, can be expected to persist for periods of several years, sometimes more than a decade.

The ARROW oil spill in Chedabucto Bay affected approximately 200 km of shoreline (Maps 2 and 3). Only about one third of this area remained oiled 3 months after the spill, due primarily to natural cleaning by wave action. Three years later in 1973, the oil cover was reduced to a patchy distribution that was restricted to low-energy lagoons and estuaries (Owens and Rashid, 1976). By 1976, 6 years after the spill, a shore survey found only traces of stranded oil in the low-energy locations (Vandermeulen, 1977). In terms of actual self-cleaning, Vandermeulen estimates that 75% of the heavily oiled shorelines were naturally cleaned within 3 years, and only 5% remained visibly oiled by 1977, after 7 years. The estimated half-life of the stranded Bunker C oil at this location was 1½ to 2 years, although the expected half-life of oil that remained beyond this period would probably be in the order of 10 or 20 years.

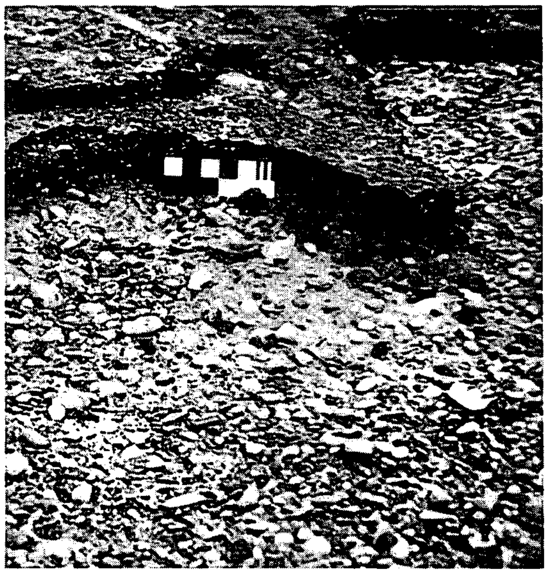


Photo 8. Erosion along the edge of an oil "pavement", south shore, Straits of Magellan, January 1977, in a sheltered environment with a mixed sand–pebble beach, 2½ years after the spill.
E.H. Owens

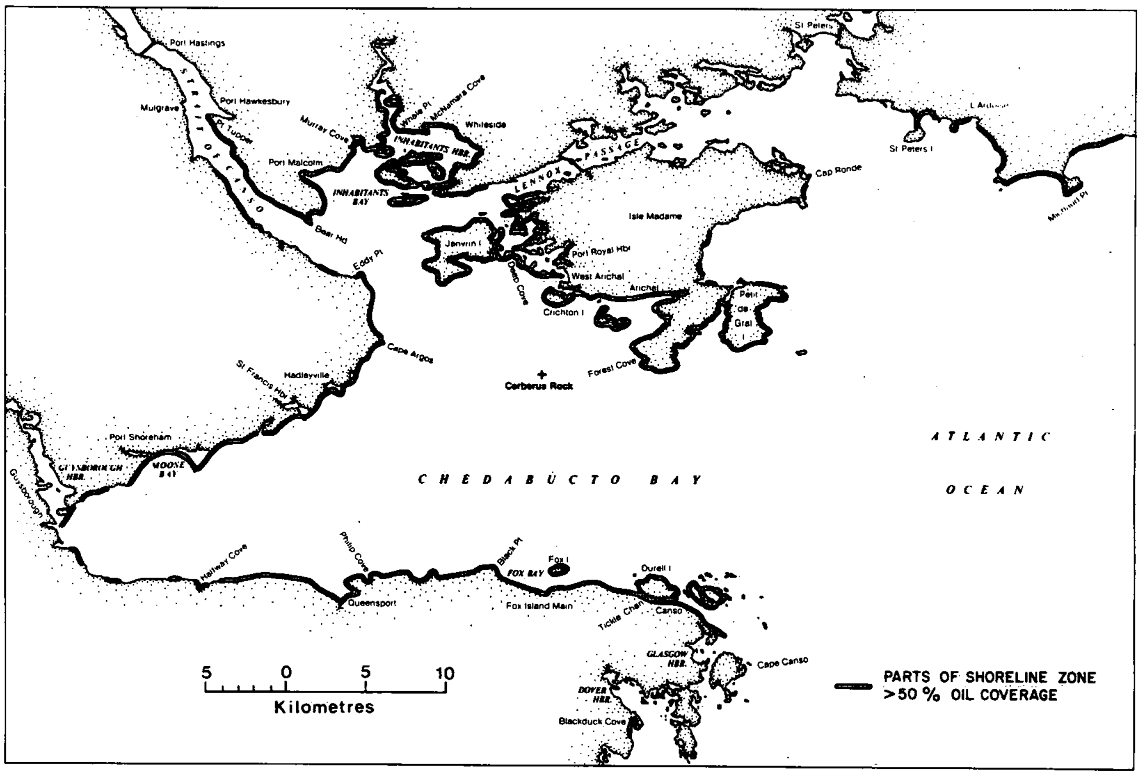
Land use

The primary effects of spills in the coastal zone are on the recreational use of the shore. Human exploitation of intertidal populations is generally restricted to shellfish. More important are the secondary effects on the coastal ecosystem that relate to its use as habitat for spawning or nursery areas for commercial or recreational species harvested elsewhere. The potential recreational use of the shore zone—bathing, walking, fishing, hunting, and boating—are not primary activities that affect the local economy to any large degree, except in certain circumstances. For example, a spill in a shore location that depends on recreation and tourism, such as Prince Edward Island, would be a major stress event.

The NEPCO 140 Spill took place during early summer in a part of the St. Lawrence Seaway that is both a high-density population area and

MAP 2.

Distribution of oil residues in the shore zone, spring 1970, following the ARROW spill in Nova Scotia

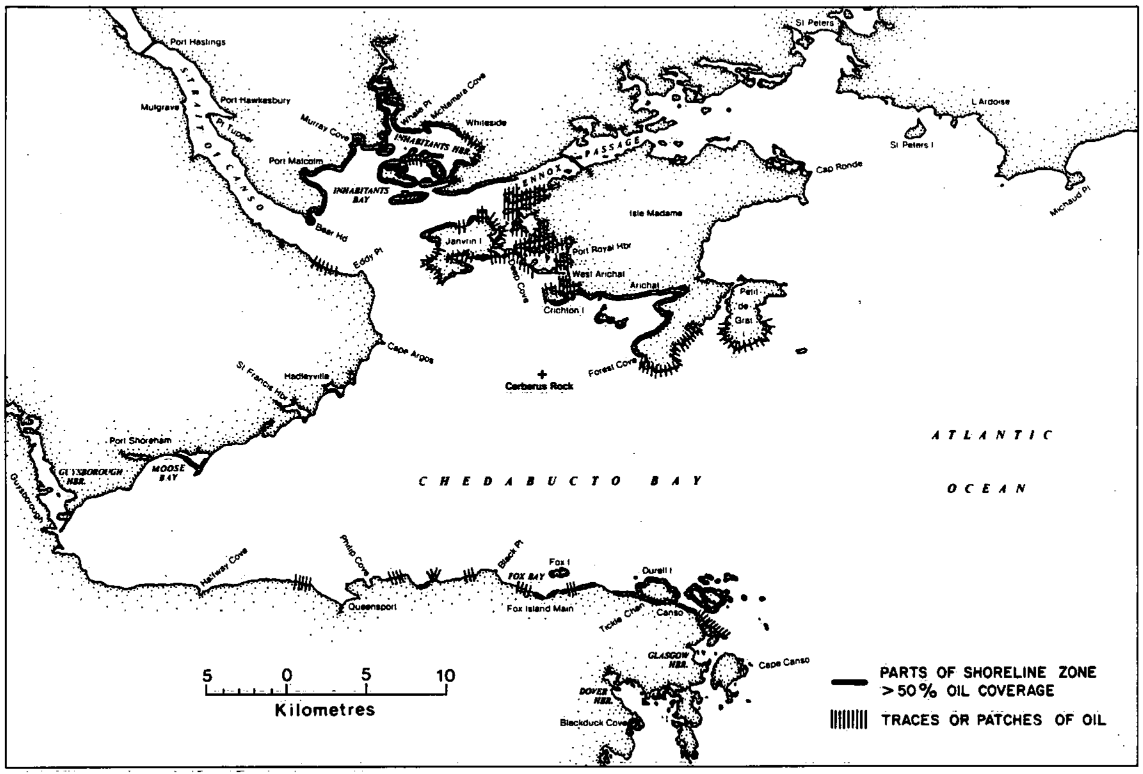


This map represents a compilation of all locations where oil was observed between March and June 1970, and indicates the maximum extent of oil distribution in the shore zone.

Source: Owens and Rashid, 1976.

MAP 3.

Oil residues in the shore zone, October 1973, from aerial observations



Source: Owens and Rashid, 1976.

a prime recreational area of Ontario and New York. The spill could not be controlled, due to fast currents, and as a result, extensive sections of shoreline were contaminated by the spilled oil. Much of the shore-zone character was marshy, a productive environment for both fish and waterfowl.

Detailed studies of the impact of the NEPCO 140 spill (Palm *et al.*, 1979) indicated there were no significant adverse effects on either fisheries or waterfowl populations. In fact, in some cases there was a noted increase in population. A significant effect of this spill was to curtail recreational activities. The impact assessment survey (Palm *et al.*, 1979) indicates that permanent residents lost an average of 8 recreational days per person and that seasonal residents lost an average of 4.4 days. Many people did not use their seasonal homes in the area because of the spill, and the number of visitors to the area was also reduced. Other adverse impacts included the presence of smells, the inability to travel to and from the mainland (because of cleanup operations), effects of the spill on water supplies, and the problem of children getting into the oil. Some commercial activities, such as guideboats, tour boats and marinas, either noted no change or had an increase in activity. Sales of gas, oil, and other supplies for marinas decreased during the spill, but this may have been a result of the cool, rainy summer as much as of the oil spill. A reduction in hotel and motel occupancy, in the order of 10%, could also be attributed to either the spill or the weather. In some cases, hotel or motel occupancy was not significantly altered during the year of the spill. Cancellations and reduced occupancy in some areas were offset by the presence of cleanup personnel.

A large number of the municipalities on the shores of the St. Lawrence use the river as a water source. Following the NEPCO 140 spill, no systems were forced to change their mode of operation, although the spill did cause some discussion about the use of alternative sources. Some delay of shipping in the St. Lawrence Seaway was caused by the spill, with 42 ships being delayed for a total of 393 hours. The region has a large number of private, state and provincial parks, some of which showed increases in attendance, whereas a few noted a decrease. Local employment suffered to some degree as a result of the spill. In the hotel and motel sector, a decreased employment in the order of 70 work weeks was attributed to the spill, but this was offset by the fact that over 800 people were employed during the cleanup operations.

It can be seen that the effects of this large spill were extremely varied, in some cases being positive and in others negative. The main conclusion is that although the spill took place in a highly populated and recreational area it caused no significant change in economic activities, either in the short or long term.

The closure of industrial operations, such as the power-generating stations and desalination plants that were threatened by the HASBAH 6 blowout in the Arabian Gulf, are not of primary concern to human health and safety in Canada. Water intakes for industrial or commercial enterprises do exist, but they are on isolated sites where shoreline protection by the use of booms could be effective in preventing closure of the operations.

Land value: visual and aesthetic changes: permanent effects

The examples of the ARROW and NEPCO 140 spills, the former having been reviewed in terms of the persistence and distribution of stranded oil and the latter in terms of the economic impact on the shore zone, indicate strongly that the stress associated with coastal oil spills is generally limited in time, and that the effects are neither permanent nor critical to human activities.

The ecological productivity of an area can be altered by the presence of stranded oil in the coastal zone. In some instances the productivity may increase, for example, in terms of the nutrient supply to the shore zone. In other instances species may be fatally affected and recovery times may be in the order of years or occasionally decades. Visual and aesthetic impacts from oil spills are usually severe immediately following the accident. However, except in very sheltered low-energy environments, shore zones generally clean themselves naturally by mechanical wave action within 1 or at the most 3–4 years following the spill.

There are no documented incidents of an oil spill that has caused irreversible damage to the shore zone. In a few localized instances, cleanup activities have resulted in beach erosion or alteration of habitat on sections of coast less than 1 km in length. These few minor examples are not considered serious in terms of regional land use or shore-zone stability. In summary, the effects of oil spills are generally short-term, and may be severe but for only limited periods. The impacts are rarely long-term and are not permanent, so that irreversible changes do not occur in the character of the shore zone, the biophysical environment, or human activities.

Mitigating actions to reduce the stress

Attempts to control oil released from the ARROW spill in 1970 employed a variety of booms to contain the oil and collection systems to remove oil from the water surface. Both commercial and "home-made" barriers were used to protect estuaries and marshes. In addition, a causeway was constructed in one location to prevent oil from entering the channels in a large archipelago. Booms are still limited in their effectiveness to sea states of approximately 3 (international code for state of sea has a range of 0–9, where 0 is flat calm), even after 10 years of further research into the problem of oil containment at sea. A causeway provides a solid, impermeable barrier that is useful in certain circumstances; the presence of one between Ile Madame and the Cape Breton mainland resulted in the protection of an extensive area where the potential stress would have been exceedingly high. The sheltered islands and channels of the archipelago are a low wave-energy environment where the persistence of oil would have been expected to be high (Photo 2). There are numerous spawning and nursery areas for fish, as well as waterfowl habitats, in the area. Construction of the causeway no doubt considerably reduced the ecological impact the oil would have had.

The containment of oil on adjacent waters, or the use of exclusion booms or dams, is a key tool in reducing the damage caused by oil spills. These techniques are generally common to all spill situations, although their exact deployment will vary depending on site-specific environmental factors.

Adverse effects of mitigating actions

There are few documented instances of cleanup or protection operations resulting in damage to the shore zone. One such instance was the removal of sediment following the ARROW spill at one location in Chedabucto Bay (Owens and Drapeau, 1973), where shore-zone erosion was documented accurately over a 3-year period. In this instance, no measures were taken to restore the damage caused by the cleanup procedures. During the ARROW spill, an attempt was made to clean up a beach at the base of an unstable, unconsolidated cliff near Arichat on Ile Madame (Photo 9). The effect of this attempt would have been to destabilize the backshore cliff, causing loss of property and possibly of dwellings due to accelerated erosion following removal of the basal beach that acted as a buffer to wave-erosion. The potentially adverse effects of this cleanup action were avoided by piling up sediments and boulders at the base of the cliff to protect it from waves.

Where sediments are removed from a beach, and where there is the likelihood of beach or backshore cliff erosion, a standard procedure is to replace the volume of material that has been removed by an equal volume of material of the same size.

Photo 9. Cliff of unconsolidated material at Arichat, Nova Scotia. Initial removal of oil and sediments from the intertidal zone by a bulldozer removed the protective beach and cut a notch (arrow) at the base of the cliff. This could easily have resulted in erosion of the cliff by wave action and consequent damage to property if remedial action had not been taken.
E.H. Owens

Although there are numerous instances of restoration following cleanup actions in other parts of the world, there are no documented examples from Canadian coasts.

Research projects

AMOP project

The Arctic Marine Oilspill Project (AMOP) was established within the Environmental Protection Service in 1977 to promote research and technology on matters relating to spills in arctic environments (Ross, 1981). The project has encompassed a wide range of studies, including:

- environmental atlases
- spill and blowout scenarios
- ice-movement studies
- equipment development and testing (booms, skimmers, incinerators)
- burning and dispersant tests
- remote sensing applications
- landfill disposal in permafrost regions

AMOP is now (1981) co-ordinating a large-scale research project on the effects of controlled oil spills on marine and coastal environments. In particular, a series of experimental spills were conducted in 1981 at Cape Hatt, on northern Baffin Island, to document and monitor the effects of spilled and dispersed oil in coastal bays and shorelines, and the efficiency and effectiveness of appropriate shoreline countermeasures for arctic coasts. These large-scale experiments are one of the first attempts at experimental analysis of both spill impacts and countermeasures in arctic environments. This type of experimentation is essential to an understanding of the stresses placed on the coastal zone. When a spill occurs, there is seldom any pre-existing information that can be used for comparing pre- and post-spill environmental and biological conditions. Only controlled experiments can provide the information needed to make accurate comparisons. The Baffin Island experiment studied three situations: a non-oiled bay, a bay subjected to oil alone, and a bay affected by oil that was chemically dispersed. The results of this experiment will be used to develop an understanding of both the fate and the persistence of spilled oil, and of the effects of both the oil and the dispersed oil on the coastal biophysical environment.

Research and development on the effects of oil spills

Continued monitoring of spills, such as those of the ARROW, KURDISTAN, and NEPCO 140, by various investigators, is an important component in the long-term understanding of the effects of spills on habitats and human activities. Experimental spills or laboratory experiments are a key element in improving knowledge and understanding of the effects that oil has on coastal ecosystems. At present, there is considerable debate on whether or not oil spills have long-term adverse effects on the environment. Observations and experiments on macro-scale flora and fauna indicate that oil spills are not a serious, long-term threat to coastal and nearshore marine environments. However, little is known concerning the sub-lethal and potentially long-term effects that oil and oil residues may have on the micro-elements of ecosystems.

Oil, even at very low concentrations, may have adverse effects on populations and in turn on coastal ecosystems without resulting in direct mortality. These sub-lethal effects on species may result in a decline in population, which could result in increases in the population of other species. This type of alteration in the natural ecological balance is subtle and requires long-term experimental monitoring. Ecological and biochemical research into these fields is taking place in both the private and government sectors.

The whole question of impact assessment is not easy to document. Usually it is difficult and expensive to acquire sufficient basic data for even a small section of shoreline. Moreover, the natural perturbations existing in any one community are frequently larger than those that could be caused by an oil spill. Therefore, to assess the environmental stress or damage that can result from one spill incident, taken in the context of other natural perturbations, is extremely difficult. Increases in knowledge and understanding of the effects of oil spills are also dependent in part on research and development on the ecosystems and food-chain networks themselves. Without an understanding of the precise processes involved in the food web, it is difficult to determine natural or man-induced alterations to that system.

Research and development and oil spill countermeasures

The principal shoreline cleanup techniques have changed little since the early 1970s. The equipment and procedures recommended for shoreline countermeasures (Foget *et al.*, 1979) are well documented, and no new ones are currently in prospect. This is partly because onshore countermeasures, to be effective, largely depend on the availability of equipment not already assigned elsewhere. Heavy earth-moving equipment, trucks, rakes, shovels, and forks are the basic tools for shoreline cleanup for most coasts (Photo 10). For the time being, research and development will be chiefly directed to improving the containment and removal of oil from adjacent water surfaces. The effectiveness and efficiency of booms in strong currents or high waves, and the efficiency of various skimmers, is a continuing research and development programme, both in Canada and other parts of the world.

Photo 10. Wheeled front-end loader removing a wide (5 m) thick (10–20 cm) layer of oil deposited at the high-water level on a pebble–cobble beach in southern Chedabucto Bay, April, 1970.
E.H. Owens

Present onshore capability of mitigating oil spills is relatively good. Its only limitations relate to the availability of equipment and manpower resources, and to accessibility and the logistics associated with mounting a cleanup operation. Shoreline protection methods could be improved by the development of more versatile booms and skimmers that can operate on adjacent coastal waters. In addition, the use of dispersants on the sea surface away from the coast is being investigated, using aircraft as well as surface vessels. Offshore capability is limited by physical environmental conditions, rather than by the available technology. Wave-splash over booms or water motion beneath a boom limits the effectiveness of the equipment in containing oil during severe environmental conditions. Larger booms can be constructed, but these are more difficult to handle and store.

Spill-threat studies (prior to event) and impact assessments (after event)

It is only in the last few years that serious attempts at relating environmental characteristics to the potential threats of oil spills have been made in any detail. For many years, a false assumption prevailed that all habitats are equally sensitive. However, all marshes are not equally susceptible to the adverse impacts of an oil spill and, in addition, the seriousness of the threat can change with time. Some marshes, for example, are major staging areas for migratory waterfowl, whereas adjacent marshes may not be used by these species. Similarly, marshes have different population distributions at different times of the year, so the potential impact on migratory species will be limited to only a few weeks during the migration season.

The development of operationally useful evaluations of potential damage depends on the establishment of a data base that includes relevant information on the distribution of species, the sensitivity of those species to oil, the timing of a potential threat, the potential effectiveness of countermeasure operations to protect the area, and the impact of biophysical and environmental changes on man's activities (Owens and Robilliard, 1981*b*). Although a location may have a very dense bird population, some of the species, such as gulls, may rarely be affected by oil spills. Other species, waterfowl and sea ducks, may have a lower population density but be more susceptible to harm from oil. Some species may be highly susceptible throughout the year, or only during specific periods of the year.

In addition to a knowledge of the potential threat facing a coastal zone, it is also necessary to take into account the persistence of stranded oil, and the operational constraints on effective countermeasures. It is only recently that consideration has been given to these interactive factors. Improvement is needed in the identification of those factors that are important and in the form in which relevant information is presented. In the past, one of the main methods has been to document all environmental information. Of greater value is a synthesis of the data, so that only relevant sets of data are considered. Several studies that address this problem are under way and, it is hoped, will yield useful results within the next year or two.

Conclusion

Oil spills are frequently dramatic and attention-catching events, but the effects of spills in the coastal zone are rarely severe or long-term. The impact is primarily on the public's perceptions and on visual and aesthetic quality. Occasional severe perturbations of coastal ecosystems can disturb man's activities and use of the shore zone, as well as temporarily altering the natural balance of populations of species. The present state of knowledge does not allow an assessment of the long-term sub-lethal effects of an oil spill, but recent experiences indicate that natural recovery of the shore zone usually takes place in less than 10 years. A stress imposed on man and the ecosystem may be severe, but is usually short-lived. No irreversible changes are known to have taken place in Canada to date, but there is also a lack of precise documentation of spill impacts. The main threat of oil spills comes from the transportation and handling of crude oil and petroleum products. As these activities continue to increase, so does the likelihood of more and larger oil spills in the future. The coasts of Atlantic Canada, including the Gulf of St. Lawrence and the St. Lawrence River, have an historic record of the highest frequency of oil spills, as this is a primary transportation corridor for imported oil.

Oil spills, in particular large marine accidents, are an easily identifiable source of pollution in coastal environments. The actual stress imposed by these events is generally limited in geographical area and in time, so that although they are prominent, their severity in terms of man-induced changes in the natural environment is probably relatively low in comparison to other pollution sources.

This text was reviewed by M.F. Fingas, Head of the Chemical and Physical Sciences Section, Environmental Emergency Branch, Environmental Protection Service, Environment Canada, Ottawa, Ontario.

APPENDIX I—PROTECTION AND SHORELINE CLEANUP OPERATIONS

Chemical and physical dispersion

The dispersion of oil in the shore zone by either chemical or mechanical methods requires the containment and removal of that dispersed oil. Chemical dispersion requires the application of low-toxic agents to the oil in order to increase its mobility by reducing surface tension. Oil is then flushed from the shore zone by man-induced or natural processes. This procedure requires permission of the regulatory agency, namely Environment Canada. Other techniques of dispersion include:

- high-pressure hoses
- steam- or hot-water cleaning
- sandblasting
- low-pressure hoses

These dispersion techniques apply mechanical energy to the oil in order to remove the contaminant from either sediments or from hard substrates. High-pressure hoses, steam- or hot-water cleaning, and sandblasting all require the input of large amounts of mechanical energy. These techniques are also harmful to flora and fauna in the shore zone, as well as being both slow and expensive. Low-pressure hoses are biologically preferable and can be used in marsh environments without causing major damage to the vegetation, provided the technique is used properly. The effective application of all these techniques either flushes the oil on to adjacent water surfaces for collection, or channels the oil–water mixture into ditches or sumps for collection.

Removal of oil and contaminated material

Techniques that involve the physical removal of oil or oil-contaminated sediments in the shore zone cover a wide range of mechanical and manual methods. The appropriate technique depends on the amount of oil in the shore zone, the type of oil, the depth of penetration, and the bearing capacity of the sediments for vehicles. On wide, flat, sandy beaches, where the oil is restricted to the surface, use of a grader or scraper is a very efficient technique for removing the oil and contaminated sediments, which at the same time minimizes removal of uncontaminated material. On pebble or cobble beaches, however, traction is usually poor, so that only front-end loaders or tracked vehicles can be deployed. For spills where there are relatively small volumes of oil stranded in the shore zone, manual techniques may be preferable. A basic rule in cleanup operations is to remove as little uncontaminated sediment as possible. Recommended procedures for all the cleanup techniques (Foget *et al.*, 1979), when implemented correctly, can result in effective countermeasures. Incorrect operations can cause grinding of oil into previously uncontaminated sediments, spillage of oil during transportation away from the shore zone, or excessive sediment removal.

Response logistics

The size of an area affected by spilled oil will largely determine the equipment and personnel requirements necessary to clean up the shore zone. It is critical that countermeasures be organized efficiently, with good communications, so that priority areas can be protected or cleaned and operations supervised to ensure the cleanup does not cause more damage than would have resulted from the spill alone.

In remote locations the logistics of countermeasures are frequently exceedingly difficult. Remoteness can seriously hamper an effective operation. Lack of available personnel or equipment in the local region often requires that necessary resources be brought in, often from considerable distances, for the duration of the cleanup. Fog, winds, cold, and snow can all limit the efficiency and effectiveness of equipment and personnel, particularly in high-latitude environments. The development of cleanup operations must therefore consider not only the response priorities, but also the safety and comfort of the cleanup team. The scope and objectives of a cleanup operation are often determined by the availability of local resources, access, and other logistic considerations. In the more populated, southern coastal areas, cleanup operations are aided by road networks, boat-access points, and the availability of manpower and equipment. In these areas a response can usually be implemented more effectively and more quickly than in remoter environments.

Cleanup costs

The cost of cleanup operations for coastal oil spills can be high. In 1970 the cleanup following the ARROW spill cost over $3 million. The smaller spill from the NEPCO 140, one-tenth the size of that from the ARROW, cost $8.6 million (U.S.) in 1976. A spill of only 45 460 L from a fuel storage tank into a river in Quebec in 1981 cost over $2 million to clean up. The increasing costs of mitigating the effects of spilled oil could become a severe problem. Studies conducted in Sweden on shoreline cleanup suggest that costs are in the order of $7 to $30 per linear metre of beach (Lingren and Norrby, 1980). The same study indicates that protection and cleanup costs range from $500 to $10 000/t of spilled oil.

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THE KURDISTAN INCIDENT: THE ONSHORE IMPACTS OF AN OFFSHORE OIL SPILL

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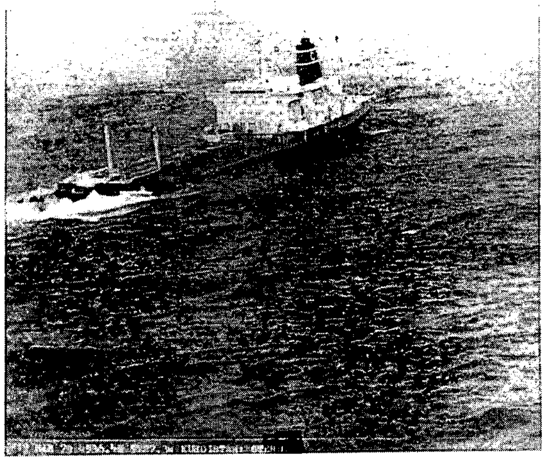


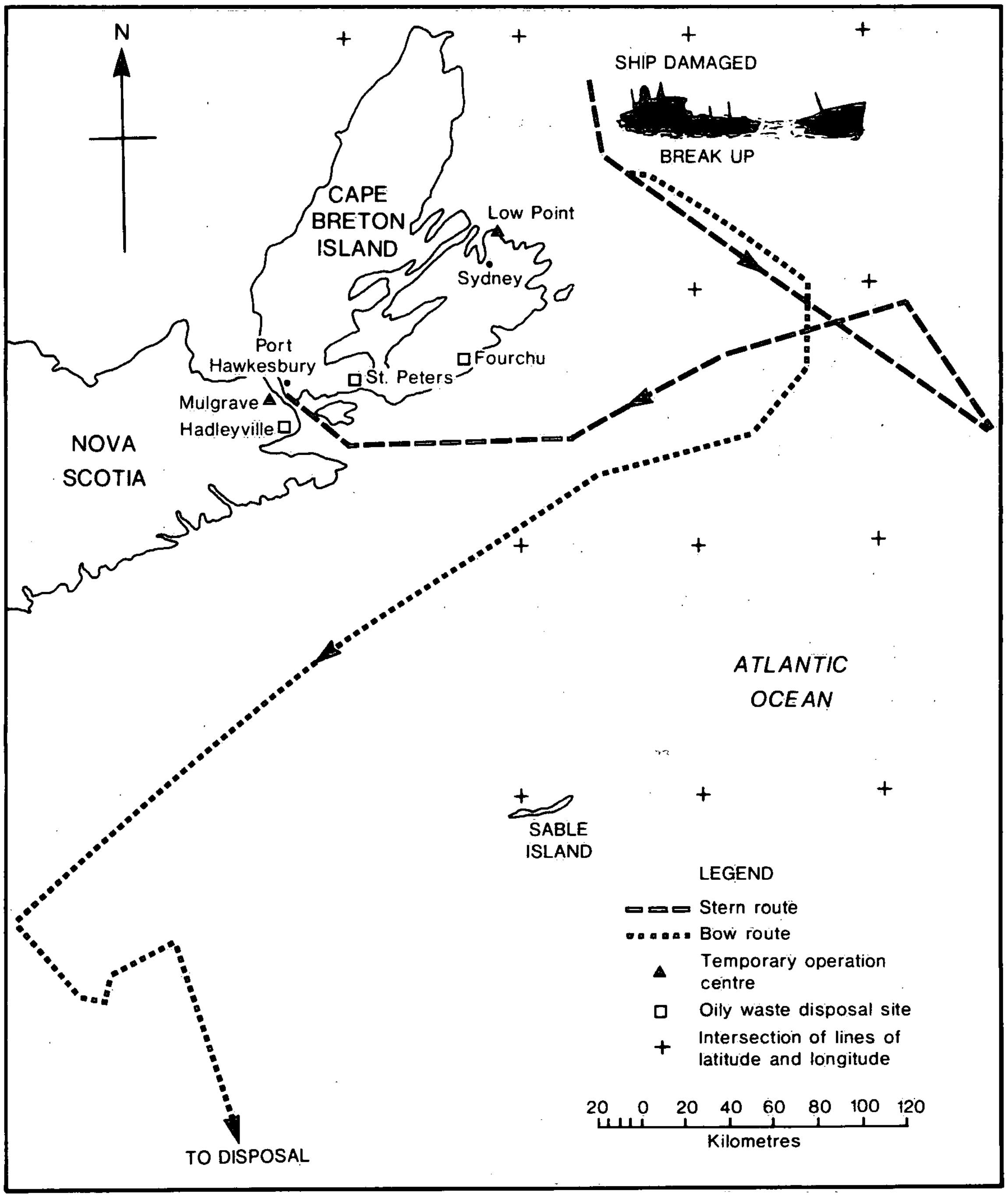
Photo 1. The KURDISTAN stern section. 1979.
Department of National Defence

While travelling in heavy ice conditions and gale force winds, the British tanker KURDISTAN broke in two on March 15, 1979, at a point 50 nautical miles northeast of Sydney, Nova Scotia. Approximately 6 800 t (metric tons) of Bunker C oil were spilled into the waters of Cabot Strait. Surprisingly, both the stern and bow sections remained afloat, as illustrated by Photos 1 and 2. They contained respectively 14 512 and 6 349 t of oil.

Photo 2. The KURDISTAN bow section. 1979.
Department of National Defence

It was determined that the larger stern section could be safely towed into Port Hawkesbury. On March 23 it arrived in port and lightering operations (the unloading or loading of ships at sea) were successfully carried out between March 28 and 30, 1979. The bow presented a different set of problems, however, and the only feasible option was to scuttle this section. On April 1, 1979, the bow was sunk at a predetermined site south of Sable Island off the Scotian shelf. The point of breakup and the routes subsequently taken by the two sections are shown on Map 1.

MAP 1.
Routes for the disposal of the KURDISTAN bow and stern



Source: Adapted from Duerden and Swiss, 1981.

Response to the situation by the federal government was rapid. The Canadian Coast Guard (CCG) Traffic Centre in St. John's, Newfoundland, received preliminary reports of the accident almost immediately; they in turn relayed the information to other concerned organizations. The CCG played the role of the On-Site Commander (OSC) and became the lead agency for the response effort. The same day, the Environmental Protection Service (EPS) of Environment Canada activated the Regional Environmental Emergencies Team (REET) to advise the OSC. Three subgroups of REET were organized to deal with the bow section, the stern section, and oil spill cleanup.

An estimated $5.5 million was spent by the federal and provincial governments in the cleanup effort. Of this the CCG spent greater than 90%. The Department of Fisheries and Oceans spent 6% and the remaining costs were split by the provinces, Environment Canada, and the Department of National Defence (CCG Maritimes, 1980).

PHYSICAL CHARACTERISTICS OF THE AFFECTED SHORELINE

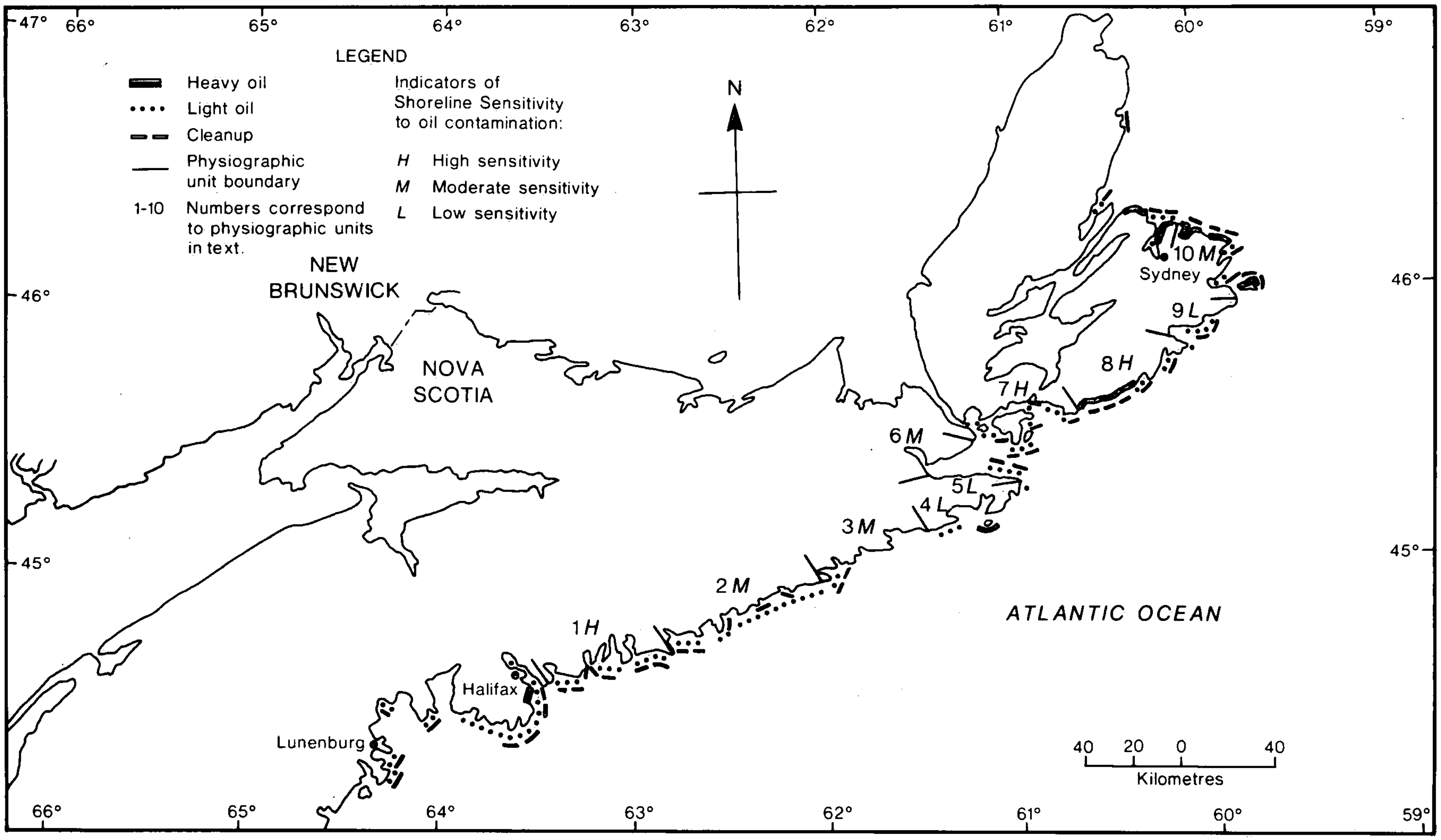
Location and extent

During the spring and summer of 1979, KURDISTAN oil spread out over a large area, eventually contaminating the shoreline of Nova Scotia just north of St. Ann's Bay, Cape Breton, to south of Lunenburg, and from Port-aux-Basques to St. Mary's Bay in Newfoundland. Because the impact was relatively minor and few data are available for Newfoundland in comparison with Nova Scotia, the information presented in this section and the section on cleanup operations refer only to Nova Scotia. The situation in Newfoundland is dealt with in the section on the impact of the KURDISTAN oil spill on Newfoundland. Map 2 provides a general indication of the extent of lightly to heavily oiled shoreline in Nova Scotia. Intermittent oiling extended even further.

The presence of ice in the Cabot Strait and along most of the shoreline (Photo 3) initially prevented oil from washing ashore but also made it difficult to monitor the spread of the oil. The monitoring of oil was hindered because the oil sank below the water surface shortly after the oil spill occurred. Two weeks passed before the first reports of onshore oil were received by the Environmental Emergencies operations centre in Nova Scotia. On March 27, 1979, reports of light oiling in the vicinity of Petit de Grat and in the Point Michaud and L'Ardoise areas of Cape Breton were received. Heavier oil patches were noticed between Point Michaud and Mira. Monitoring of the shoreline was carried out daily throughout the spring and into the summer by a network of Fisheries officers, Parks personnel, and provincial and federal environment personnel. In addition, daily flights were conducted by CCG and the Department of National Defence (DND).

Photo 3. Gabarus area—Oil on shore ice. 1979.
Environmental Emergencies Division, Environment Canada, Dartmouth

MAP 2.
Impact of the KURDISTAN oil spill on Nova Scotia shoreline



Source: R. Simmons, personal communication, 1981; P. LeBlanc, personal communication, 1981; Reinson, 1979a and b; Owens, 1971a.

Shoreline physiography

The physical properties of a shoreline determine in part the impact of oil on the land resource. The natural ability of a shoreline to clean itself is influenced by physiography.

From information compiled by Reinson (1979*a*, 1979*b*) and Owens (1971*a*, 1971*b*) the coastline of Nova Scotia from Halifax to Glace Bay can be divided into ten physiographic units. These are shown on Map 2. A brief discussion of each unit follows:

(1) Hartlen Point to Stoddart Point—This stretch of coastline is characterized by exposed bedrock, till-cliff headlands, and deeply indented bays that are often partially enclosed by barrier beaches and spits. Lagoons and bays possess extensive tidal flats and marshes. Exposed headlands and beaches are in a high wave energy environment in contrast to the protected marshes, lagoons, and partially enclosed bays. The widespread occurrence of marshes and other such protected environments make this unit very sensitive to oil pollution.

(2) Stoddart Point to Liscomb Point—The shoreline here is highly indented and irregular with numerous shallow bays. Ship Harbour Bay and Sheet Harbour Estuary are the only exceptions as they have large indentations. Bedrock outcrops occur on numerous islands, reefs and shoals as well as on the shoreline of the mainland. Small boulder and cobble pocket beaches have developed. The shoreline is in a zone of moderate to low wave energy, much of the energy having been expended on the offshore islands and reefs.

(3) Liscomb Point to New Harbour—Large, linear, deeply indented bays and estuaries distinguish this shoreline. Bedrock predominates and well-developed beaches are rare. This is an area of moderate to high wave energy.

(4) New Harbour to Cape Canso—This shoreline unit may be generally described as a bedrock-controlled, sediment-starved, irregular shoreline with numerous inshore islands. A few cobble pocket beaches occur. Cobbles and boulders commonly overlie the bedrock. With the exception of Tor Bay, this is an area of high wave energy. Relative to units 1–3, it has low sensitivity to oil pollution.

(5) South Shore, Chedabucto Bay—Between Canso and Guysborough the shoreline may be described as a straight, steep coast with a narrow offshore shelf. The orientation of this unit is structurally controlled by the Chedabucto fault and contrasts markedly with the irregular north shore. Rock platforms and low cliffs with pocket beaches of shingle and coarse sand predominate. The amount of sediment increases from east to west but generally there is a small amount of material available for reworking in this zone.

(6) West Shore, Chedabucto Bay—The west shore from Guysborough to the Strait of Canso is also characterized by a generally straight shoreline resulting from a uniform slope of the land surface to the southeast. The shore consists mainly of actively eroding till cliffs separated by wide, accretional shingle beaches. Because much of the till is composed of clay or silt it has been removed from the base of cliffs by wave action. Little sediment is therefore provided to the beach zone.

(7) North Shore, Chedabucto Bay—The north shore, distinguished by a complex series of islands and inlets, results from the drowning of an undulating lowland. The islands protect much of the coast from the direct force of waves and beach development has been inhibited in these areas of low wave energy. Beaches found in sheltered locations usually consist of coarse sediments resting on a till platform, backed by a low till cliff or natural vegetation. Storm ridge development is seldom noticeable. As with the west shore, there is little sediment derived from the land; landward movement of sediments in the offshore zone has been a more significant source.

(8) Point Michaud to the head of Gabarus Bay—This stretch of coastline features numerous eroding drumlins, gently seaward-sloping rock platforms with extensive reefs and shoals, and low sandy barrier beaches connecting drumlin cliffs with lagoons and extensive wetlands. The relative straightness of this coast offers few sheltered locations; this area is almost entirely in a high wave-energy environment.

(9) Head of Gabarus Bay to Scatarie Island—Low-lying, highly resistant metamorphic rocks with a variable layer of till cover typify the coast in this area. Other associated features include low sloping rock shore platforms overlain by till bluffs, cobble and pebble pocket beaches, and open-ended bays. A steep nearshore gradient reduces wave energy at the shore.

(10) Scatarie Island to Glace Bay—Three large northeast-trending bays dominate the coastline in this zone. Bayhead barrier beaches enclose large lagoon-like estuaries. The bayheads are exposed to high wave energy. Sandstone cliffs rising 5–20 m are common features.

Shoreline sensitivity

Assessment of the vulnerability of each physiographic unit to oil contamination is of value in determining priorities for cleanup and prevention. Generally, marshes and lagoons are considered to be most sensitive, followed by sheltered environments or pocket beaches, exposed beaches, mud flats or sand flats, and exposed rocky coasts, which are the least sensitive. Map 2 indicates relative levels of sensitivity for the 10 units.

(1) Hartlen Point to Stoddart Point—The numerous bays and lagoons present in this area make it highly sensitive to oil contamination. Particularly vulnerable are the shallow lagoon systems at Cow Bay, Cole Harbour, West Marsh, Lawrencetown Lake, Chezzetcook Inlet, Petpeswick Inlet, Musquodoboit Harbour, Jeddore Harbour, and Clam Harbour. Under stormy conditions the relatively low and narrow barrier beaches at Martinique, Lawrencetown, Clam Bay, and Cow Bay can be overtopped and the marsh areas behind them flooded.

(2) Stoddart Point to Liscomb Point—Relative to unit 1, this area is low in sensitivity. Tidal flats at the heads of bays are most susceptible.

(3) Liscomb Point to New Harbour—The most vulnerable areas in this zone are the upper reaches of the estuaries and bays, where marshes are common.

(4) New Harbour to Cape Canso—This unit has a low degree of sensitivity to oil pollution. With the exception of small inner harbours and re-entrants in Tor Bay and Dover Bay, the coast is exposed to the cleaning action of high wave-energy levels.

(5) South Shore to Chedabucto Bay—This unit has a relatively low sensitivity to oil contamination. There are few protected bays or lagoons along this straight coast, thus the development of beaches for recreation is limited.

(6) West Shore, Chedabucto Bay—The west, like the south shore, has a fairly regular shoreline. The presence of depositional features such as bars, spits, and tombolos has produced a variety of protected lagoons or ponds that could suffer from oil contamination under storm conditions. Sensitivity is moderate.

(7) North Shore, Chedabucto Bay—The numerous low energy sites along this stretch of irregular coastline make this unit more sensitive than the west or south shores. Several sandy beaches make this coast attractive for recreation but they are susceptible to oil contamination.

(8) Point Michaud to head of Gabarus Bay—This unit is highly sensitive to oil contamination. A system of productive lagoons and marshes has developed behind narrow barrier beaches. Overwash channels breach the dunes; under storm conditions or high spring tides, waves may reach the marsh system carrying oil with them. The marshes, bays, lakes, and flats support waterfowl production and are used as migration stopover sites for shorebirds and waterfowl; they also serve as feeding areas for ospreys, bald eagles, and great blue herons. Green Island off Cape Gabarus is an important seabird nesting site.

(9) Head of Gabarus Bay to Scatarie Island—No significant barrier beach or lagoon development occurs here; thus the sensitivity level is

lower than for unit 8. The most vulnerable areas are the Main-a-Dieu and East Scatarie Island beaches, Louisbourg Bay, and a number of exposed east- and southeast-facing pocket beaches. There are also three large sandy beach areas.

(10) Scatarie Island to Glace Bay—As was the case between Point Michaud and Gabarus Bay, there is a well-developed system of barrier beaches and lagoons. Barrier beaches are found at the heads of Glace, Schooner, Morien, and Mira bays. All are narrow, face northeast, are composed mainly of sand, and are pierced by inlets. Because it was heavily oiled, Big Glace Bay Lake Marsh drew considerable attention following the KURDISTAN spill. This marsh is important to wildlife as it is used by migrating waterfowl, supports a tern colony, and is a feeding area for great blue heron and bald eagle among others. Morien Bay has similar importance to wildlife. Hence this area is moderately sensitive to the impact of an oil spill.

CLEANUP OPERATIONS

The CCG and EPS collaborated in recording pollution reports and carrying out cleanup work. Operations were directed from temporary centres established at Low Point and Mulgrave and from Halifax. Approximately 880 km of shoreline in Nova Scotia (see Map 2) were manually cleaned during the spring and summer of 1979. As oil continued to come ashore throughout the spring and summer, re-cleaning was necessary in numerous locations. As time passed, cleanup crews had to deal with the oil in a variety of forms as a result of temperature change and weathering (Photos 4 and 5).

Photo 4. Petit de Grat – Arichat Area—Oiled boulder-cobble beach. 1979.
Environmental Emergencies Division, Environment Canada, Dartmouth

Photo 5. Point Michaud Beach—Weathered oil blobs on sand beach. 1979.
Environmental Emergencies Division, Environment Canada, Dartmouth

Approximately 1 000 000 plastic bags and 1 500 195-L drums were filled with oil or oily waste. Most of this was disposed of at three provincially approved oily-waste disposal sites, with lesser amounts being disposed of at municipal dump sites or by incineration. Figure 1 summarizes the progress of cleanup efforts in graphic form.

Bags and drums were removed from the shore by truck where roads existed. In a few instances, a short temporary access route was constructed to facilitate removal of oiled material. In areas where access was difficult or where the shoreline was highly sensitive, helicopters removed oiled material (Photo 6).

Photo 6. Big Glace Bay Lake Marsh—Use of helicopters facilitated surveillance and removal of waste from sensitive or inaccessible areas and reduced impact on contaminated shoreline. 1979.
Environmental Emergencies Division, Environment Canada, Dartmouth

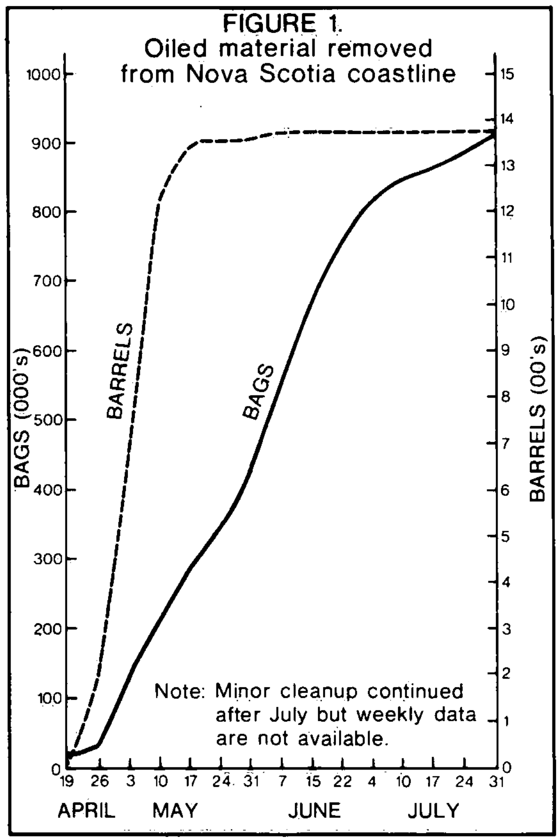


FIGURE 1.
Oiled material removed from Nova Scotia coastline

Note: Minor cleanup continued after July but weekly data are not available.

Source: Environmental Protection Service, Environment Canada, 1979.

Priorities for cleanup were based on the degree and type of oiling, accessibility, and shore type as well as on the significance of the shoreline to the fishing industry, recreation, and conservation. Aesthetic concerns often dictated that additional cleanup work be carried out even when there was no longer any threat to the environment, particularly on recreational beaches and in populated areas. Cleanup efforts were directed not only at the shoreline but also at fishing gear, slipways, booms, and the like. A laundromat, developed for the ARROW cleanup, was brought back into operation from June 13 to July 20. More than 100 nets were cleaned, as well as traps, oil retainer booms, and rainwear.

Cleanup methods

The removal of oil and oiled debris from the shoreline was carried out manually, using garden tools such as rakes and shovels (Photo 7). Experience with heavy equipment, used for cleanup after the ARROW spill in Chedabucto Bay on February 4, 1970, showed that significant alterations to the shoreline can result from removal of large quantities of beach material and from movement of heavy equipment over the ground.

When oil first appeared onshore it was in a viscous state, having been cooled by the icy Atlantic water. Except on rock coastlines, the oil was generally deposited as continuous or discontinuous sheets or pans less than a few centimetres in thickness. Thicker deposits occurred, particularly along the shores of Big Glace Bay Lake,

Photo 7. Three Fathom Harbour—Manual cleanup in progress. 1979.
Environmental Emergencies Division, Environment Canada, Dartmouth

on Scatarie Island, and near Point Michaud. The heaviest concentrations of oil were deposited near the high tide level, where a hard surface or pavement was formed. As time passed, the oil became increasingly mixed with sediments and seaweed. Re-oiling occurred in numerous locations throughout the summer. Where beaches were re-oiled, the proportion of oil to sediment decreased markedly. Cleaning after re-oiling was often necessary for aesthetic reasons. During the summer period of sand accumulation, burial of oil on active beaches (those where sedimentation and erosion processes occur) was common.

Taylor and Frobel (1979) reported on cleanup operations in southeast Cape Breton. The situation was discussed in terms of the type of coastal environment. Sand beaches were the easiest beach type to clean. The initial viscous oil deposits did not penetrate the sand to any depth and were easily scraped from the beach with little loss of sediments or mixing of clean and contaminated material. As temperatures rose the oil became fluid but even then penetration was minimal.

Pebble–cobble beaches presented more of a problem. Because of the difficulty of removing oil from between larger cobbles and boulders, greater reliance was placed on the natural cleaning action of waves and on sediment transport. Kelp banks along the upper foreshore, which absorbed much of the initial oil, were removed with relative ease as were small amounts of oiled pebbles. Oil that had formed a hard pavement at high tide limit was broken up to allow more effective erosion.

Because of the difficult access, rocky shores were usually left to be cleaned by natural processes. One of the problems that resulted was re-contamination of nearby beaches. As the oil warms it flows down to the water level and produces a sheen. This has little environmental effect but detracts from the aesthetic quality.

Marshes at Big Glace Bay Lake and Framboise Cove were both heavily oiled. With few exceptions, however, the oil was confined to the edge of the shores and small channels through the marshes. The use of rakes and shovels was generally effective. Cleanup efforts were eventually halted at Big Glace Bay Lake as more harm was being done by trampling of the vegetation than by the presence of the small amount of oil that remained. A minor problem was the spillage of oil material from the plastic bags stacked on higher ground prior to disposal.

Oily-waste disposal sites

The effect of oil on coastal systems depends in part on the speed with which the contaminated areas can be restored. The ready availability of appropriate disposal sites for oily waste is therefore an important aspect of the cleanup operation.

In 1976 the Nova Scotia Department of the Environment initiated a program to identify environmentally acceptable land disposal sites for oil and oily wastes and procedures for the use of these sites. Two of the sites that had been identified before the KURDISTAN spill were successfully used, as was one site identified after the spill (Letson, 1980). Factors considered in site selection included ownership, access, land use, location, containment and water quality. Briefly, sites were to be on Crown land to ensure long-term maintenance and responsibility for buried waste. An access road to the boundary of the Crown land was required. Use of the site for disposal of oily waste was to be compatible with both on-site and adjacent land uses. If possible, the site was to be within 10 km of the coast, as measured by a straight line. And lastly, the site was not to become a source of water pollution.

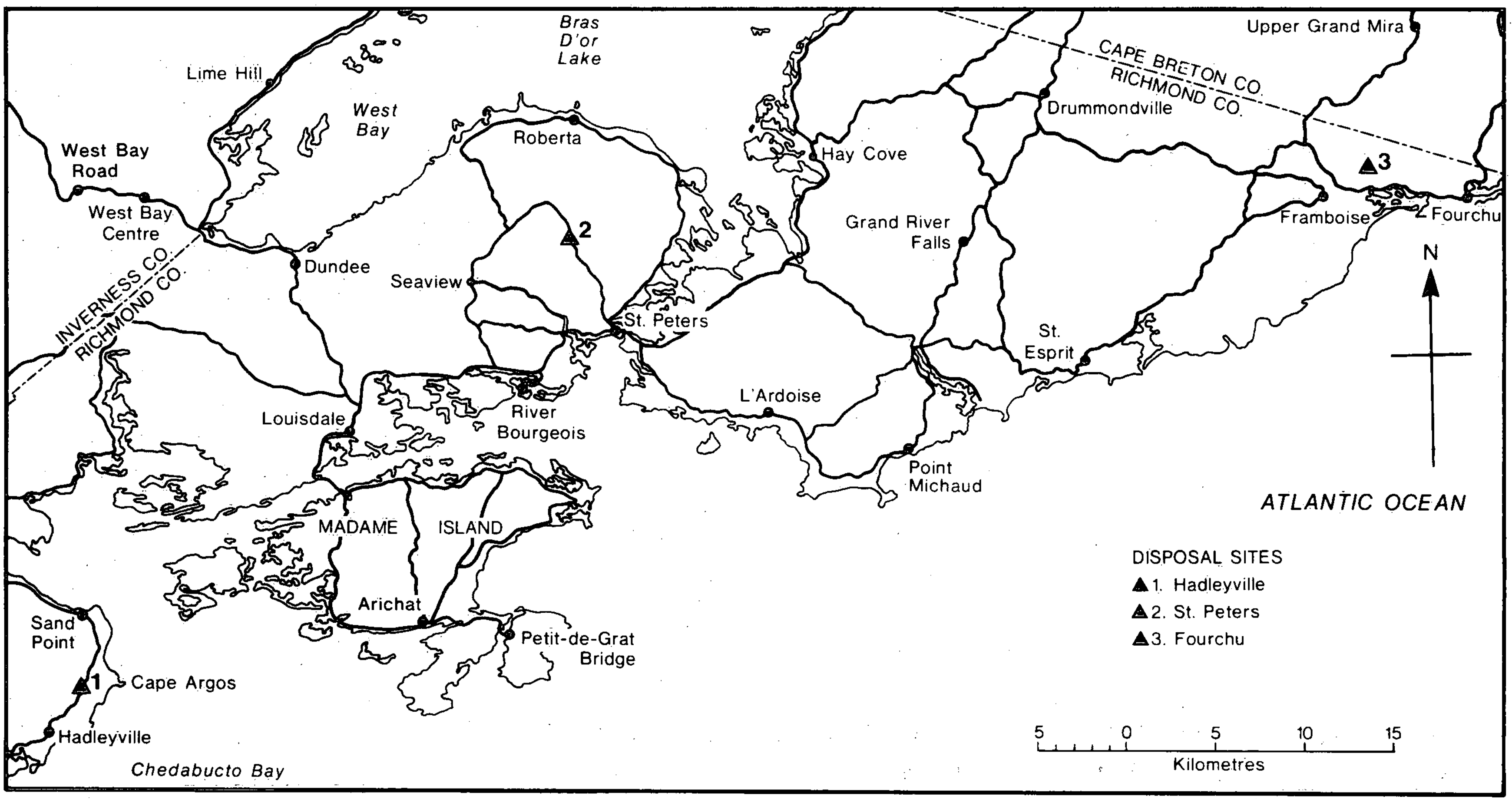
Site-specific guidelines for design and operation were prepared. However, certain general operational and design requirements applied to most sites. These are summarized under the headings: (1) site opening; (2) trench construction; (3) waste burial; and (4) site closure.

Site opening—As the CCG was responsible for payment of all disposal costs, it participated in the selection of contractors hired to carry out site preparation and disposal work. The Nova Scotia Department of Lands and Forests, as managers of Crown land, were notified before the opening of a designated disposal site and, if the site were leased for logging, arrangements were made with Lands and Forests to cut pulp wood and pile it off-site. Provincial Environment personnel, the contractor, and the on-site equipment operator discussed all aspects of the operation. Well-drained, all-weather access roads with controlled entry were constructed, and suitable helicopter landing sites were made ready.

Trench construction—Topsoil was to be preserved for later site restoration. Trenches were to be at right angles to the slope and spaced approximately 20 m apart; depth was not to extend below the water table. A monitoring well was to be located at the deepest point in each trench. The CCG was to be notified when the site was ready to accept waste.

Waste burial—As each load of debris was placed in the trench, a tractor would run over the bags, breaking them and thus facilitating biodegradation of the oily debris. At the end of each day waste material was to be completely covered with fill sloped toward the monitoring well. During periods of heavy rain, it was recommended that burial operations be temporarily halted; waste delivered at this time was

MAP 3.
Disposal sites for KURDISTAN oil*



* Other disposal sites were also used for the KURDISTAN oil wastes but these are not indicated.

to be piled near the trench and covered with a tarpaulin or plastic sheet. After the rain stopped, excess water was to be pumped from the trench. The trench could be filled to within 0.5 m of the ground surface. The top layer of fill was to be free from large roots or branches, which would increase porosity. A clean clay till cover would further promote surface run-off and decrease filtration. After mounding the trenches, a gravel roadbed was to be constructed beside each trench to allow access to the monitoring wells. A record of the debris contained in the trench would be kept.

Site closure—After the top layer of till had been placed in the trench, it was to be topsoiled and seeded. If necessary, surface water ditches should be dug. De-watering of the trenches, by pumping monitoring wells, would be necessary to keep the debris dry. Tags indicating the amount and type of contaminant, name of spill, year, and trench number were to be placed on each well. The site was to be surveyed to aid in hydrological monitoring.

The three designated sites used for disposal of KURDISTAN oil and debris were located near Fourchu, St. Peters, and Hadleyville, as shown on Map 3. The site characteristics are summarized in Table 1.

TABLE 1.
Site characteristics of oily waste disposal sites

Site feature	Fourchu	St. Peters	Hadleyville
Location	Richmond County, 4.8 km west of the village of Fourchu.	Richmond County, 6.5 km northwest of the town of St. Peters.	Guysborough County, north shore of Chedabucto Bay. 3.2 Km northeast of Hadleyville
Access	A gravel N.S. Forest Industries lumber road joins paved secondary Highway #327.	Adjacent to a good quality secondary gravel road joining St. Peters and Oban.	Adjacent to Highway #344 which joins the T.C.H. at Auld's Cove.
Ownership—size	2 ha released by N.S. Lands & Forests (NSL & F) to N.S. Environment (NSDOE); land leased to N.S. Forest Industries.	2 ha released by NSL & F to NSDOE; leased to N.S. Forest Industries.	2 ha released by NSL & F to NSDOE.
Vegetation	Area was recently logged; dense but low lying undergrowth covers property.	Mixed forest; softwood predominates; raised sphagnum bogs occur.	Mixed forest; softwood predominates.
Topography	Hummocky; disposal site near the crest of a topographic high on a south facing slope.	Gently undulating; site on the northeast side of a small hill.	Hilly; site on northeast slope of a drumlin.
Geology	Basal till depth 3.5 m; no outcrops; bedrock consists of volcanics, sandstone, shale, chlorite, schist.	Basal till depth 4.6 m; no outcrops; bedrock consists of conglomerate, sandstone, shale, limestone.	Basal till depth 4.6 m; no outcrops; bedrock consists of conglomerates, shales, sandstone.

TABLE 1.

Site characteristics of oily waste disposal sites (*continued*)

Site feature	Fourchu	St. Peters	Hadleyville
Hydrology	Site lies on a drainage divide; direct drainage is to a bog at the base of the hill; distance to the nearest tidal inlet is 500 m. Water table at 0.6–0.9 m. Bedrock tight – fracture flow predominates; closest well 1.6 km west.	Site lies in River Tillard watershed; drains south through a sphagnum bog into Browns Lake; there is a thin interflow zone above tight basal till; no wells or houses within 1.5 km of site.	Surface drainage rapid; flow northeast into a minor creek which empties into Chedabucto Bay; basal till is highly impermeable; a spring located on the north bank of the stream into which the site drains is used by a few local people.
Site status & use	90 km of oiled shoreline from the Grand R. to Louisbourg serviced by this site; site preparation including building a 100 m road, clearing 1.1 ha installation of dewatering drain, excavation of 4 trenches 2.5 m deep with monitoring wells; final grading and seeding completed.	340 km of oiled shoreline from Canso Causeway to St. Peters serviced by this site; site preparation included 0.5 ha cleared, 140 m of road constructed, 4 trenches dug 4.6 m deep with wells; final grading and seeding completed.	275 km of oiled shoreline from Country Harbour to the Canso Causeway serviced by this site; site preparation included 0.5 ha cleared, 245 m of road constructed, dewatering drain dug, 3 trenches dug to 3.7 m, 5.2 m, and 6.1 m with monitoring wells; final grading and seeding completed.

THE IMPACT OF THE KURDISTAN OIL SPILL ON NEWFOUNDLAND

The impact of the KURDISTAN oil spill was felt later and to a much lesser degree in Newfoundland than in Nova Scotia. Nevertheless, some contamination of shores did occur from Port-aux-Basques to Portugal Cove, although the Burin Peninsula was barely affected. Map 4 shows the locations of onshore oil that were reported to EPS.

Cleanup efforts were directed to assisting the fishing industry; fortunately, the appearance of oil did not coincide with the fishing season and there was little oiling of fishing gear. Slipways and wharves often required cleaning, however. Cleanup crews also cleaned recreational beaches. As in Nova Scotia, manual methods of cleanup were utilized. Oily wastes were disposed of in nearby municipal dump sites or behind storm surges at the site of cleanup. Rocky isolated coastlines were generally left to be cleaned by natural processes.

The following discussion is based mainly on data provided by EPS St. John's; the extent and nature of shoreline contamination and cleanup operations are dealt with only sketchily in existing literature. Coastal mapping was carried out by the Department of Geography, Memorial University, in 1977; the Lands Directorate, Atlantic Region, conducted more detailed mapping of the Avalon-Burin Peninsulas in 1980–81.

Extent of contamination and cleanup

The earliest reports of onshore oil were received from Port-aux-Basques and Isle-aux-Morts during the fourth week of April 1979. The coastline in this area is rocky; no cleanup was conducted.

As time passed, sightings of onshore oil were received from points further east. Rose Blanche and Grand Bruit were contaminated; the oil came ashore as a tarry substance with little sediment incorporated. Cleaning of rocky coasts in this region was left to natural processes but slipways at Grand Bruit were cleaned and two sand beaches were cleaned by local residents in August 1979.

Onshore oil was first reported at Burgeo on June 7. Re-oiling of the shoreline in this area occurred many times throughout the summer. The cleanup efforts in this area were extensive enough to warrant establishment of an operations centre early in July. Burgeo has significance both for fishing and recreation. One of the high quality sand beaches along the southern coast has been developed for recreation at Sandbanks Provincial Park. To preserve the aesthetic value of the park, manual cleanup of this site was given a high priority. Cleanup began on July 10 by a crew of twelve. The oily waste was disposed of at the Burgeo town dump or in pits, which were dug behind the storm surge within the park boundaries. Slipways used by fishermen were cleaned manually.

The shoreline at Ramea, also a fishing community, received moderate oiling. Wharves were steam cleaned and efforts were made to remove oil manually from the cobble beach. Two recreational beaches on Ramea were also cleaned.

Heavy oiling at Bay de Loup caused concern for the salmon population. However, no cleaning was carried out along the rocky coastline or the high quality beach in this area.

Dog Cove is used by fishermen from Grey River for drying nets. The shoreline where nets are spread was cleaned and oily waste was taken by boat to Burgeo for disposal. Other sections of coastline in this area were not cleaned.

Slipways were cleaned at Francois where moderate oiling was experienced; no cleaning was carried out along the shore.

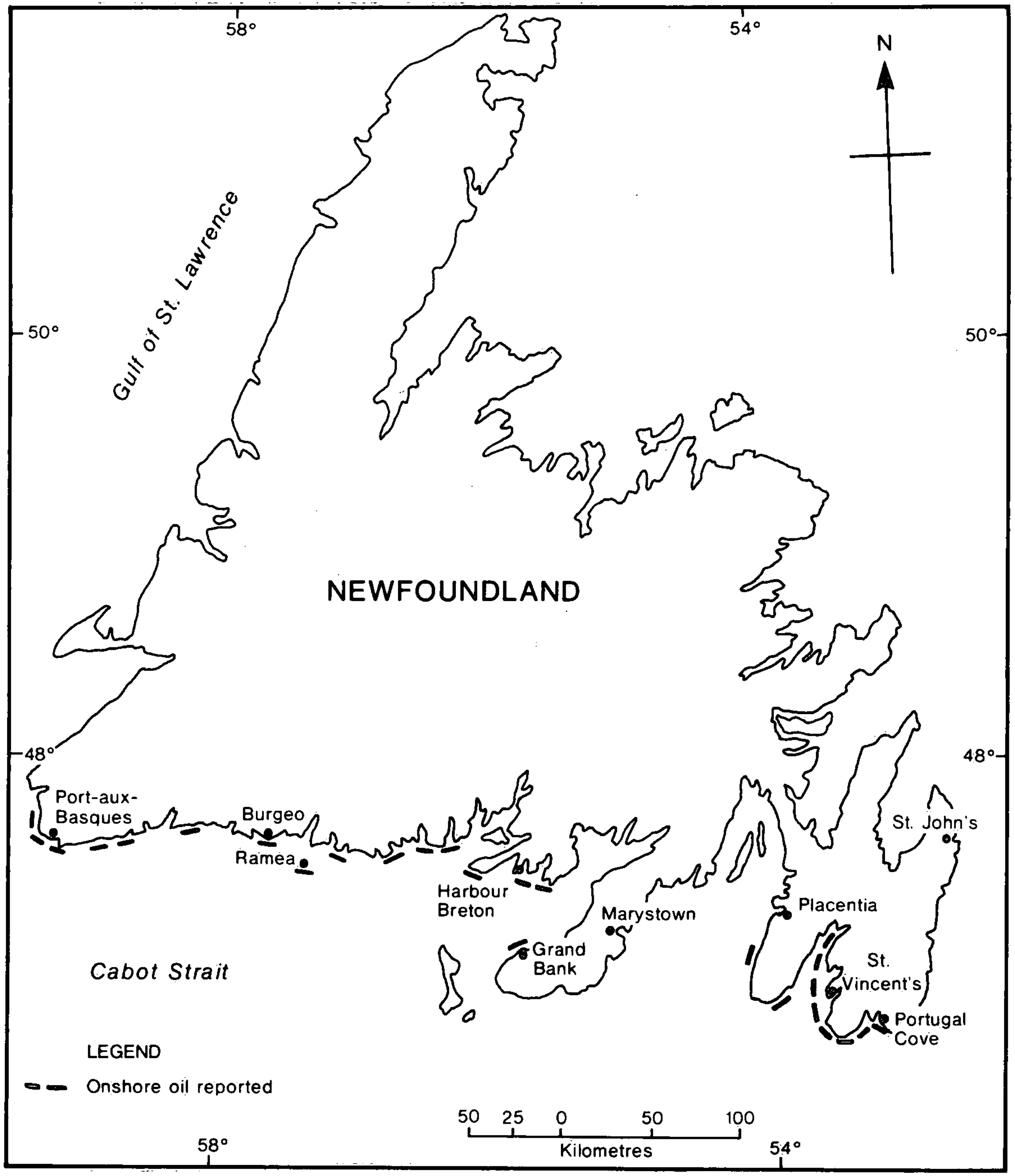
The Harbour Breton and Coombs Cove area was oiled heavily in comparison to other parts of southern Newfoundland. A high priority for cleanup was assigned to a relatively large sand–pebble beach used for recreational purposes by Harbour Breton residents. The oily material was disposed of partly at the Harbour Breton town dump and partly in pits dug behind the storm surge. The beach and cribbings at Coombs Cove were manually cleaned, the oily waste being disposed of at the Coombs Cove dump site.

The presence of oil in St. Mary's Bay on the Avalon Peninsula caused concern for the large bird population at Cape St. Mary's; some bird mortality occurred. Shoreline contamination extended to the head of the bay at Haricot. Other sites reporting oiled shorelines were Point Lance, O'Donnells, Point La Haye, and St. Vincent's. Oiled pebble–cobble beaches at O'Donnells and Point La Haye were manually cleaned.

In summary, light to moderate oiling was reported along the southern coast of Newfoundland from north of Port-aux-Basques to Portugal Cove. Concentrations of oil were heavier in the east than in the west. Given the considerable extent of rocky and unpopulated coastline and the lighter contamination, cleanup efforts were less extensive than in Nova Scotia. Manual cleanup of the shore was carried out to restore the visual appeal of recreation areas, such as at Sandbanks Provincial Park, and in support of the local fishing industry. More often, cleanup efforts were directed to manmade structures such as slipways and wharves. The contaminated shoreline itself was often left to be cleaned by natural processes.

Although damage to fishing gear was small because the appearance of oil did not coincide with the fishing season, the fishing industry was, in fact, the most strongly affected on the southwest coast. On the southeast coast, however, treatment of recreation areas was given priority.

MAP 4.
Extent of oiled shoreline in Newfoundland



Source: Environmental Protection Service, Environment Canada, 1981.

LAND USE IMPLICATIONS

The total impact on land use resulting from the KURDISTAN oil spill was relatively minor and short term. By far the largest number and value of claims are related to fisheries. To the end of July 1979, 181 fisheries-related claims and 30 personal property claims had been filed with the CCG. Only a small percentage of the property claims were for large sums. Unless stated otherwise, the following impacts refer to the situation in Nova Scotia.

Fisheries

Most of the damage to the fishing industry resulted from (1) oiled nets, traps, boats, and other gear, (2) lost catches, and (3) lost time. Nets could be cleaned at the laundromat established near Mulgrave, but lost catches and lost time required compensation. Problems arising from oiled wharves or other similar structures were negligible. Oiling of shellfish areas, such as that at Framboise Cove – Fuller's Bridge, elicited concern over possible shellfish contamination. Tests indicated that clams and mussels were susceptible to oil pollution and advisory notices were posted on certain clam flats.

Wildlife conservation

The most obvious impact of the oil spill on wildlife was the high mortality among seabirds, particularly dovekies and murres. More than 2 600 oiled seabirds are known to have been washed ashore in Nova Scotia; the total estimated loss was 25 000 birds (Vandermeulen, 1980). Many of the birds were removed from the shoreline during cleanup.

Although the presence of oil at any point along the coast poses some threat to wildlife, certain sites are more critical. A survey of important wildlife sites from St. Ann's Bay to Capelin Cove in Cape Breton during the latter part of April provided little evidence of damage to wildlife (Barkhouse *et al.*, 1979). At that time, wildlife was generally not present in large numbers where shorelines were contaminated. For instance, large populations of great black-backed gull, herring gull, and great cormorant were observed on the Bird Islands but there was no evidence of onshore oil. Oiled herring gulls were noted, however, along other parts of the coast. There was no sign of oil on waterfowl seen in Indian Bay, Big Glace Bay Lake, or Morien Bay; however, three dead great blue herons were observed at Big Glace Bay Lake. Very few birds were noted between Gabarus and Framboise; of those observed, one or two purple sandpipers appeared to be oiled. No other oiled birds were observed during the survey.

The Big Glace Bay Lake Marsh, an area of importance to wildlife, was heavily oiled. Cleanup was intensive; crews were kept to a minimum when it became apparent that they were causing greater damage to the marsh than that resulting from remaining oil.

Recreation

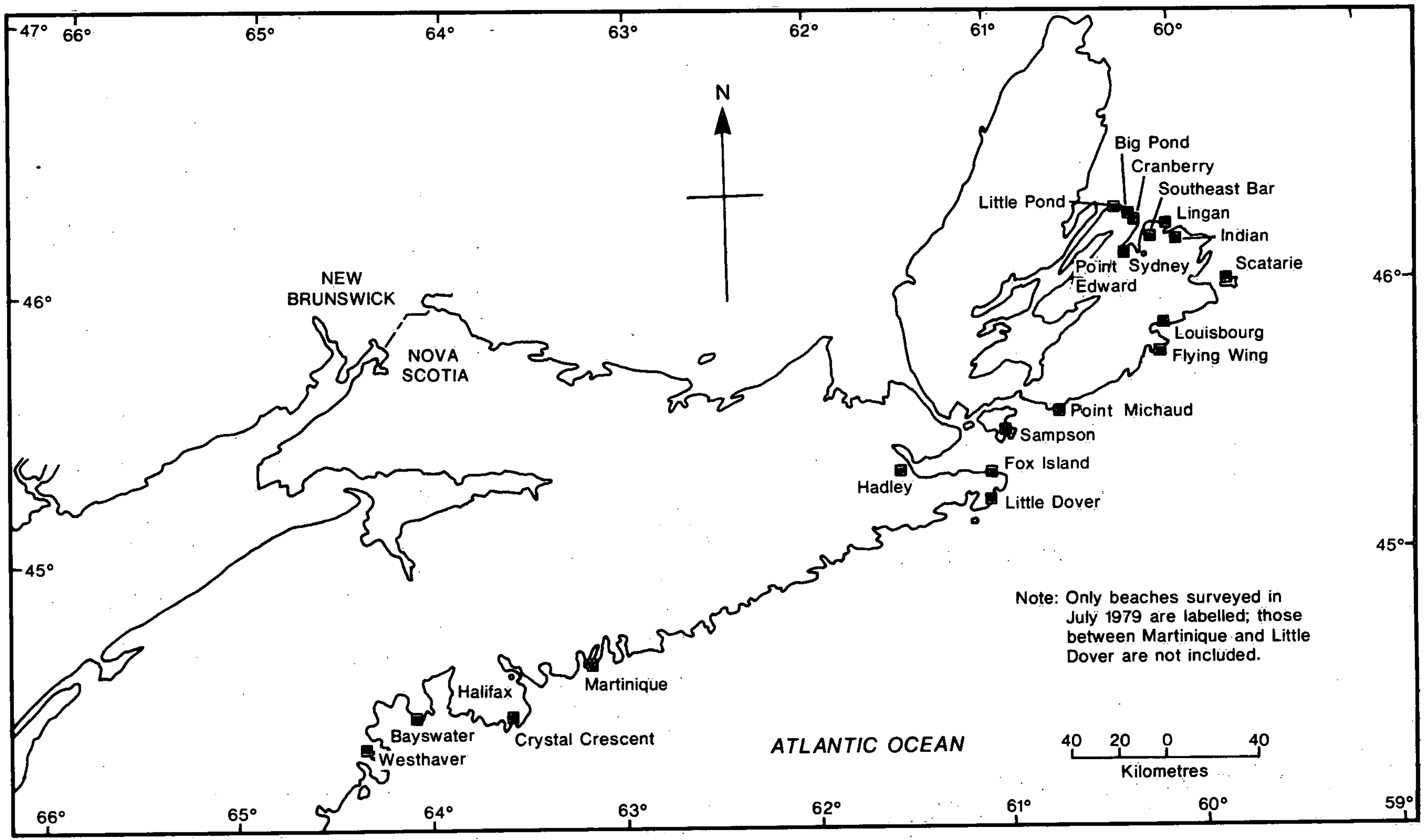
Given the time of year when the spill occurred, recreational use of beaches was little hindered. Cleanup was carried out soon after oil appeared onshore and because of public demand beach areas were given high priority. A survey of recreational beaches on July 11 and 12 by EPS showed that most required no further cleaning, the criteria used being aesthetic rather than environmental. Beaches included in the survey are shown on Map 5.

Private operators of recreation developments expressed concern over the potential loss of business or value due to oiling of their shorefront properties. A significant claim for compensation was made by one operator on the south shore of Chedabucto Bay. Owners of recreation properties complained of loss of access to the beach.

Agriculture

The impact on agricultural land use was minimal. In one instance, sheep that had been grazing on kelp along the shore suffered from ingesting oil; claim for compensation was made by their owner. No other effects were apparent.

MAP 5.
Recreational beaches in Nova Scotia



Note: Only beaches surveyed in July 1979 are labelled; those between Martinique and Little Dover are not included.

Source: Environmental Protection Service, Environment Canada, 1979.

Aggregate extraction

A single case was encountered where oil contaminated beach gravel was used for a crushed stone screening operation. Cleanup was carried out and the extraction operations were resumed within the year. Although operations resumed within a short period, some financial loss was suffered as the sand was not of highest quality until some time later.

Forestry

Minimal impact on the forest resource was caused by the development of oily-waste disposal sites on Crown forest lands. The total area cleared was approximately 6 ha. Access roads were short and entry was controlled. Pits were seeded over soon after they were filled.

SUMMARY AND CONCLUSIONS

Although the greatest and most visible impacts of the KURDISTAN oil spill were on the seabird population and the fishery, the contamination of much of the coastline from north of St. Ann's Bay to south of Lunenburg, Nova Scotia, and from Port-aux-Basques to Portugal Cove in Newfoundland was not without repercussions. Fortunately, these were generally short-lived and of a relatively minor nature.

Priorities for cleanup were based on the amount and type of oil contamination, the biophysical site characteristics, and human use of the site. Experience gained in cleanup operations following the ARROW spill in 1970 was applied to the cleanup of KURDISTAN oil; manual methods were used exclusively. Only at Big Glace Bay Lake was concern expressed that cleanup crews were causing more damage to the marsh than was the oil. A small amount of oily material was disposed of at municipal dumps, but most of the waste from Nova Scotia was sent to one of three oily-waste disposal sites, which were properly constructed and maintained.

Use of the shoreline was restricted for a short time; by July most of the shores had been cleaned and in some cases re-cleaned. Table 2 summarizes the chronological sequence of events in the cleanup effort. Recreational beaches required a very high standard of cleaning; a lower standard was applied to those areas used less intensively. Rock shores were most often left to be cleaned by natural processes.

Very little impact on land use was experienced for more than a period of several months. Damage to onshore fishing gear or structures was minimal. The onshore wildlife suffered little although some mortality was reported among gulls. Generally recreational use of the beaches was little hindered; there were, however, certain private individuals who felt that their property had lost value as a result of the oil. Other isolated incidents were recorded affecting use of the shore for sheep grazing and for a crushed stone screening operation. With the exception of small amounts of oily waste deposited at town dumps, disposal of waste required only small parcels of carefully selected land. Consequently the impact of disposal was minor.

TABLE 2.
Chronological summary of events

March 15, 1979	—the British tanker KURDISTAN broke in two, 50 nautical miles northeast of Sydney, Nova Scotia, spilling approximately 6 800 t of Bunker C oil into Cabot Strait
	—the CCG at St. John's and EPS, Halifax were notified
March 16, 1979	—the REET met; it was decided to tow the bow section to deep water and action was taken
	—DND and CCG commenced daily tracker flights
March 18, 1979	—it was decided to salvage the stern section
March 21, 1979	—Port Hawkesbury was approved as the site for lightering of the stern section
March 23, 1979	—stern section arrived at Port Hawkesbury
March 27, 1979	—the first reports of contaminated shoreline in Cape Breton were received
March 28, 1979	—lightering operations began and were completed in two days
	—clean-up crews were sent to Isle Madame; within the week crews were working at numerous sites
April 1979	—the bow was scuttled south of Sable Island on April 1
	—new sightings of oil were made almost daily
	—clean-up crews operated throughout the month; by the third week work had extended to Tor Bay
	—Province of Nova Scotia assigned temporary disposal sites during the third week
	—oil was reported onshore at Port-aux-Basques and Isles-aux-Morts, Newfoundland, during the fourth week
May 1979	—numerous reports were received during the first week of oiled shoreline from Lunenburg to Clam Bay; re-oiling occurred in many areas
	—cleanup crews continued efforts throughout the month
	—EPS assisted the Province of Nova Scotia in selecting disposal sites at Fourchu, Hadleyville, and St. Peters during the last week
	—a large number of dead and oiled seabirds and shoreline contamination were reported at Sable Island late in May; dead or oiled seabirds had been seen on the mainland earlier
June 1979	—oiling of shoreline in the vicinity of Burgeo, Newfoundland was noted during the first week
	—a fish gear laundromat was installed at Port Hawkesbury and began operation June 13
	—re-oiling of Nova Scotia's shoreline persisted and cleanup continued
July 1979	—an increasing number of reports of oiled shoreline along the south coast of Newfoundland necessitated establishment of an operations centre at Burgeo
	—light and spotty re-oiling was still occurring in Nova Scotia but clean-up crews were much reduced in number and level of activity
	—the laundromat stopped operation July 20

ACKNOWLEDGEMENTS

Information was obtained from numerous sources during the course of the research, but I should like to acknowledge with gratitude the special assistance provided by Mr. Randy Simmons, Environmental Emergencies Division, Environmental Protection Service, Dartmouth, Nova Scotia. Mr. Simmons offered valuable first-hand knowledge as well as reports and photos. I should also like to thank Mr. Gordon Pelly, Environmental Protection Service, St. John's, Newfoundland. Without his assistance, the section on Newfoundland would not have been written.

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INLAND OIL SPILLS AND THEIR IMPACT ON LAND

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Introduction

The phrase "oil spill" creates a strong and immediate emotional response in most members of the public. But the image formed is generally that of a marine spill; strong public reaction to inland spills is not evident, nor does it seem justifiable. The public's environmental concerns about inland oil spills that do not enter major waterways are much less intense than the concerns of landowners and those in the oil industry, a reversal of the usual situation. Oil spills have an acute economic impact on the party responsible and present a prospect of potential lost production for the landowner. These two considerations have stimulated a more concerted effort in reclamation research than in the documentation of environmental impact in agricultural areas. In less intensively utilized lands the emphasis has been on environmental impact assessment; reclamation-oriented activities are carried out only where governmental regulations require them. However, as the cost of these activities increases, so too does interest in effective and efficient reclamation strategies.

Inland oil spills represent a stress on the land as a consequence of additions to it, chiefly to the soil. The sources of inland oil spills are predominantly in the energy sector and include: exploration and production; transportation of oil via pipeline, motor vehicle, or railway; the refining process; and marketing and storage. Some indication of the relative importance of these sources can be gathered from Tables 1 and 2. Exploration and production activities are the major source of oil spills by both number and quantity. But if examining only by quantity spilled, then marketing and storage, as well as pipelines, are also significant sources.

Oil spills become a stress on land when the oil comes into contact with soil and surface vegetation, producing the various physical effects described in a later section. The addition of oil to soil and vegetation occurs because the infrastructure (extraction, transportation, and storage facilities) exists on the soil, and in some cases, such as pipelines, actually within the soil. Furthermore, free oil moves under the influence of gravity into the soil, where extensive downward movement may bring it into contact with ground water. Depending on the absorptive capacity of the soil, the oil may either flow over the surface with little entry or be absorbed at the immediate site of the spill. Oil may flow laterally along textural and structural discontinuities in the soil for several tens of meters before coming to the surface. Photo sequence 1 shows some of the ways oil can move and some of its effects. One unique aspect of this type of stress is that the agent causing the stress—oil—is biodegradable to varying degrees and in some instances may actually improve land capability.

TABLE 1.
Spill events in Canada (1978) according to source

Source	Petroleum spills	Non-petroleum spills
Watercraft	89	2
Marine terminals	24	0
Motor vehicle transport	208	33
Trains	29	36
Aircraft	47	10
Exploration/production(1)	675	513
Pipelines	24	1
Refineries	18	3
Other industrial plants	40	44
Marketing/storage	137	18
Other	115	10
TOTALS	1 506	670

Note:

(1) In exploration and production, 613 (91.4%) of the petroleum spills are crude oil and 499 (96.5%) of the non-petroleum spills are production water.

Source: Beach, 1979.

Oil spill effects on land productivity, use and value are difficult to separate from effects of petroleum production and refining activities. Petroleum production with its associated exploration seismic lines, roads, well sites, sumps, and battery sites creates a separate set of disturbances with distinct land-use impacts. The land-use impacts caused by the construction of refinery and storage facilities frequently overshadow the effects of oil spilled within those facilities. Only with pipelines do oil spills have an impact unique to the spilled material and distinct from the impacts of the conveyance, storage or refining facility.

History

Oil spills may be both natural and anthropogenic. Man's contribution has been to alter the scale and some of the locations of oil entry into terrestrial systems, as well as the nature of the oil. Oil spills are expected as a possible outcome of the production and transportation of petroleum.

TABLE 2.
Spill quantities in Canada (1978) according to source (metric tons)

Source	Petroleum spills	Non-petroleum spills
Watercraft	916.1	501.1
Marine terminals	165.1	0.0
Motor vehicle transport	1 193.4	467.4
Trains	588.1	57 829.0(1)
Aircraft	12.8	14.7
Exploration/production(2)	6 542.2	30 689.0
Pipelines	3 126.6	2 450.0
Refineries	1 347.0	16.8
Other industrial plants	382.9	31 157.6(3)
Marketing/storage	4 428.3	62 850.5(4)
Other	485.5	2.6
TOTALS	19 188.0	185 978.7

Notes:

(1) Sulphur accounts for 53 138 t of the non-petroleum spills from trains. One event alone totalled 49 760 t.

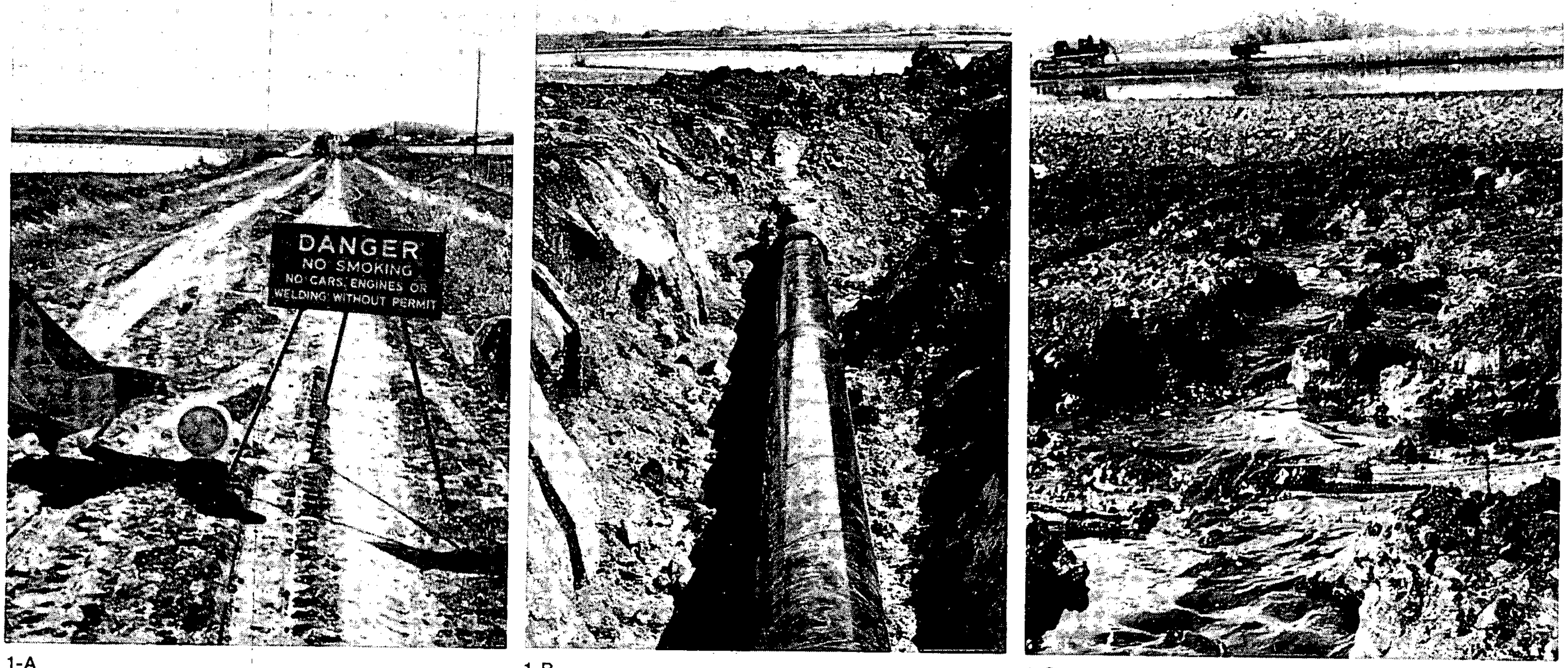
(2) In exploration and production, approximately 5 980 t (96.5%) of petroleum spilled is crude oil; about 26 100 t (84.1%) of the non-petroleum spills is production field water.

(3) Spills of industrial process waste total 11 230 t and represent 36% of this category.

(4) One event, the release of approximately 62 600 t from a mine tailings pond accounts for 99.6% of the total quantity spilled in this category.

Source: Beach, 1979.

In the Middle East, there is evidence from buildings erected about 6 000 years ago along the banks of the Euphrates that asphalt (dark bituminous pitch from petroleum) was then used in mortar. One source of such asphalt may have been the "fountains of pitch" which are still evident near Hit in Iraq. Natural petroleum seepages have been documented in nearly all parts of the world, including the Middle East, China, the Indus valley, Europe, South America, Africa, and North America. North American Indians skimmed oil off streams with wooden pallets, considering it "an excellent medication for sprains, bruises, coughs and sores" (Purdy, 1957). The Seneca Indians of the east coast traded in oil for so long and its use as a medication was so widespread that it was called Seneca Oil when Europeans arrived. In 1531 Pizarro found a well-developed asphalt industry in what is now Peru at La Brea. Llama wool, which would soak up oil and not water, was used to collect oil from the watery pits. It



1-A 1-B 1-C

Photo series 1. Oil on the surface is a fire hazard until the light ends have dissipated (1-A). Once a small puncture is made in a pipe, through corrosion by micro-organisms, by failures along welds, or by soil slumping, the pressure of escaping oil often makes the hole much larger and increases the amount of oil lost. Large sections of pipe must be replaced (1-B) causing disturbance to the land surface, which is short-lived if the soil is not completely saturated with oil. In some instances the oil that has escaped moves laterally from the pipe (up to 800 m in one case) before appearing at the surface. Once at the surface it runs through ditches and low channels in fields (1-C) to collect in depressions. In this spill the oil collected on top of the water visible in the background of all the photos, was skimmed off, and caused little permanent damage to the site. Some of the more serious damage to many sites is caused by heavy machinery and attendant physical disruption. Small amounts of oil collected in micro-depressions left by previous cultivation.

1-A M.J. Rowell, Norwest Soil Research Limited
1-B W.B. McGill
1-C W.B. McGill

was then heated in clay cauldrons until it reached the desired consistency. The product was used, among other things, for embalming and for waterproofing jars to store water (Purdy, 1957).

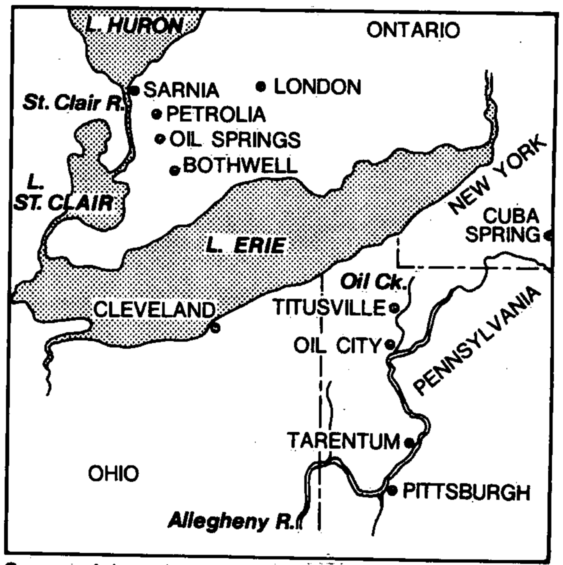
The first recorded petroleum use is at Baku on the Caspian Sea with its earliest commercial use in that area lost in antiquity. According to Purdy (1957) the burning gas seeps also gave rise to a cult of fire worshippers before 1 000 BC. Marco Polo described use of oil from Baku in the 13th century and oil wells in the area supplied all of Persia in the 16th century. In the 18th century (1723) Peter the Great of Russia conquered the region and established a "Master of Refining" to handle oil products and their shipment to Russia.

Natural petroleum seeps along the Athabasca river in Alberta have long been known and Alexander Mackenzie noted their occurrence on the Mackenzie River in 1789. The first major recorded oil spill in North America may have occurred in 1829 when a well drilled to obtain salt near Barkesville Kentucky hit oil. Apparently some 160 m³ of oil a day flowed from the well and into the surrounding region, including the Cumberland River (Purdy, 1957). No efforts were made to use the oil or to prevent its contamination of the countryside. Its effects have not persisted.

The capacity of natural terrestrial systems to deal with the presence of petroleum is almost ubiquitous (McGill *et al.*, 1981) although in some northern soils it appears that oil-degrading organisms are not indigenous. Such widespread toleration by terrestrial ecosystems of low level exposure to oil is not surprising given the long history of the natural presence of oil in those environments.

In Canada, the history of oil spills is as old as the petroleum industry, which predates that of the USA. The earliest manufacture of petroleum products in Canada dates back to 1852, although it was not until 1854 that the International Mining and Manufacturing Company was granted a charter at Enniskillen, Ontario, for that purpose. Interestingly, from the standpoint of land use, it was during a soil survey of the Enniskillen area that the "gum beds" which gave rise to this industry were discovered. Unfortunately, and perhaps characteristically Canadian, this first company started selling off its oil properties in 1856 and later the company disappeared. The first wells were rudimentary and by today's standards oil spillage around the sites was massive in proportion to the amount of oil produced. Between 1857 and 1860 a well was dug at Oil Springs near Enniskillen (Map 1). It was "49 feet [15 m] deep, 7 by 9 feet square [.65 × .8 m²], and cribbed with small logs" (Purdy, 1957). The owner, J.M. Williams, was the first person in North America to dig for oil, and to obtain it in sufficient quantities to refine and sell it as illuminating oil and lubricant. The next major oil field was discovered at Petrolia in 1860 and the

MAP 1.
Where the oil industry began in North America



Source: Adapted from Purdy, 1957.

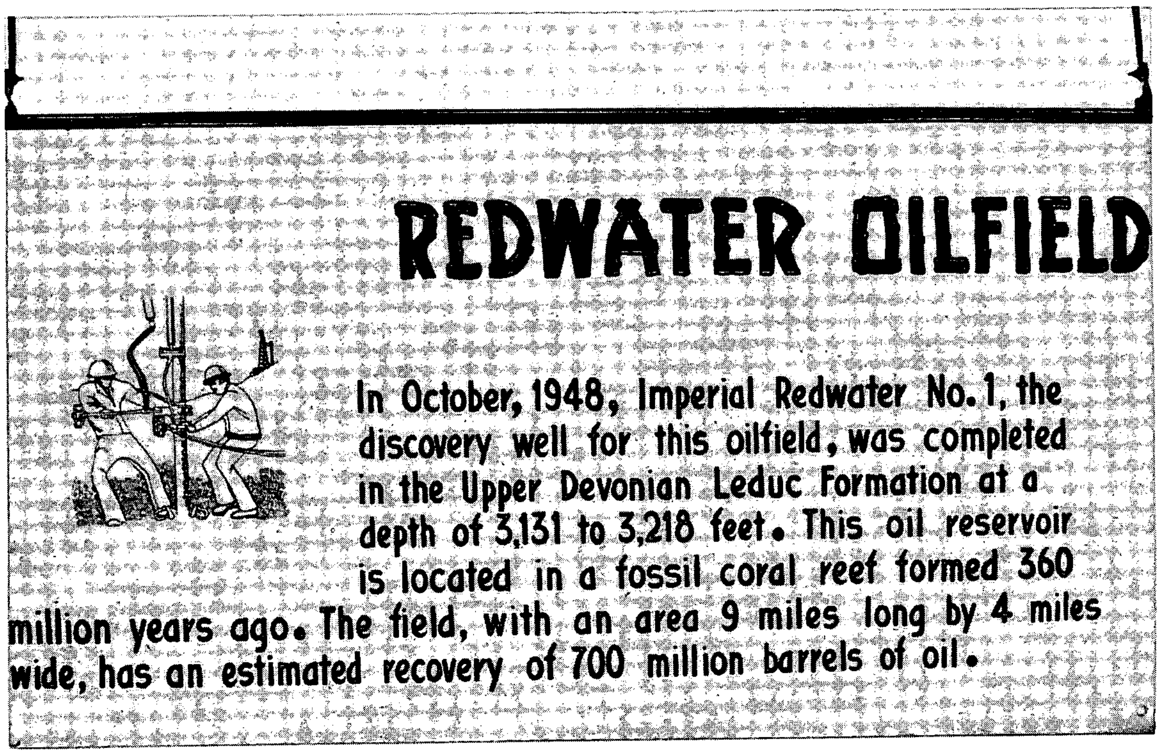
Bothwell field was opened shortly thereafter. A field discovered in New Brunswick in 1875 today no longer produces oil.

The next development occurred in 1920 with discovery of oil along the Mackenzie River (Norman Wells) near the Arctic Circle (Purdy, 1957). Oil spills in the Arctic are obviously not new, but no persistent ecological or land-use impacts from spillages are evident. Land-use effects in the North seem more related to the developments associated with production and transportation.

Canada's first major oil spill was at Petrolia, Ontario in 1862, where an oil well gusher blew oil over "the tree tops, covered fifty acres [20 ha] with oil from one to three feet [.3 - .9 m] deep and poured enough oil into Black Creek to blacken Lake St. Clair" (Purdy, 1957).

In western Canada, Indians had commented on oil seeps near Pincher Creek, Alberta, and in 1866 John Brown collected and used the oil as a lubricant; later others used it and sold it to cattlemen. Drilling started in 1891 (Purdy, 1957) and although the amounts of petroleum and gas found were small, they encouraged further exploration and satisfied some local needs. In 1913 a well in Turner Valley (west of Calgary) struck a naphtha-rich zone that was commercially viable, but total production between 1914 and 1921 was only 3-5 m³ per day.

In 1924 Canada's first great gas blowout occurred in Turner Valley. The gas in the well pushed the casing out and blew wild. It burned for several weeks before being brought under control. An estimated 5 700 000 m³ of natural gas and 80 m³ of naphtha escaped daily. Following this, naphtha production from Turner Valley increased markedly. By 1942 the Turner Valley field was producing 4 770 m³ of petroleum daily, was the third major Canadian oil field (after Petrolia and Norman Wells), and the second to provide oil to Canadian refineries. The fourth major field was found in Leduc, Alberta, in 1947 (Photo 2).



REDWATER OILFIELD

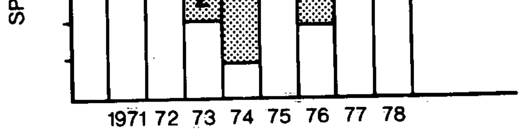
In October, 1948, Imperial Redwater No. 1, the discovery well for this oilfield, was completed in the Upper Devonian Leduc Formation at a depth of 3,131 to 3,218 feet. This oil reservoir is located in a fossil coral reef formed 360 million years ago. The field, with an area 9 miles long by 4 miles wide, has an estimated recovery of 700 million barrels of oil.

Photo 2. Discovery of the Redwater oil field in 1948 after the Leduc field in 1947 confirmed the expectation that oil should be present in Western Canada and helped compensate for the long apparently fruitless search for oil until that time.
W.B. McGill

The first, and largest, oil spill in Western Canada was at the Leduc-Woodbend field. In March 1948 the Atlantic No. 3A oil well, about 30 km southwest of Edmonton, blew out of control for 5 months. During this period nearly 160 000 m³ of oil were produced which flooded about 40 ha of land. Today, the whole area is revegetated (Brushett, 1975) through a combination of man's efforts and natural processes.

The reporting of oil spills to the Alberta Energy Resources Conservation Board began in 1971. Spills are now reported regularly throughout the entire country; data are compiled by various provincial agencies and, nationally, by the National Analysis of Trends in Emergencies Systems (NATES), Environment Canada. Both sources have been consulted for the discussion to follow on the scope and significance of oil spills on land use. Direct comparisons of data from the various sources are difficult and dangerous because of differences in reporting procedures throughout Canada.

FIGURE 1.
Oil spill volume during 1971-78 in Alberta



Note: The screened area shows the number of major spills that occurred each year, and their total volume.

Source: Brushett, 1979.

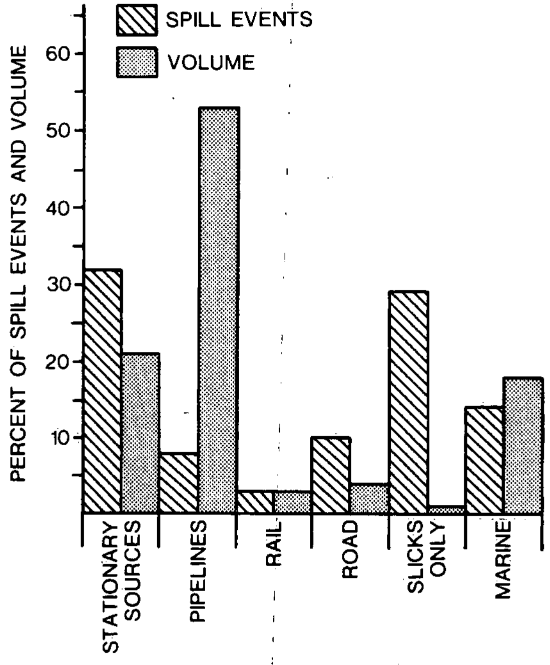
Scope

Oil spill volumes in Alberta, the major producing area in Canada, vary between 0.01% and 0.03% of total production. Oil spill volumes vary from year to year, reflecting the impact of one or two large spills each year on the total volume (Figure 1). With the exception of 1972, oil spill volume in Alberta has varied between 6 000 and 11 000 m³ annually. According to Brushett (1975) the main sources are pipeline failures resulting primarily from internal corrosion, secondarily from external corrosion.

On a national basis, data have been summarized for 1974–75 into six main categories (Figure 2). Although stationary sources and slicks accounted for about 60% of the oil spill events and marine sources for another 18%, pipelines released over 50% of the volume of oil spilled, while accounting for only about 8% of the events.

A more detailed breakdown for 1978 of total oil spill events in Canada (Tables 1 and 2) shows that exploration and production accounted for the largest number and volume of spills; marketing and storage facilities contributed about 23% of the petroleum spilled in 9% of the events. There seems to be a discrepancy between the 1974–75 data and that for 1978. One of the problems with the national data is that reporting intensity is not consistent in all

FIGURE 2.
Breakdown of oil spills by source in Canada, 1974-75



Source: Pettigrew, 1975.

provinces and territories. As a result, large annual variations can result as much from shifts in relative reporting intensity as from changes in oil spill frequency. Another problem in the national data available is that the consequences of spill events are not well documented, so that no firm conclusions about these can be drawn.

Data for 1979 and 1980 have been summarized nationally by region. They are voluntarily contributed to NATES from each region. Regional discrepancies result from differences in reporting systems within the various provinces, consequently the totals calculated for each region are of only limited value for comparisons with other parts of Canada. Differences in types of spills and spill volumes are sufficiently marked throughout the various parts of Canada, however, for some general trends to become clear.

The total quantity of reported crude and condensate spilled varied between 6 500 and 8 000 t annually, which was between two and four times greater than the quantity of refined product spilled. The number of refined product spills, however, is only slightly less than that of crude oil spills (Table 3). Interestingly, the largest reported product spill in 1979 was bigger than the largest reported crude spill in 1980, indicating some overlap in volumes of individual spills, although crude oil spills normally tend to be the larger. Nationally, product and crude spills occur with a combined frequency of about five spills every two days.

TABLE 3.
Total quantities of crude oil and refined products spilled on land in Canada during 1979 and 1980

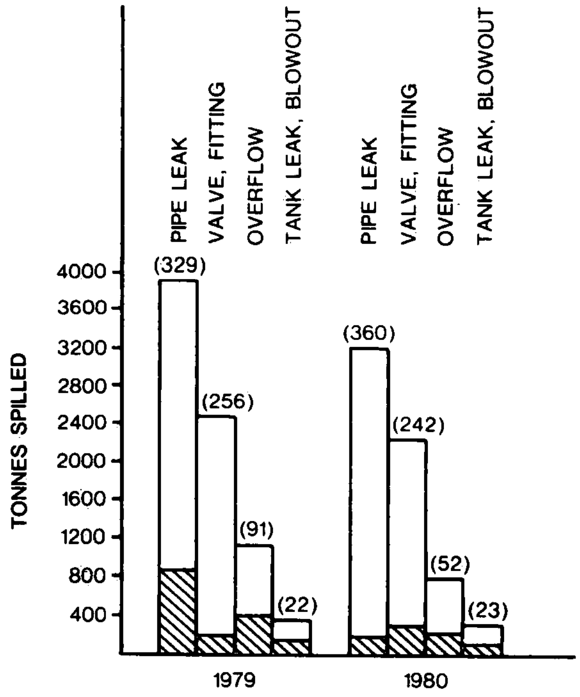
	Crude		Refined product	
	1979	1980	1979	1980
Number of events	698	677	511	453
Total mass (t)	7 763	6 617	3 884	1 838
Largest event (t)	855 (Pipe leak)	339 (valve, fitting)	367 (Derailment)	134 (Pipe leak)

Designations in brackets ( ) under largest event indicate the source of that single event.
Source: NATES, unpublished.

As with the data for 1974 and 1975, spill quantities vary widely from year to year, but the number of spill events varies less, reflecting the influence of one or two large spills each year (Figures 3 and 4).

The major source of crude oil spills, according to the 1979 and 1980 data, was pipelines (see also photo 3); overflows tended to be more common and important sources of refined product spills. This difference has implications for the impact of spills on land. Pipelines, which traverse a wide range of landscapes, release predominately crude oil when ruptured. Storage facilities, however, occupy a limited space and spills from them can be more easily confined than spills from pipelines could ever be. Consequently, a unit volume of crude oil spilled is likely to affect more land than a unit volume of spilled refined product.

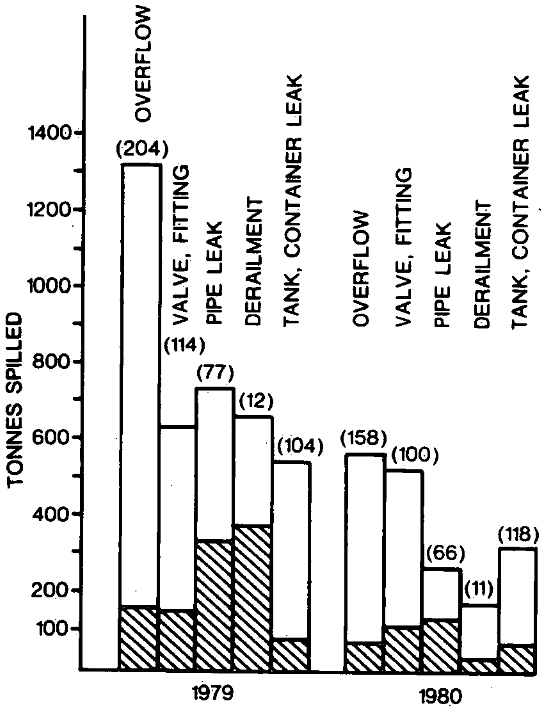
FIGURE 3.
Source of crude oil and condensate spills in Canada on land during 1979 and 1980



Note: Shaded areas represent largest single spill. Numbers in brackets ( ) indicate total number of events.

Source: NATES, unpublished.

FIGURE 4.
Sources of gasoline, fuel (2, 4, 5, 6), waste oil, asphalt, and other products spilled in Canada on land during 1979 and 1980



Note: Shaded areas represent largest single spill. Numbers in brackets ( ) indicate total number of events.

Source: NATES, unpublished.

Most of the total reported spill volume occurs in the prairies. Nationally, crude oil spills predominate over refined product spills and 99% of the crude oil spilled is in the prairies (Figure 5). Product spills were larger in central Canada than in the west, but not necessarily more frequent. Between 33% and 47% of the reported product spilled is in Ontario and Quebec. Very little product and virtually no crude oil was spilled on land in the Atlantic provinces.

Significance

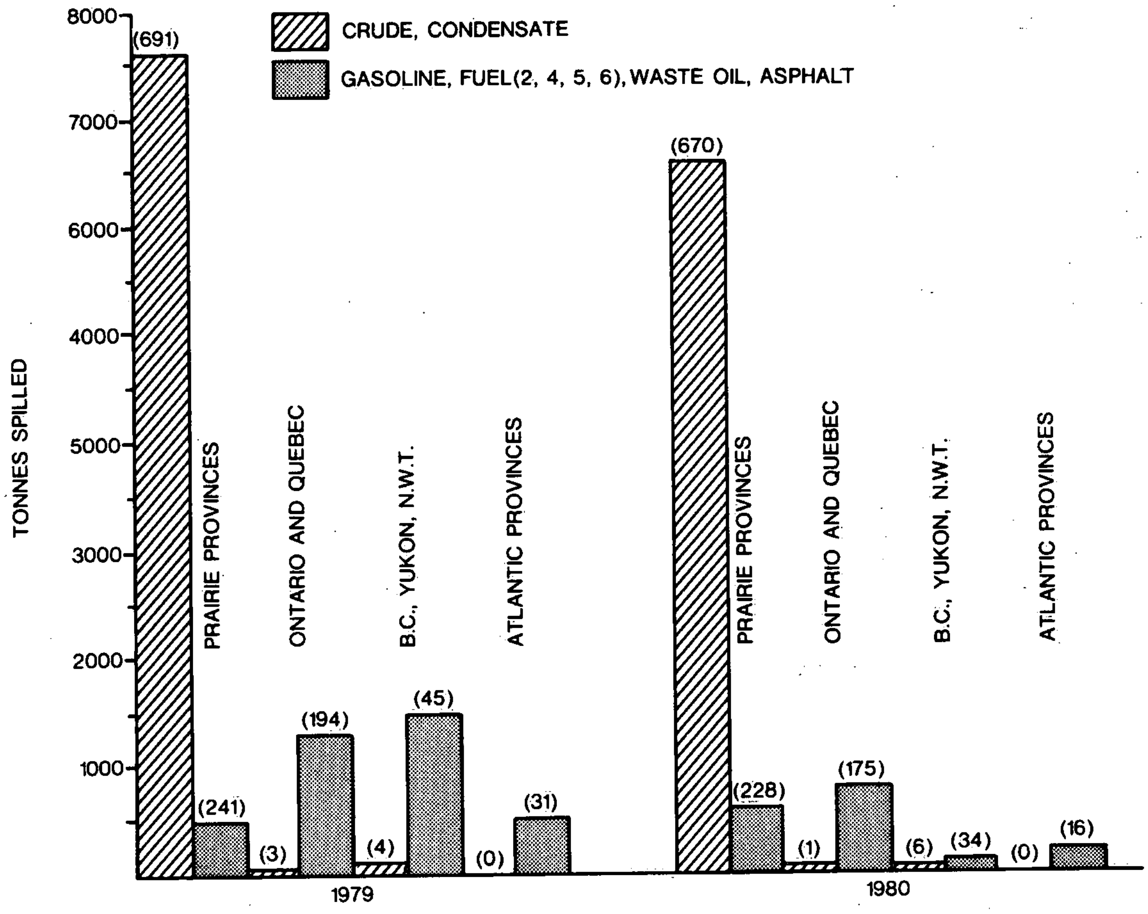
Before 1965 spill records were scant. It may be assumed, however, that pipelines, which are now a major source of spills, cannot have been so important a factor before 1960 for two reasons. First, most pipeline spills are related to corrosion, which takes time, and second, the age-times-length factor before 1960 is small. For example, by 1950 there was only 2 130 km of pipeline in Canada. By 1960 this had grown to 13 580 km and by 1978, 34 420 km (Table 4). Major pipelines can be found in most of Alberta, the interior of British Columbia, the southern third of Saskatchewan, and the extreme southern part of Manitoba (Map 2).

MacKay *et al.* (1974) summarized spill data from Alberta and the rest of Canada. They concluded that with pipelines of a diameter of 15 cm or greater, annual spill frequency was about one for every 1 600 km. For pipes of smaller diameter, the annual frequency was one spill for every 820 km. In examining pipeline lengths by size (diameter) in the various regions, it becomes evident that if spill frequency is calculated as a function of pipeline length, Alberta and Saskatchewan can be expected to suffer a very large number of small spills whereas in Ontario one would expect a smaller number of spills but of greater volume (Table 5). The total length of oil pipeline in Alberta is 50% of that in all of Canada and 5.1 times that in Ontario.

TABLE 4.
Oil pipeline lengths in Canada

Year	Length (km)	Source
1931	273	Purdy (1957)
1945	627	"
1950	2 130	"
1955	7 570	"
1960	13 580	CPA (1979)
1965	19 850	"
1970	27 850	"
1975	32 000	"
1978	34 420	"

FIGURE 5.
Geographic location of spills in Canada on land during 1979 and 1980



Note: Numbers in brackets ( ) indicate number of events.

Source: NATES, unpublished.

Spill volume risk

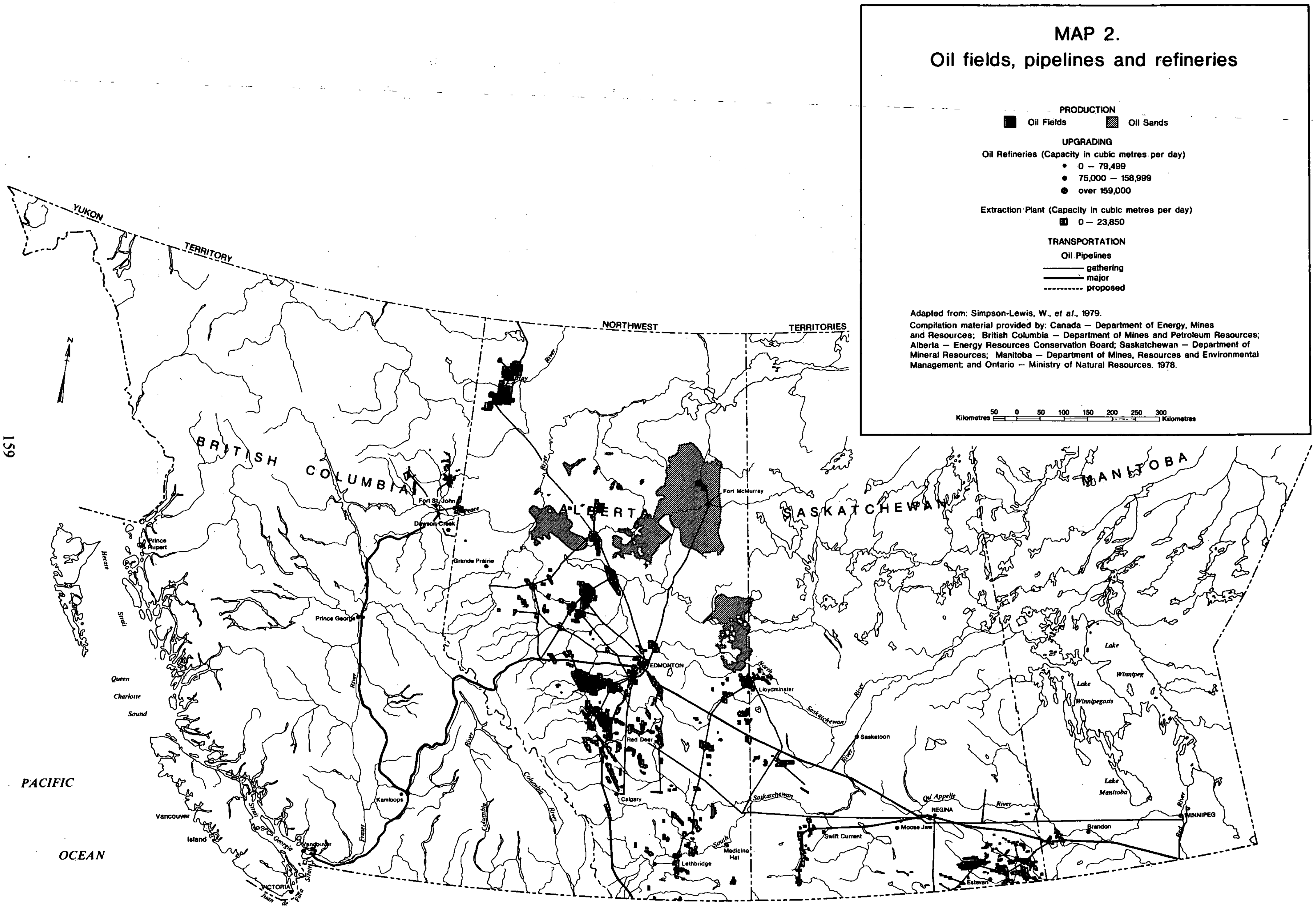
A factor indicating spill volume risk has been calculated using average spill volumes as a function of pipe diameter as reported by MacKay *et al.* (1974), total pipeline lengths, pipeline sizes in each region, and probability of a spill as a function of length. This integrates some of the variables and permits comparisons to be made of land-use risks in the different

TABLE 5.
Lengths (km) of oil pipelines in various regions of Canada at year end, 1978

Diameter of pipe (cm) Region	0–14.9	15.0–32.9	33–48.0	> 48.0	Total
Yukon	89	—	—	—	89
British Columbia	539	1 264	—	838	2 641
Alberta	5 183	7 984	1 303	2 895	17 365
Saskatchewan	2 122	3 436	670	1 950	8 178
Manitoba	251	628	426	720	2 025
Ontario	1	1 971	102	1 348	3 422
Quebec	—	334	142	224	700
Totals	8 185	15 617	2 643	7 975	34 420

Source: CPA, 1979.

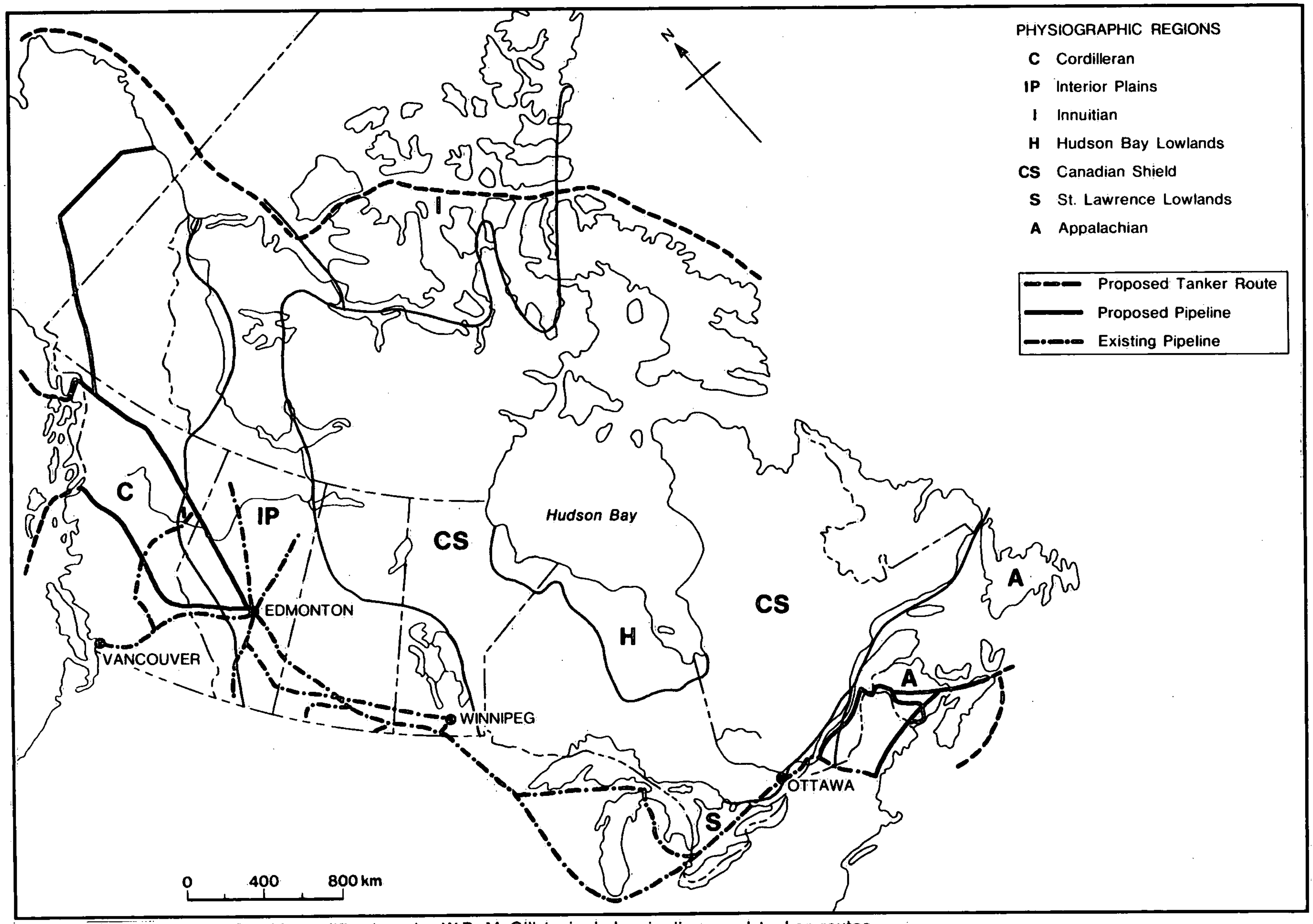
MAP 2.
Oil fields, pipelines and refineries



Adapted from: Simpson-Lewis, W., *et al.*, 1979.

Compilation material provided by: Canada – Department of Energy, Mines and Resources; British Columbia – Department of Mines and Petroleum Resources; Alberta – Energy Resources Conservation Board; Saskatchewan – Department of Mineral Resources; Manitoba – Department of Mines, Resources and Environmental Management; and Ontario – Ministry of Natural Resources. 1978.

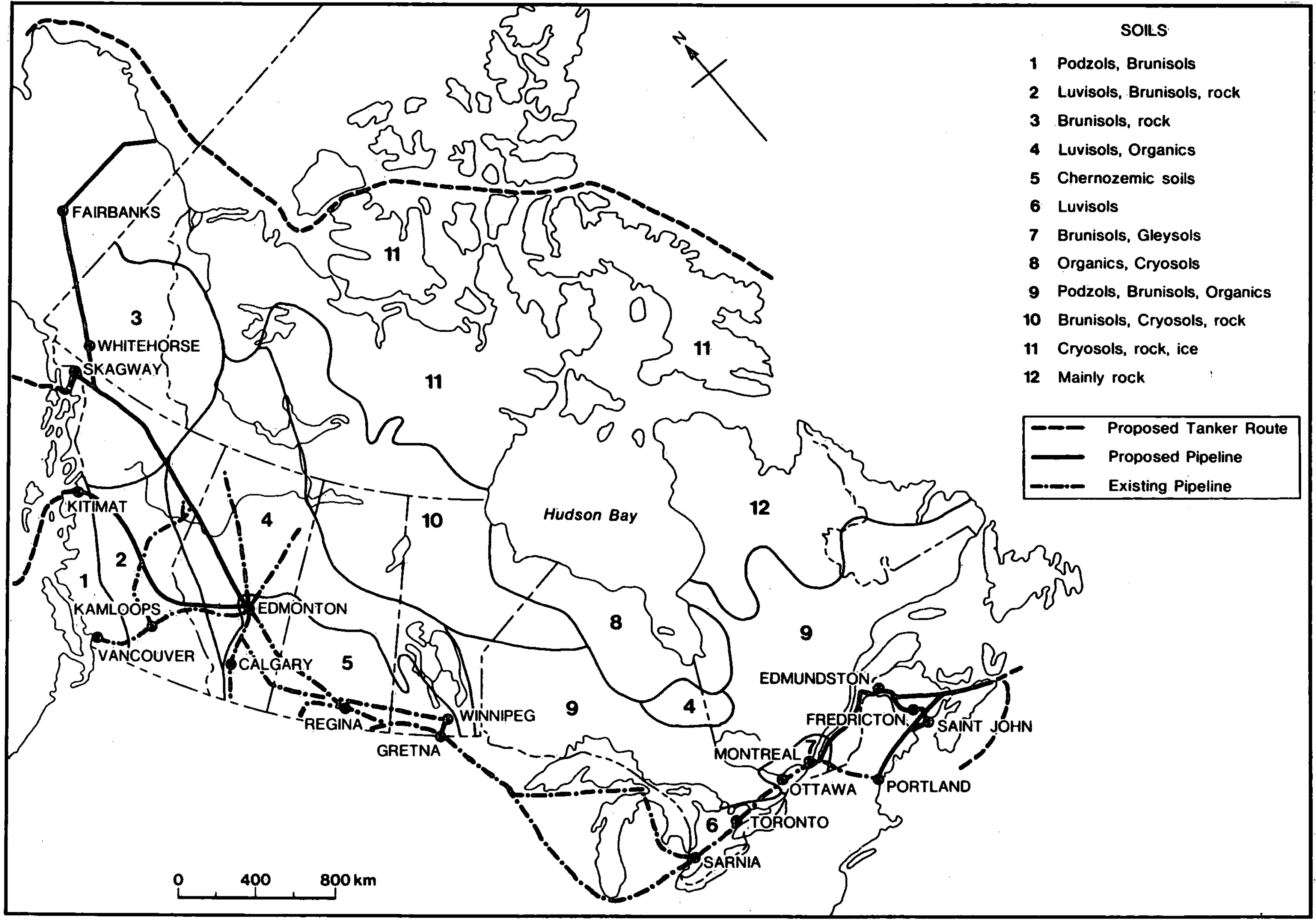
MAP 3.
Major physiographic regions of Canada and major oil pipelines



Source: Lord *et al.*, 1978, with modifications by W.B. McGill to include pipelines and tanker routes.

MAP 4.

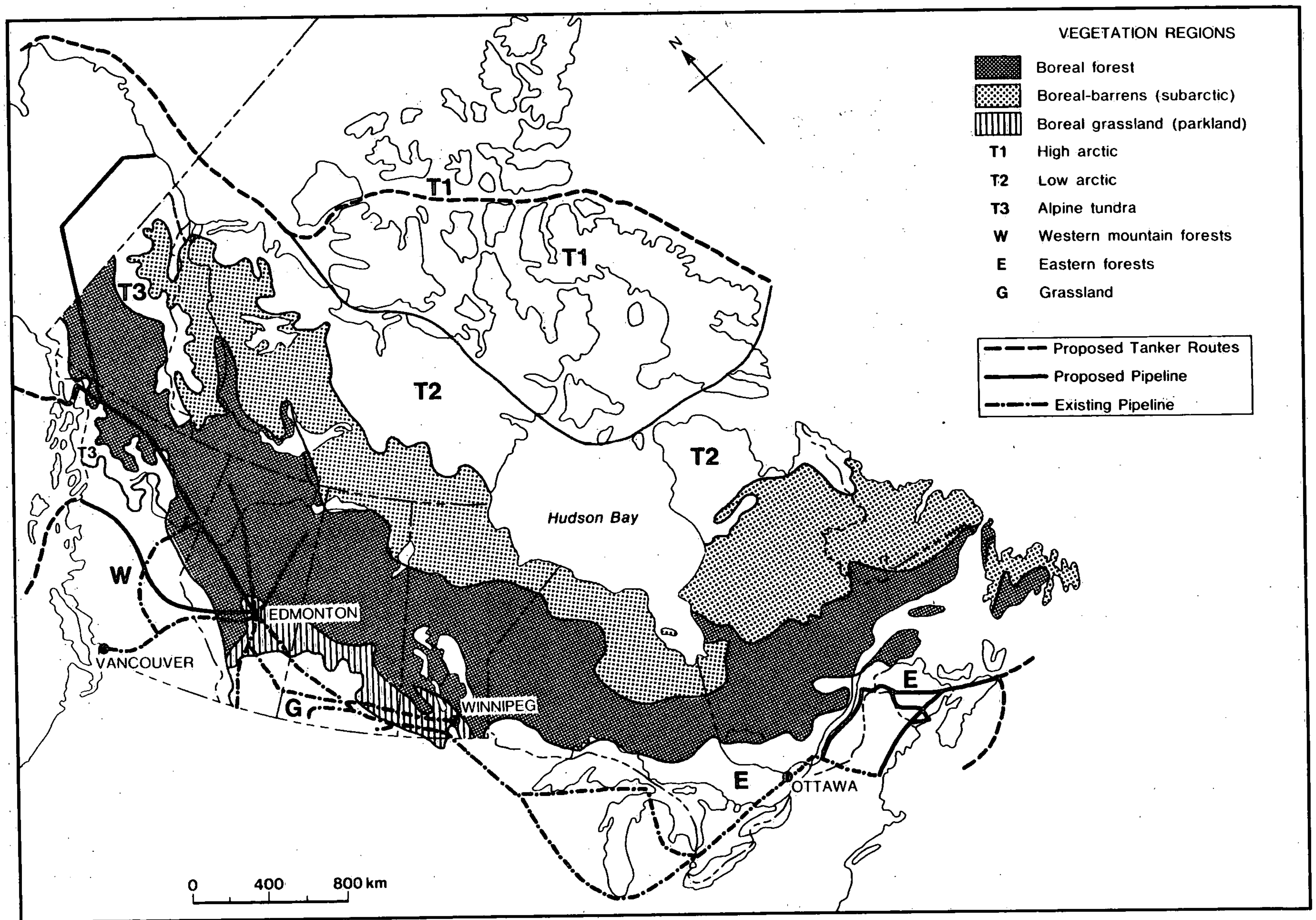
Major soil regions of Canada and major oil pipelines



Source: Lord *et al.*, 1978, with modifications by W.B. McGill to include pipelines and tanker routes.

MAP 5.

Vegetation regions of Canada and major oil pipelines



Source: Lord *et al.*, 1978, with modifications by W.B. McGill to include pipelines and tanker routes.

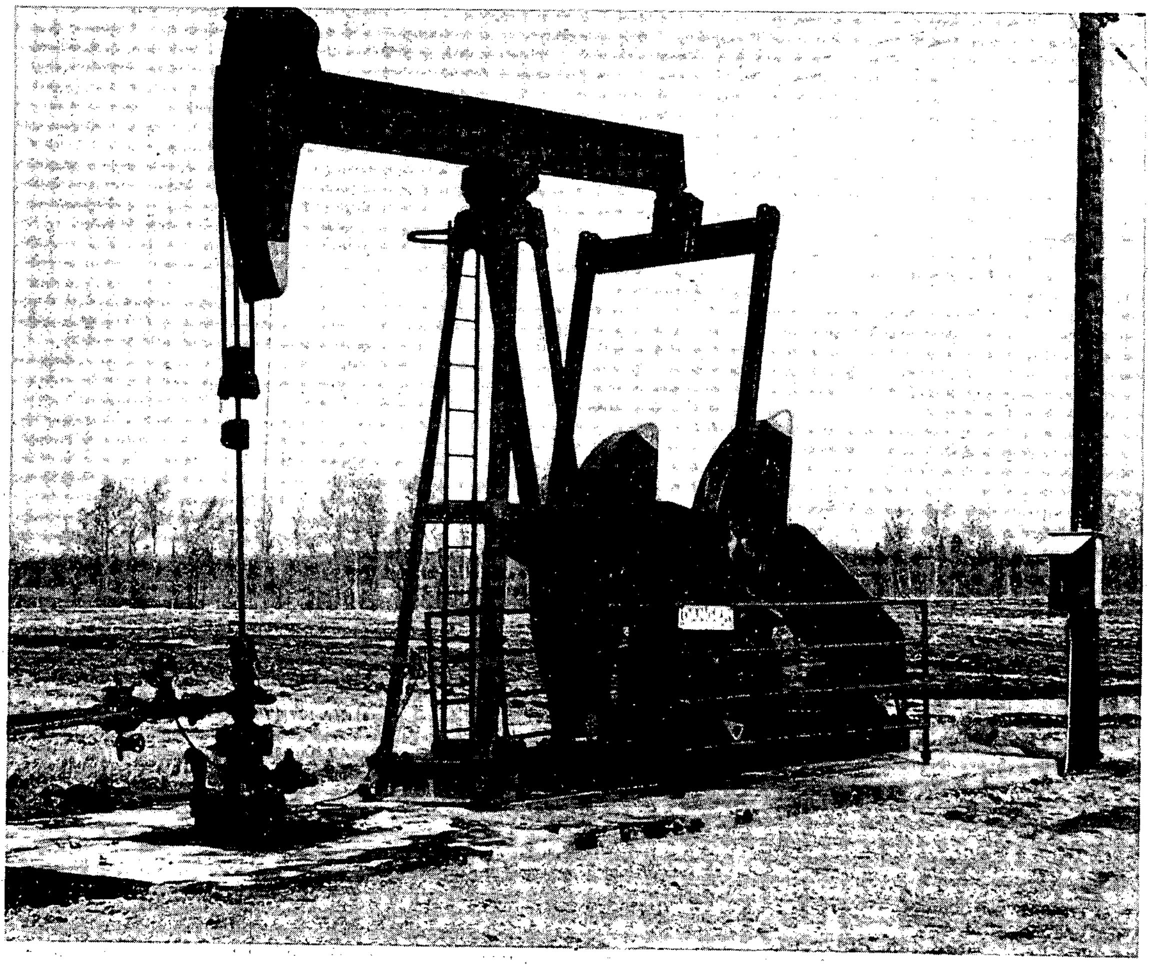


Photo 3. Oil spills may also be caused by problems (valve leakage, blown stuffing boxes, etc.) at the well head. These spills often result in sprays of oil over large areas but the effects on land used for annual crops are minor. Such sprays onto coniferous trees, however, are usually lethal but have less effect on deciduous species. Obviously if a crop is sprayed a year's crop is lost, but succeeding crops are normally unaffected. The effects of pumps themselves, when located in the middle of quarter-sections, are greater than the effects of oil spilled from them.
W.B. McGill

regions. Using this factor, the spill volume risk per unit of pipe length is greatest in Ontario and Manitoba which have 2.13 and 1.93 times greater risk per kilometre than Alberta; next in order of risk are Quebec, British Columbia, Saskatchewan, and Alberta. Only the Yukon has a lower spill volume risk per kilometre than Alberta (Table 6). The total spill volume risk is highest in Alberta, followed by Saskatchewan, and then Ontario, which can expect about 42% as much oil spilled as in Alberta. Manitoba and British Columbia are next with 22–26% of the spill volume risk and finally Quebec and the Yukon with only 7% and 0.09% of the spill volume risk of Alberta respectively.

Land-use insult has been defined as the potential reduction in land-use options or in land value if appropriate reclamation is not undertaken. It is determined by the type of oil spilled, the amount per spill, and the land value for non-urban uses prior to the spill. Examination of where the major pipelines are in Canada in relation to soils, vegetation, and physiographic regions (Maps 3, 4, 5) indicates considerable heterogeneity in the physical environment, land use, and value. Such heterogeneity leads to variations across the country in the potential land-use impact of a defined volume of spilled oil. Moreover, refined product pipelines, which are relatively important in Ontario (Table 7), create greater problems than trunk lines carrying crude oil. Crude oil is less water soluble, less toxic, and usually less mobile than most refined products; it covers less area and does not seem to interfere with land use for as long as other refined products. Gathering lines, which transport oil from the well to battery sites for removal of water, carry some salt water which creates an additional problem. Consequently, some way must be found to integrate the effects on land use and value with types of oil and expected spill volume risk.

Land-use impact index

A land-use impact index has been developed to indicate, on a national basis, the relative extent of potential land-use interference, or reduction in land-use options, created by oil spills from pipelines. Usually pipeline corridors are expected to continue to be used for agriculture, forestry, or recreation; stationary oil storage and refining facilities are not. An oil spill from a pipeline affects other land uses, usually limiting land-use options. An oil spill at a refinery has essentially no impact on land use because the land had already been pre-empted by the battery or refinery. When the oil leaves these sites, however, it affects land-use options. The index is based, in part, on indices of land value for agriculture, recreation, and forestry (Table 8) for the areas of Canada traversed by major pipelines. For example, pipeline corridors in Saskatchewan occur in areas of low landscape attractivity for outdoor recreation, whereas those in British Columbia and Ontario are in attractive areas. Similarly, the value of agricultural land (dollars of capital farm value per hectare) is lower in the prairies than in Ontario and Quebec. The land-value index has been combined with an index for each region based on the weighted oil type—weighted on the basis of length of pipeline carrying various types of oil—although a better weighting factor would be oil volume. The final component is the spill volume risk from Table 6, which incidentally has units of barrels. The spill volume risk has been converted to an area risk factor using the equation of MacKay *et al.* (1974). The three component indices are multiplied together to obtain the Land-use impact risk index (Table 9).

The impact of pipeline oil spills on land use appears to be potentially as great or greater in Ontario as in Alberta (Table 9). Possibly this is to be expected, because Alberta is the main oil-producing province in Canada and Ontario is the main consumer. Land value has a profound effect on the impact index and compensates for some of the oil volume differences. For example, many of the pipelines in Alberta run through areas of very limited agricultural or commercial forestry value and only slight recreational value. In Ontario, most pipelines are in the productive area of the Province. Because of high land values in areas traversed by pipelines, oil spills in British Columbia, in spite of their low volume, have an impact about half that in Alberta and Ontario.

Regional awareness of oil spills is probably more dependent on spill number than on volume. Consequently, spill awareness is probably highest in Alberta even though the total actual spill impact there may be no greater than in Ontario. The impact of oil spills in Canada in relation to other disturbances, such as forest fires, strip mining, urban development etc. is hard to assess but the area affected is less than 1 000 ha. Effects of salt water spills from the petroleum industry are more serious, and longer lasting. The volume of salt water being produced is increasing as oil fields become depleted.

TABLE 6.
Oil spill volume risk factors in Canada

Region	Pipe diameter (cm)	Length of pipe (km)	Spill(1) volume risk per kilometre (bbls)	Spill volume risk	Relative(2) spill volume risk	Relative(2) spill volume risk per kilometre
Yukon	0–15	89	0.154	13.7	0.0009	0.17
British Columbia	0–15	539	0.154	83	0.26	1.74
	15–48	1 264	0.166	210		
	> 48	838	4.38	3 670		
totals		2 641		3 963		
Alberta	0–15	5 183	0.154	798	1.0	1.0
	15–48	9 287	0.166	1 540		
	> 48	2 895	4.38	12 680		
totals		17 365		15 018		
Saskatchewan	0–15	2 122	0.154	327	0.64	1.35
	15–48	4 106	0.166	682		
	>48	1 950	4.38	8 541		
totals		8 178		9 550		
Manitoba	0–15	251	0.154	39	0.22	1.93
	15–48	1 054	0.166	175		
	> 48	720	4.38	3 154		
totals		2 025		3 368		
Ontario	0–15	1	0.154	—	0.42	2.13
	15–48	2 073	0.166	344		
	> 48	1 348	4.38	5 904		
totals		3 422		6 248		
Quebec	15–48	476	0.166	79	0.07	1.76
	>48	224	4.38	981		
totals		700		1 060		

(1)Calculated from data of MacKay *et al.* (1974).

(2)Alberta arbitrarily set as 1.0 to obtain relative ranking.

TABLE 7.
Types of oil pipelines in various regions of Canada (1978)

Length of oil pipeline (km) Region	Gathering	Trunk	Refined product
Yukon	—	—	89
British Columbia	830	1 755	56
Alberta	7 973	8 539	853
Saskatchewan	3 268	3 569	1 341
Manitoba	323	1 389	313
Ontario	1	1 474	1 947
Quebec	—	452	248
Totals	12 395	17 178	4 847

Source: CPA, 1979.

NATURE OF THE STRESS

Introduction

The stress on land produced by oil spills of various kinds can be described in terms of the degree of threat, which is a function of human activity in the production, refining, transportation, and storage of oil, and the sensitivity of a geographical area (Pettigrew, 1975). The sensitivity of a particular area to terrestrial (as opposed to marine) oil spills is measured by two components: first, changes that occur in the soil as a result of the addition of oil, together with concomitant and resulting effects on vegetation; second, effects on land use. Thus the sensitivity component must first be evaluated in terms of soil processes and vegetation effects that occur at the spill site. The expression of the stress, together with its impact on land use, value, and capability can then be examined.

The stress produced by oil spills can be defined in terms of the resulting effects on land value and capability for agriculture, forestry, wildlife, and recreation. Because inland oil spills generally occur outside the urban environment, human settlements are little affected by oil spills in terms of a change in the land resource capability. Oil spills usually result in a deleterious effect on the land resource, particularly when evaluated on the basis of their short-term effects. Long-term beneficial effects, however, have been observed in some instances. Oil spills on land used for agriculture and forestry may reduce or eliminate the capability of the site for production of a specific crop for a period varying from months to decades following the spill if appropriate reclamation practices are not followed. Yet with appropriate reclamation techniques oil spilled on agricultural or forested lands may not affect their capability in the long term.

On land used for wildlife and recreation there may be destruction of habitat and loss of aesthetic value through the spoiled appearance of the spill site. The surface is usually blackened by the oil and the understory damaged. Frequently sites are burned and the charred remains of trees, together with the black tarry crust remaining on the surface, presents a repulsive sight, totally unsuited to recreational use. On occasion, birds become trapped in the oily residue left after burning, but this is rare. Thus in many recreational areas oil spills combine the worst features of spilled oil with those of small intense forest fires. Some of the visual effects are exacerbated by heavy equipment used to contain and recover spilled oil.

For most spills on land used for agriculture, forestry, wildlife or recreation the rate and extent (in the case of large spills) of natural restoration processes are unacceptable, hence remedial action by man is required, particularly

TABLE 8.
Indices of land value for three major land uses in Canada for areas traversed by major pipelines

Region	Recreation*	Forestry	Agriculture	Total
Yukon	9.5	1.0	1.5	12.0
British Columbia	10.2	3.8	4.6	18.6
Alberta	7.3	1.6	0.8	9.7
Saskatchewan	4.0	0.0	0.5	4.5
Manitoba	5.3	0.0	0.6	5.9
Ontario	11.8	5.0	6.0	22.8
Quebec	9.5	4.0	4.0	17.5

*Index for recreation is the weighted average index for landscape attractivity for outdoor recreation (Simpson-Lewis *et al.*, 1979, p. 74) for areas of each province traversed by major pipelines. For forestry the index was similarly arrived at by weighting the various forest types on a scale of 1–10 from p. 163 of Simpson-Lewis *et al.* (1979). For agriculture the index is based on total capital value of census farms (Simpson-Lewis *et al.*, 1979, p. 25).

TABLE 9.
Expected relative magnitude of pipeline oil spill impacts on land use in Canada

Region	A Area risk factor	B Type severity index	C Land value index	Land-use impact risk index
Yukon	0.0103	2.0	12.0	0.25 (0.003)
British Columbia	1.59	1.33	18.6	39.3 (0.51)
Alberta	5.22	1.51	9.7	76.5 (1.0)
Saskatchewan	3.49	1.56	4.5	24.5 (0.32)
Manitoba	1.38	1.31	5.9	10.7 (0.14)
Ontario	2.39	1.57	22.8	85.6 (1.1)
Quebec	0.493	1.35	17.5	11.6 (0.15)

$$A = 53.5\,[(\text{Volume risk})(.152)]^{.89 \times 10^{-4}}$$

$$B = \frac{\Sigma(\text{type factor})(\text{pipeline length})}{\Sigma\text{pipeline length}}$$

$$\text{Land use impact} = A \times B \times C$$

Type factor: trunk line = 1
gathering line = product line = 2
(see Table 7).

Numbers in brackets ( ) indicate relative impact, with Alberta arbitrarily set to 1.0.

where land value is high. An appraisal of the effects of oil spills on land use, value, and capability normally presumes that remedial action will be taken, and so is partly based on an assessment of reclamation possibilities, procedures, and effectiveness.

Cleanup and reclamation

Effects of oil spills on land use are strongly tied to two considerations: first, cleanup practices following the spill; and second, policies of reclamation or compensation. In several instances severe damage to spill sites has resulted from over-zealous use of heavy equipment, burning, and diking during site cleanup (Photo sequence 4). Some of this damage could have been prevented by less drastic action.

A second spill of about the same volume as that shown in photo sequence 4 occurred in the winter of 1975 only a few metres east of the first spill. The lessons learned from the first spill were applied. Dikes were not constructed, but trenches were cut to collect oil, and burning was used only in the trenches. Consequently oil was not buried and mixed into the soil to seep out later, and drainage was not impeded by unnecessary dikes. The burning system used removed oil and the toxic light components. Any fire damage side-effects were restricted to the small narrow trench areas. This burning system also helped remove oil from below the surface. Because the cleanup was done in winter, rather than waiting until spring or summer, access to the site was no problem and surface soil disturbance was negligible compared to the first spill only a few metres away. The area was disced, fertilized and reseeded, and by 1976 supported a healthy forage crop. Even areas that were not seeded had been invaded by native plants by July of 1975. Thus in one case the impact lasted about 10 years, in the other about 1 year.

Before the 1970s, site reclamation was seldom attempted by those responsible for spills; land owners and oil people were content to settle for mutually agreed compensation. Changes in land use from tilled agriculture to rangeland occasionally occurred. In some instances, where tilled agriculture was continued, surface soil became non-wettable and, together with subsurface persistence of oil, reduced productivity to zero. These effects have persisted for 20 years in some places. Possible beneficial effects on productivity have been observed where the same land use, e.g. tilled agriculture, has persisted following small spills of crude oil onto the soil surface.

During the 1970s compensation demands rose sharply. For example, demands exceeding $10 000 have been made for about 2 ha of uncultivated, poorly drained, low-lying land used for cutting native hay in Alberta. At the same time reclamation methods improved. Landowners now prefer complete reclamation to monetary compensation. This trend has been due to two factors: first, to a recognition that although oil spill sites may be gradually restored by "letting nature take its course", the time needed was never easy to estimate. Second, the highly technical approach needed to achieve proper restoration without causing secondary problems such as salinization from added fertilizers or toxicities from degradation products, is now available.

Reclamation experts now know that oil spill site restoration on agricultural soils and on many forested soils requires balancing the nutrient supply to soil organisms that decompose the oil. In addition, each site must be treated individually and a proper restoration program developed, usually requiring a professional agrologist

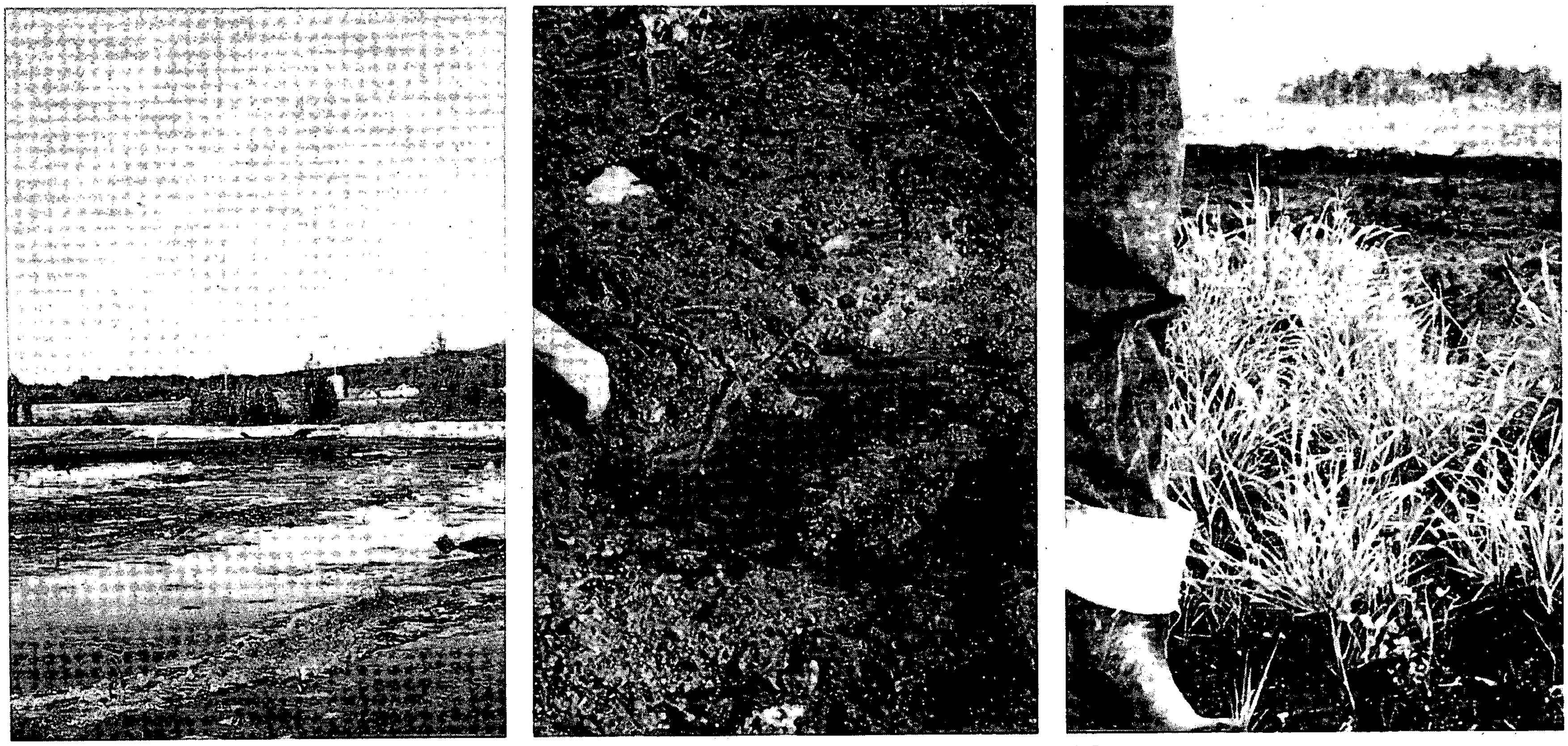

4-A 4-B 4-C

Photo series 4. Approach to initial cleanup significantly affects the persistence of land-use impacts following oil spills. This site (4-A) is a pipeline rupture in native pasture land in a flat low-lying imperfectly drained area. The site was diked and trenched. The dikes were intended to prevent oil from migrating from the site but their main impact was to prevent drainage and the site kept getting wetter. Most of the trees were destroyed and the surface of the site was thoroughly disturbed. Pools of oil that had been buried during the "cleanup" kept coming to the surface (4-B) creating a major problem for complete oil removal and site restoration. Birds landing in such pools become oiled and die. Fortunately, the extent of such occurrences is small. The spill occurred in November of 1972 when about 6 000 bbls of oil leaked from a corroded pipeline. The spill area was slightly less than 2 ha. By running a pipe under the dike to improve drainage, the high spots could support a vegetative cover if they were tilled to break the crust left by burning, then fertilized and seeded. Growth through the crusted area can be substantial if the crust is first broken to allow plant emergence (4-C). This site has since been properly drained and is now nearly restored (10 years after the initial spill).

4-A M. Nyborg, University of Alberta
4-B D.R. Shaw, Energy Resources Conservation Board of Alberta
4-C W.B. McGill

trained in Soil Science. Landowners have decided to let the party responsible for the spill finance the restoration program.

The trend toward improved restoration has prevented much change in land use or capability as a result of oil spills in agricultural areas. Because of its small area and its acute effect on aesthetics, contaminated soil in urban and recreational areas is usually dug up and replaced to avoid changes in land use, value, or capability. Whether or not inland oil spills in the Arctic should be cleaned up is still being debated. Suggestions have been made that the effect on the terrestrial ecosystem is so small, and the cleanup costs so high that cleanup is a waste of effort and money.

Biophysical Effects

In defining the physical effects of oil spills on land it is necessary to consider the nature of the spilled material. All types and grades of oils are spilled in Canada, from high octane jet fuels to Bunker-C; spills of crude oil and diesel fuel top the list in volume (Pettigrew, 1975). A few general comments about the effects of the nature of the oil follow. Details can be found in the references cited within this section.

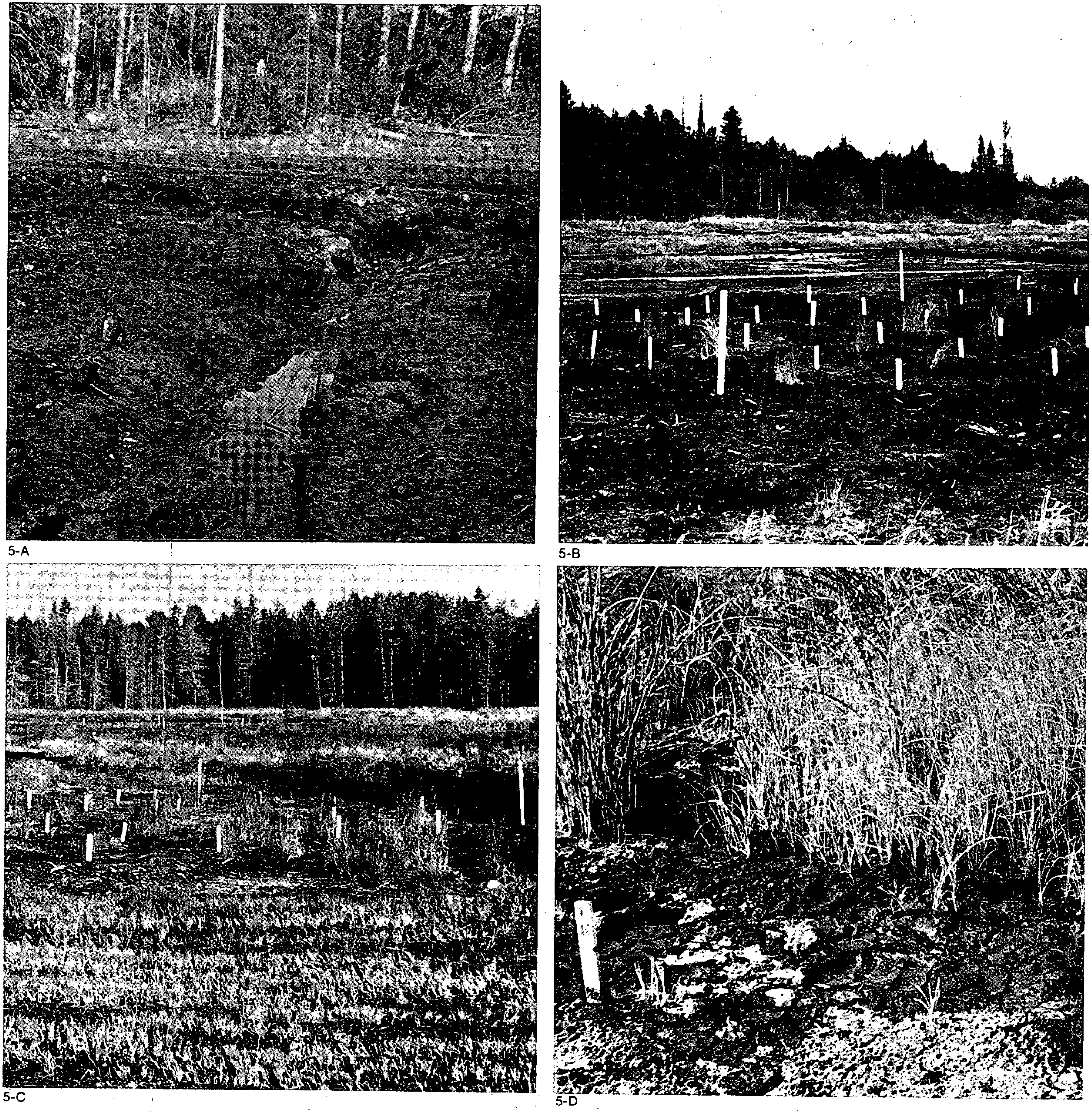
Although the lack of living plants is frequently the most obvious symptom of an oil spill, the main problem is the actual presence of oil—not merely the lack of plants. In many spill situations an inordinate amount of energy, money, and effort has been wasted in trying to re-establish plant growth before the oil content of the site has been sufficiently reduced. As a result, the whole reclamation process has to be started anew (Photo series 4 and 5). As in many situations, the symptom is often treated in place of the real problem. Many other symptoms, themselves serious problems, have also been recognized (Figure 6). If all the spilled material is recovered, no residual problem remains.

Nature of the oil

Oil in contact with plants is harmful in nearly all situations and lethal in many. The most toxic portions of crude or refined petroleum are the small molecules; they are more mobile and often more soluble than some of the large molecules. Because most spilled oils consist of a continuum of molecules from very small and volatile to large high boiling molecules, the toxicity to plants and animals of an oil spill can range from acute to minor. Generally, the materials present in refined products are more toxic than those in crude oils. However, synthetic crudes can also be quite toxic (McGill *et al.*, 1981). Immediately following a crude oil spill, sulphur-containing materials such as hydrogen sulphide and mercaptans[1] (see glossary) can cause serious problems for humans; in some instances large areas have to be evacuated. Such effects, however, are transient.

Very heavy oils are produced in parts of Saskatchewan and Alberta near Lloydminster. These crudes present less problem for cleanup and consequently cause less impact on land use than lighter more volatile oils. The sump materials from such heavy oils were at one time disposed of in pits, on the assumption that they would never move. They do, however, move slowly, and in some instances have migrated laterally to appear at the surface of slopes. From there they run down the slope, completely coating the area with a viscous tarry cover. Fortunately the area so affected seldom exceeds 2 ha.

The extent of land-use impact from oil spills is determined in part by the length of time oil persists in the soil. The final steps in oil removal from soil are usually biological. Hence factors that influence biological activity in the soil also influence the land-use impact of many oil spills.



5-A

5-B

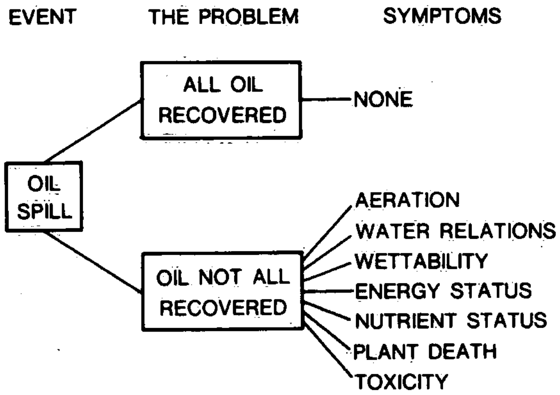
5-C

5-D

Photo series 5. Oil spills cause continuing serious problems if information on their proper treatment, within the context of the site character, is not brought to bear on the problem. For example, (5-A) represents a site at which an estimated 28 000 bbls of oil had been spilled, followed by recovery of an estimated 27 600 bbls. There must have been some error in either estimated spill volume or recovery volume, because the soil contained a large quantity of oil 4 years after the spill. The spill area was 3–4 ha initially but spread to 11.5 ha during cleanup. The site was burned to ensure final removal of oil but this left a crust that prevented plant growth. The site had sand added to it and was then seeded to timothy grass. The oil still in the soil, however, rose with the water table and revegetation was unsuccessful (5-A). A second program, started 5 years after the spill, employed drainage to intercept and remove subsurface oil, the addition of peat as a diluent, tillage, fertilization, reseeding, and the use of plugs of native plants from the area to initiate re-colonization (5-B). This was successful; 4 months later the reseeded areas (foreground of 5-C) were healthy and the transplanted plugs had spread to cover a large area (background of 5-C). In areas where peat had not been mixed well into the former contaminated sand, revegetation was nonexistent; revegetation was completed in areas receiving proper peat amendments. The crust left by burning and the extension of sedge plants up through cracks in the crust can be seen in 5-D. The site is now restored (10 years after the initial spill and 5 years after initiating the second restoration program). It is now being used for grazing. Previously, it had not been used by the farmers owning it, who had not cleared the trees from the site.

5-A W.B. McGill
5-B M.J. Rowell, Norwest Soil Research Limited
5-C M.J. Rowell, Norwest Soil Research Limited
5-D M.J. Rowell, Norwest Soil Research Limited

FIGURE 6.
Flow chart representation of problems caused by oil contamination of soil



The composition of the oil spilled also affects its degradability, and thus its biological removal *in situ* by soil micro-organisms. There are four classes of hydrocarbons that are major components of crude petroleum: alkanes (paraffins)[2], cycloalkanes (naphthenes)[3], aromatics[4] and asphaltic[5] compounds. The n-saturate, or straight chain paraffin fraction, is the most readily degradable component, followed by the naphthenic and aromatic fractions; the heavy asphaltic components are broken down at much slower rates (Cook and Westlake, 1973; Parkinson, 1973). Because oil decomposition in soil occurs at the oil-water interface, solubility in water or tendency to form emulsions can significantly influence decomposition rate and thus land-use impact. The most rapidly degraded hydrocarbons, the n-saturates, tend to be in the middle of the solubility range. The most soluble hydrocarbons, however, tend also to be the most toxic.

Under optimum conditions decomposition of oily materials in soil is generally related to the balance among five groups of properties of the materials: 1) surface area, or amount of oil-water interface; 2) solubility; 3) toxicity; 4) structure, as it relates to complexity of the decomposition pathway; and 5) resources obtained from the materials and additional resources needed to maximize their utilization (McGill, 1981).

In normal soils, conditions are seldom optimum, so that oil decomposition and subsequent land-use effects are usually more a function of the soil and its environment than of the chemical nature of the oil. For example, biodegradation may be accelerated by an order of magnitude by fertilizer additions (Cook and Westlake, 1973; Rowell, 1975; McGill, Rowell and Westlake, 1981).

Physico-chemical effects

The biophysical component of the stress on the land resource produced by inland oil spills can be defined in terms of the physical, chemical, and microbiological effects on the soil, and direct effects on wildlife and vegetation.

The effects on the soil are expressed in their influence both on plant production at the spill site, and on migration of soluble hydrocarbons to groundwater; these are the primary determinants of the subsequent impact on land use, value, and capability. Literature dealing with the fate of oil in soil and with its effects on soil properties has been reviewed by Ellis and Adams (1961), Rowell (1977), and McGill, Rowell, and Westlake (1981), and the subject of the effects of oil on plants has been reviewed by Baker (1970).

Oil spills make mineral soils hydrophobic or non-wettable. Consequently water tends to run off rather than soak in, thereby increasing the danger of erosion, which would ultimately reduce the long-term capability of the land. The soil also becomes very dry if it is on a well-drained slope. Low-lying sites that receive drainage from surrounding areas have the opposite problem; the water fills macropores between soil aggregates but does not readily penetrate the aggregate. Effective pore space is reduced and, if the water table is high, air is excluded from the macropores, the site becomes almost impossible to treat or cultivate, and anaerobic conditions quickly develop (McGill, 1975*b*). Photo series 6 shows such a situation; all cropping of the area had to cease until the moisture regime was restored. Photo series 7, by contrast, shows the results of a second spill, which occurred at the same time as that in series 6; the spill was on a totally different soil-plant system and had a totally different outcome.

Aeration is affected both by waterlogged conditions, which usually develop following crust formation (a consequence of cleanup techniques such as burning), and by displacement of air by water and oil from soil pores. Reduced gas exchange with the atmosphere and a high potential oxygen consumption rate cause the anaerobic conditions so often associated with oil spills on land. Another physical phenomenon occurring with spills is the leaching of oil components or degradation products through the soil, in some cases reaching the water table and contaminating groundwater. Although Toogood (1977) concluded from a preliminary groundwater study that there was little lateral or vertical movement of oil below the surface horizons in an experimental spill on a cultivated Chernozemic soil, Duffy, Peake, and Mohtadi (1975) stated that the water-soluble components of crude oil are very persistent and may represent serious long-term environmental threats to groundwater. Movement of oil downward in the soil profile depends on various factors such as the moisture content, the depth to the water table, the nature of oil, and the absorptive capacity of the soil, which is affected by organic matter content and soil texture. For

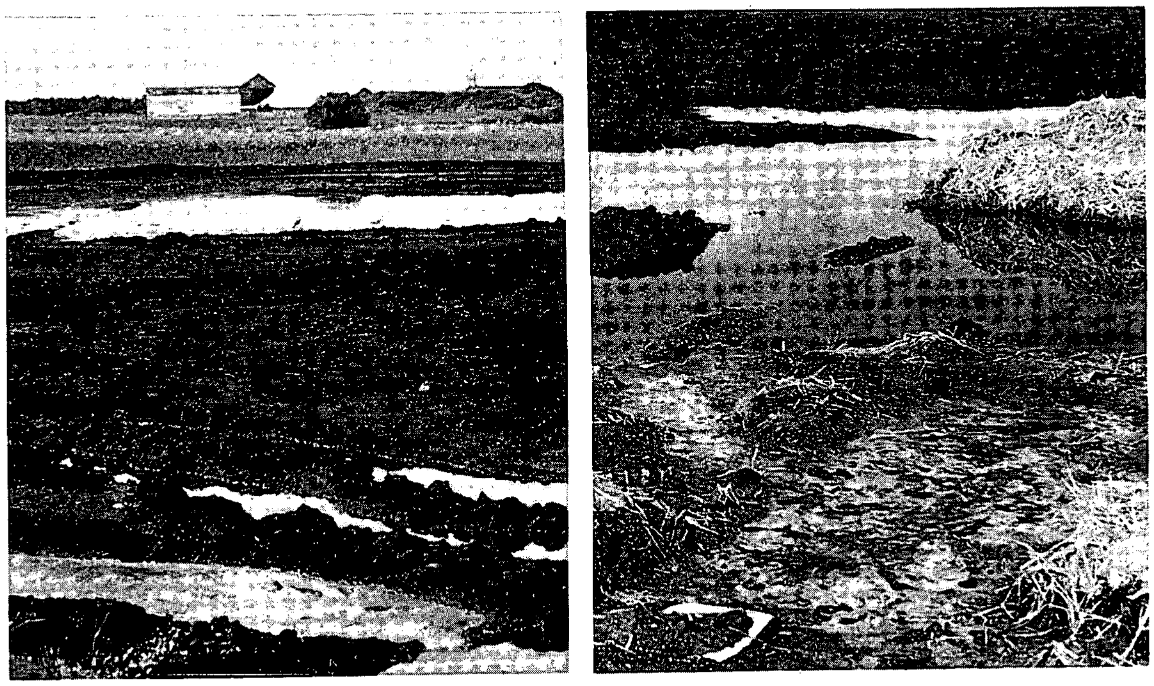

6-A
6-B

Photo series 6. Pipeline ruptures are a common cause of oil spills on agricultural land. The time of year at which breaks occur is an important factor determining land-use impact of a spill, as is the nature of the soil-plant system on which the spill occurs. This is a spill site on a farm field following a spill in winter. The oil has been cleaned up physically and the site smoothed out. Penetration of the oil into the soil, however, was possible because of its porous nature and because of the physical disturbance of the site during cleanup. Consequently, efforts to restore the site (6-A) were hampered and ineffective because the oil in the soil interfered with water relations making it too wet to move on. This wet condition persisted throughout the summer (6-B) and for 2 years thereafter. This spill site was gradually restored over a period of 5–7 years.

6-A W.B. McGill
6-B W.B. McGill


7-A
7-B
7-C

Photo series 7. Spills on to pasture land cause less severe problems than on cropland because the oil tends to penetrate the soil less. The spill site in this sequence is about 50 km from the spill site in photo series 6. It occurred on the same line, and at the same time of year, winter. When the snow melted, there were ponds of water left (7-A) which soon drained away. Oil penetration was only 2–3 cm in most areas. In some it reached 20 cm. By June most of the site had drained (surface), had been fertilized and reseeded, and the pasture vegetation was generally returning. A few of the wettest areas were still not revegetated (7-B) by July, nor was the area immediately over the break itself (7-C), but most of the site (90 %) supported a vigorous grass cover.
7-A W.B. McGill
7-B W.B. McGill
7-C W.B. McGill

example, leaching may be a significant factor in the removal of oil from organic soils (McGill *et al.*, 1974). Leaching is also affected by degradation of oil because some of the partially degraded oil leaches faster than the original oil. The thermal regime in soils is affected by oil spills, with decreases in albedo and evapotranspiration, and increases in infrared re-radiation from the ground surface and downward soil heat movement (Hutchinson and Freedman, 1975).

Chemical effects on the soil are closely associated with physical and microbiological phenomena. The reduced gas exchange, the microbial production of carbon dioxide, and the consumption of oxygen all promote anaerobic conditions. Under these conditions the solubility of manganese and iron may increase, with toxic effects on plant growth. In addition, microbial reduction of sulphur may result in the buildup of toxic sulphides. Long-term changes related to oil spills include the transformation of residual oil components into the more stable soil organic matter fractions, with subsequent beneficial effects on fertility and soil structure.

Biological effects

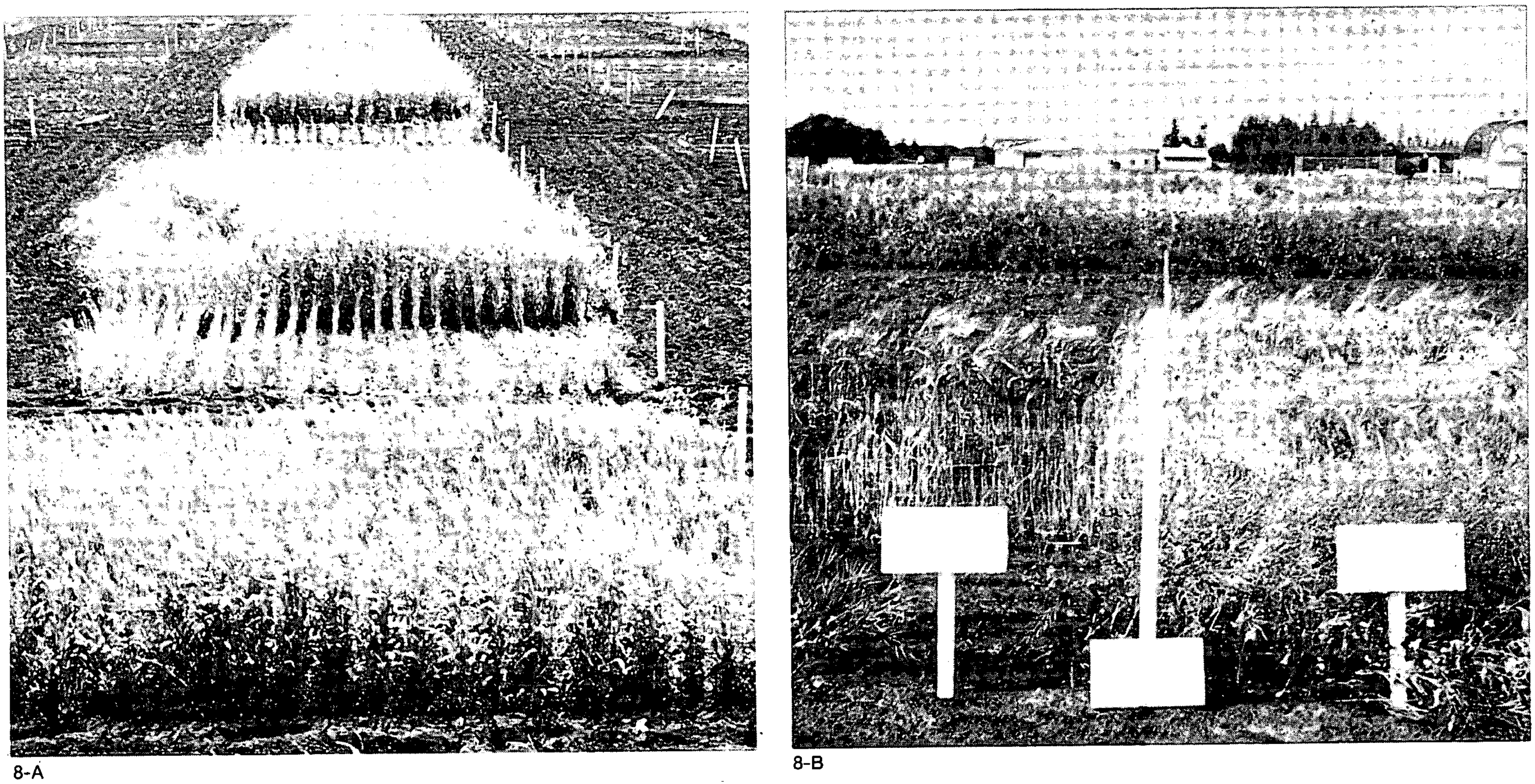
Microbiological changes resulting from oil spills include initial lethal effects on certain microorganisms, followed by increased soil respiration and numbers of bacteria that use oil as a substrate for growth. Although the species diversity of soil organisms is reduced, total numbers increase. The microbial growth on oil often creates nutrient deficiencies for plants because inorganic nutrients such as nitrogen and phosphorus are temporarily converted to microbial biomass and become unavailable to plants until they are recycled.

The direct or herbicidal effects of spilled oil on vegetation produce a variety of results, ranging from the yellowing and death of individual oiled leaves to death and complete temporary elimination of vegetation at the spill site. The herbicidal action produces phenomena such as cell membrane damage with subsequent leakage of cell contents, decreased transpiration rates, reduced photosynthesis, and interference with respiration (Baker, 1970). Re-vegetation of the spill site is also affected because oil delays or prevents seed germination. Oil appears to have a more harmful effect on photosynthetic plant parts than on roots or bark. Roots may be partly protected because the oil may not be available immediately due to adsorption by soil particles. Sprays of oil from pipeline punctures appear to be more harmful to coniferous than to deciduous trees. Moreover, although oil sprayed on to the vegetative parts of plants such as grasses may kill the top growth, the belowground root system is seldom killed. Saturation of soil with oil, however, will kill plant roots.

The severity of damage to vegetation depends on the constituents and amount of the oil spilled, on the species of plant concerned, and on the environmental conditions (Baker, 1970). It should be emphasized that the herbicidal effects of oil represent only one component of damage to vegetation; other environmental effects also occur at the same time. As already stressed, the death of vegetation at the spill site is a symptom and should not be treated as the real problem (McGill, 1975*b*), which is oil remaining in the system (Figure 6). Because the toxic effects of an oil spill are broad-spectrum events rather than specific to individual species, only a few species will re-establish naturally, thus species diversity will be reduced and the ecosystem changed. The effects of oil spills on vegetation may last only a season, in the case of light sprays, or up to several decades where an entire forest system has been destroyed. Such long-term effects are similar to those produced by forest fires, in that succession must again start at a very early stage, usually with annuals and grasses.

The most significant effect of oil spills on wildlife is through loss of habitat. Although oil is toxic to animals under some conditions, their great mobility compared to the slow spread of oil permits most vertebrates to escape. Invertebrates come into more direct contact with oil and suffer greater damage but the area is usually re-invaded after removal of the oil (McGill, Rowell, and Westlake, 1981).

Most research on the effects of oil spills on wildlife has dealt with marine or aquatic situations. The effects of inland oil spills differ from these, because, first, inland oil spills generally cover smaller areas, and second, the animals affected have greater ability to avoid contact with the spilled material. Shaw (1975) described the effects of crude oil on wildlife and noted that toxicities from hydrocarbons, mer-



8-A

8-B

Photo series 8. Oil in agricultural soils influences crop production by affecting germination, growth, and final yield. The inhibition of germination by oil in the foreground compared to the unoiled soil in the background can be seen. Once germinated, the hydrophobic character of the soil can kill the crop because of the lack of available water. Treatment during restoration markedly affects crop growth. The plot in the middle of 8-A was oiled at a rate of 14 kg oil m^{-2} 2 years before seeding but received no nutrient additions. The plot in the foreground received the same oil but nutrient additions were made to supply the microbial need for added nutrients during oil decomposition. Similarly in 8-B both plots received the same high rate of oil (25 kg oil m^{-2}) 3 years before seeding. The plot on the right received nutrients, the plot on the left did not.

8-A W.B. McGill

8-B M. Nyborg, University of Alberta

captans, hydrogen sulphide, and salts resulted. He stated that animals that are oil-wettable, such as insects and their larvae, absorb oil easily through the cuticle or spiracles and quickly die. Experimental arctic spills have been shown to severely deplete the numbers of soil arthropods (Hutchinson, Hellebust, and Telford, 1974). Oil spilled into a body of water has a pronounced effect on fish and other aquatic life. Small mammals, such as beaver and muskrats, and waterfowl quickly succumb to exposure when they become oil-wet as oil-coated fur and feathers do not provide adequate insulation (Shaw, 1975). Large mammals that consume oil can detoxify some of it. The effect of crude oil on an animal varies; for example, a cow may drink several litres of oil and survive, though suffering for a time from diarrhoea, whereas if as little as half a cup of crude oil is breathed in, the animal will likely die of some form of pneumonia (Shaw, 1975). As stated earlier, light oils and refined products are generally more toxic than crude oil. In addition to toxicities, wildlife is affected indirectly, such as by damage to habitat. The extent of this disturbance however is very small for inland oil spills.

EVALUATION OF IMPACT ON LAND USE, VALUE AND CAPABILITY FOR SPECIFIC USES

The specific nature of the physical effects on land, caused by inland oil spills, is mainly determined by the environment in which the spill occurs. Three general types of environment are considered here: agricultural land; forested land, including that serving a recreational use; and arctic land (tundra and taiga), characterized by permafrost. These three general types of environment are defined in terms of various physical site characteristics such as climate, soils and vegetation, together with land use.

Impact on agricultural land

The primary effect of an oil spill in the agricultural environment, which includes both arable and grazing land, is a reduction in, or the elimination of, the productivity of the site for crops or forage. Damage to plant production can last

Photo 9. Plants vary in their response to oil in soil, and therefore cropping options can be reduced by oil spills. This photo shows a plot 3 years after oil addition. Rapeseed (in the foreground) is more sensitive to oil than barley. The plot on the left was limed and fertilized, that on the right was not.

M.J. Rowell, Norwest Soil Research Limited from 1 to 25 or more years, depending on the amount of oil spilled and the reclamation procedures applied. Toxic effects on vegetation resulting from the herbicidal action of spilled oil (Baker, 1970) often occur during and immediately after the spill. Long-term effects on vegetation usually result from soil problems such as structural damage, reduced wettability, and nutrient deficiencies resulting from competition between micro-organisms and plants. Some of these effects, as well as the influence of crop species, are illustrated in Photo series 8 and 9. McGill (1975*a*) has provided an estimation of the relationship between the oil content of soil and the degree of injury to plant growth for both organic and mineral soils (Table 10). The agricultural environment discussed here is limited to mineral soils; for oil spills on organic soils (peats) used in crop production (other than vegetables), information pertaining to organic forest soils may be applicable. Table 11 provides some information on tolerance of native and tame plant species to oil.

On agricultural land the critical reclamation process is the microbiological degradation of the oil remaining in the soil after the initial cleanup of the spill site. Attempts to burn oil off the soil are usually ineffective. Photo 10 shows part of an oil-burning experiment on agricultural land. As stated by de Jong (1980*a*), the procedures for enhancing the biological degra-

TABLE 10.
Relationship between oil content and degree of damage caused to mineral and organic soils—tentative guidelines

Damage	Oil by weight (%)* Mineral soil	Oil by weight (%)* Organic soil
Slight–moderate	0.5-2	4-15
Moderate–severe	2.0-5	15-75
Very severe	> 5	> 75

Description of above terms:

Moderate:	Some reduction in plant growth if nothing is done.
Severe:	Only certain plants will grow and careful management is necessary. With very careful management a wider range of plants may be grown.
Very severe:	Very few plants will grow and seeding may not be advisable until the oil content of the top 10 cm of soil is reduced.

* The quoted values will vary considerably with differences in soil characteristics within the two soil categories listed.

Source: McGill, 1975*a*.

TABLE 11.
Species tolerance to oil

Common name	Scientific name	Relative tolerance
Oats	*Avena sativa*	High
Reed canary grass	*Phalaris arundinacea*	"
Streambank wheat grass	*Agropyron riparium*	"
Alsike clover	*Trifolium hybridum*	"
Sunflower	*Helianthus annuus*	"
Brome grass	*Bromus inermis*	"
Cotton grass	*Eriophorum chamissonis*	"
Buck-bean	*Menyanthes trifoliata*	"
Beggar-tick	*Bidens cernua*	"
Willow	*Salix* sp.	"
Dogwood	*Cornus stolonifera*	"
White spruce	*Picea glauca*	Medium
Larch	*Larix laricina*	"
White clover	*Trifolium repense*	"
Creeping red fescue	*Festuca rubra*	"
Barley	*Hordeum vulgare*	"
Timothy	*Phleum pratense*	"
Rapeseed	*Brassica campestris*	Low
Alfalfa	*Medicago sativa*	"
Black spruce	*Picea mariana*	"

Source: McGill, 1976.

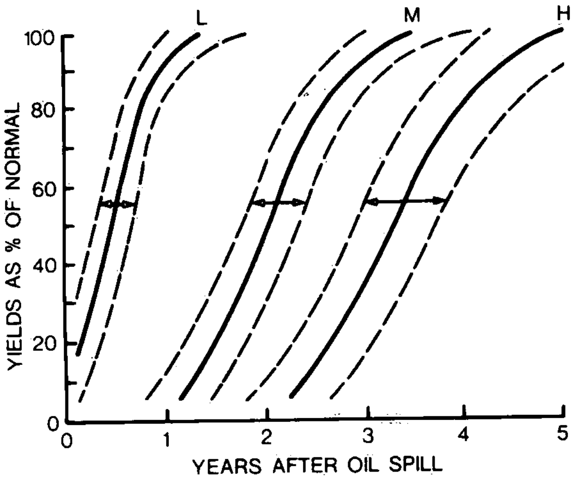
Photo 10. Burning of oil from the soil seems not to kill soil organisms because the movement of heat downward is not great. The problems with burning seem to be associated with migration of hydrophobic materials downward in the vapour phase and with the tarry unburned residue left after the burning, which creates lots of smoke and eliminates puddles but does little to hasten restoration.
W.B. McGill

dation of spilled oil are well understood, and by their use contaminated topsoils can be reclaimed in a few years. Fertilizer application (of nitrogen, phosphorus, potassium, and sulphur), cultivation to promote aeration of the soil, and liming to maintain a neutral pH have all been used to promote biological degradation (McGill *et al.*, 1974; Rowell, 1975; Toogood and McGill, 1977; de Jong, 1980*a*; and McGill, Rowell, and Westlake, 1981). During active microbial degradation of oil, immobilization of nitrogen and other nutrients makes crop growth difficult to sustain. Furthermore, Toogood and McGill (1977) reported that soil at an intermediate stage of reclamation was suitable for germination and early growth of the crop but unfavourable for the maturing crop, probably because of poor moisture relations. Hence for major spills revegetation of the site must wait until most of the oil is gone (McGill, 1975*b*). Once the rate of oil decomposition declines, recycling of previously added nutrients becomes important. For example, Toogood and McGill (1977) noted that on soils receiving a heavy oil spill, where applications of up to 1 420 kg/ha of nitrogen were made over a 4-year period, in the final year fertilizer application needs were reduced because of the recycling of added nitrogen.

The amount of time required for biological degradation of oil in soil varies. McGill *et al.* (1974) estimated that biological decomposition could probably be achieved economically in 1–4 years. Under field conditions prevailing near Edmonton the oil used in this experiment appeared to have a half-life (time for half the oil to decompose) of about 1 year with optimum soil management (McGill, 1975*b*). The monthly rates of oily waste decomposition in soil range from 76 kg/ha for the low application rates of Gudin and Syratt (1975) to 35 000 kg/ha of oil oxidized at high rates of oil addition and high rates of fertilization (Francke and Clark, 1974). When calculated on the basis of oil decomposed as a percentage of oil present in the soil per unit of time, variation in the decomposition rate is substantially reduced because the amount of oil decomposed per unit time is a function of the amount of oil present. Most rates fall between 0.1% and 1% per day according to data summarized by McGill, Rowell, and Westlake (1981). Toogood and McGill (1977) have estimated the time for reclamation of Alberta soils with oil spills equivalent to 2.5%, 6.1% and 11.1% by weight of the soil to plow depth (Figure 7).

FIGURE 7.

Reclamation timetable for Alberta soils showing probable success, using recommended techniques on low, medium and high rates of oil spills



Note: The broken lines suggest variability in time requirement resulting from differences in time of oil-spill, in soils, in climate, in management, and in crop grown (assumed to be wheat, oats or barley).

L = low = 5.54 kg/m²
M = medium = 13.7 kg/m²
H = high = 24.9 kg/m²

Source: Toogood and McGill, 1977.

Non-wettability of soil and dry powdery conditions at the surface are other problems that may occur. For example, Rowell and McGill (1977) observed these problems on an Orthic Luvisol at a spill site located about 10 km west of Edmonton that had been contaminated by crude oil from a wildcat blowout some 25 years earlier. The unaffected soil in the area was rated as class 2–3 capability in the Canada Land Inventory for agriculture, and most of the spill site had recovered naturally and was producing good yields of agricultural crops. There remained in one field scattered patches (estimated to cover 1–2 ha) where the surface 10–20 cm of soil was powdery and hydrophobic. The area was barren, or supported a sparse growth of deep-rooting weeds such as Canada thistle (*Cirsium arvense*). They determined that the surface problems did not arise from the presence of residual oil but rather from a reduced infiltration rate and water-holding capacity, and suggested the cause was the accumulation of high-molecular-weight products from microbiological oil decomposition under conditions of low available nitrogen, phosphorus, and sulphur.

Although the techniques for reclamation of contaminated top-soils have been successfully applied to spill situations, contaminated subsoils still present serious long-term problems (de Jong, 1980*a*). Movement of oil from the subsoil to the surface with a rising watertable was observed by Rowell and McGill (1977) to cause widespread death of the surface cover of grasses on an apparently successfully reseeded spill site. A winter spill of crude oil from a ruptured flow line had resulted in oil soaking deeply into the soil profile prior to the upward movement of the water table three years later.

Saskatchewan case study

The case study for agricultural land is drawn from data published by de Jong (1980*b*). It describes the biophysical effects of a winter oil spill that occurred just north of Moose Jaw, Saskatchewan, on the Saskatchewan Plain. The soil affected was a Dark Brown Chernozemic heavy lacustrine clay. Soils of this type are typically associated with a cool, semi-arid to subhumid continental climate. The spill of asphalt-base crude oil occurred in late January 1974 from a pipeline with a diameter of 40 cm, buried 1 m deep. It was estimated that at the time of the break the top 1 m of soil was frozen. Oil moved extensively underground from the break, and was first detected approximately 850 m south of the pipeline. Trenches and boreholes were dug to collect the oil, and of the approximately 2 500 m³ of oil that were spilled, about 1 600 m³ were recovered. As a result of the spill an area of land just under 16 ha was affected, the contamination varying considerably both vertically and horizontally.

In applying reclamation techniques two major problems were encountered due to the extremely varied distribution of oil throughout the profile. First, degradation of oil in the subsoil could not be enhanced by cultivation to ensure adequate aeration or by the application of nitrogenous fertilizers. Second, the maximum rate of application of nitrogenous fertilizer to the contaminated surface was limited by the need to avoid burning of the crop by excessive fertilizer in unaffected areas.

Table 12 provides the details of fertilizer application and cropping from 1974 to 1978. Serious yield decreases occurred in the summer following the spill, as a result of both the presence of oil and structural damage to the soil from the initial cleanup attempt. Soil structure was no longer a problem in 1975; all areas of poor growth were associated with oil contamination. De Jong (1980*b*) examined the effect of the oil content in the soil on above-ground dry matter production (Table 13), and concluded that even very small amounts of oil (less than 0.25%) caused a reduction in yield. He explained this result by pointing out that non-uniform distribution of oil in the soil led to much higher than average concentrations of oil at spots in the root zone. He also showed that the oil reduced both the level of available nitrogen and the soil moisture uptake by the crop. Oil contents over 0.5% by volume were associated with reduced uptake of soil water from the contaminated layer and from greater depths. Yields were reduced by about 180 kg/ha for each centimetre of soil water not used. This decrease is about twice that normally observed, suggesting a soil moisture–nitrogen interaction.

The major land use (cereal production) was affected by the oil spill, but not changed. Fur-

TABLE 12.
Crops, fertiliser applications, and yields on the oil-contaminated area

	1974	1975	1976	1977	1978
Crop	Barley	Oats	Oats	Fallow	Wheat
Fertiliser (kg/ha)					
Nitrogen	44	65	65*	3 × 63	6
Phosphorus	13	16	16*	3 × 27	13
Yields (kg/ha)					
All sampling sites, range					
Total	0–6 300	34–5 980	359–10 810	—	695–8 990
Grain	—	—	12– 3 880	—	276–3 690
Non-contaminated sites, mean and standard deviation					
Total	3 060±2 270	4 900±1 680	8 730±1 740	—	6 230±1 370
Grain	—	—	3 000± 640	—	2 490± 591
As reported by farmer					
Grain	—	1 520	3 270	—	2 630

* A little more applied on areas that were obviously contaminated.

Source: de Jong, 1980*b*.

TABLE 13.
Effect of oil content in soil on above-ground dry matter production

Ether-extractable(1) material % air-dry soil	Relative production(2) (%)					
	Total above-ground			Grain		
	Mean	sd	*n*	Mean	sd	*n*
0–30cm						
< 0.05	99	23	32	101	23	28
0.05–0.25	70	21	11	63	26	7
0.26–0.50	67	41	6	66	46	4
0.51–1.00	43	20	5	34	33	2
1.01–2.00	29	18	14	31	20	10
2.01–4.00	17	16	21	22	16	10
> 4.00	13	15	4	16	19	3
0–90 cm(3)						
< 0.05	100	22	29	100	22	26
0.05–0.25	81	26	13	87	35	9
0.26–0.50	64	37	5	35	22	2
0.51–1.00	32	18	11	29	20	9
1.01–2.00	26	20	19	26	19	11
2.01–4.00	9	12	10	19	16	3
> 4.00	25	—	1	24	—	1

(1) Uncontaminated soils contain less than 0.05% wt. of ether-extractable material.

(2) The average production of the uncontaminated sites in any year is assigned a value of 100%.

(3) Average of the ether-extractable material in the 0–30, 30–60 and 60–90 cm core segments at each site.

sd = standard deviation.

n = number.

Source: de Jong, 1980*b*.

thermore, the spill had no impact on surrounding land use. The yield data (Table 12) showed that the productivity of the land for cereal crops was reduced in the five growing seasons following the spill. The yield of wheat in 1978 on some of the contaminated areas was still depressed, so the decrease in productivity lowered the land value. The negative visual effects on the 16 ha contaminated area were limited to the year following the spill, after which the soil structural problems were no longer evident. It should be noted that the reclamation of an area does not require a change in land use, even though there may be a reduction in crop yields.

Impact on forested land

In the context of the present discussion, forested land is not necessarily that used by the forest industry; it may serve as recreational land or mainly as a watershed.

Oil spills on forested land produce some problems that are similar to those of agricultural land. For example, Nyborg and McGill (1975) found that low contents of available nutrients (especially nitrogen) for decomposition and growth of plants contributed to slow revegetation of spill sites in forests. The discussion in the previous section of biological degradation of spilled oil can be applied to spills on forested land. Although long-term problems can be caused by oil spills in forests, some are very transient (Photo 11).

Forested spill sites are often characterised by the presence of organic soils, poor drainage, and crust formation after burning, illustrated in Photo series 12 and Figure 8. All three are important in determining the extent of damage to the site from oil and the reclamation possibilities. Oil spilled in forests usually accumulates in low-lying poorly drained sites. Poor drainage at the spill site may result from diking for containment of oil in the initial cleanup operation. The excess water thus created causes two problems; first, anaerobic metabolic processes will dominate, with production of sulphides, toxic organic acids, and a reduced decomposition rate; and second, wet sites are very difficult to manage mechanically (McGill and Nyborg, 1975). The problem of poor drainage is aggravated on barren sites by lack of vegetation and crust formation because water losses from transpiration and evaporation are reduced (McGill and Nyborg, 1975). Formation of a crust or scum of tarry unburned residues on the soil surface, from burning of oil during the cleanup operation, has detrimental effects on decomposition of oil and on revegetation (McGill, 1975*b*). In wet forested situations greater leaching of oil may occur in organic soils than in mineral soils. McGill *et al.* (1974) reported that large quantities of water-soluble materials can be recovered from organic soils during oil decomposition. On organic soils in

Photo 11. A winter spill in the forest (11) has little permanent effect if handled properly. This is the site of an oil spill in winter from a battery site. It was cleaned up well and was fertilized and seeded to grasses in the spring following the spill. By July the site was progressing well and even the wettest parts were healthy. In the better drained areas growth was good by September and extension of grasses and sedges in along the edges helped restore the site. No effects of the spill were evident after a year.
W.B. McGill

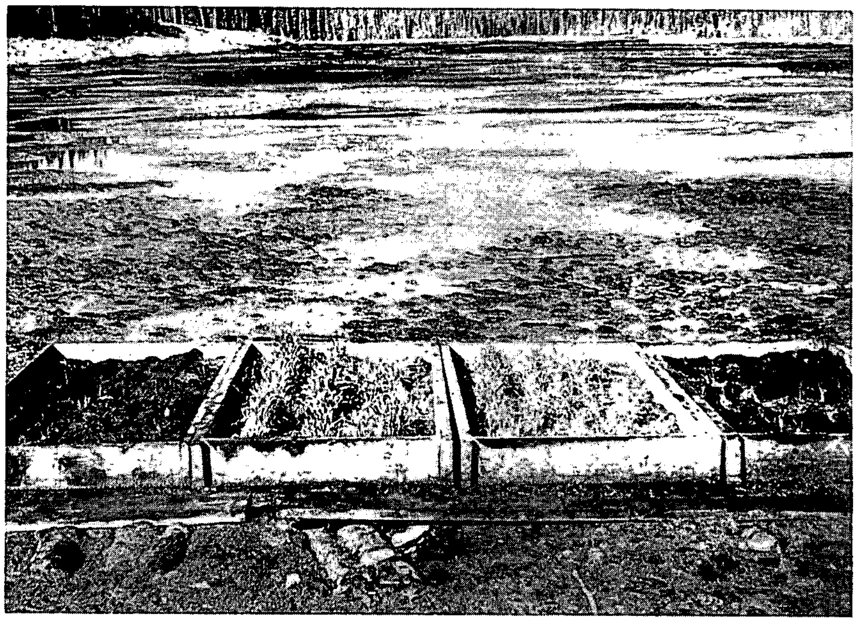
forested areas the height of the water table, which depends on the time of year, can be a critical factor in determining the extent of damage from a spill (McGill, 1975*b*). In fall, when the water table tends to be lower, oil will penetrate deeper and a greater amount of oil will be retained by the soil. Other problems, such as erosion and site disturbance by machinery, are depicted in Photo series 13.

Estimates of the time required for reclamation of oil spills in forests vary. Nyborg *et al.* (1974) noted that in small spills the vegetation may recover in 1 or 2 years but the sites of heavy spills on some organic forest soils can remain completely barren for decades. Similarly, McGill and Nyborg (1975) stated that although many sites are quickly and completely restored, the effects on a few have persisted for 25 years or more. With regard to the effectiveness of reclamation techniques, Nyborg and McGill (1975) concluded that on organic forest soils the application of nitrogen and lime can speed the decomposition by a factor of about 10. Natural revegetation of forested sites has frequently been observed. An example is shown in Photo 14.

Alberta case study

The case study for forested land is drawn from a report by Rowell and McGill (1977) which

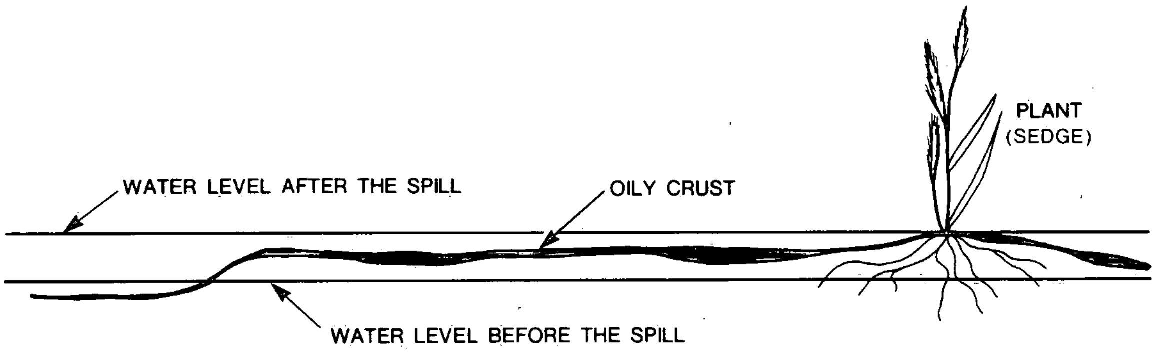
12-A



12-B

Photo series 12. Battery sites are contributors to oil spills in forested areas. Oil from this battery site ran down into a low area following a winter spill. This site has been the scene of several spills starting about 1966. Cleanup consisted mainly of burning, leaving a barren site that was devoid of all vegetation in 1973 (12-A) and too wet to walk on because of dikes (which had little effect on the oil but a lot on the water) and the sealed surface caused by the tarry crust. The patchy appearance of the site reflects small changes in micro-relief, which caused the greatest crusting problem to occur on the dry high spots because they burned better and the water table initially prevented oil from penetrating deeply. Effective drainage, breaking of the crust, fertilization (to accelerate oil decomposition) and seeding revealed the site could be restored in one season if those conditions could be met (12-B); this has been found feasible in the winter when such sites are frozen. Many sites like this are now treated in the winter using large mulching equipment to break surface crusts and incorporate fertilizers, which aid in microbial decomposition of the oil prior to revegetation. Another approach that was effectively used at this site is insertion of plugs of native sedges which have spread throughout the area. The site is now nearly completely revegetated. Results of studies at this site have helped develop ways to minimize the effect of oil spills on land capability in these areas.
12-A M. Nyborg, University of Alberta
12-B M. Nyborg, University of Alberta

FIGURE 8.
Schematic representation of an oil crust

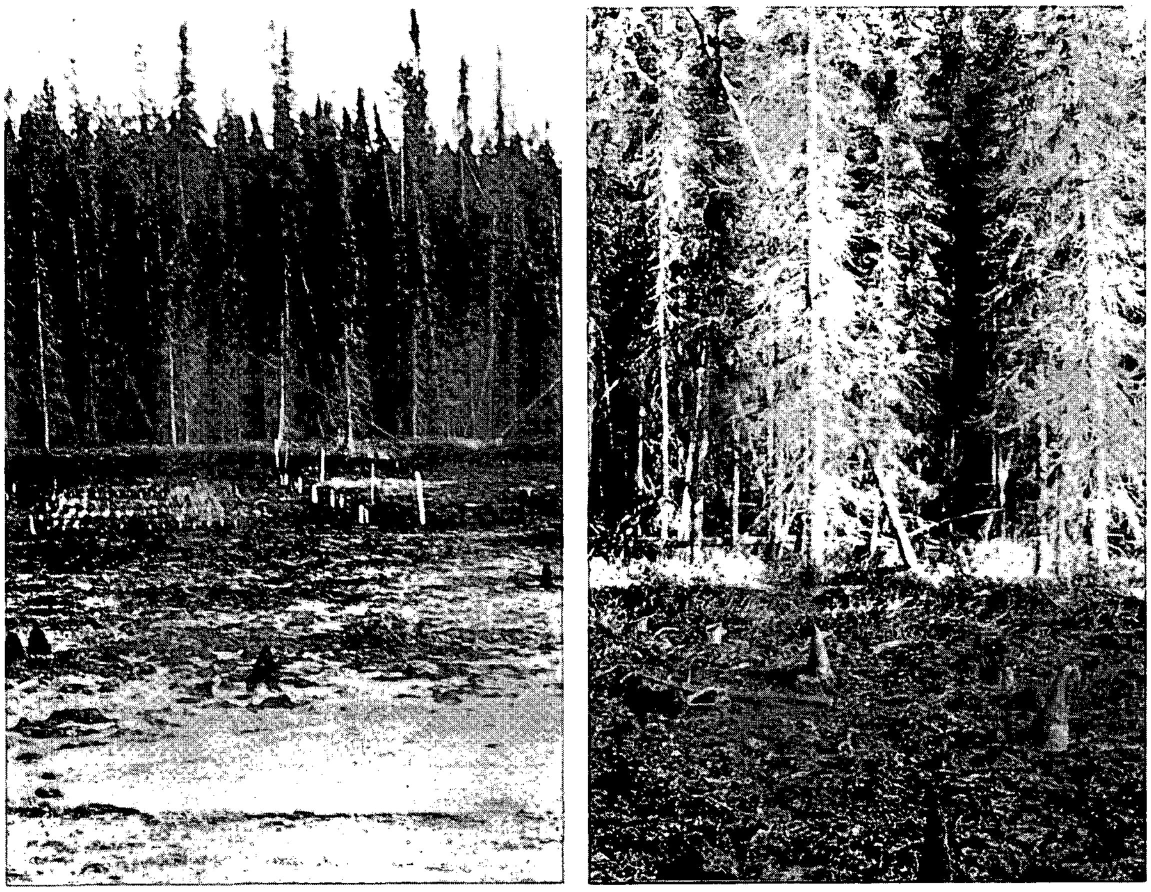


Note: This is a schematic representation of an oil crust left on a wet forest site after burning. It shows the rise in water level associated with the sealing effect of the crust, and the lack of plants.

TABLE 14.
Oil contents in soil around plants growing in isolated groups on oil spill site

Group	Location of sample	Oil content (%)
1	Surface	63.7
	Around root	43.9
2	Surface	59.2
	Around root	30.6
3	Surface	63.2
	Around root	23.8

Source: Rowell and McGill, 1977.


13-A

13-B

Photo series 13. One problem in forested regions is that removal of surface vegetation on slopes leads to erosion. The light-coloured material in the foreground of 13-A is soil that has eroded from the slope which was cleared of trees during oil cleanup. The site was burned, leaving a tarry residue (13-B) which remained barren until the crust was broken and the site seeded. Growth can be luxurious where the site is properly managed while all around is barren if the burn residue is not broken.

13-A W.B. McGill
13-B W.B. McGill

examined the reclamation of five oil spills in Alberta. The site was located approximately 6 km west of the town of Swan Hills in the Swan Hills Upland of northern Alberta. It was situated in a depressional area previously covered by black spruce (*Picea mariana*), sedges (*Carex* spp.), and Labrador tea (*Ledum groenlandicum*), with sphagnum moss (*Sphagnum* spp.) and cottongrass (*Eriophorum* spp.) in the wetter parts. The peat in the area was acid (pH 4.5), classified as "fibric", and reached a depth of 90–150 cm. The site had not been used for recreation or commercial fibre production prior to the spills. Over a 7-year period prior to 1973 the site received several spills of a light, paraffin-based crude oil with a low sulphur content.

The spill site covered an area of 4–5 ha, and was very wet during the spring and summer. Burning of excess surface oil had left a tarry layer of residues forming an oily crust a few centimetres deep. The heavier oil fractions had not penetrated below the crust. The oil content varied between 200% and 300% of the dry oil-free peat weight in the top 4 cm. In the 4–15 cm depth the oil content declined to only 35% of the weight of the dry oil-free peat. Depth of oil penetration varied between 15 cm in the dry areas of hummocks and 2 cm in wet micro-depressions. Oil containment methods such as diking had contributed to the poor drainage at the site.

Rowell and McGill observed that the drier areas of the site were being slowly re-colonized by native sedges and grasses which spread by rhizomes or creeping root systems. Other plants that appeared to be successful in revegetating the wetter areas along the perimeter of the spill site were cottongrass and buckbean (*Menyanthes trifoliata*). Table 14 lists the oil content around sedge plants found growing in three oily areas.

Experiments showed that reclamation of the site would be improved by cultivation, to break the surface crust and improve aeration, and by the addition of lime and fertilizers. The wet barren sites were difficult to reclaim without drainage, although growth of sedge plugs inserted throughout the site was successful. They concluded that the main factors restricting plant growth were poor drainage, the presence of a tough crust with a high oil content, and the apparent lack of viable seed and root stock in barren areas of the spill site. The excess of water at the site was a result of poor natural drainage, lack of evaporation and transpiration from the crusted barren areas, and prevention of surface drainage by diking. Establishment of plants accelerated the drying process.

They estimated that growth of the sedge plugs would produce within 3 years a dense mat of sedges over the plot area. They estimated that the front of a stand of cottongrass in a wet area extended two meters on average during a 1-year study period, and concluded that natural re-colonization of wet areas could be quite rapid.

Photo 14. Natural restoration of an oil spill site in the forest.
W.B. McGill

Evaluating the impact on the land resource was more difficult for the forested land than the agricultural. The spill was unsightly producing negative visual and aesthetic effects but no specific land use was affected, nor was there a change in land use. There was no impact on surrounding land uses. The oil spill reduced the plant productivity at the spill site, but because it is crown land it is difficult to estimate whether this produced a change in land value. By the end of the study period the spill site had not yet completely recovered. Thus it remained a potential source of hydrocarbons for entry into surface and ground water. McGill and Nyborg (1975) stated that when forest oil spills are left unrestored they are potential hazards to wildlife and to water supplies. For this particular spill there was no direct evidence of toxicities to wildlife. Nevertheless, the recreational value of the land was destroyed, and all timber production was eliminated until satisfactory restoration was achieved. Where spills occur in open flat areas of forested sites waterfowl may mistake them for ponds and try to land. Dead oiled birds are occasionally seen in such areas. This case study described a forest oil spill site where the only negative long-term changes were in site productivity and appearance.

Arctic regions

Arctic and northern regions are characterized by continuous or discontinuous permafrost, and are covered by tundra or taiga vegetation or consist of polar desert. Hence this third category of environments includes lands of varied surface cover. For arctic regions most of the information describing oil spill effects is based on experimental spills that have two characteristics: first, a spill is usually a uniform application of oil to the plot surface; and second, it has a lower volume of oil than in an actual spill. Furthermore, the long-term effects of such spills have not yet been appraised. It should be recognized that inland spills may be less devastating than marine or coastal spills in the Arctic, so that predictions by the news media of catastrophic ecological effects from "arctic oil spills" cannot be extended indiscriminately to the inland situation.

MacKay (1975) predicted the physical behaviour of oil spills in northern terrain, specifically for a proposed Mackenzie Valley pipeline. He briefly described the terrain that such a pipeline would cross. In the north it would pass through tundra, where the mineral soil is covered by an organic layer 20–30 cm thick. The vegetation consists of mosses, shrubs, and low bushes. South of the tundra the pipeline crosses taiga, dominated by black spruce (*Picea mariana*) with some birch (*Betula* spp.) and larch (*Larix* spp.). The organic layer at the soil surface in the taiga region is 30–100 cm thick, and insulates the permafrost below it. By analysing spill frequency data MacKay (1975) predicted that a Mackenzie Valley pipeline may produce two spills annually, with an average volume of 1 600 m^3 for each spill. He emphasized that the physical behaviour of the spill would vary with the weather (or climate), the characteristics of the oil, the conditions of the soil and ground cover, and the topography. Each spill situation will therefore be different, just as in forested and agricultural lands. The season of the year is a critical factor in estimating the area affected. For a spill volume of 8 000 m^3 (the largest possible case) the prediction of area affected in winter and summer varied between 1.6 and 8.9 ha. For a spring spill (a less frequent event) the area could be as much as 30 ha. MacKay went on to describe the impact of such spills. He stated that the spill area would be very unsightly, with almost complete death of vegetation, but if a spill was effectively contained it would cause little damage to the environment outside the immediate spill area. MacKay (1975) compared the impact of such a spill to that of forest fires, or of intense local activities such as the construction of roads and seismic lines. He concluded that the effects had limited temporal and spatial impact on the regional ecosystem.

In the high Arctic, several "oases" areas have been defined that have unique microclimates, high productivity for the region, and are fundamental to the functioning of high arctic ecosystems. Such areas are usually low lying, are major primary production locations in the region, and would be devastated by oil spills. Although the extent of a spill in such an area may be small, its ecological impact is likely to be disproportionately large.

Various studies using experimental spills have examined the effects on soils and vegetation in the Arctic, particularly in the Mackenzie Valley. A major concern has been effects of spilled oil on the active layer depth. MacKay, Charles, and Philips (1974*a*) examined the hypothesis that a change in the thermal regime resulting from the penetration of oil into the surface organic layers would cause melting of permafrost, ground instability, and both biological and hydrological changes at the spill site. From further observations made on experimental spills at Norman Wells, N.W.T., they concluded that an oil spill would not have severe effects on the thermal regime of the organic layers, hence there was little risk of the development of ground instabilities (MacKay, Charles, and Phillips, 1974*b*). Although Hutchinson and Hellebust (1974) reported a 15–20% increase in the depth of the active layer from an oil spill on an exposed (burnt forest) site, in a later report it was concluded that permafrost was little affected by experimental crude oil spills, despite changes in the site energy budgets and active layer depth (Hutchinson and Freedman, 1975).

The effects of oil spills on vegetation in the Arctic are the product of the interaction between the environment and the herbicidal action of spilled oil. Surface spills had a devastating effect on above-ground vegetation (Hutchinson and Freedman, 1975). Plant species differ in sensitivity to injury from oil spills (Hutchinson and Hellebust, 1974); for example, the ground cover of lichens and mosses was severely affected by spilled oil. Hence species diversity as well as vegetative cover are reduced at spill sites. Re-growth is slow. The phytotoxic effects of winter spills appear to be less severe than those of summer spills. Similarly, damage on tundra appears to be less severe than in taiga (Hutchinson, Hellebust, and Telford, 1974). They concluded that the general effects of oil on vegetation were similar to those of fire. Foliage loss, which causes decreased production of storage material, can result in increased winterkill at the spill site (Hutchinson and Freedman, 1975). Flowering and reproduction are also severely reduced. The poor fertility of arctic soils, together with nutrient deficiencies resulting from microbial growth on oil carbon, would inhibit revegetation of spill sites (Hutchinson and Hellebust, 1974).

Microbiological effects resulting from oil spills on arctic soils are similar to those described earlier for agricultural and forested land. For example, Cook and Westlake (1973) and Parkinson (1973 and 1974) observed degradation of the n-paraffin fraction of spilled crude oil by micro-organisms in arctic soils. Application of fertilizer nitrogen and phosphorus increased the degradation rate. The rate of biodegradation can be expected to be low in arctic soils for several reasons. First, oil-digesting activity has not been uniformly found among indigenous microflora of arctic soils (Cook and Westlake, 1973) and the degradation rate of the n-paraffin fraction was reduced at low temperatures. Second, Parkinson (1974) suggested that degradation by anaerobic bacteria would be important in wet sites, but would proceed more slowly than with aerobic bacteria. Oil decomposition rate (hence site restoration rate) has been calculated to be about one-third as rapid in the Mackenzie valley as in the Canadian Great Plains and only one-sixth as rapid as in southern U.S.A. (Rowell, 1980).

Evaluating the impact of oil spills on land use, value, and capability in the Arctic is difficult. A spill site is unsightly, causing negative visual and aesthetic effects and its productivity is reduced, sometimes drastically. The regional importance of oasis sites may be critical. Contamination of drinking water supplies by leaky storage facilities or other sources is an obvious problem, which must be rectified. Damage from oil spills, however, has not yet changed man's use of the land, which is not well-defined in the first place, nor has it prompted a change in land use. The lack of appraisal of the long-term effects of arctic oil spills makes it difficult to determine the time needed for site reclamation.

MacKay (1978) has discussed the reasons for oil spill cleanup, particularly in remote arctic regions. He stated that for some small oil spills the intrinsic value of the oil is negligible in relation to the cleanup cost, there is little economic loss, no endangered species are likely to be destroyed, and ecological damage probably does not persist for more than a few years. There is no effect on human health, and the spills occur in a seldom frequented area. Hence MacKay (1978) suggests there are no sound economic or ecological reasons for cleanup. According to MacKay (1978):

> "Most evidence suggests that oil spills have a localised disruptive effect which lasts a few days or weeks in the water column, and possibly a few years in marine sediments or shores. The ecosystem probably restores fairly rapidly and no irreversible changes are evident. Some would argue that we should not allow oil to alter ecosystems. We do modify ecosystems in farming, fishing, hydroelectric schemes, mining, forestry and urbanization. We accept some degree of ecological disruption and indeed the "green and pleasant lands" are rarely the original ecosystem; they are a man-made modification. It is inconceivable that oil could disrupt ecosystems to the extent that is done in overfishing, desertification through poor soil maintenance, by lake acidification, by strip mining or clear-cutting forests."

The main reason for cleanup in the Arctic is that society regards an oiled environment as offensive. MacKay (1978) went on to point out the importance that industry should give to this social attitude when developing programs in relatively pristine areas. The Arctic cannot be treated as a single ecosystem. Several different environments lead to a diversity of systems with both varying sensitivity to oil spills and contributions to regional productivity. In sites with future recreational value, oil spills, if they persist, would cause serious reductions in capability. Consequently, public reaction to Arctic oil spills and concern about their potential impact must be based on an objective evaluation of the specific sites involved and their roles within the regional ecosystem in which they are located.

Conclusion

Interest in and concern over oil spills on land in Canada is most acute among the oil industry and landowners. Consequently, in agricultural areas, more effort has been expended in reclamation research than in the documentation of environmental impact, beyond observations by landowners that crops cease to grow. If growing a crop provides your livelihood, there seems little need of more environmental investigation; rather the need is for detailed information on how the oil behaves in the system, how the soil and oil interact and how to accelerate system recovery. In forested areas the effort has been balanced between environmental impact assessment and reclamation. In the Arctic, only impact assessment has been undertaken in any significant way.

The impact of inland oil spills on land use, value, and capability in Canada may be assessed in terms of the negative effects on the present use, as in a reduction in the productivity of agricultural land, or in the elimination of land-use options as described for oil spills on forested land, or in aesthetic effects and the public's attitude toward modification of natural ecosystems, which affects land use indirectly. Adjacent land uses are normally not affected by oil spills or by the threat of oil spills from pipelines. Pipelines through agricultural lands are expected to be constructed in such a way that the lands can be cultivated and cropped as before. In urban areas, oil, and gas lines in particular, are segregated from residential areas by easements because of danger of fires etc., not oil spills. In forested areas, a right of way over the line is maintained clear, but adjacent forest areas and their uses are not directly affected. People using pipeline rights of way as access to adjacent forest areas can affect them significantly.

Impacts of oil spills on land capability need not be permanent and seldom are. Length of impact varies from less than 1 year to more than 20 years, primarily in response to manner of site cleanup and environmental conditions. Consequently, a steady-state is expected in which the amount of land restored to original capability is balanced by the amount of new land being affected by new oil spills. Amounts of land actually affected by oil spills are not documented, only amounts of material spilled. Based on personal observations of the time required to restore land-use options, and data on amounts of oil spilled annually, we have estimated that land-use options or productivity have been reduced on less than 1 000 ha of land in Canada. This estimated area is not expected to increase much in the next decade because as new spills occur land-use options on old ones become restored and the present steady state is likely to remain.

Biophysical changes in soil, and to some extent in vegetation, are of primary importance in defining spill effects on land-use options because soil properties create many of the options. Biophysical effects vary among environments. Generally, on agricultural land, procedures for enhancing biodegradation of spilled oil in topsoil permit successful reclamation in 2–4 years. Oil-contaminated subsoil presents a more lasting problem. Forested and arctic lands are environments where reclamation of oil spill sites is more difficult and sensitivity to the timing and location of spills is greater. The negative effects usually persist longer than those on agricultural land. Oasis areas in the North are especially sensitive and deserving of protection but concerns about oil spills in unproductive polar desert areas may be ill-conceived. Inland oil spills cannot be indiscriminately grouped with marine and aquatic spills when making an assessment of the magnitude and persistence of the environmental damage that results. If the movement of solubles from contained terrestrial spill sites into waterways and drinking water supplies is a problem, its magnitude has not been documented.

Land-use impacts of oil spills have two time scales. An immediate effect often results from hydrogen sulphide gas in the spilled oil. This gas is toxic and in some instances areas must be evacuated for a period of hours to several days while the gas disperses. Persistent effects of this pollutant on land use have not been observed. On the longer time scale is the residual effect on the terrestrial ecosystem of the oil itself.

The history of oil spills is as old as the petroleum industry, which in Canada predates that of the U.S.A. Significant long-term land-use impacts of oil spills, as distinct from effects of storage tanks, pipeline installations, battery sites and refinery facilities, are hard to find. One must conclude that oil spills have only a minor land-use impact nationally, although they do create acute local problems which last a few months to a few years or in rare cases decades.

This text was reviewed by M.F. Fingas, Head of the Chemical and Physical Sciences Section, Environmental Emergency Branch, Environmental Protection Service, Environment Canada, Ottawa, Ontario.

GLOSSARY

[1] Mercaptan	A substance like an alcohol but with sulphur in place of oxygen.
[2]Paraffin	A waxy substance obtained from the distillation of crude oils. Paraffin is a complex mixture of higher carbon number alkanes that is resistant to water and water vapour and is chemically inert. The term is sometimes used to refer to alkanes as a class of compounds.
Alkanes	A class of hydrocarbons (compounds of hydrogen and carbon) characterized by branched or unbranched chains of carbon atoms with attached hydrogen atoms. Alkanes all have the general formula C_nH_{2n+2}, and contain no carbon—carbon double bonds (i.e. they are saturated). Alkanes are also called paraffins and are a major constituent of natural gas and petroleum. Alkanes containing less than 5 carbon atoms per molecule ("n" in above formula is less than 5) are usually gases at room temperature (e.g. methane), those having between 5 to 15 carbon atoms are usually liquids, and straight chain alkanes having more than 15 carbons are solids. Low carbon number alkanes produce anaesthesia and narcosis (stupor; slowed activity) at low concentrations and at high concentrations can cause cell damage and death in a variety of organisms. Higher carbon number alkanes are not generally toxic but have been shown to interfere with normal metabolic processes and communication in some species.
[3]Naphthenes	A class of hydrocarbons with similar physical and chemical properties to alkanes but characterized by the presence of simple closed rings. Like alkanes, naphthenes are also saturated (i.e. they contain no carbon–carbon double bonds), and have the general formula, C_nH_{2n}. Naphthenes are found in both crude oils and refined petroleum products. This class of hydrocarbons are insoluble in water, and generally boil at 10–20°C higher than the corresponding carbon number alkanes.
[4]Aromatics	A class of hydrocarbons characterized by rings containing 6 carbon atoms. Benzene is the simplest aromatic and most aromatics are derived from this compound. Aromatics are considered to be the most immediately toxic hydrocarbons found in oil, and are present in virtually all crude oils and petroleum products. Many aromatics are soluble in water to some extent, thereby increasing their danger to aquatic organisms. Certain aromatics are considered long-term poisons and often produce caricinogenic effects.
[5]Asphalt	A black or brown hydrocarbon material that ranges in consistency from a heavy liquid to a solid. The most common source of asphalt is the residue after the fractional distillation of crude oils. Asphalt is primarily used for surfacing.

Source for Nos. 2 to 5: Fingas *et al.*, 1979.

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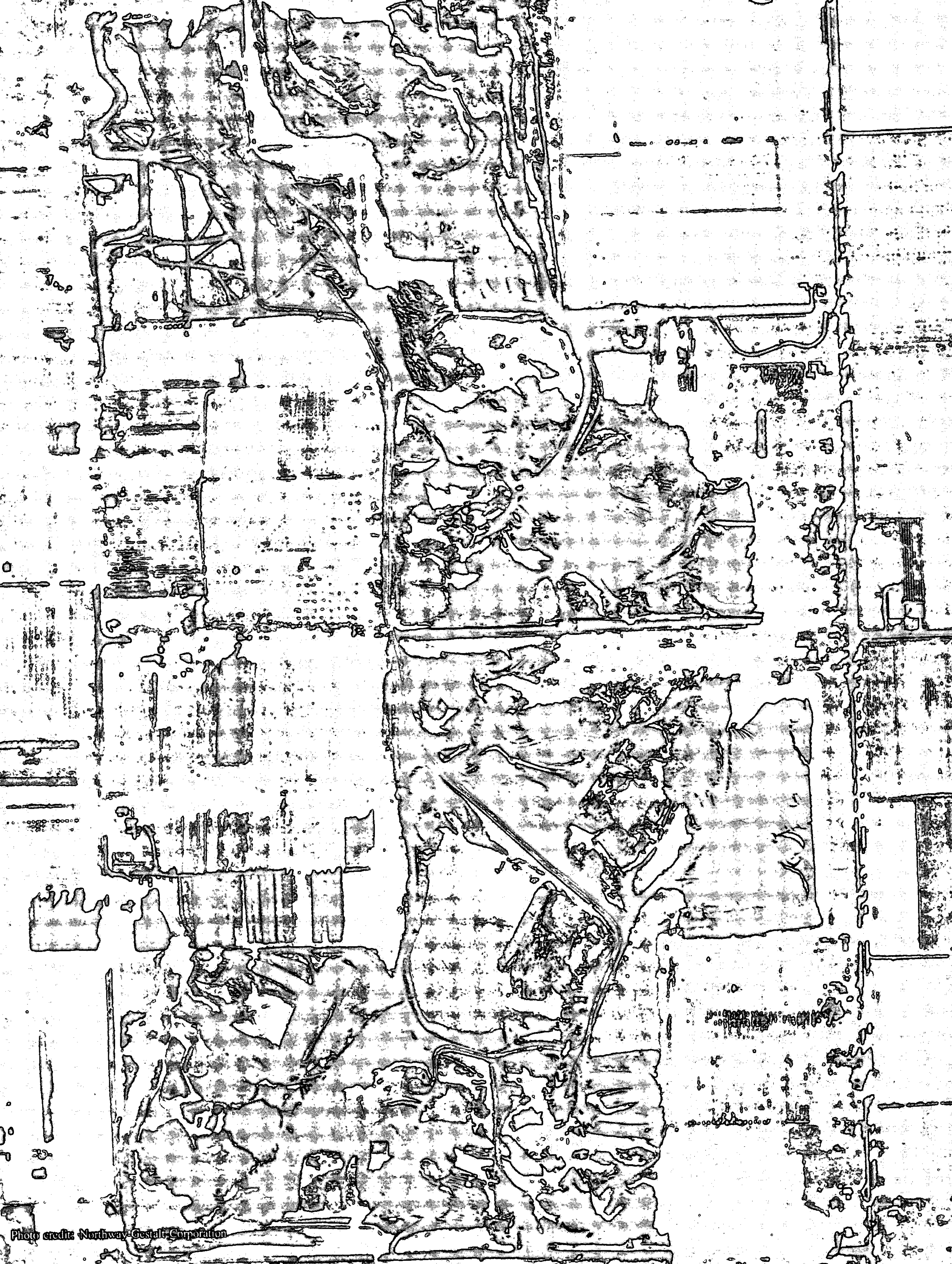
PITS AND QUARRI



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TS AND QUARRIES – THEIR LAND IMPACTS AND REHABILITATION

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ental Studies, University of Waterloo and is President of Geoconcepts and
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Introduction

Since the end of the Second World War, Canadians have shown greater concern and more awareness of how national resources are utilized, exploited, regenerated, and conserved. The basic resource is the land itself. This chapter examines how the use of land for the extraction of aggregate materials affects this resource, and how the impacts can be minimized.

Pit and quarry owners have in the past been branded by some as the worst kind of robber barons because the product of their ventures has often been the wholesale destruction of considerable areas of the Canadian landscape. Such despoliation has often meant that for many years after extraction ceases the land is still an eyesore, incapable of being used by others. The picture is not all so black, however; many former pits and quarries, which supplied construction materials for the rapid urban growth in Canada during the three postwar decades, now provide the sites for other land uses within urban boundaries. Nonetheless, the transition was not always easy or swift.

In the 1980s the area of land occupied by pits and quarries will continue to be prominent; landscape changes will continue to be dramatic; appropriate legislative control will become more widespread provincially. At the same time, however, the reduction in the rate of urban growth will mean that more distant rural locations for pits and quarries will not be economically attractive and will not present the numerous urban rehabilitation opportunities, such as playgrounds, schools, shopping plazas, and commercial and industrial parks. Moreover, an informed public is likely to reject the destruction of land and to insist on enlightened pre-planning and effective land restoration. These are some of the issues that will be examined in this chapter.

The part played by pits and quarries in placing a stress on land will become clear in the course of this chapter. It is sufficient to note here that in the past, pits and quarries have been operated in a thoughtless, haphazard manner which has led to less than optimal after-uses of the land affected. Inadequate collection of pre-planning data, poor topsoil retention (or none at all), inadequate consideration of future uses to which the land can be put, and shoddy reclamation/rehabilitation procedures have caused a wide range of stressed land conditions. It is, therefore, imperative that we continue to improve the ways in which we utilize subsurface resources and subsequently restore the land resource.

Pits and quarries

Perhaps the most pertinent piece of Canadian legislation is the Ontario Pits and Quarries Control Act (1971). In this the following definitions can be found:

> *"pit" means a place where unconsolidated gravel, stone, sand, earth, clay, fill, mineral or other material is being or has been removed by means of an open excavation to supply material for construction, industrial or manufacturing purposes, but does not include a wayside pit;*
>
> *"quarry" means a place where consolidated rock has been or is being removed by means of an open excavation to supply material for construction, industrial or manufacturing purposes, but does not include a wayside quarry or open pit metal mine.*
>
> *"wayside pit or quarry" means land from which consolidated or unconsolidated aggregate ... has been, is being or may be excavated for use in a project of a public authority and that is located outside the limits of the right of way of a highway ....*

The removal of subsurface sand, gravel, and stone resources (collectively known as aggregate materials when used for construction) normally means a complete modification of the land surface. Traditionally, a first step is the removal of all vegetation and the stripping of topsoil and the underlying overburden that covers the aggregate resource. In the past this procedure was undertaken carelessly; the valuable topsoil was often sold at a substantial profit or pushed aside without regard to its vital fertility ingredients. When the aggregate source was exhausted, topsoil was either unavailable for reclamation or so deteriorated by site operations, improper storage, or erosion and neglect that its vegetative capacity could not be restored without expensive artificial aid.

The end result is that the aggregate producers in their desire to tap the underlying valuable resource overlooked a primary consideration, the restoration of the equally considerable, overlying land resource for the use of future Canadian generations. Unless reasonable precautions are taken, therefore, all pits and quarries might result in land under stress.

In rural or isolated areas the demand for aggregates is low, so that small parcels of land, typically 1–5 ha, are used for pits and quarries. On the peripheries of metropolitan districts, however, the large urban demand for aggregates results in much larger areas being used for extraction, ranging from 50 ha to, in one Canadian instance, 600 ha. The cumulative impact of such large-scale use of land for pits and quarries clearly imposes a significant stress.

Dereliction and rehabilitation

One of the major reasons why pits and quarries first became an environmental and land resource issue in the 1960s was because of the abandonment of mined-out areas whose potential land-use value had been severely depreciated. In its ultimate form such areas constitute land dereliction. Yet significantly, perhaps the most important document ever written on this subject (the United States Department of the Interior Report on Surface Mining and Our Environment) whilst pointing out that the United States by 1965 had 1.3 million hectares of land disturbed by surface mining (and using terms such as unsightly, repellent, discarded garbage and adequate reclamation), omits to precisely define their use of the term "derelict land". In this chapter, a broad definition of derelict land has been adopted, similar to that used by the former Ministry of Town and Country Planning in Britain: "Land so damaged or otherwise affected by industrial or other development that it is incapable of alternative use without further treatment" (Beaver, 1969).

A more ecological restatement of this might be given in terms of the removal or destruction of the native vegetation, animal communities, and most of the topsoil. When this occurs, the drastically disturbed sites will not completely heal themselves through normal secondary succession processes within a human lifetime (Coates and Scott, 1979).

Clearly not all land that has been exploited is derelict in accordance with these definitions. Much of it, however, has had its future productive capacity so severely reduced that it can appropriately be called land in stress. Even land that has been treated with some sensitivity may never regain its former value subsequent to mining activity. In many instances this is an unfortunate and unnecessary result of extractive mining. Current research, technology, and legislation should help prevent additional dereliction in the future. Boivin (1982) has pointed out another aspect of dereliction: "In the past, operators were not required to cap or fence abandoned excavations; these openings are still unsafe today and should be considered a matter of urgent concern by the provincial governments". He cites as examples the dangers of falling, drowning, and other injuries to humans and animals.

The term "rehabilitation" is perhaps more familiar in housing, medical, and psychological usage, where it roughly describes the process of returning a person to good health. Rehabilitation in the medical sense is brought into play after the sickness has occurred. Until recently, landscape rehabilitation has also been a process implemented after the fact. Today, however, there is increasing appreciation of preventive approaches, and rehabilitation in the future may be more apparent in preparatory planning than in the curing of past despoliation. Research in the late 1970s has focused on these approaches (Bradshaw and Chadwick, 1980; McLellan, 1981; Mackintosh and Mozuraitis, 1982).

In a 1974 publication, the National Academy of Sciences proposed the following definitions:

> *"Restoration implies that the exact conditions of the site before disturbance will be replicated after the disturbance. Thus, complete restoration is seldom, if ever, possible...*
>
> *Reclamation implies that the site will be habitable to organisms originally present in approximately the same composition and density after the reclamation process has been completed...*
>
> *Rehabilitation means that the disturbed site will be returned to a form and productivity in conformity with a prior use plan. It implies that a stable condition will be established that will not deteriorate substantially with the projected land use ... consistent with surrounding aesthetic values. It also suggests that the selected land use should be both ecologically stable and of high value to society."*

The notorious coal mining practices in Appalachia resulted in landscape degradation to the point where remedial rehabilitation was almost impossible. The lesson is that we should consider rehabilitation procedures before starting to disturb the land.

Viewing land as a basic resource

Despite biblical admonitions of wise stewardship of the land, and despite humanity's dependence on it, we have frequently treated it unwisely. Aldo Leopold (quoted in Schaller and Sutton, 1978) has perhaps best stated this dependence in his land ethic:

> *"All ethics so far evolved rest upon a single premise; that the individual is a member of a community of inter-dependent parts. His instincts prompt him to compete for his place in that community, but his ethics prompt him also to cooperate (perhaps in order that there may be a place to compete for). The land ethic simply enlarges the boundary of the community to include soils, water, plants and animals, or collectively: the land."*

Thus land becomes the stage for humanity's ecological interrelationships with the other animate and inanimate objects in our environment. Today, there is a new appreciation of conservation, a questioning of our former profligacy with natural resources, and cavalier attitudes to land use are no longer acceptable.

In Canada, planning regulations are designed to avoid the many forms of land abuse. Indeed, the last 20 years have seen the removal of private ownership rights to do as we see fit with "our land". Attention seems to have been successfully drawn to the responsibilities as well as the privileges of private land ownership, even though not all private landowners are in agreement with this contemporary planning stance. In the future, increasing public and governmental concerns should be directed to ensuring that future generations can be assured of a land resource capable of sustaining production, all life forms, and the other activities necessary for national well-being.

THE NATURE OF AGGREGATE DEPOSITS

The origin and the characteristics of sand and gravel deposits

Although the general weathering or breakdown of the rocks of the earth's surface is the initial mechanism whereby all sand and gravel materials are produced, it is the reworking of these materials by fluvio-glacial, river, and sea waters that gives them their present characteristics. As a result of the widely varying conditions during their period of deposition, no two sand and gravel deposits are exactly alike. Their surface relief and landforms, proportions of sand to gravel, impurities, rock types, and shrinkage values are all important factors in commercial sand and gravel extraction and can all be explained by an examination of their origins.

By far the largest proportion of Canadian sands and gravels owe their origin to the several periods when the ice sheets covering Canada began to melt and wane. During these periods vast torrents of meltwaters were released which laid down extensive sheets of sands and gravels. These materials are generally termed *fluvio-glacial deposits*.

These widespread deposits often provide the origin of the two other major groups. Thus in the second most important type *alluvial deposits*, much of the material has been derived from the erosion of the fluvio-glacial deposits lying on the earth's surface. However, because a small fraction of their existence has been in rivers these materials have their own peculiar characteristics.

The third important type of deposits is of *marine-lacustrine* origin. Here the original source of the sands and gravels may be either fluvio-glacial or alluvial or both. The important difference, however, is that lakeshore or seashore materials were, during the most recent phase of their deposition, subject to the conditions of the lake or marine environment. These deposits may still be found at the edge of the water body or left exposed due to the lowering of glacial lake levels or isostatic recovery of the adjacent shorelines.

Inventory technique

In the past, ineffectual planning controls and thoughtless approaches by operators resulted in landscape eyesores due to the ill-advised development of marginal deposits, which were shallower than anticipated or more varied than expected or did not meet the commercial qualities demanded by the marketplace. It is now accepted (and demanded by sophisticated planning approval processes) that a detailed inventory of the resource is essential to effective planning of sand and gravel pits.

Inventories can best be obtained by an intensive geological (for consolidated deposits) or geomorphological (for unconsolidated deposits) surveys, by aerial photography and site investigation. The following features, provided by the surveys, are essential to the aggregate producer: extent of deposit; thickness variations; surface relief (landforms); proportions of the various sand and gravel sizes; occurrence of nuisance bodies, e.g. peat, silt and clay bands, and till lenses; and rock type quantities, e.g. drying shrinkage index and presence or absence of inferior rock types, coal, some brittle sandstones, clayballs, shales, and mudstones. This information, not usually available from existing sources, is of great significance to efficient operation and plant installation.

The site survey, supplemented where necessary by borehole and electrical resistivity subsurface investigations, reveals not only the extent but also the volume of the deposits available. With fluvio-glacial sands and gravels it is the depositional environment during the period of ice melt

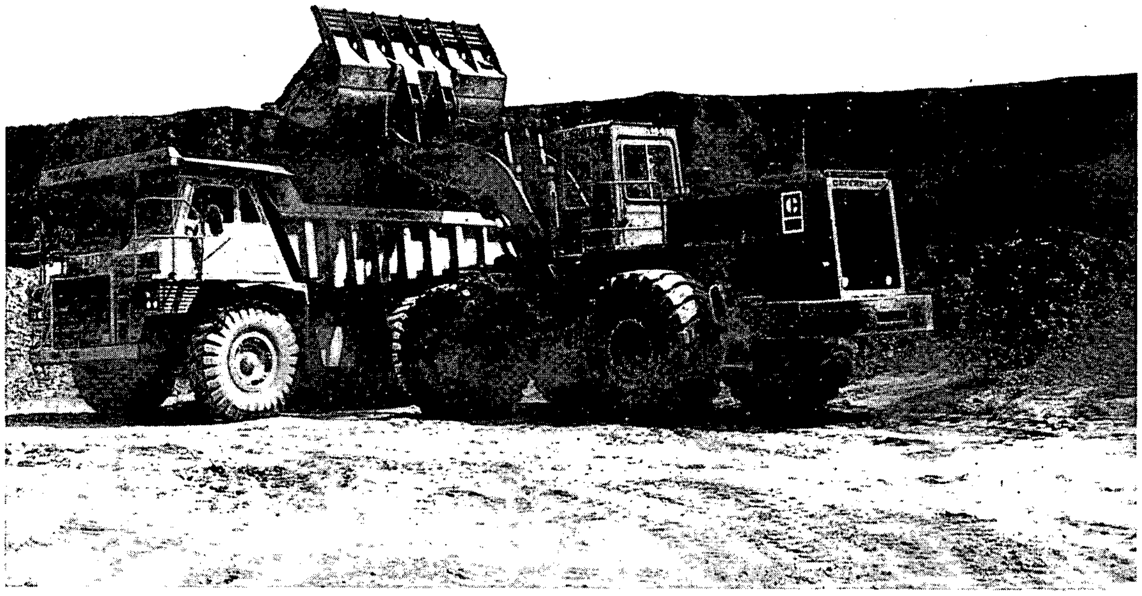


Photo 1. The investment costs of pit and quarry operations have increased enormously in the last 15 years. The front-end loader and truck in this photograph cost approximately one-half million dollars and an operator may have several such vehicles. The use of such heavy equipment, without proper muffling devises, will give rise to complaints from nearby residents about noise and dust.
A.G. McLellan

that influences their depth, extent, morphology, and composition.

Other sources of information – Pleistocene geological mapping, air photographs, soil reports, and regional resource inventories – are helpful but not as useful as the detailed site investigations alluded to above (McLellan, 1969; 1975).

It is important to recognize the role that adequate inventory can play in reducing stress through wise pre-planning and in minimizing future conflicts among aggregate producers, future land users, and the general public.

Further resource differentiation

Because sands and gravels are unconsolidated, do not require blasting, are easier to handle, and provide generally as good a commercial aggregate source, they are usually cheaper than, and favoured over, crushed stone sources. However, they normally yield only 30–40% stone content, i.e. particles greater than 6.3 mm in diameter – what is generally known as gravel. As the market demands volumes much closer to 50% sand and 50% gravel, the deficit is made up from crushed rock sources, which theoretically can produce 100% stone (gravel) content, although at higher prices.

In many parts of Canada there is a shortage of available sand and gravel resources and various crushed rock sources act as substitutes. Stratigraphic rocks, which can readily be broken up into size suitable for processing, are favoured, e.g. limestones and dolomites. However, special strength and wear qualities are often obtained by using volcanic/trap rock sources. The average commercial quarry today, because of greater capital investment, tends to be larger both in size and annual production than a sand and gravel pit.

HISTORICAL REVIEW OF PIT AND QUARRY IMPACT IN CANADA

The history of Canadian pit and quarry development

The impact of pits and quarries on the landscape is as old as civilization itself. The demands of the industrial and technological revolutions of the last two centuries have magnified this impact immeasurably. In Canada, the effects of pits and quarries in early times were restricted to the localities of major construction projects. The building of Fort Louisbourg and the Rideau and early Welland canals all left their scars. Even construction of early stone monuments such as the Brock Monument at Queenston Heights in the Niagara Peninsula occasioned the quarrying of stone at a nearby locality.

Increasingly throughout the late 19th and early 20th centuries, the pockmarks of aggregate extraction spread in and around fledgling Canadian cities. Increasing traffic required more durable roads, with metalled, macadamised, and latterly asphalt and concrete surfaces, which all required rock, gravel, and sand products. Rarely, however, was there any concern about the effect on the landscape of such pits and quarries; if anything it was probably regarded as an essential element of modernization. Neither legislation nor public awareness of environmental issues was available to oppose the free-wheeling scramble for profits that characterized the period.

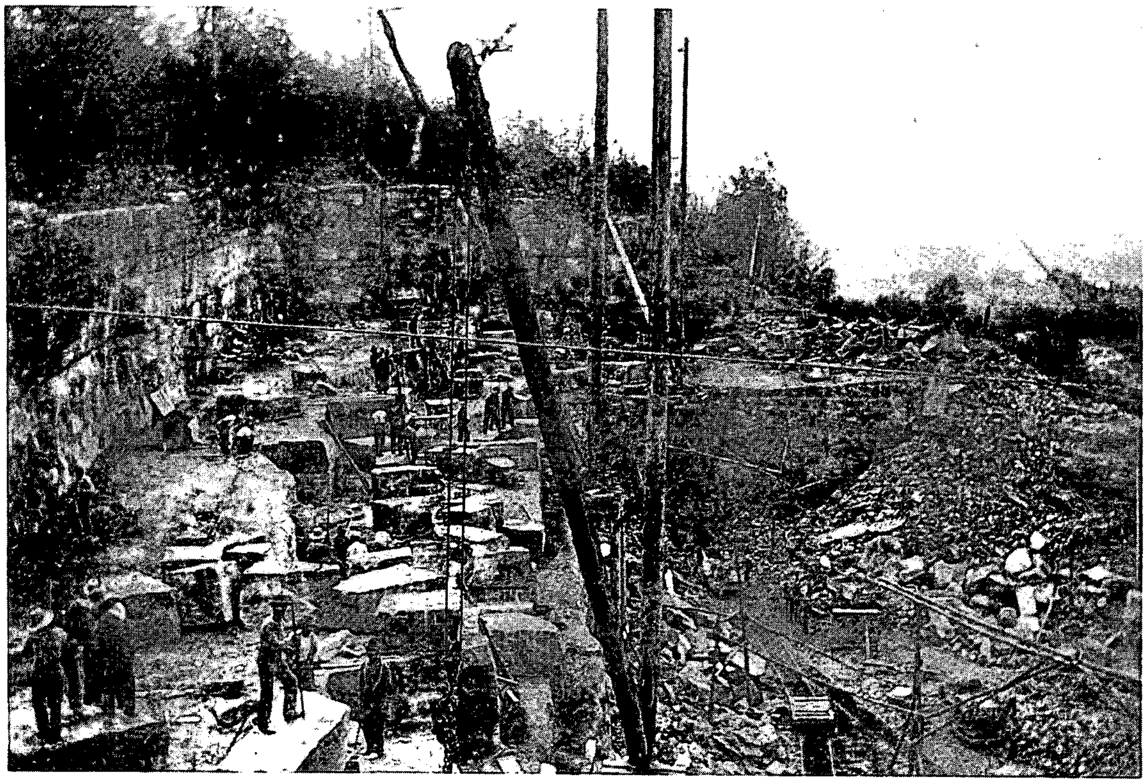


Photo 2. Pits and quarries have a long history in Canada. This 1898 photo of Stewart's Quarry near Rockland, Ontario shows the significant landscape alteration that resulted even without modern extraction equipment.
PA-51315/From the Geological Survey of Canada Collection, Public Archives Canada

Until the 1950s, the relatively slow rate of urban growth and technological development limited the demand for aggregates. But this constraint ended with the influx of population and the growth of industrial, manufacturing, and transport capacity during the 1960s and 1970s. An increasing proportion of the population was concentrated in metropolitan and urban areas. Ever larger numbers of larger pits and quarries began competing for land on the fringes of cities. As a result, by the 1980s, the number of gravel pits operated in urban areas by small entrepreneurs and farmers was diminishing; pits were being located in the rural hinterlands. The problems of this period were summarized thus:

> *"Perhaps Ontario serves as our best example. Here we have the basic ingredients of the problem. The aggregate industry is amongst the largest and fastest growing in the primary sector of the Ontario economy. The excavations produced, in contrast to hard rock mining operations, are frequently shallow – rarely more than 50–60 ft [15–18 m] in depth – and therefore the industry is an extensive land user with a major impact.*
>
> *Since the commodities produced, i.e. sand, gravel and crushed rock, are bulky, low-cost and not easy to transport, most of the production tends to be oriented very closely around its largely urban markets. As more and more of these commodities are required for building and highway construction, so the acreages involved increase. This, unlike the hard rock mining operations of Northern Ontario, means expansion in Southern Ontario – the most heavily populated and intensively used part of this province. The aggregate industry therefore is competing in a very competitive and high-priced land use market. Not only that, its location foci around urban peripheries means it is very visible.*
>
> *In the late 60's inadequate planning and excessive constraints imposed under the Municipal Act chapter 249 and the Planning Act chapter 296 began to restrict and indeed prohibit extractive operations in many parts of Southern Ontario. Although major reserves of aggregates have been lost through actual exhaustion and, around the periphery of growing cities, by unnecessarily precocious construction over them, by far the most serious problem currently is legislative sterilization.*
>
> *This is the crux of the aggregate industry crisis in Ontario. Increased public awareness and concern for the quality of the environment, particularly that on the doorsteps of urban municipalities, resulting in a decreasing availability of reserves for an industry at present engaged in a vigorous expansion to meet public demands [is] an interesting conflict of interests"* (McLellan, 1975).

Towards an inventory of pit and quarry sites

It is difficult to make an accurate assessment of the total land impact of the aggregate industry in Canada because of the lack of adequate statistical data. Attempts at providing statistics were limited to specific municipalities (Saint John, New Brunswick; Sault Ste. Marie, Ontario) or occasional provincial statements, e.g. Hora and Basham, 1981, (British Columbia); Department of Energy & Mines, 1981, (Manitoba). Because the industry is a provincial concern, no national or federal survey was available. Even in the late 1970s, only Thirgood, with his considerable personal experience, could attempt to provide a statement on land disturbed by surface mining of all types across Canada (Schaller and Sutton, 1978).

The most recent and most useful document on the assessment of pit or quarry disturbance in Canada, is an Environment Canada publication, <u>Mining, Land Use and the Environment – A Canadian Overview</u> by Marshall (1982). He states that, even in 1982, data available on the number, size, and location of pits and quarries (including abandoned operations) are too limited to provide an accurate nation-wide assessment of the aggregate industry. Previously, to indicate the extent of construction material operations in Canada, a limited inventory of pits and quarries in eastern Canada had been conducted as a part of an Environment Canada study in 1977 (Tables 1 and 2).

> *"The inventory concentrated on those sites in Ontario, Quebec, New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland which, combined, account for 78 percent of aggregate production in Canada, and which are located near populated centres (greater than 500 inhabitants). Of 4,997 pits and quarries identified, more than 90 percent were sand and gravel pits. This figure included currently operating sites as well as abandoned or temporary closed sites. Eighty-one percent of the sites were located in Ontario and Quebec. Sixty-eight percent of the sites were located within 8 kilometres of a populated centre and 46 percent were within 5 kilometres [Tables 1 and 2]. There were only 36 lime and cement operations across Canada in 1978 which utilized their own quarries for materials. The remainder obtained their supplies from other independent quarries"* (Marshall, 1982).

In a recent survey of southern Quebec, Boivin (1982) stated that abandoned quarries and open pits (178 and 35 respectively) outnumbered active ones (108 and 9). Employing a locational classification different from Marshall's, Boivin reported abandoned sites were distributed as follows: urban 39, urban fringe 27, rural farming land 149, rural wooded land 42 – a distribution that will be commented on later.

TABLE 1.

Area of land (in hectares) disturbed by pits and quarries in eastern Canada

		Sand and gravel pits		Quarries/open-pit mines	
Location	Total area disturbed	Disturbed land area	Mean pit size	Disturbed land area	Mean pit size
			(area in hectares)		
Northern Ontario	2 658	2 561	10.4	97	19.4
Western Ontario	6 610	5 667	6.7	943	24.8
Central Ontario	6 820	5 680	9.1	1 140	18.1
Eastern Ontario/Ottawa Valley	4 836	3 935	4.2	901	10.7
Northwest Quebec	452	446	3.5	6	3.0
Quebec - St. Lawrence Valley/Eastern Townships	8 821	7 310	6.6	1 511	17.5
Quebec–Lower St. Lawrence	643	643	3.9	–	–
New Brunswick	729	622	3.0	107	5.9
Nova Scotia	1 768	904	4.3	864	29.8
Prince Edward Island	400	400	3.5	–	–
Newfoundland	335	268	3.1	67	5.1
TOTAL	34 072	28 436	7.3	5 636	16.7

Reproduced from Marshall, 1982.

TABLE 2.

Area of land (in hectares) disturbed and number of pits and quarries within 8 km of populated centres in eastern Canada

	Distance from populated centre					
	0.16 km		0.16–4.8 km		4.8–8 km	
Location	Area (ha)	No. pits	Area (ha)	No. pits	Area (ha)	No. pits
Northern Ontario	28	2	1 641	123	565	55
Western Ontario	1 171	54	3 461	405	648	111
Central Ontario	773	70	2 774	350	1 482	253
Eastern Ontario/Ottawa Valley	528	62	2 035	438	602	140
Northwestern Quebec	6	1	118	34	116	23
Quebec - St. Lawrence Valley/Eastern Townships	889	56	2 927	320	1 782	226
Quebec/Lower St. Lawrence	52	3	269	71	53	29
New Brunswick	45	12	307	91	105	34
Nova Scotia	44	9	755	61	163	274
Prince Edward Island	10	3	75	31	19	4
Newfoundland	29	8	163	54	29	11
TOTAL	3 575	280	14 525	1 978	5 564	1 160

Reproduced from Marshall, 1982.

The amount of land disturbed or left abandoned by the extraction of construction aggregates in Canada is at least equal to if not greater than, the amount disturbed by all other forms of mining. Marshall (1982), in the study referred to above, concluded that in eastern Canada

> "*4,997 sites affected 34,072 hectares of land for an average disturbance of 6.8 hectares (6.1 hectares for sand and gravel; 16.7 hectares for quarries)... Over 80 percent of the individual sites were found in Ontario and Quebec, affecting 30,832 hectacres (20,916 hectares in Ontario).*
>
> *More-detailed studies at the county and municipal level conducted by the provinces of Nova Scotia and Ontario suggest that the above figure represents only a portion of the total land area affected. Sand and gravel pits in Colchester County, Nova Scotia were not included in the Environment Canada inventory, yet a provincial inventory (Simmons, 1971) identified 126 pits covering an area of 455 hectares.*
>
> *The Ontario Mineral Aggregate Working Party (1977) reported that there were only 1,200 licensed pits and quarries in the three Southern Ontario regions designated under the Pits and Quarries Control Act of 1971, covering 11,534 hectares for an average disturbance of 9.7 hectares. If all the lands in those three regions were designated under the Act, the number of pits would increase to 2,100 and affect an estimated 20,396 hectares. This report did not provide figures for abandoned or previously unlicensed pits and quarries (pre-1971) and those areas not designated under the Act in Northern Ontario.*
>
> *In 1977, estimates by the Ontario Ministry of Natural Resources indicated that 1,497 pits and quarries were licensed under the Pits and Quarries Act, and a further 2,893 to 2,943 were not licensed under the Mining Act on Crown Lands. If the average disturbance figure for the Environment Canada study (6.8 hectares) is used the overall estimate of the amount of land disturbed by pits and quarries in Ontario is in excess of 39,000 hectares (96,370 acres).*
>
> *In response to the findings of the Working Party, the Ontario Ministry of Natural Resources commissioned two additional studies to further investigate and quantify the amount of land disturbed and rehabilitated to date over a larger area. This included the counties of Brant and Wellington, and the regional municipalities of Durham, Halton, and Peel. It identified 258 sites, covering an area of 10,294 hectares, but limited its investigation to only licensed pits and quarries (Coates and Scott, 1979). Of this total, 33 percent [of the sites] showed that partial, progressive, or completed rehabilitation had taken place. A further 10.9 percent had begun preliminary rehabilitation earthwork. [No rehabilitation activities had been initiated at the remaining sites.] The figure for the same counties and municipalities in the Environment Canada study was 6,567 hectares for disturbed and partially reclaimed land. The detailed, field-checked Coates and Scott study, however, more accurately reflects the true situation within the two counties and the three municipalities. But even its figures are potentially low, since it excludes unlicensed abandoned operations and wayside pits.*
>
> *The data indicated that far more land in Ontario has been affected by pit and quarry operations than previously known, particularly the cumulative total that remains from the period prior to the 1971 Act. This situation is more or less true for all the provinces, since Ontario introduced the first act in 1971 to attempt to exclusively control pits and quarries and enforce reclamation. It was not until 1973 that similar legislation was passed in Alberta (Land Surface Conservation and Reclamation Act) and 1977 in Quebec. Indeed, it was the same proliferation and lack of control evident in southern Ontario that led to the special regulations in Quebec (Pits and Quarry Regulations under the Environmental Quality Act).*
>
> *Comparable information for the western provinces is limited but shows that, between 1945 and 1975, within a 48 kilometre radius of Winnipeg the amount of land disturbed by pit and quarry operations increased from 790 to 2,466 hectares, an average of 56 hectares/year (RPC Ltd., 1975). In Saskatchewan in 1975, there were a total of 815 outstanding permits accounting for 16,387 hectares of crown land. Over 80 percent of the pits were used by the Department of Highways (Poliquin, 1977). The actual amount of land disturbed by sand, gravel, and clay pits was 10,926 hectares (Land Use Policy Committee, 1978). The area disturbed in Alberta was 9,090 hectares in 1977, with an anticipated future increase of 4,545 hectares (Thirgood, 1978).*
>
> *In the light of that information, together with the annual production figure for structural materials, the per capita consumption (13 tonnes/year), and the distribution of population, an order-of-magnitude estimate of the minimum area disturbed by the production of structural materials in Canada (excluding the territories) is 120,000 hectares*" (Marshall, 1982).

The very considerable increase in numbers and in area that Marshall records is the result of the phenomenal development in Canada in the 1960s and early 1970s. However, production projections such as those by Proctor and Redfern, done for the Ontario Government in the mid 1970s, which estimated that available

Ontario aggregate resources would be exhausted by the year 2000, have already been discredited. The world-wide recession has significantly decreased the rate of development in Canada, so that the demand for construction materials from pits and quarries has been severely reduced. In Ontario the most recent statistics show a continuing decline in 1980 and 1981 from the peaks reached in the mid 1970s.

Expansion continued to occur in locations, generally in Alberta and particularly near the large urban areas of Calgary and Edmonton, which in the late 1970s still experienced construction growth. It is also occurring in localities where specific large-scale development projects still create an intense local demand for construction aggregates, such as pipelines, nuclear power plants, and airports. It would however be fair to say that even here there has been a noticeable decline recently.

> *"The United States Bureau of Mines (1976) forecast an annual growth rate of 2.8 percent for sand and gravel, and 3.2 percent for crushed stone between 1973 and 2000. Because Canada's per capita demand for these materials is similar to that of the United States these figures can be used for the purpose of comparison. Similar annual growth rates in Canada would result in an increase in sand and gravel production from 327 to 568 million tonnes between 1980 and 2000"* (Marshall, 1982).

In the light of the situation outlined above and the declining production in most provinces in Canada between 1976 and 1982, it would be unwise to overly depend on such projections.

The land stress and its unacceptability

It is clear that pit and quarry development has produced a considerable stress on Canadian land resources in the past. The impact has varied and continues to vary from province to province, but the loss of good agricultural land, the ugliness, the negative environmental impacts, and the incompatibilities of the aggregate industry caused it to be seen at best as an unfortunately necessary evil. However, the industry's past tendency to exploit with such profligacy an important natural resource – the land – is no longer acceptable.

Physical landscape impacts

Modern extraction procedures in large-scale aggregate production tend to follow those outlined in the flow diagrams (Figures 1*a* and *b*). The main impact is that all surface vegetation, topsoil, and overburden lying above the aggregate source has to be removed. This has often been accomplished in a less than sensitive manner, with little attempt being made to utilize timber stands for fenceposts, firewood, or other commercial purposes. Until comparatively recently the valuable topsoil, so vital to rehabilitation, was either sold or improperly stored. Moreover, little regard was paid to the natural habitat, which was being lost with potentially disastrous effects, especially when the animal or plant species present were already rare or endangered. Local residents observing the apparent destruction of a familiar landscape were often vociferous in their objections, but frequently too late.

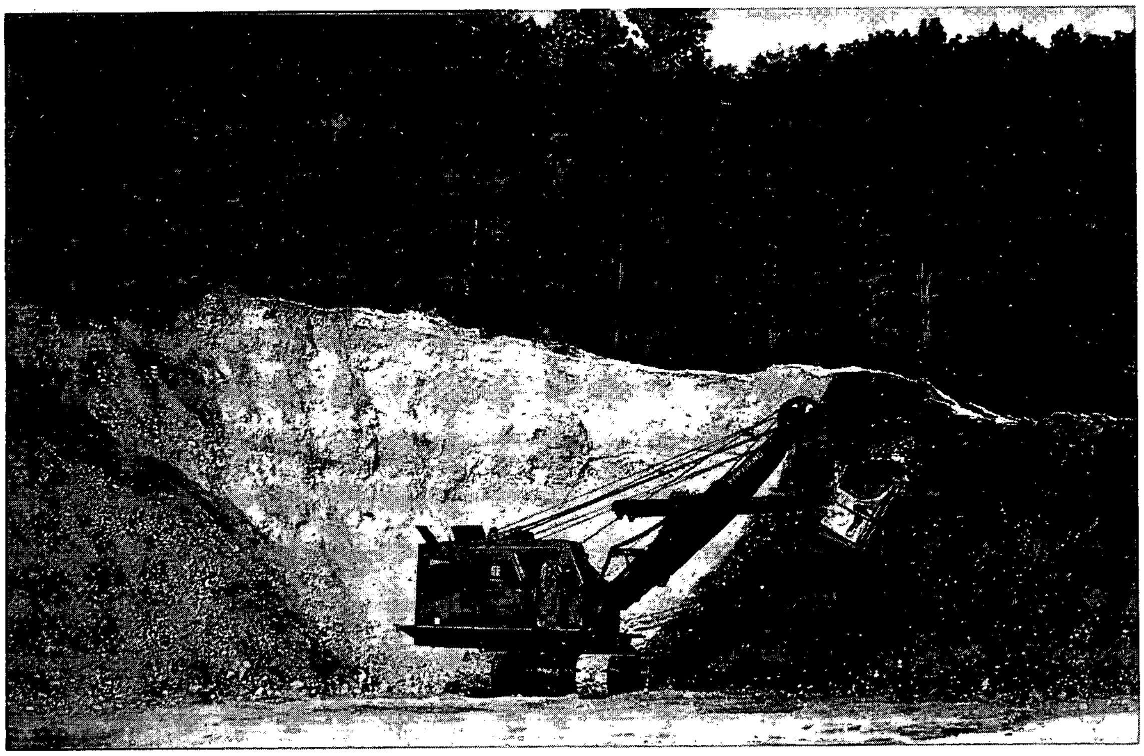


Photo 3. Unfortunately, some resources (woodlots, wildlife, and attractive landscapes) are lost at least temporarily to permit extraction of another resource – aggregates. In the past, insufficient effort was made to rehabilitate the site and return the land to its original or other appropriate after-use.
A.G. McLellan

Disruptions and impairment to the quantity and quality of surface and subsurface waters have occasionally resulted from surface mining. Streams have dried up or have been diverted or silted out of existence, with irreversible effects on fish and other aquatic populations. The overuse and pumping off of excess water from aggregate operations (particularly associated with quarries) have caused draw-downs in the local water table, affecting domestic wells and threatening those farms that must be assured of consistent water supplies, e.g. livestock, mink, and those dependent on irrigation.

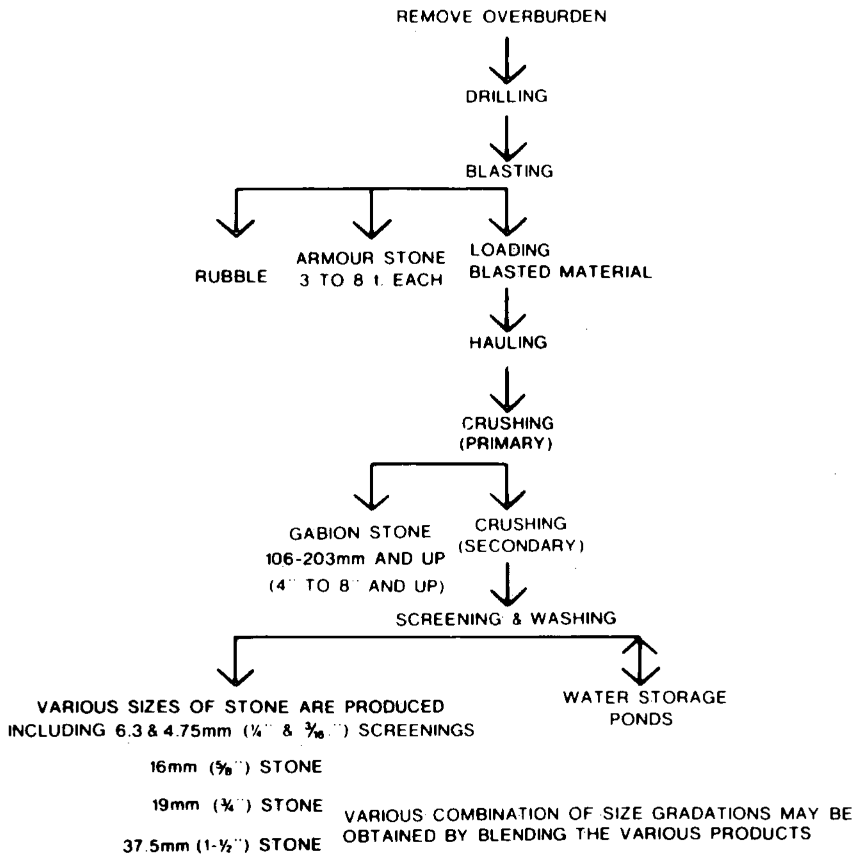
The compaction of subsoils and drainage impoundments due to the construction of haulage routes and siltation ponds are further consequences of aggregate extraction that can have destructive effects on both past and future vegetative growth.

While Marshall's (1982) survey reveals the truly extensive impact of pits and quarries on the Ontario landscape, it does not reflect the intensity of the impact on the local level. Pits and quarries can be small operator/consumer excavations a fraction of a hectare in size, e.g. many farmers have small operations which are only used sporadically when a local construction project generates demand. These are small and rarely extend below the water table. Their landscape impact and re-integration back into a farming land use can be achieved without great expense and difficulty. In contrast, normal commercial operations demand numerous buildings, plant and processing facilities, stockpiles, siltation ponds, generate heavy truck traffic, noise, dust, etc. and are generally disruptive influences if local land uses are residential in nature. These operations can be large, 100 ha is common but the writer knows of many over 200 ha and 1 pit over 600 ha in size. The annual output may frequently exceed 1 million tonnes. Processing involves using normally recycled well water, requires extensive siltation ponds and obtrusive pyramidal stockpiles. Steep excavation faces, deep excavations (occasionally waterfilled) where draglines have removed materials from below the water table, and the other features associated with large commercial operations mean that pits and quarries are viewed as, and often are, overwhelming disruptions incompatible with the idyll of quiet residential, rural enjoyment. The fact that large commercial operations with 30–60 million tonnes of reserves will last 20–50 years hardly appeases residents concerned with this "interim" disruptive land use.

Steps involved in the extraction and processing of aggregates

FIGURE 1a.

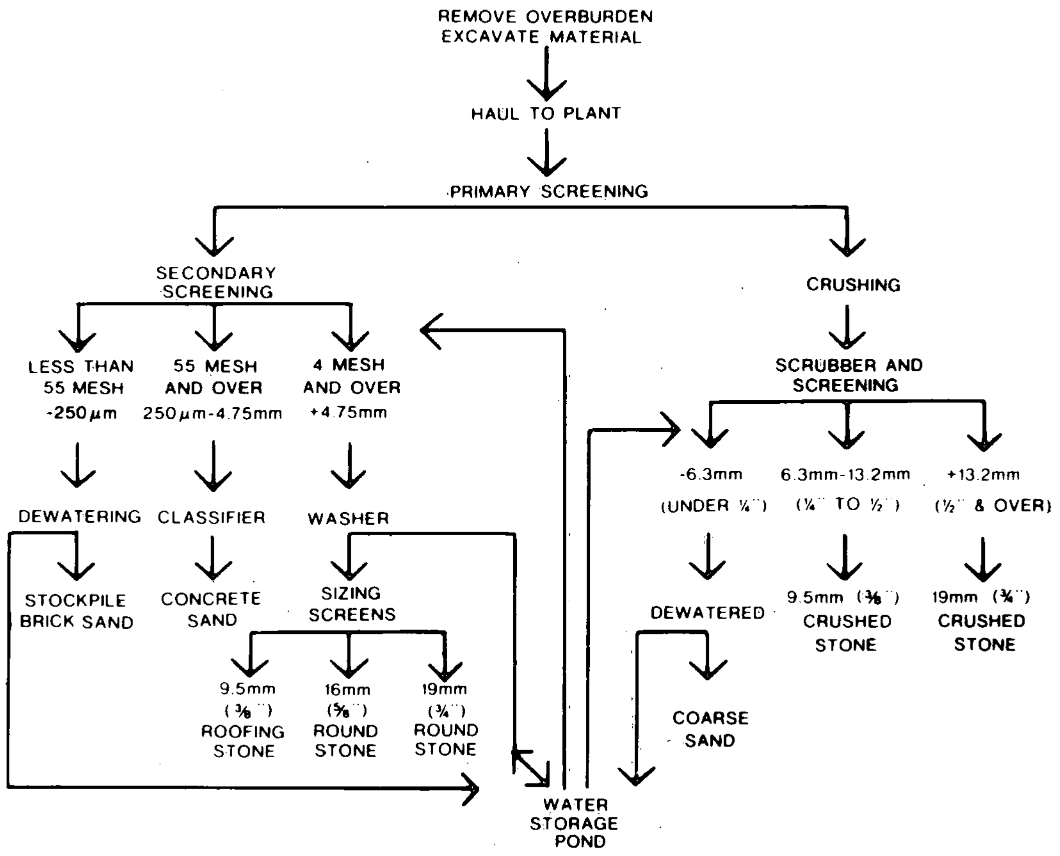
Flow diagram for a crushed stone operation



Source: Ontario Ministry of Natural Resources, n.d.

FIGURE 1b.

Flow diagram for a sand and gravel operation



Source: Ontario Ministry of Natural Resources, n.d.

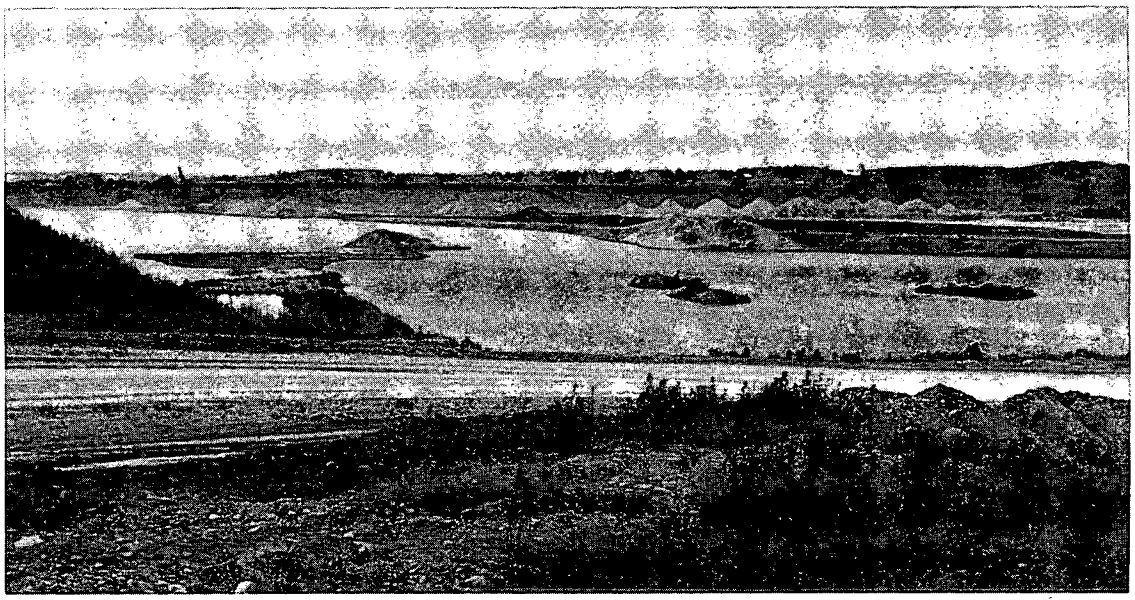


Photo 4. The process of aggregate extraction transforms the previous landscape into a vastly different and unattractive terrain. Where gravel deposits are below the water table, draglines can be used to excavate to a depth of 11 m below the water table. Stockpiles are later removed for processing but in the interim constitute an eyesore.
A.G. McLellan

The physical effects of aggregate production on the landscape are disruptive, highly visible, and in the past have been difficult to correct; more than many other disruptive land uses, this has rendered them unacceptable neighbours to the public at large.

Land-use conflicts

In their preferred urban fringe location, pits and quarries are often in competition with other less visually destructive land uses, which puts puts them at a disadvantage with the public and the local municipalities.

In a local 1971 survey in the Waterloo–Ontario area, aggregate extraction was found to be the most extensive land user after 1) agriculture, and 2) all other urban land uses combined. Not only this, but pits and quarries were the cause of 93% of all examples of land destruction and 75% of the area destroyed (McLellan, 1973). Those concerned with agriculture and food production in this country can look with dismay at these figures. Until the late 1970s, and even today, aggregate extraction and subsequent agricultural activity were considered incompatible. Many examples of land, formerly farmed, then extracted for gravel and abandoned in a condition where subsequent farming use is impossible without expensive remedial treatment can be found. The sites often provide unintentionally a focus for illegal dumping. Encroachment by weeds and scrubby woodland slowly removes most of the eyesore but does not return the farmland. Perhaps more importantly, in densely populated and intensively farmed parts of Canada, (e.g. the Windsor–Montreal axis, the Lower Mainland of British Columbia, and around our large metropolitan centres Edmonton, Winnipeg, etc.) large areas being licenced for pits and quarries are unavailable, albeit temporarily, for farming. Perhaps legislation should demand progressive extraction and rehabilitation which insists on limited disturbed land hectarage on any site. With modern sophisticated planning, a 200-ha pit should have a maximum of perhaps 20–50 ha unavailable for farming purposes at any one time. Recent guidelines from the Ontario Ministry of Agriculture and Food (Feb. 1983) are designed to protect specialty food crops and high quality farmlands.

More recently, however, experience has shown that careful rehabilitation can fully restore former agricultural productivity after removal of the aggregate. Much research remains to be done on the impact of extraction on agricultural lands. The disturbance of fertility and the normal drainage, horizons, and other structures of soils consequent on mining and improper storage in thick stockpiles can do almost irreparable damage. Even with enlightened handling techniques it often takes 3–5 years for the land to return to previous agricultural productivity levels. Today recent research and new government legislation tend to view the two land uses as compatible sequentials and room must be made for both.

Despite the success of rehabilitation technology (discussed later), in one major respect agriculture and pit and quarrying activity will remain incompatible. This is where the aggregate to be extracted is located below the groundwater table. In these circumstances, the land surface is replaced, following removal of the aggregate, by a water body. Although the design, depth, and quality of such water permits many subsequent uses, e.g. fish stocking, and recreation, and provides attractive opportunities for leisure activity, it clearly precludes future crop production on the land affected. In such instances it is probably wise to assess the agricultural quality of the land in question before considering its use for aggregate extraction. In the United Kingdom, land that has high agricultural capability is now protected against mining. In Canada there is no similar legislation based on differential land productivity.

The importance of preparatory planning is also evident in land devoted to forestry and wildlife. In the past, an ineffective or a complete lack of inventory of site characteristics has made it difficult to preserve areas and features considered worthwhile, or to restore healthy wildlife and forestry conditions. During the past 20 years ecologists have made great strides in identifying areas of natural habitat important to the continued well-being of fauna and flora. Their use of the various planning, legislative, and regulatory measures to protect environmentally sensitive and nature reserve areas has reduced the dangers to natural habitats by preventing pit and quarrying activities in them, for example in the Niagara Escarpment. New site plans in areas of valued woodland, whether for aesthetic, biological, or commercial reasons, must be sensitive of issues such as forest removal and replacement. Without this, disturbances to human and wildlife communities can prove disastrous on the local level.

Many areas of Canada considered valuable for recreational activity are already protected by the federal and provincial parks systems; other areas are protected by private companies and private ownership. Nevertheless, many recreational areas remain vulnerable to aggregate extraction. The presence of high quality bedrock or sand and gravel deposits can threaten the existence of a ski hill or the quality of a sport fishing location. In the Maritime Provinces, beaches have traditionally provided sources of sand and gravel. Their value as an important recreational resource in a tourist region resulted in an emerging conflict. Public pressure has resulted in action designed to alleviate the problem. In Nova Scotia, buffer zones are used to keep the incompatible recreation, residential, and mining areas apart. Information is provided to new home builders about blast effects (ground and air shocks and noise) from more distant quarries. Not all problems are easily resolved however. In Prince Edward Island, lack of comparable quality aggregate substitutes means that substantial quantities of sand and gravel are still extracted from the south shore. On the other hand, landscapes that are now only marginally useful can be changed in positive ways by careful pre-planning. Following the extraction of aggregates, there is an opportunity to rework, regrade, and redesign the landscape so that it has an enhanced value for a different final use. Judicious use of gravels has led to better golf courses, township parks, and moto-cross courses than were provided by nature.

The past conflicts between pits and quarries and other land uses are giving way to constructive compromises and landscape re-creation. In this respect, the future looks much more promising than the past. If constructive and effective rehabilitation are seen as essential concomitants of resource extraction, aggregate removal will no longer mean the inevitable production of derelict, ugly, and abandoned land.

Ancillary impacts – noise, dust, and aesthetics

To many people the stresses of pit and quarry operations are less the impact on the land surface and more the perceived effects on their living environment. After approximately 5 years of experience with pit and quarry control legislation, a representative sample of Ontario residents was asked to respond to what were considered the main problems with aggregate operations (Figures 2*a* and *b*). It is clear, first, that increased truck traffic, noise, dust, safety, and the effects on road surfaces and maintenance costs are of major concern to the residents affected, even though they may in fact live at a considerable distance from the aggregate operation along well travelled haulage routes. Second, pits and quarries are perceived as having a deleterious effect on the quality of the residential environment – noise, dust, and ugliness are all frequently mentioned.

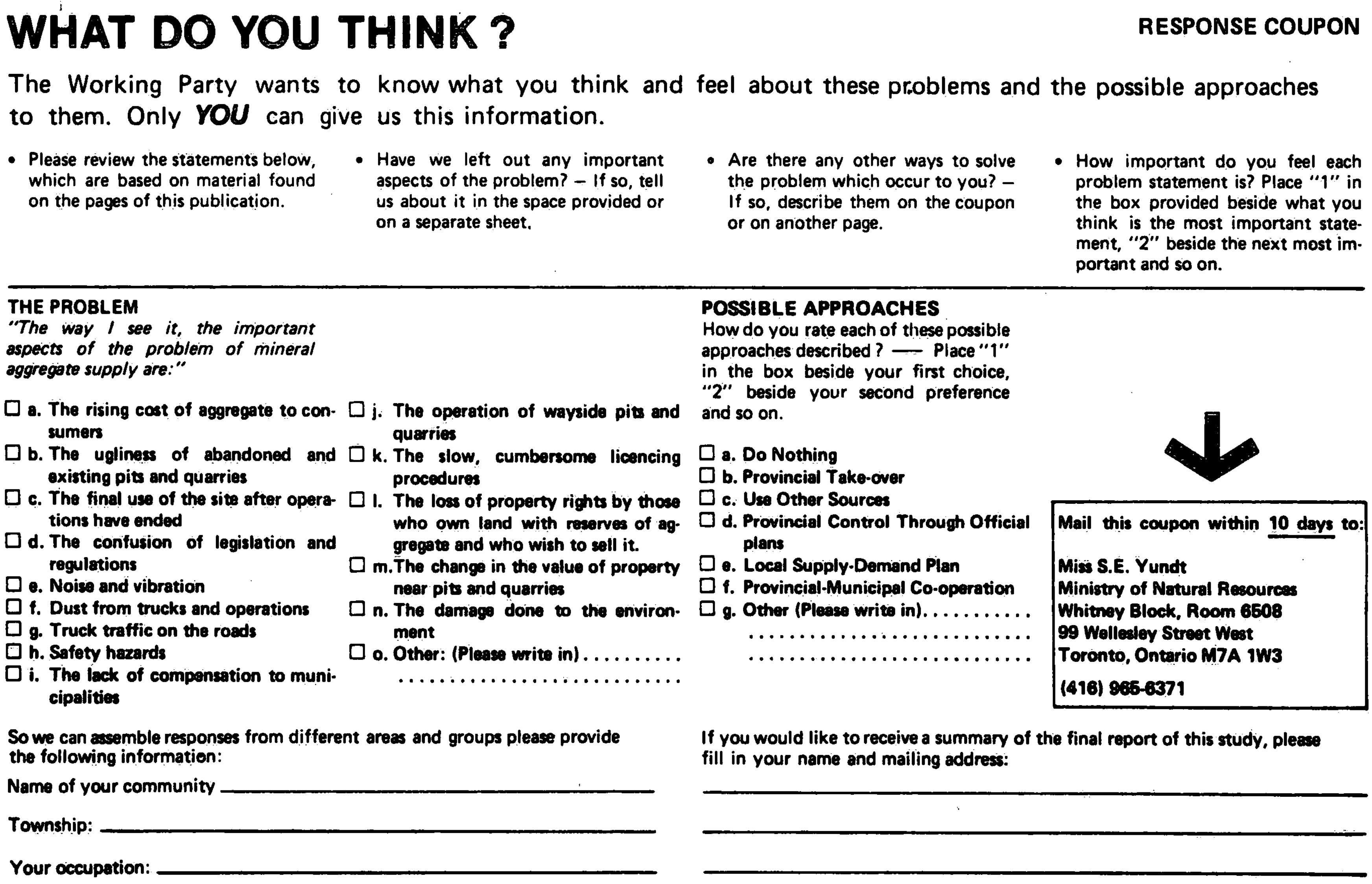
This chapter is written in a positive, forward-looking manner. It is felt that the implementation of pre-planning research, the sensitization of site plans to human and physical issues, the utilisation of our sophisticated planning, and legislative apparatus provide reassurance that the mistakes of the past will not be perpetrated in the future. However, it is evident that despite recent sensitive site planning and design measures, pits and quarries do not make compatible neighbours to many land uses such as hospitals, residential neighbourhoods, schools, greenhouses, and mink ranches where a quiet, dust-free, low-traffic environment is important.

Many newcomers to rural areas tend to see only idyllic rustic landscapes, the smells of the barnyard and topsoil spraying, the heavy machinery noise and dust of agricultural activity are ignored. However, to these rural residents, new aggregate operations mean a depreciation in the quality of both rural life and property value. The former has been more easy to prove than

Responses to pit and quarry problems

FIGURE 2*a*.

One form of public participation



WHAT DO YOU THINK?

RESPONSE COUPON

The Working Party wants to know what you think and feel about these problems and the possible approaches to them. Only ***YOU*** can give us this information.

- Please review the statements below, which are based on material found on the pages of this publication.
- Have we left out any important aspects of the problem? – If so, tell us about it in the space provided or on a separate sheet.
- Are there any other ways to solve the problem which occur to you? – If so, describe them on the coupon or on another page.
- How important do you feel each problem statement is? Place "1" in the box provided beside what you think is the most important statement, "2" beside the next most important and so on.

THE PROBLEM

"The way I see it, the important aspects of the problem of mineral aggregate supply are:"

☐ a. The rising cost of aggregate to consumers
☐ b. The ugliness of abandoned and existing pits and quarries
☐ c. The final use of the site after operations have ended
☐ d. The confusion of legislation and regulations
☐ e. Noise and vibration
☐ f. Dust from trucks and operations
☐ g. Truck traffic on the roads
☐ h. Safety hazards
☐ i. The lack of compensation to municipalities
☐ j. The operation of wayside pits and quarries
☐ k. The slow, cumbersome licencing procedures
☐ l. The loss of property rights by those who own land with reserves of aggregate and who wish to sell it.
☐ m. The change in the value of property near pits and quarries
☐ n. The damage done to the environment
☐ o. Other: (Please write in)..........
....

POSSIBLE APPROACHES

How do you rate each of these possible approaches described? —— Place "1" in the box beside your first choice, "2" beside your second preference and so on.

☐ a. Do Nothing
☐ b. Provincial Take-over
☐ c. Use Other Sources
☐ d. Provincial Control Through Official plans
☐ e. Local Supply-Demand Plan
☐ f. Provincial-Municipal Co-operation
☐ g. Other (Please write in)...........
....
....

Mail this coupon within 10 days to:

Miss S.E. Yundt
Ministry of Natural Resources
Whitney Block, Room 6508
99 Wellesley Street West
Toronto, Ontario M7A 1W3

(416) 965-6371

So we can assemble responses from different areas and groups please provide the following information:

Name of your community ______________________

Township: ______________________

Your occupation: ______________________

If you would like to receive a summary of the final report of this study, please fill in your name and mailing address:

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Reproduced from Ontario Mineral Aggregate Working Party, 1977.

the latter. Nevertheless, it is certain that the number of potential buyers for (and the retail value of) a home located close to a major pit or quarry and its ancillary activities has been severely reduced. Such adverse effects on nearby residents and communities can lead to decreased land values and these impacts must be reduced, compensated for, or considered unacceptable. Issues such as these have not yet been resolved and will continue to face the aggregate industry.

FIGURE 2*b*.

Rating of elements of the problem by areas

Areas:	Caledon		Guelph		Kitchener	
Problem Elements	Checked (N-37)	Ranked* (N-35)	Checked (N-20)	Ranked* (N-20)	Checked (N-33)	Ranked* (N-27)
a. Cost	5	2	3	7(2)	8	7
b. Ugliness	27(2)	11(2)	8	8(1)	25(1)	18(1)
c. Final Use	19	4	12(1)	5	20(3)	13(2)
d. Legislation	16	8	10(2)	3	18	8
e. Noise & Vibration	23	9	7	—	13	3
f. Dust	24	9	6	—	15	5
g. Trucks	30(1)	14(1)	9	2	17	4
h. Safety	23	4	5	—	16	2
i. Compensation	16	7	5	1	12	8
j. Wayside pits	12	—	5	2	13	—
k. Licencing	4	3	6	5	10	5
l. Property rights	8	3	6	5	8	1
m. Property value	22	9	10(2)	3	16	3
n. Environment	26(3)	11(2)	7	7(2)	24(2)	11(3)

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*The number indicates how often this item was ranked 1, 2, or 3.

Source: Ontario Mineral Aggregate Working Party, 1977.

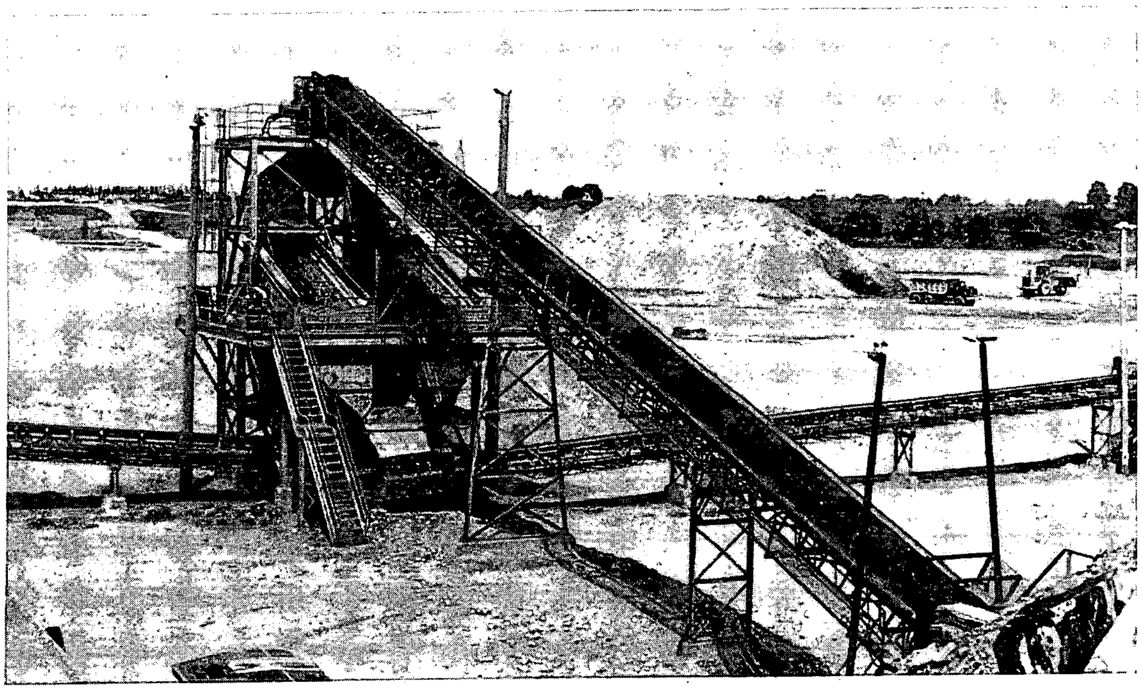


Photo 5. The processing plant at an aggregate extraction site can be elaborate and expensive but it performs quite simple functions – crushing, size selection and segregation, as well as washing (see Figures 1a and b). Such processing plants are another major source of noise and nearby residents often view these operations as incompatible with other land uses in urban, suburban, or rural settings.
A.G. McLellan

PLANNING TO REDUCE LAND IMPACTS — SENSITIVE AND COMPREHENSIVE SITE PLANNING

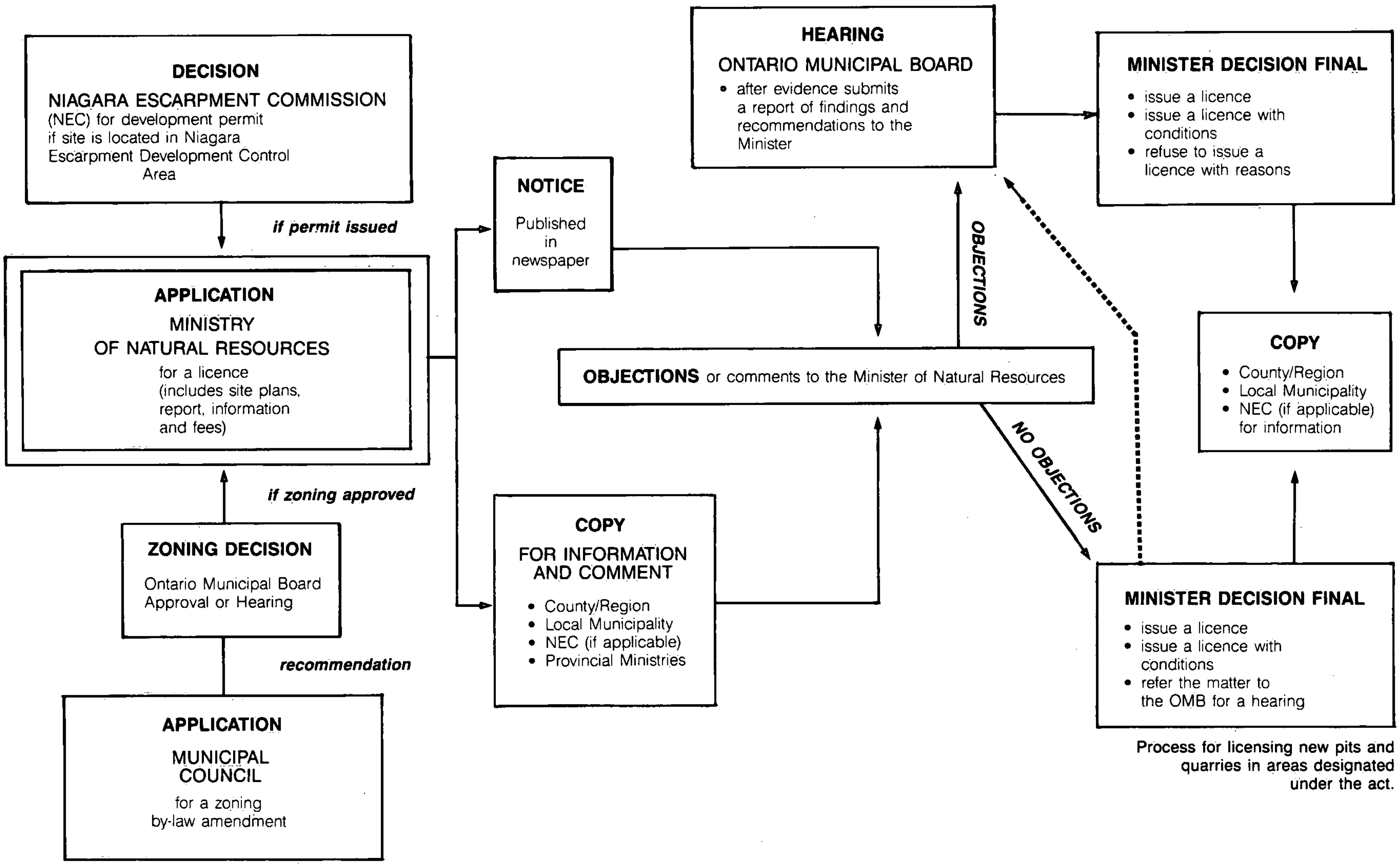
The theory and the new spirit of compromise

Although existing legislation and regulatory controls are often not explicit about the practices to be used by the aggregate extraction industry, they do ensure that most developers will be subject to close public and government scrutiny. This is a legacy inherited from past abuses. Practices considered acceptable, perhaps even sophisticated, in the 1960s may be outmoded and unacceptable in the 1980s. Research and experience have shown the value of sequential land use, pre-planning inventory, orderly production, and progressive rehabilitation schemes. Governments recognize that aggregate resources must be protected and will be utilized; complementing this view is a feeling that a more enlightened regulatory approach to pit and quarry development can therefore be expected, concentrating on aspects of rehabilitation.

In a 1980 position statement by the Soil Conservation Society of America, one of the groups formerly opposed to the surface mining industries, a new spirit of compromise was evident, which may well succeed the old conflict positions.

> *"... the Society ... is concerned about the growing impact of surface mining on soil, water, plants and related natural resources.*
>
> *The impact is growing because the domestic mineral industry continues to explore and expand. It must! Minerals played a major role in the development of both the United States and Canada. Their importance to our material well-being, to the economies of both countries, and to the continent's security cannot be underestimated.*

FIGURE 2c.
Proposed new planning process for licensing pits and quarries in Ontario



Process for licensing new pits and quarries in areas designated under the act.

Source: Yundt and Messerschmidt, 1979.

The Society is concerned about surface mining's impact precisely because of its nature. It can affect a wide range of soils, vegetation, ecosystems, and watersheds. In addition, surface mining often competes with agriculture for the use of the land.

Granted, the acreage disturbed by surface mining is a small percentage of the total land converted to nonagricultural uses annually, and in many cases the conversion is temporary. But, concentrated geographically, surface mining can result in intense hydrologic and aesthetic alterations in the environment. This, in turn, can often affect an area much larger than that which has been physically disturbed.

Surface mining need only be a multiple use of land or a nonconsumptive use. After mining, the land can be returned to its pre-mining state or to some alternate use demanded by society. What's important is that reclamation be carried out properly.

This statement provides broad guidelines to be used by the Society, its chapters, private groups, schools, local and state/provincial governments, and industry for carrying out resource conservation activities related to surface mining and reclamation. It sets forth general principles as an aid to formulating policies respecting all natural resources during mining, restoring newly mined land to its original levels of productivity, and reclaiming abandoned mined lands to a beneficial use ..." (Soil Conservation Society of America, 1980).

The Society also found that more than one-quarter (27.6%) of all land needing reclamation in United States (427 711 ha) was the result of sand and gravel extraction. Although no comparable Canadian figure is available, the percentage is possibly higher. The Society suggests the following goals (which are presented in full in Appendix I):

- Encourage research and development in land reclamation technology.
- Encourage better planning before mining.
- Encourage reclamation techniques that provide the greatest choice of alternative land uses.
- Encourage government agencies to work together.
- Encourage an economically sound and stable mining industry.
- Encourage conservation and recycling of existing materials.
- Encourage legislators to keep reclamation laws current.
- Encourage local input into mine planning and land-use decisions.
- Encourage public awareness of the cost of mining and reclamation.

TABLE 3.

Potential Inputs in Environmental Impact Statement of an aggregate surface mining operation

Physical studies
- Air photo investigation
- Groundwater
- Surface water
- Soils analysis
- Ecology (fauna and flora); water and land area
- Geological investigation
- Archaeological and historical
- Visual aesthetics
- Preservation and buffer considerations

Mining interference and reclamation
- Optimal phasing plan for operation
- Progressive rehabilitation model
- Agricultural interference and restoration
- Reforestation program
- Wildlife corridor maintenance and improvement
- Final land-use design

Operation studies
- Market analysis and economic justification
- Transport and haulage routes (on and off site)
- Community relationships
- Planning study
- Attitudinal studies of nearby residents towards mining operation
- Noise production and amelioration
- Site plan design (slopes, entrances, plant machinery, etc.)
- Coordination with all planning and institutional authorities

Reproduced from McLellan, 1981 in Canadian Resource Policies.

The role of pre-planning and public input

Comprehensive inventory and pre-planning should be mandatory; detailed information should be demanded for both the site and the surrounding areas liable to be affected. Only then can effective rehabilitation be accomplished. Research related to pre-planning may determine areas worthy of being preserved and retained in their present condition. Table 3 lists the kinds of information required for effective pre-planning and reflects the author's participation in the preparation of over 30 site plans for new pit and quarry operations in Ontario. However, it does not indicate the amount of effort needed to integrate the information and to reach effective compromises.

The objectives of site planning are many, but can simply be stated as, first, to render the operational programs as inoffensive to the social and physical environment of the area as possible; second, to ensure that at any specific time the area of land disturbed is minimized, and that progressive rehabilitation techniques are vigorously implemented (see Figure 4, in which categories B and C occupy as small a proportion of the total area as possible); and third, to leave a landscape that is in all respects suitable for the intended future use(s). It is important that the research conducted and the recommendations produced be closely integrated with the implementation program and not considered as an unavoidable bureaucratic exercise.

Photo 6. Effective planning is necessary to minimize the impact of pit and quarry operations. Vegetation screens and berms can be useful in visually isolating extraction activities. However, as in this example in Ontario, tree screens planted too late do not always provide as effective a barrier as they might.
A.G. McLellan

It is clear that timing is important to the design of an effective site plan. All the data on the nature of the resource, on the site, and on the adjacent areas should be collected before design and procedural decisions are made. People liable to be affected by the proposal and its ancillary impacts, e.g. dust dispersal, traffic haulage routes, and surface and groundwater impacts, should be given the opportunity to comment before final decisions are made.

Nowadays, members of the public who are concerned about the direct or indirect effects of mining on their lifestyle demand a hearing as objectors or participants. Citizen groups occasionally hire experts and lawyers to present their viewpoint. At another level, public organized bodies seek to influence major policy decisions and guidelines for operational control.

The public's right to participation is ignored at peril. In a recent Ontario survey (McLellan *et al.*, 1981) after examining the attitudes of residents, aggregate producers, elected officials, and government inspectors, and the way in which disputes are resolved at the Ontario Municipal Board, it was recommended that:

1) Local municipalities should encourage residents, particularly those who think they might be affected, to look at the applications for proposed pits and quarries. Compromise should be attempted before resorting to litigation.
2) The problem of technical jargon and intelligibility should be resolved. It is the Ontario Municipal Board's responsibility to ensure that experts' testimony is general but this does not always occur. However, the onus should not be entirely on the Board; possibly an aggregate producer should have to arrange a public hearing, at which the proposal is explained in layman's terms, prior to any formal hearing.
3) Recently proposed legislation requires a 5-year review. Municipalities should use this opportunity to conduct a regular follow-up study. This could establish if residents' initial concerns have been alleviated and what new ones have arisen. Monitoring, management, and follow-up studies have been one of the weakest components of environmental control in Ontario's history.

4) The provincial government, with input from public groups, should make some comprehensive attempt to assess the benefits and disadvantages of current and proposed planning decision-making processes in terms of public participation.
5) To hasten the approval process, the aggregate producer should accept the responsibility of determining the needs of the public and obtaining its support. Where no formal means of communication exist, the producer should accept the responsibility of establishing the contacts.
6) Studies should include at least the following:
   a) assessment of the existing natural and human environment;
   b) assessment of the natural, historical, and cultural uniqueness of the site in a regional context;
   c) an evaluation of the local and regional market for aggregates in order to determine the need for production from the site;
   d) traffic impact studies for the entire haulage route including matters of safety, nuisance, and possible road deterioration;
   e) assessment of existing surface and ground water characteristics and an evaluation of possible changes to them that might occur during the proposed operation; and
   f) an assessment of the quantity and quality of the deposit itself.

   This last study is highly desirable from the point of view of the producer. First, the potential importance of the deposit will be more accurately known and the need for it assessed. Second, extraction and rehabilitation plans can be based on more precise information so that alternative designs can be better assessed and efficiency can be maximized. Knowledge of potential impacts often helps the producer to select appropriate equipment, haulage routes, extraction patterns, and alternative methods of screening and rehabilitation, which might not have been immediately apparent or seen as necessary. The justifications for the choice of a specific site will be contentious; an examination of alternatives and of government inventory statements should form an important part of the proponent's research.
7) The research reports presented by the aggregate producers or their experts should take account of the following:
   a) technical jargon, statistical tables, and mathematical models should be kept to a minimum in the text of the report; as far as possible this type of information should be placed in an appendix;
   b) any terminology or special research techniques should be fully explained and defined in the simplest terms;
   c) the author should try to describe possible impacts in terms which an average person can relate to, e.g. noise expressed in terms of automobile horns as well as in decibels or LeQ (the current noise calibration unit);
   d) impacts on the human environment should relate to the characteristics of the actual population, not simply to statistical probabilities and preferences; and
   e) maximum use should be made of graphic representation.
8) The present practice is for initial site plans to be drafted in a fairly complete form before seeking public comment. To avoid confrontation with the public, initial site plans should include only blank maps and outline descriptions of the operational procedures to be followed. A short informal workshop at an early stage can do much for establishing good relations with the residents of a community.
9) Legislation should require aggregate producers to undertake the various impact studies specified, using a standardized method of analysis to determine the spatial extent of certain impacts. Once these are completed, attempts should be made through local newspapers, local authority councils, or other forums to communicate with the entire population in the affected areas.

All too often individual applications have been assessed on their own merits. We should now expect that proposed pit and quarry development conform to stated official plans and relate to adjacent uses, including other nearby pits and quarries and the human and natural systems beyond the boundaries of the application, e.g. wildlife corridors and river and stream systems. In other words, applications should show evidence that they have taken account of the broad regional implications of their approval.

Suitable opportunities for public statements and reaction should become part of the planning process. But the reaction, "we just don't want a pit or quarry in our backyard", and its inevitable implication "why don't you put it in someone else's" are no longer good enough. Aggregate producers have the same rights as members of the public, namely that elected officials and civil servants will do their jobs honestly and fairly. Opposition groups should have to prove their case just as a proponent does. All parties, however, should become more aware of the necessity of understanding the full effects of utilizing and managing the land and the subsurface resources.

One note concerning post-approvals monitoring is warranted. Contemporary approval of pits and quarries operations usually follows rigorous scrutiny of the many factors involved. However, similar rigour has not been applied to the management and monitoring of operations carried out after approval is granted. Given the experience of the last two decades, it is likely that some aggregate producers will not live up to the spirit of recent legislation. Ineffective monitoring by government agencies harms the good producer as much as the bad; public attitudes seem to be affected more by the worst examples than the best ones.

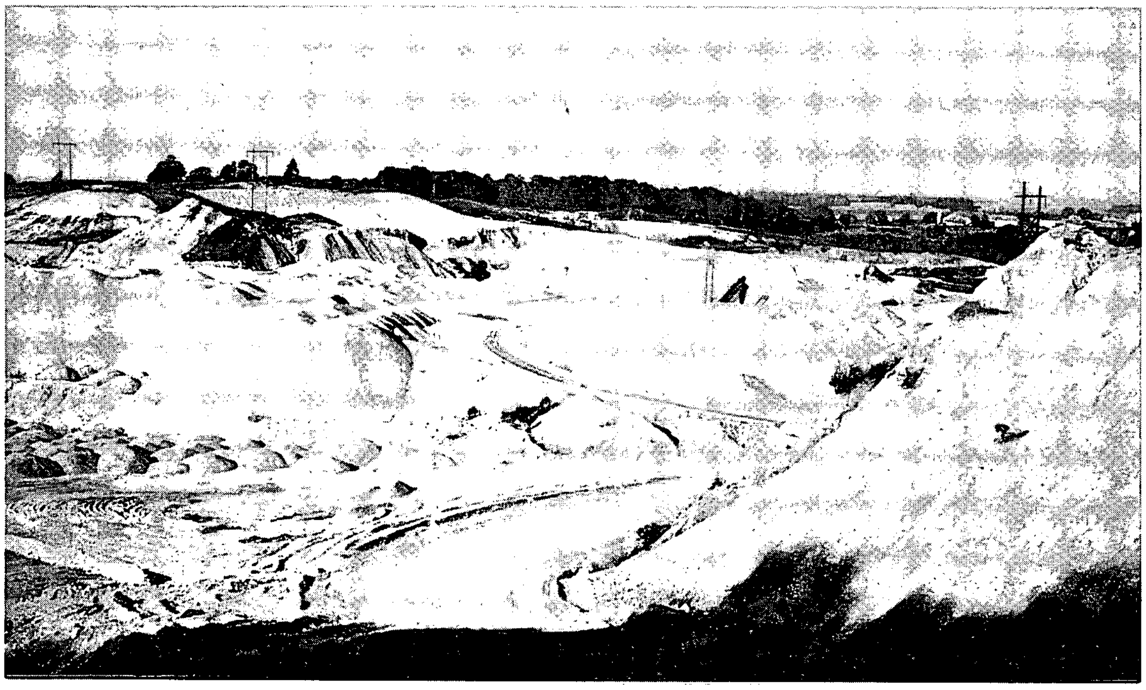


Photo 7. Close examination of the interior of pits rarely reveals the sense of order and sequence that consultants' site plans imply.
A.G. McLellan

CURRENT TRENDS AND ISSUES

The problem of past abandonment and returning land to a useful condition

The legislation recently and currently being enacted across Canada concerns present and future operations and generally does little to resolve the problems of the past – the land left derelict and abandoned as a consequence of earlier pit and quarry activity. The scale of these problems across Canada is not known. The Ontario government recognized that new legislation should tackle this issue (1977) and 1) indicated that new legislation would collect funds from active pits to pay for the rehabilitation of abandoned ones, and 2) commissioned a study in 1978 to be conducted by one of its own senior civil servants (supervisor of the Industrial Minerals Section), a senior planner in the study area (Director of Development, Department of Planning, Regional Municipality of Waterloo), and a university geography professor with research experience in the topic. The stated reasons for the study and its location were:

> "*1. To determine the location, condition and extent of land made derelict by surface extraction activities,*
>
> *2. To investigate the range of alternative and more appropriate uses which could be made of such lands, and*
>
> *3. To develop a methodological framework which would help the municipalities charged with resolving the problem make the most efficient and sensible use of the monies made available through the Rehabilitation Fund....*" (McLellan *et al.*, 1979).

The Regional Municipality of Waterloo, shown in Map 1, was selected as the case study site for the following reasons:

> "*1. It was, is and will continue to be a major aggregate producing area in Ontario.*
>
> *2. The Council of the Regional Municipality of Waterloo has identified the need for rehabilitation of abandoned pits and consequently strongly supports the rehabilitation study.*
>
> *3. Also, related research has been conducted by A.G. McLellan and others from the University of Waterloo. These past studies allow a very revealing time perspective not necessarily available elsewhere....*" (McLellan *et al.*, 1979).

Without recounting all the findings of the study, certain important and perhaps unexpected conclusions should be mentioned here. In Ontario the problem of abandoned pits varies across the province; parts of Ontario with no aggregate resources clearly have minimal problems. In the Waterloo area many of the unlicensed and apparently abandoned operations were very small (less than 1 ha) and were still being privately used by the landowner. So, in general, abandoned pits were not perceived as a major problem in Waterloo.

Where the public complained about abandoned pits, the study found that most were in active, licensed, extractive areas. The Ontario Mineral Aggregate Working Party, in its earlier report, has suggested improvements designed to speed the rehabilitation process in active licensed areas and this together with greater responsibilities and profit motivations on the part of aggregate producers should mean that abandoned land may become less of a public problem in the near future.

The 103 instances of abandoned pits and quarries which were found in the Regional Municipality of Waterloo, although large in number, comprise a small total area (160 ha). The small size of most sites is a major constraint on potential future uses. On the other hand, the rehabilitation costs for such small sites should not be high, meaning that a large number of sites could be returned to some useful condition in a short period of time.

A first step in resolving the problem of abandoned pits and quarries is an inventory of the areas affected and an appraisal of related problems and opportunities. Armed with this information, municipal authorities can assess how best to use the sites in the wider community interest.

The results of the Waterloo study indicate that the amount of money available under the proposed new legislation in Ontario, when matched with the scale of the problem typified by the Regional Municipality of Waterloo, will be almost certain to eradicate the problem of abandoned extractive land in 10 years.

The study also found that the general definition of rehabilitation is too vague. Many abandoned sites were found to be serving useful purposes despite having received no rehabilitation. The study therefore established definitions for the two common descriptions of land conditions: rehabilitated and reclaimed. Rehabilitation is the treatment of disturbed land to develop and improve it into a beneficial form. It is the outcome of human or natural action that makes the land's appearance blend into the surrounding landscape, while at the same time serving a specific, beneficial social use. In other words, both the physical appearance and the land use have been changed to an acceptable condition.

Reclamation, for the purpose of the study, is only partial rehabilitation, in the sense that only one of the two necessary components of total rehabilitation is present, i.e. an acceptable change in either the physical appearance or the use of the pit or quarry. Reclamation can be viewed as a first step to eventual rehabilitation. Either the site is vacant but has a reasonably presentable appearance or the pit/quarry floor may be used for the storage of machinery, vehicles, etc.

The rehabilitation of abandoned pits, whether done individually or co-operatively, requires some degree of advanced planning. Regional rehabilitation clearly requires a planning process carried out by the regional government, based on a regional planning survey whose purpose would be two-fold: first, to obtain information concerning community-wide needs that might be served by the rehabilitation of abandoned pits and quarries; second, to discuss present and alternative planning and financing procedures that will achieve rehabilitation goals.

A basic tenet of the 1979 Waterloo study was that even derelict and abandoned land can be converted to satisfy a community need. It is therefore necessary to know what the demands for various land uses are in order to return derelict land to a productive state. In the Waterloo survey, the respondents were asked to comment on the need for various uses within the Regional Municipality of Waterloo, and then to put them in order of importance. The most commonly discussed uses were recreation, housing, agriculture, forestry, sanitary landfill, and industrial–commercial, in that order.

The survey examined the implementation of a program for rehabilitating specific abandoned sites with different characteristics and looked at different options for using the available monies, *viz.* outright land purchase by the municipality, financial incentives to private landowners, and an aesthetic improvement program. In the guidelines it was noted that choices of land use may be limited by certain criteria:

Agriculture

- not adjacent to incompatible urban activities
- adjacent to existing agricultural land
- requires adequate topsoil

Forestry

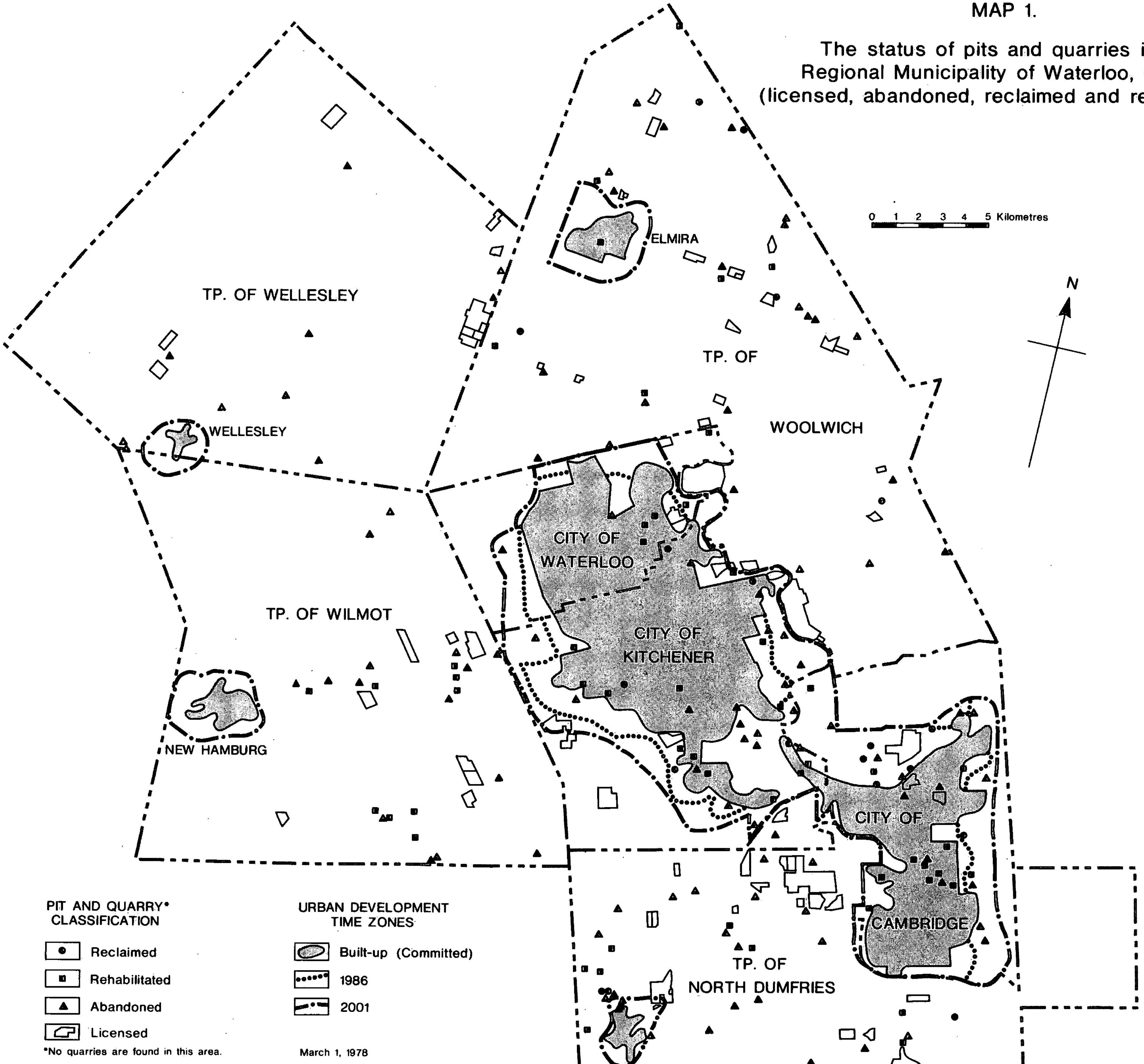
- near existing woodlot (for ecological or commercial reasons)
- at least 2 ha if purpose is for wood production
- long-term investment: land must be in this use for at least 20 years
- can also be used as part of aesthetic improvement program, in which case it can be smaller than 2 ha

Housing

- not adjacent to industry
- in built-up areas

MAP 1.

The status of pits and quarries in the Regional Municipality of Waterloo, Ontario (licensed, abandoned, reclaimed and rehabilitated)



Sources: Regional Municipality of Waterloo, Department of Planning and Development.
McLellan *et al.*, 1979.

- if in rural areas, it should be self-contained with buffer zones around it

Recreation

- if intensive use, then near built-up residential area
- if passive use is intended, it should have some natural amenities or be next to an existing recreation area, where it can be used as a service area (parking, etc.)
- if picnic area, it should be on a scenic road

Sanitary landfill

- requires compatibility with surrounding land use
- geological and hydrological suitability

Industrial–Commercial

- in or near urban areas
- not adjacent to residential area
- at least 2-ha sites so light industry can be grouped

In the course of the Waterloo study it became clear that certain sites were more likely to be rehabilitated because their location gave them a higher land value. Indeed some sites changed from abandoned to useful land uses during the short time of the study. Hence the study recommended that the Provincial Rehabilitation Fund should be used first to subsidize the rehabilitation of those sites with least potential land value, i.e. those least likely to be marketable, in order to ensure that the money is used where it is most needed. As a guide to use of the Fund, the study defined a rank order of site conditions; Rank 1 is most eligible for subsidy, Rank 4 least (McLellan *et al.*, 1979).

Rank 1—rural area – no development pressures

Rank 2—development by 2001

Rank 3—development by 1986

Rank 4—land already committed for development

This regional study, although not necessarily representative of all parts of Ontario and Canada, was reassuring. Several provinces have already addressed many of the perceived public concerns. The scale of the true abandonment problem seemed not as great as previously feared and the forces of the market place and the program suggested by the Waterloo study seem capable of facilitating the rehabilitation of abandoned pits and quarries.

Flexible approaches – types of stress and some rehabilitation solutions

It is important to recognize that the problems and our remedies for land under stress will vary according to the location of the land parcels. Three brief examples, representing three important locational categories: 1) the urban fringe, 2) distant rural areas, and 3) the North, are presented.

Pits and quarries in urban fringe locations

Not without cause, some aggregate producers complain that many good aggregate resources were denied to them as a result of the prolific expansion of Canadian cities in the 1960s and 1970s. This did not necessarily reflect uncontrolled or unplanned growth. Planners did not, at the time, have resource mapping or legislative controls that would have enabled them to determine the quality of aggregate resources or to conserve them. Some provincial governments are now insisting that such inventory mapping takes place and that appropriate policies be established.

As near-urban aggregate resources were exhausted new reserves were sought at greater distances from the urban centres. At the same time, urban expansion meant that urban land uses, and not always compatible ones, surrounded the locations of many pits and quarries. Hence in many large urban communities, e.g. Montreal, Ottawa, and Winnipeg, large pits and quarries are now found within the urban area. This gives them high visibility, which has contributed to the conflicts and antagonisms they have aroused toward this socially unacceptable land use. It became increasingly complicated and difficult in the 1970s to license and open new operations if they were anywhere in the city's countryside (Bryant *et al.*, 1982). Frequently a group of concerned citizens, often with justification, were prepared to oppose the development application and would present vigorous and frequently effective arguments against it.

An interesting opportunity for compromise has arisen, which in some measure resolves this problem. Old pits and quarries, long-established land users before the encroachment of urban growth, do not face the heavy costs of new plant, new land acquisitions, or the increasingly difficult and costly zoning and licensing procedures. Neighbours in nearby communities cannot complain of no foreknowledge of the incompatible land use. At the same time, resources far from the market for aggregates are expensive to develop and transport. Traditionally, urban fringe expansion has often meant precocious sterilization of good farmland by speculators and a loss of potential aggregate resources. The slowing of urban growth in Canada in the last 5 years has seen some of this land come back into more active farming.

The City of Kitchener has taken the initiative to improve this situation by using a multiple-resource development policy. Where farm landowners anticipate urban development and know they have commercial aggregate deposits on their lands and where official plan policies indicate a change from rural to urban land uses is contemplated, the owners are encouraged to consider removal of all or part of the aggregate resources prior to the conversion of the land to urban uses. In one such situation, two farm landowners on the eastern edge of the city, anticipating industrial sub-division development in the 1980–1985 period, approached a consultant to investigate and inventory the aggregate resource potential of their lands. Approximately 2.5 million tonnes of economically acceptable sands and gravels were found. A nearby aggregate producer, the last in the built-up area of Kitchener, facing the imminent exhaustion of the aggregate resources of his 200-ha property after 35 years, agreed to a royalty/tonne purchase of the landowners' sands and gravels. Arrangements and appropriate permissions were obtained from the City of Kitchener, Grand River Conservation Authority, Canadian National Railroad, Ministry of Transportation and Communications, Ministry of Natural Resources, and the Regional Municipality of Waterloo. Plans were produced to remove the bulk of the sands and gravels in a way that would ensure that the final terrain conditions would be suited to industrial subdivision development.

Multiple resource use and sequential planning, such as in this example, although doing nothing to prevent loss of farmland, can often result in significant benefits. In Kitchener the obvious benefits were: 1) preventing the sterilization of 2.5 million tonnes of valuable aggregates; 2) utilizing blocks of land for which a new urban use is readily available, thus ensuring rapid transformation and short-lived stress conditions; 3) prolonging the life of a long-established aggregate operation by 5–10 years (this period includes time for selling stockpiled resources); 4) maintaining local ancillary operations – ready-mix concrete and building block plants; 5) preventing new, heavy and expensive truck haulage from elsewhere; 6) avoiding the establishment of a new operation in perhaps a less advantageous and more contentious locality; 7) keeping costs and prices lower for local users of aggregate materials; and 8) effectively financing and producing much needed industrial development land for the surrounding municipality.

The financial benefits to the landowners and the aggregate producers are obvious. The extraction and sale of the sands and gravels over a relatively short period (3–6 years) provides an income perhaps considerably in excess of the original purchase price of the whole property, and delays only by a short time the profitable sale of industrial subdivision lots. As a result of planned extraction, the land is left in exactly the condition required for the subsequent

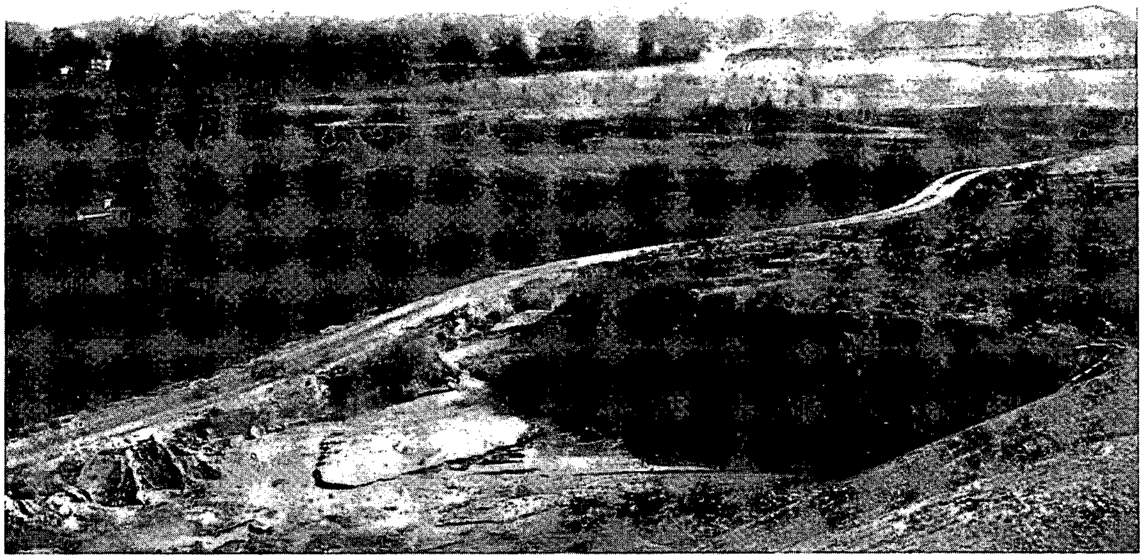


Photo 8. In this photograph of an outstanding example of progressive rehabilitation (Steed and Evans, Fonthill, Ontario) the land in the centre has recently been converted from a gravel pit to a golf course. Notice the preservation of mature trees in the background and the new planting of mixed species. Both land uses – extraction and recreation – exist in reasonable harmony.
A.G. McLellan

Photo 9. This is an airphoto of the same area shown in Photos 8 and 10 but taken seven years earlier. The top left corner shows the protection of mature trees and the newly created lakes. The main golf course area shown in Photo 8 was previously an extensive siltation pond (centre left). The forage crop field (Photo 10) was land only then being stripped in preparation for excavation (centre right).
Northway-Gestalt Corporation

development. The interests of developer, industrialist, local municipality, and the public are all well served. Indeed, the City of Kitchener has recognized the values of such near-urban resources and in a 1982 staff report identifies them and recommends "Encouraging their extraction before development sterilizes the resource" (Kitchener Staff Report P.D. 60/82). It is to be hoped that projects such as the one at Kitchener will be more common in the future. With the varied land-use possibilities of the urban fringe and the higher land values there, such initiatives should become increasingly attractive. Planning constraints should be re-examined to ensure that multiple resource opportunities are supported.

Because of urban fringe locations, the subsequent use of many pits and quarries has been urban rather than rural. In a recent study of the fate of former aggregate extraction sites in metro Toronto, some reassuring and positive evidence was found. Of 67 sites investigated, 34% are now used for recreation, 27% for residential purposes, 13% for educational and institutional uses, 10% for industry, 8% for commercial purposes, 5% for sanitary landfill sites, and the remaining 3% is land now seeded, cropped, and left as open space (Yundt and Augaitis, 1979). This is not to say that aggregate producers had the foresight to leave land in a condition that facilitated its transformation to the subsequent land use. However, the often enhanced value of such sites, particularly when used for residential, industrial, or commercial development, has a forceful educational effect. This is encouraging evidence that planning intervention of a positive nature can relieve much of the stress on land resources associated with pit and quarry activity.

Pits and quarries in more distant rural agricultural areas

The solutions described in the previous section are only partial. In many instances opportunities for such compromises do not exist. Long-term planning will have to take account of increasingly distant resource locations and increasingly long and costly haulage routes. A recently released report (Peat, Marwick and Partners and M.M. Dillon, 1980) has suggested that lengthy truck haulage routes and present technology will continue in the future. Barge or boat and railway haulage, although cheaper, can only supply a feasible alternative where several conditions are present, e.g. suitable rail beds and routes, appropriate handling facilities, and aggregate resources of sufficient volume and in suitable locations to make the project profitable.

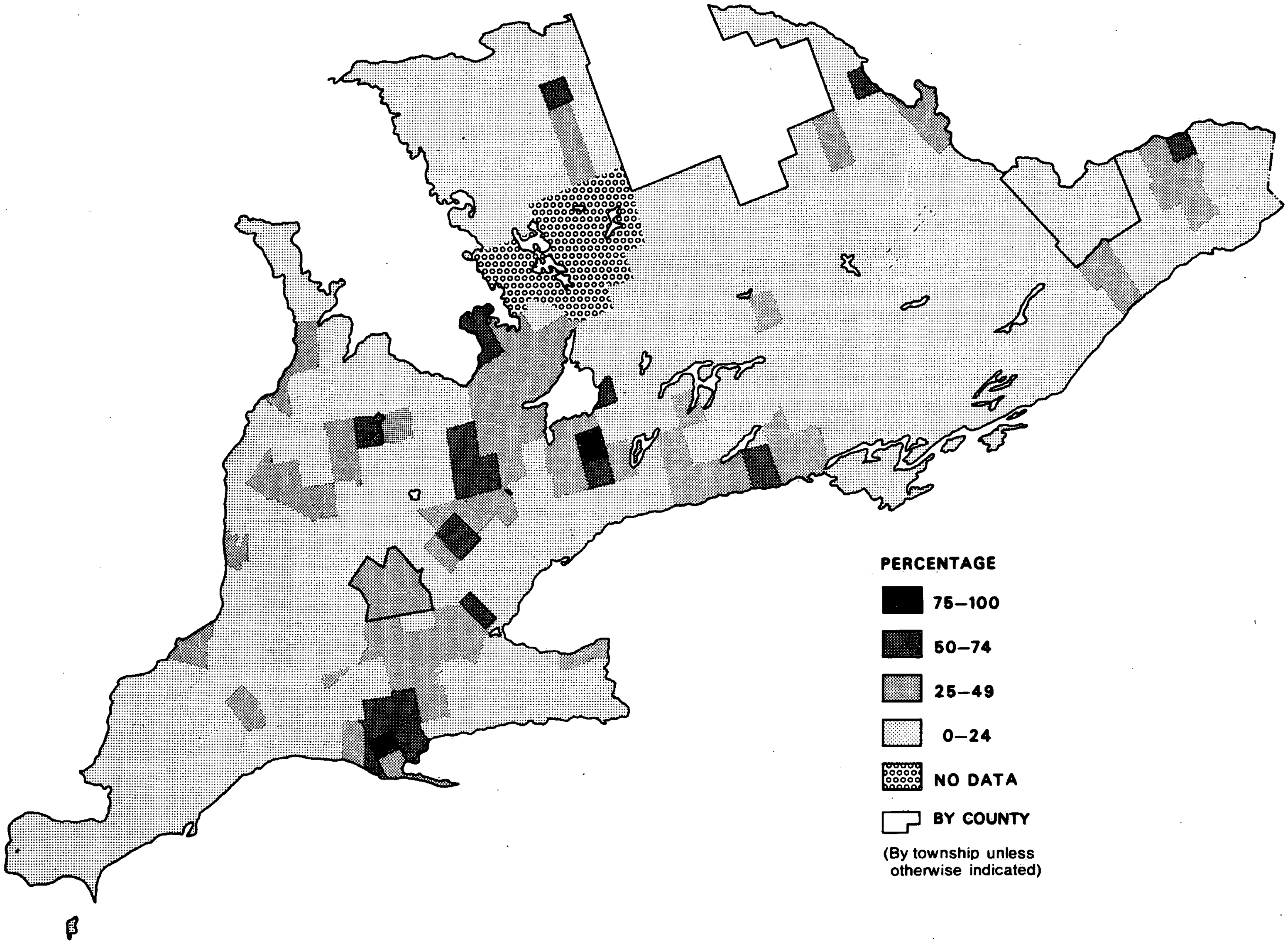
For most hinterland areas, truck haulage will be the means of bringing aggregates to the urban markets. Unlike the situation described by Yundt and Augaitis (1979), the rapid urban expansion common in the 1960s and early 1970s will not provide a ready-made after-use in the 1980s. Rehabilitation will have to take account of what is appropriate and acceptable in farming areas; rehabilitation projects in the urban fringe, such as golf courses or shopping plazas, are obviously unsuitable. In rural areas, land disturbed by extraction operations must be returned to its original use – agriculture. Making sure this transition is rapid and effective needs both forethought, e.g. careful topsoil removal and storage, and subsequent control for several years after rehabilitation, e.g. stone removal, crop choices, and drainage manipulation. Maps 2, 3, and 4 reflect the concerns of some agriculturalists in the 1960s and 1970s that the aggregate industry, which can exert considerable economic and political influence, might be capable of adversely affecting agricultural land uses. Indeed, where gravel extraction would produce water bodies (because of extraction below the groundwater table) where once prime quality farming land existed, perhaps protective regulations similar to those in the United Kingdom should be considered. There is probably a limit to our need for recreational ponds, however picturesque and ecologically sound they might be.

The study by Mackintosh and Mozuraitis (1982) found agricultural restoration to be in its infancy but developing. Most examples of site restoration to an agricultural use in the

The potential threat of pits and quarries to agriculture

MAP 2.

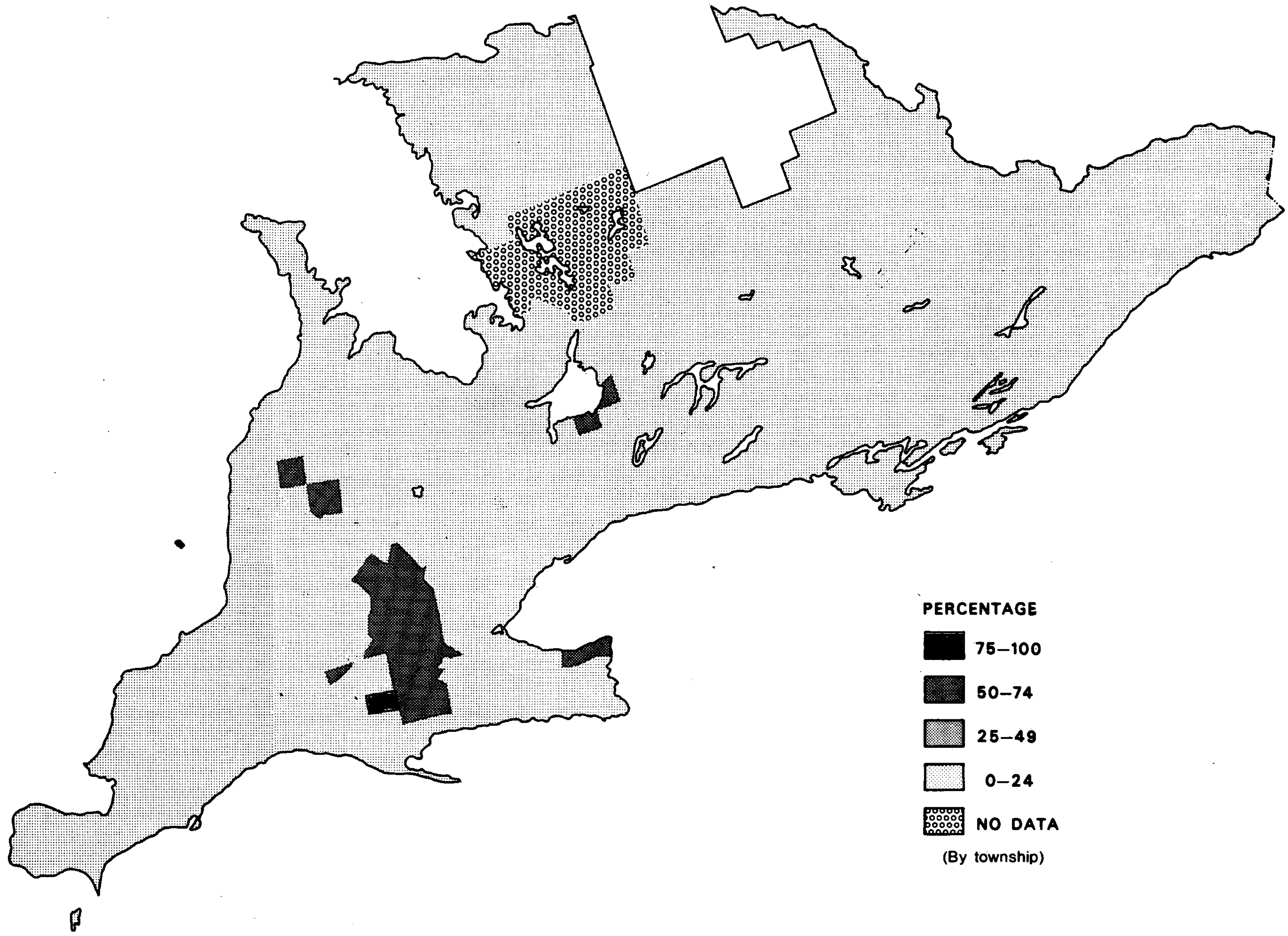
Soils underlain by sand and gravel as a percentage of total soils in southern Ontario



Reproduced from Centre for Resources Development, University of Guelph, 1972.

MAP 3.

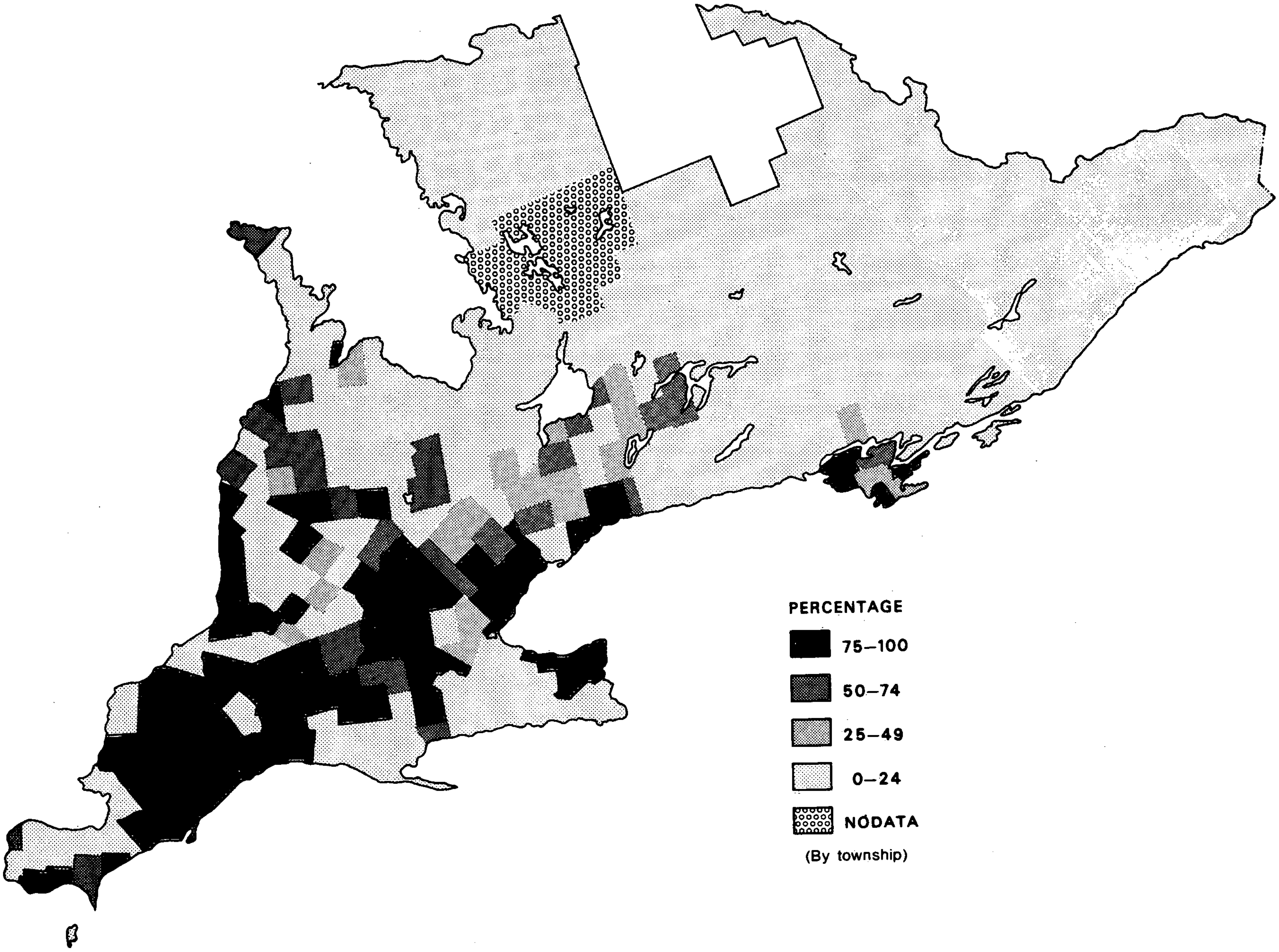
Class 1 and 2 soils underlain by sand and gravel as a percentage of total soils in southern Ontario



Reproduced from Centre for Resources Development, University of Guelph, 1972.

MAP 4.

Class 1 and 2 soils underlain by sand and gravel as a percentage of total sand and gravel soils in southern Ontario



Reproduced from Centre for Resources Development, University of Guelph, 1972.

sample area of southern Ontario were small in area: approximately 70% less than 3 ha and only two sites of more than 10 ha. A complete range of agricultural crops is grown on the properties, including grain corn, soybeans, tobacco, coarse grains, forages (grasses and legumes), and tree fruits (apples and sour cherries). Detailed information on yields before and after aggregate extraction is inconclusive, although it seems that in many instances it may take several years to re-establish the pre-extraction yields; typically, yields on restored land reach only 60% of their pre-extraction levels in the first year (D.W. Hoffman, personal communication).

Mackintosh and Mozuraitis (1982) examined soil capability classes before and after extraction. Because most sites were less than 3 ha in area, this analysis is potentially subject to considerable error. Nonetheless, if one uses pre- and post-extractive soil capability class as the criterion for success, the comparison indicated that 60–70% of the sites studied can be considered successful in their rehabilitation programs. Considering the lack of guidelines available to the industry on rehabilitation to agriculture, this success rate is remarkably high and presents an optimistic outlook for rehabilitation programs in the future. Governments, at any rate, no longer consider aggregate extraction and agriculture to be incompatible land uses.

Problems encountered in agricultural rehabilitation

A problem common to many old abandoned pits is the absence of topsoil and subsoil for site reclamation. The unwise mixing of topsoil and subsoil is also a frequent problem. Before site rehabilitation requirements were introduced in Canada, topsoil and subsoil were often sold as an additional source of revenue. Consequently, agricultural reclamation costs could be prohibitive and an alternative land use had to be sought (see McLellan *et al.*, 1979). Today topsoil has to be retained on site and normally 15–20 cm are required for optimum restoration (Ontario experience).

Excessive wetness (poor drainage) originates from one of several conditions: extracting down to water table levels or below groundwater levels; extracting down to underlying impermeable layers of silty or clayey materials; or failure to design outlets for surface runoff from the site. In agriculture, a minimum of 1 m of combined topsoil and subsoil overlying a zone saturated with water is a common guideline for adequate plant growth during the growing season.

Other common problems for successful agricultural restoration are excessive stoniness, choice of subsequent cropping programs, and compacted pit floors. The first of these can be corrected by remedial stone picking, the second by using forage crops that include deep-rooted legumes such as alfalfa which add to organic matter in the soil, build up natural soil fertility levels, and improve soil structure. Deep-rooted legumes also tend to reduce soil compaction, which is one of the more common conditions on many properties. Excessive compaction of soils and subsoils, caused by heavy equipment, may require ripping and deep tillage using subsoilers.

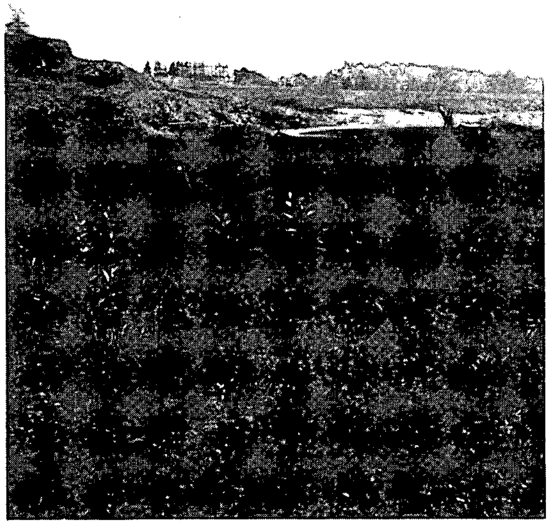


Photo 10. In agricultural areas, new crops can quickly follow the mining activity if topsoil is properly stored and replaced. Here, a forage crop of alfalfa has been grown successfully on properly rehabilitated land (Steed and Evans, Fonthill, Ontario).
A.G. McLellan

One interesting issue will be the evaluation that farmers put on rehabilitated land. So far, pertinent evidence is scanty. To the lay person the results may seem impressive, but how will the professionals react? How often will the previous farmer be prepared to rent a farm or buy back his original farm? How will buy-back prices compare with earlier sales? How will productivity compare? Can wise management ensure profitable operations and in what period of time? Many interesting questions remain to be answered.

Costs of agricultural rehabilitation

Under the contemporary regulations of Ontario's Pits and Quarries Control Act, 1971, an operator is required to pay 8¢/t on material removed in the previous calendar year as a security deposit to ensure rehabilitation of the site. The maximum security deposit paid is $3 000/ha for each hectare requiring rehabilitation. Where progressive rehabilitation is being practised, the security deposit may be reduced to a minimum of $1 000/ha.

Using the Ontario Ministry of Natural Resources' Rehabilitation Claims Reports for the Cambridge District, Mackintosh and Mozuraitis found

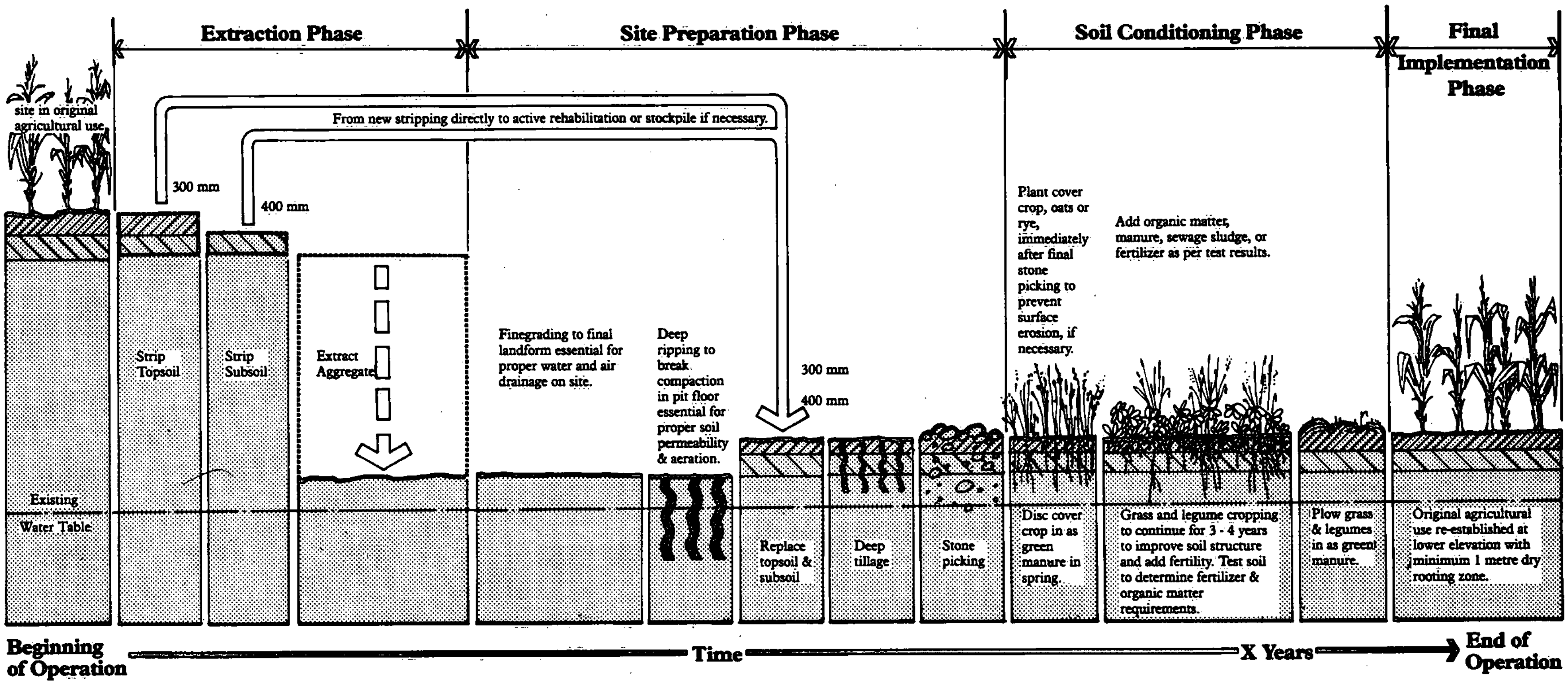
> *"the cost of rehabilitation to agriculture ranged from $1,712.21 to $13,710.68 per hectare. On a metric tonnage basis, the average cost of the successfully rehabilitated sites was 4.6¢ per tonne, ranging 3.5 to 5.5¢ per tonne. These costs included all necessary earth moving, trimming, grass seeding and mulching, and the initial planting of grass and legumes, together with chemicals and fertilizers.*
>
> *Using the information presented here, it appears as though the 8¢ per tonne security deposit is adequate to ensure successful rehabilitation to an agriculture afteruse. Further, once a portion of a pit is depleted, it no longer brings the operator any returns while in its unrestored state. Unless sold, which is highly unlikely, it is to the producer's advantage to rehabilitate in conjunction with extraction.*
>
> *Progressive rehabilitation is less costly at this stage since the necessary equipment is readily available and most of the soil is handled only once. The minimum amount of security deposit required will be lower as the amount of land still requiring rehabilitation is reduced. This in effect increases the amount of money that is reimbursed from the fund to the producer and lowers his production costs"* (Mackintosh and Mozuraitis, 1982).

Mackintosh and Mozuraitis further recommend 12 steps for successful agriculture rehabilitation:

> " *1. Preplanning. It is vital to know, in advance, what has to be done, but the plan should allow for modifications if these become necessary.*
>
> *2. Strip the topsoil, subsoil, and overburden separately. The materials must be handled and stored separately. Do not intermix topsoil with other soil material.*
>
> *3. Strip small areas at a time. Stripping off ground cover exposes the soil to increased erosion and sediment loss. Only strip small areas that can be extracted within a reasonable time.*
>
> *4. Move soil materials under dry conditions. Soils are more easily damaged when wet and should be moved mainly during the drier months of June through September inclusive.*
>
> *5. Rehabilitate progressively. Topsoil may deteriorate in storage, i.e. berms, or may be lost. Progressive rehabilitation allows for direct movement of soil and*

FIGURE 3.

A progressive rehabilitation sequence for restoration to an agricultural after-use



Reproduced from Mackintosh and Mozuraitus, 1982. Mineral Resources Branch, Ontario Ministry of Natural Resources.

prevents these harmful effects as well as reducing the cost of earth moving.

6. Grade and contour the pit floor. There must be an overall plan for draining the land including a drainage outlet for surface water runoff. Slopes between 2 and 5 per cent are desirable for agriculture purposes.

7. Replace overburden (if any), subsoil and topsoil in the correct sequence. There should be about one metre of topsoil/subsoil/ overburden overlying ground water levels to provide for adequate plant growth.

8. Calculate volumes, depth and areas to be covered carefully. A common problem encountered is insufficient soil to finish restoration.

9. Eliminate severe soil compaction. Severe soil compaction can be avoided by moving soil materials when dry and by using lighter equipment. Where severe soil compaction has occurred, it may be necessary to undertake deep ripping (subsoiling) in conjunction with the reapplication of topsoil/subsoil/overburden.

TABLE 4.

Progress of mining/rehabilitation 1973–1979:
Actual case of a sand and gravel operation near London, Ontario

Commencement 1973		Year 1 (1974)	
D	24 ha	D	13 ha
B	3 ha (production 25 400 t)	B	6 ha (production 190 500 t)
C	0 ha	C	8 ha (72 600 t stockpiled)
A	0 ha	A	0 ha
Year 2 (1975)*		Year 3 (1976)	
D	6 ha	D	5 ha
B	6 ha (production 244 900 t)	B	6 ha (production 371 900 t)
C	8 ha (90 700 t stockpiled)	C	8 ha
A	7 ha	A	8 ha
Years 4 and 5 (1977–1978)		Year 7 (1980–1981)**	
D	3 ha	D	0 ha
B	6 ha (production 635 000 t)	B	1 ha
C	10 ha	C	2 ha
A	8 ha	A	24 ha

A, B, C, and D refer to the land categories depicted in Figure 4.

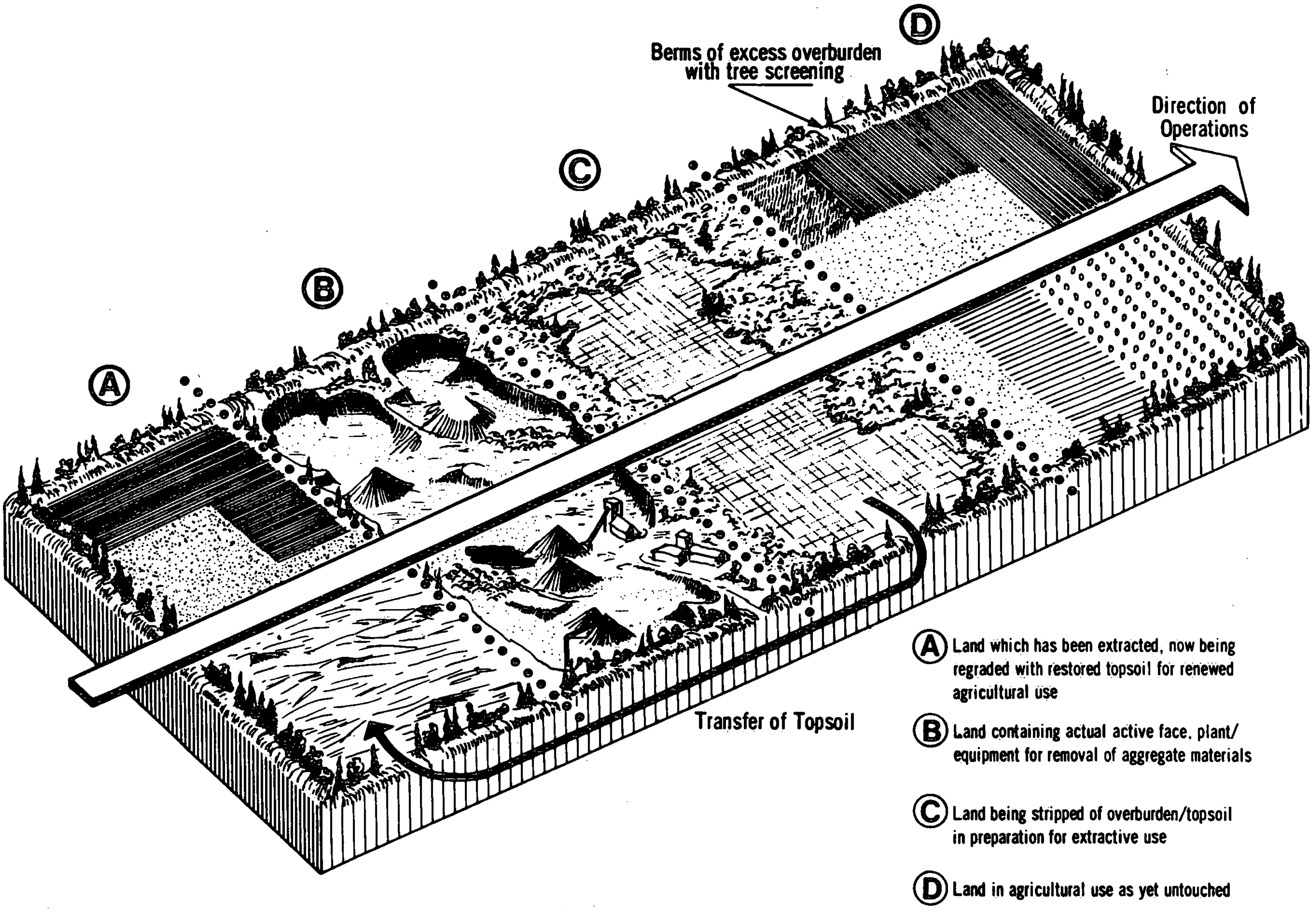
* Restoration begins after 2 years operation.

** October 1981 termination date.

Reproduced from McLellan and Graham, 1979 in Interface.

FIGURE 4.

A model for progressive rehabilitation



Reproduced from McLellan and Graham, 1979. "Phased Rehabilitation System Guidelines." Interface.

10. A post rehabilitation management program is critical for success. A period of at least five years is required to restore the soils to their original pre-extracted productivity levels. The choice of crops is crucial and emphasis should be placed on increasing soil fertility and improving structure by use of legumes.

11. Use good agriculture practices. A local area farmer should be retained for undertaking agricultural operations. Strict control of choice of crops, deep tillage and fertilization should be exercised by the operator.

12. Be patient. Successful restoration is a slow process. Any attempt to shortcut the procedures outlined will only increase the opportunity for failure."

Figure 3 shows many of these steps in a schematic way (Mackintosh and Mozuraitis, 1982). The spatial organization is shown in Figure 4 and the accompanying Table 4 shows how the theory has operated in one actual example (McLellan and Graham, 1979).

With increasing education and experience, successful rehabilitation will become widespread. There are no acceptable reasons why aggregate producers cannot leave the land capable of its previous agricultural production. Unlike many coal mining or hardrock ore mining areas, toxicity is not a problem.

The Canadian North – different developments and different impacts

Although greater attention has been given to the negative impacts of large-scale development projects in the North – pulp and paper mills; oil, gas, and ore extraction; and pipelines – pits and quarries have also had significant effects. All large-scale projects require construction aggregates. For example, borrow pits for gravels needed to alleviate the effects of drainage impoundments and permafrost heaving, and to provide construction foundations, are found along the length of all northern Canadian pipeline projects.

A number of factors specific to the North intensify the stresses on land posed by pits and quarries. Land in the North has for the most part been considered as a mere repository of resources rather than as a resource in itself. For this reason, and because the land appears to be so limitless in area, little real effort has been made to rehabilitate extraction sites and the population is too sparse to constitute effective pressure groups. In high latitudes, the fragility and slow-growth characteristic of northern ecology mean that land disturbances caused by aggregate extraction take much longer to heal. The North is further distinguished by its pattern of land tenure. In the south, 85–90% of pits and quarries are located on private land (Marshall, 1983). However, virtually all the Yukon and Northwest Territories, and much of the northern districts in the provinces, are Crown lands and thus not subject to provincial legislation designed to prevent environmental damage or promote rehabilitation.

In the Yukon and Northwest Territories, there are about 25 different pieces of government legislation (Acts, Ordinances, and Regulations) that control land development; however, only a few apply to pits and quarries. Among the major Acts and Regulations that deal with pit and quarry development are: Territorial Lands Act, Territorial Land Use Regulations, Territorial Quarrying Regulations, and the Fisheries Act.

Around many of the communities in the Yukon and Northwest Territories, land has been transferred from the Federal Government to the Territorial Government; these lands are known as Commissioner's Lands. The Territorial Government and/or the community does the initial opening up of a community pit. The administration of the pit then becomes the responsibility of the community council. Permits are still required to extract material from the community pit and the permits can be obtained from the Territorial Government (MacLaren Plansearch, 1982).

In the North, environmental concerns have rarely received adequate attention during siting and operating stages of aggregate extraction. In the past, there existed little planning or coordinating of pit and quarry activities. Numerous pits in small areas created unsightly landscapes and were harmful to the environment. Once the extraction site was exhausted there was little if any effort spent on appropriate rehabilitation of the land.

More recently, however, useful information is being made available to pit and quarry operators. A new handbook Environmental Guidelines: Pits and Quarries (MacLaren Plansearch, 1982), published by the federal Department of Indian and Northern Affairs, presents environmental guidelines for pit and quarry development and restoration in the Yukon and Northwest Territories. This publication does not establish new standards but does describe recommended procedures to ensure that cultural, aesthetic, and ecological values will be preserved within the constraints imposed by the current state of technology. This handbook recommends operating procedures that are both sensitive to environmental issues and efficient for the operator.

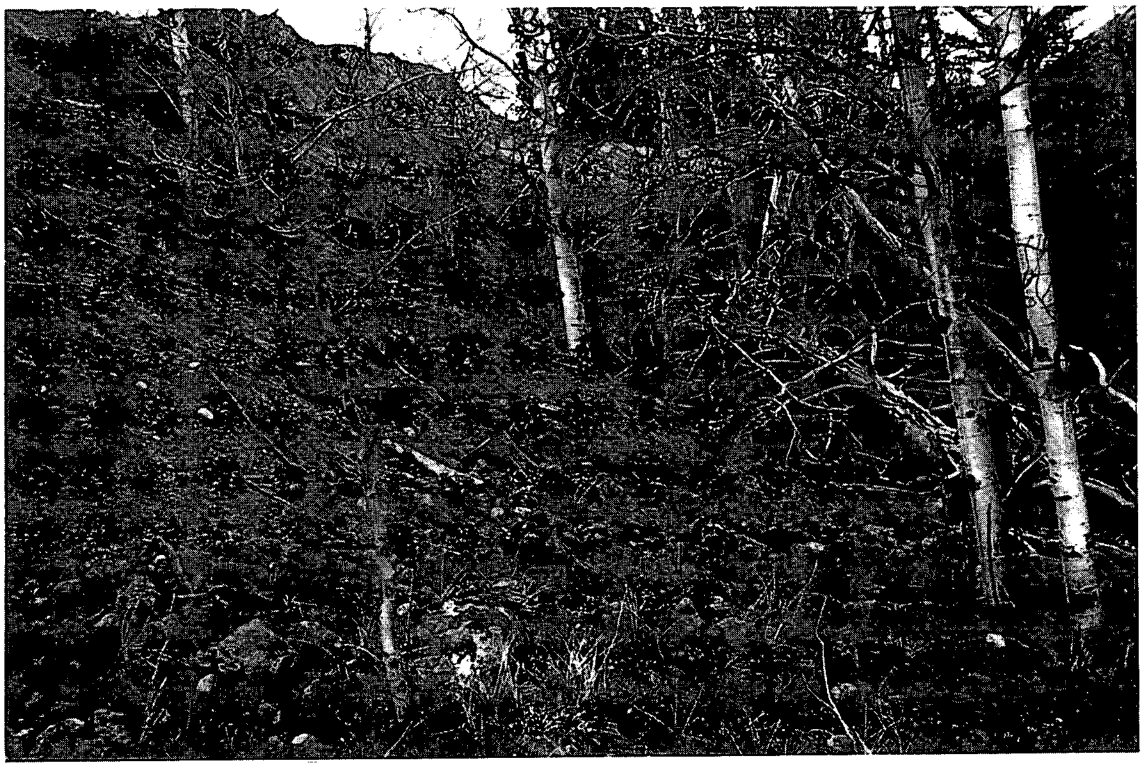


Photo 11. In the North, the depth of overburden varies from a few centimetres to several metres, but however thick, it should be saved for pit restoration. The organic layer (topsoil and muskeg) must be removed and stored separately from the inorganic layer. In this example of poor land management, the topsoil and overburden have been mixed and dumped among nearby trees. Not only will the overburden be of little value for pit reclamation (should it even be attempted) but the trees died.
Northern Affairs Program, Department of Indian and Northern Affairs

Although subordinate to all Acts, Ordinances, and Regulations, the guidelines will also be a useful tool for reducing environmental impact. Some of the procedures or recommendations contained in the guidelines are:

- determine how much aggregate material is needed before extraction;
- use an existing pit if possible; develop a new pit only if no existing pit can supply the materials;
- a pit must be at least 30 m away from a water body;
- excavate from river beds and beaches only when no other source is available;
- do not harass wildlife;
- do not conduct any operations in sensitive areas or during critical times;
- all operations must be a specified distance from a known archaeological site;
- avoid all present and planned recreation sites;
- do not locate pits in heavy public use areas;
- machinery, vehicles, and equipment are not allowed within 150 m of a pingo;
- any topsoil must be removed and stored separately;
- screen pit where possible;
- all pits must be restored;
- check future use of site before restoration begins;
- when no future public use is planned for the pit site, the pit must be restored so that it will blend in with the local landscape and vegetation.

Pits and quarries will undoubtedly continue to be a necessary adjunct of development in the North. Oil, gas, and mineral exploration and extraction activities stimulate the growth of a number of northern communities. Aggregate materials are required for road and building construction, airstrips, work camps, staging sites and other infrastructure. The relative scarcity of granular resources in the North and the

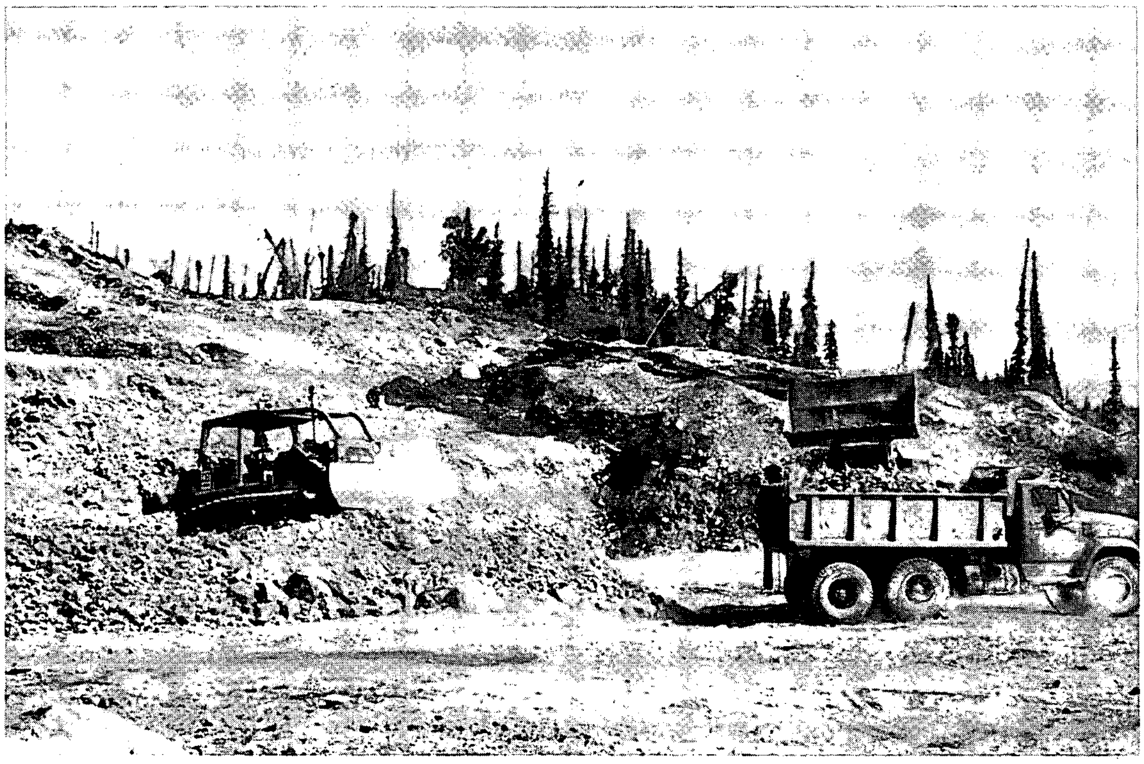


Photo 12. When a permit is issued, the Inspector will attach a number of conditions which the operator must follow. These conditions may concern sensitive areas such as lakes and streams, wildlife, archaeological sites and monuments, recreation areas, unique geographical features, or permafrost conditions, any of which could be disturbed or ruined by the development of a pit or quarry.
Northern Affairs Program, Department of Indian and Northern Affairs

past record of poor site planning and management of pits and quarries resulted in environmental problems. Although the lack of high quality materials remains a problem, other opportunities exist to reduce the land impacts of extraction activities. Using such references as Environmental Guidelines: Pits and Quarries, efficient siting and operating of pits and quarries, maximizing the quantity of material excavated at each site, and improving restoration of completed sites will reduce some of the stresses on land.

Planning issues facing concentrated aggregate mining areas

Aggregate sources are not evenly dispersed or necessarily well located in relation to the major demand centres. The question arises, therefore, of how much stress and disruption the landscapes (and the residents) of those areas rich in aggregate sources should be expected to withstand. Such areas present a challenge to local planning authorities. An extensive but interim land use must be accommodated which can have dramatically disruptive impacts on the community, but, this extensive land use may not be perceived by the local residents as benefitting the local community.

Three areas that demonstrate these issues in Ontario are in the townships of Uxbridge and Caledon, which are rich in sand and gravel, and in the townships along the Niagara Escarpment, which contain high quality dolomite bedrock.

Uxbridge Township

This township lies approximately 40 km to the northeast of the city of Toronto. In the 1950s and early 1960s Toronto's expansion rapidly consumed nearby sand and gravel resources. As local supplies were exhausted or, as in some instances, were sterilized by development that took place without consideration of multiple use, aggregate producers began to look for the next closest resource to supply the apparently endless appetite of the Toronto market. The obvious location was the Oakridges Kame Moraine located in Uxbridge.

The rapidity with which sand and gravel pits were developed in the Township dismayed many local residents (see the sequence as documented in Maps 5 and 6). Suddenly this attractive rolling landscape, with its farms, woods, recreational areas, and picturesque villages, seemed to be overrun by the juggernaut of aggregate mining. The distant vistas of Lake Ontario and high-rise buildings in Toronto were superceded by the scars of local and ugly mining operations. The Uxbridge area seemed to be paying the price for Toronto's expansion.

By the mid 1960s the voices of local residents and environmentalists were united against the onslaught of extraction activity. Bylaws were quickly passed and associations formed specifically to restrain the further expansion of the aggregate industry. Costly legal battles and lobbying by both sides helped precipitate the Ontario legislation of 1971. Today, although the two sides are not entirely reconciled, the aggregate producers are beginning to demonstrate an understanding of the public perception of their activities. Operations are now better screened from highways and residences; much of the mined-out land has been returned to agricultural use; compromises have been reached on truck haulage routes and safety designs; and aesthetically and environmentally acceptable planning is more common than in the past. The government has ruled that local and regional planning authorities must recognize the provincial significance of aggregate sources. Antagonisms do still exist, however; they reflect the fundamental incompatibility between concentrated aggregate extraction operations and people's concern about the character of their community – a conflict which, despite strong legislation and admirable progressive rehabilitation, may never be fully resolved.

Caledon Township

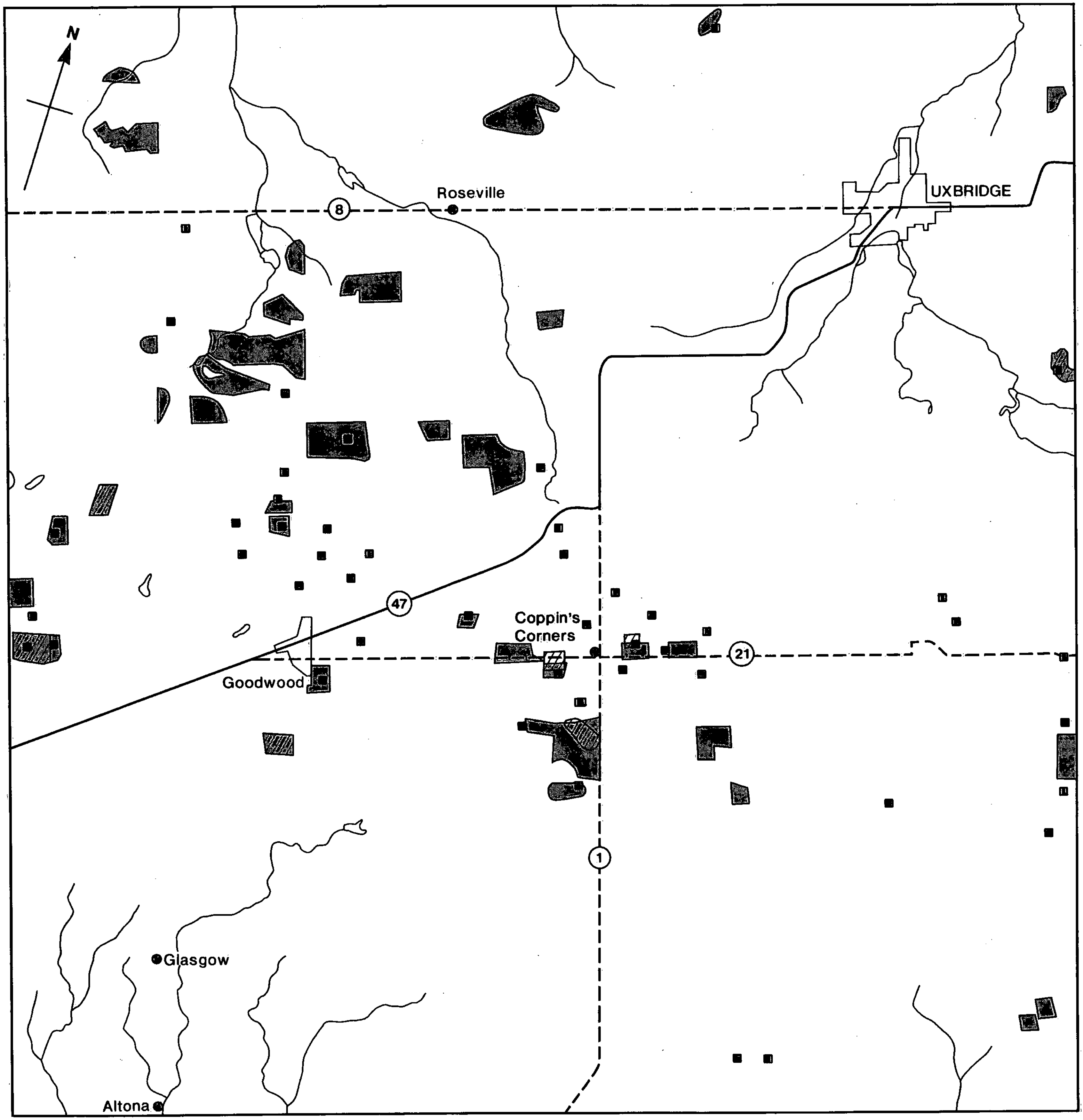
In Caledon Township a thick, extensive series of ice-contact and spillway sands and gravels bury the Niagara Escarpment in the vicinity of Caledon Village and Forks of the Credit. Here in one of the most attractive parts of Ontario is an aggregate source which is for West Toronto, Mississauga, and Brampton, what Uxbridge is for East Toronto. A major highway system provides an apparently ideal truck route to serve all the developing areas to the west of Toronto.

The impact on local land use is staggering. In Map 7 and Photo 13, the area of land affected can be seen. One long-established company (Company A on Map 7) has 650 ha already licensed for sand and gravel extraction. The land was originally a series of adjacent horse ranches. Now at least 200 ha of this has been used for aggregate extraction. The bulk of this land will be lost from agricultural productivity forever because much of the aggregate resource is below the water table. The company is at present financing a sophisticated program of rehabilitation, which will see the early release of rehabilitated land for a country club, low-density residential use, recreational water bodies, etc.

A second company (Company B) has two currently licensed properties, of about 200 ha in total, which are rapidly becoming exhausted. A third property is in the early stages of being licensed. The company is now beginning to realize the advantages of integrative planning. A third company (Company C) with extensive holdings has about 150 ha already under licence, much of it worked out. Adjacent reserves for future extraction have already been investigated and could add another 150 ha. This company is owned by a group of Toronto businessmen who, like the first company, are well aware of the significant advantages their scenically located property enjoys – adjacent to a

MAP 5.

Progress and expansion of aggregate extraction in the former Township of Uxbridge, Ontario (1954-1966)



▨ Existing extractive use - 1954

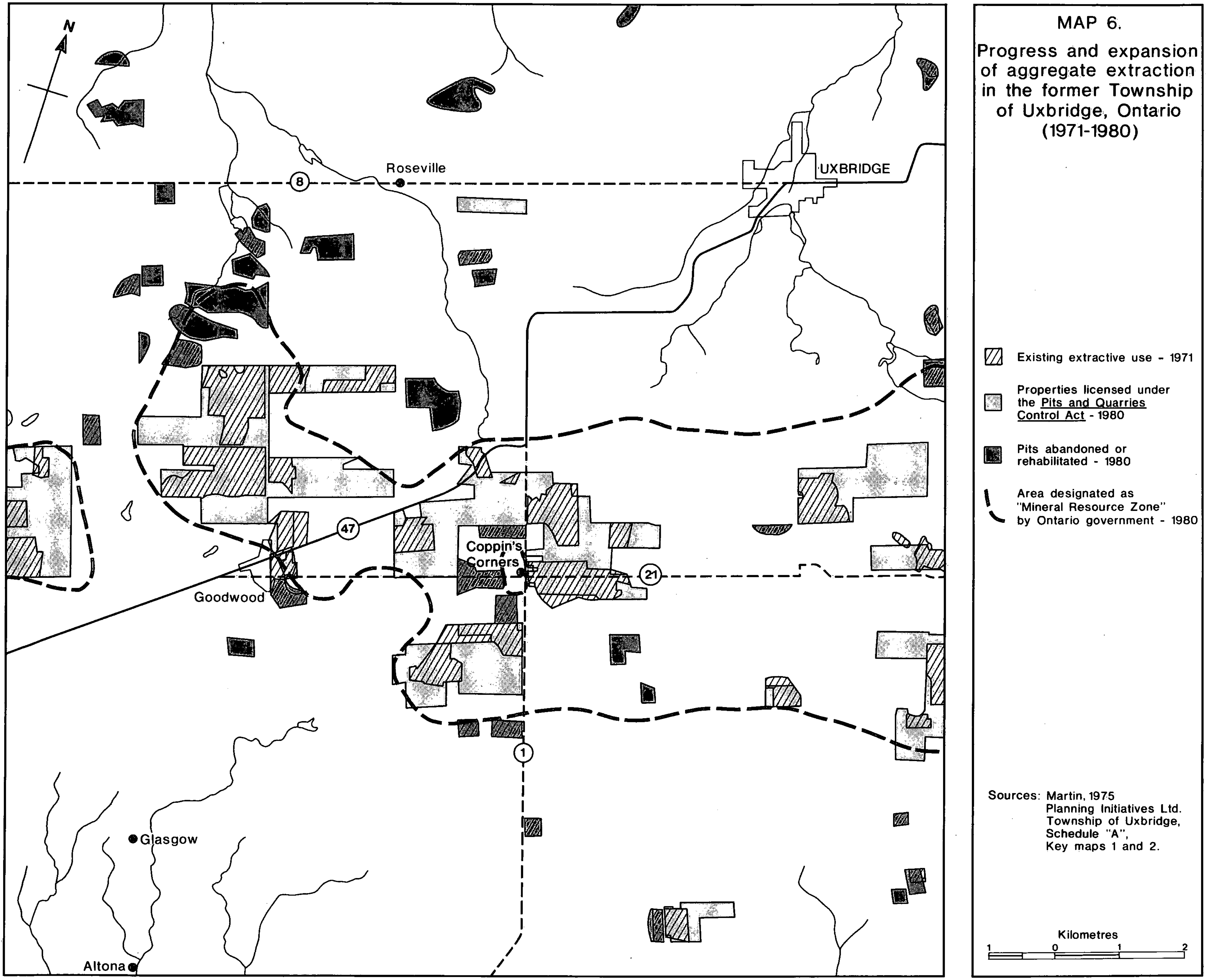
▩ Existing extractive use - 1961

■ Location of sand and gravel pits - 1966

Sources: Hewitt, 1969
Martin, 1975
Planning Initiatives Ltd.

MAP 6.

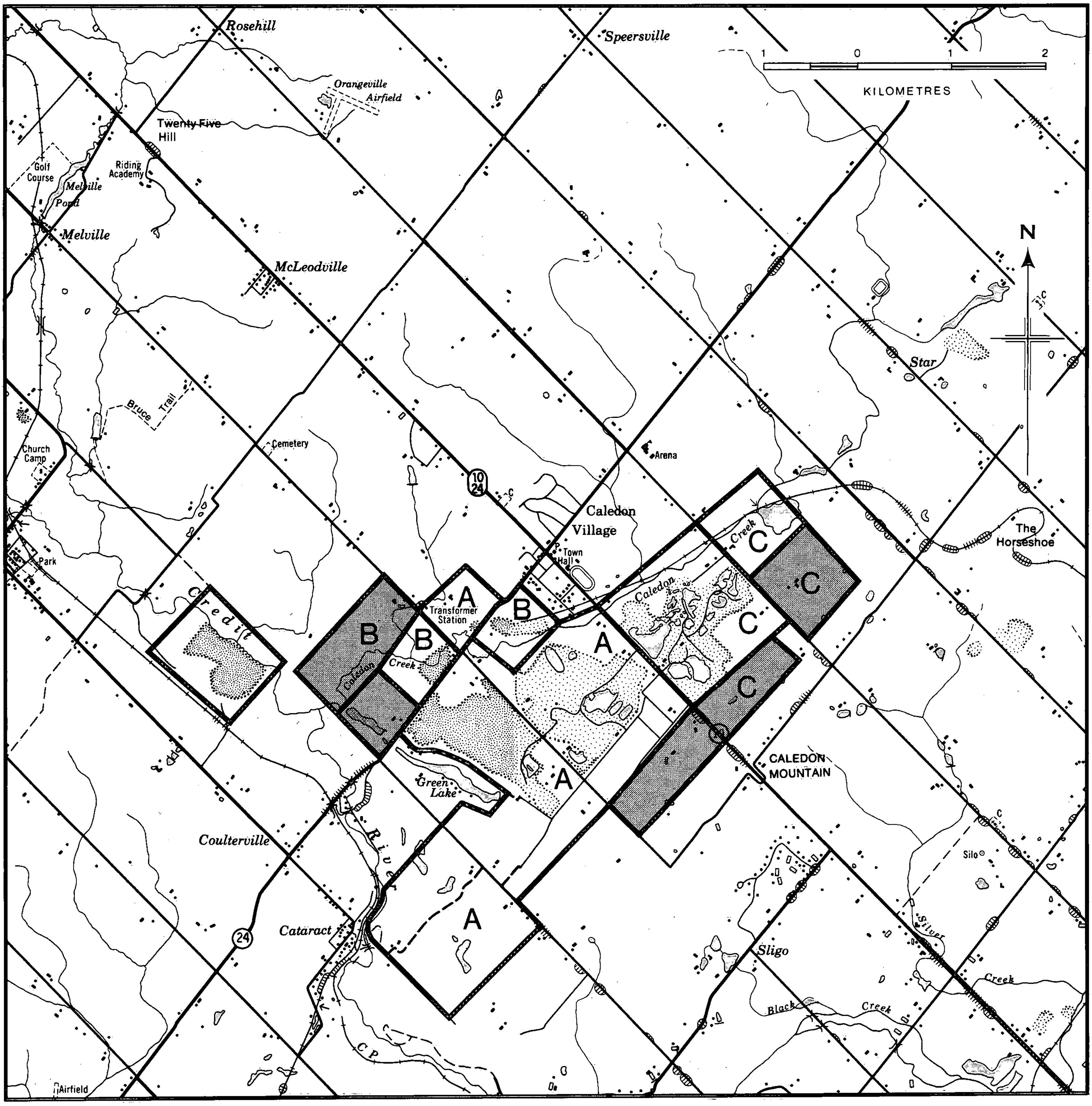
Progress and expansion of aggregate extraction in the former Township of Uxbridge, Ontario (1971-1980)



Sources: Martin, 1975
Planning Initiatives Ltd.
Township of Uxbridge, Schedule "A", Key maps 1 and 2.

MAP 7.

Area around Caledon, Ontario showing extent of areas either under licence for aggregate extraction or being considered for extraction



☐ Areas licensed for extraction (1981)

▨ Areas being considered for extraction (1982)

A....Company A

B....Company B

C....Company C

Base map reproduced with permission of Energy, Mines and Resources Canada.

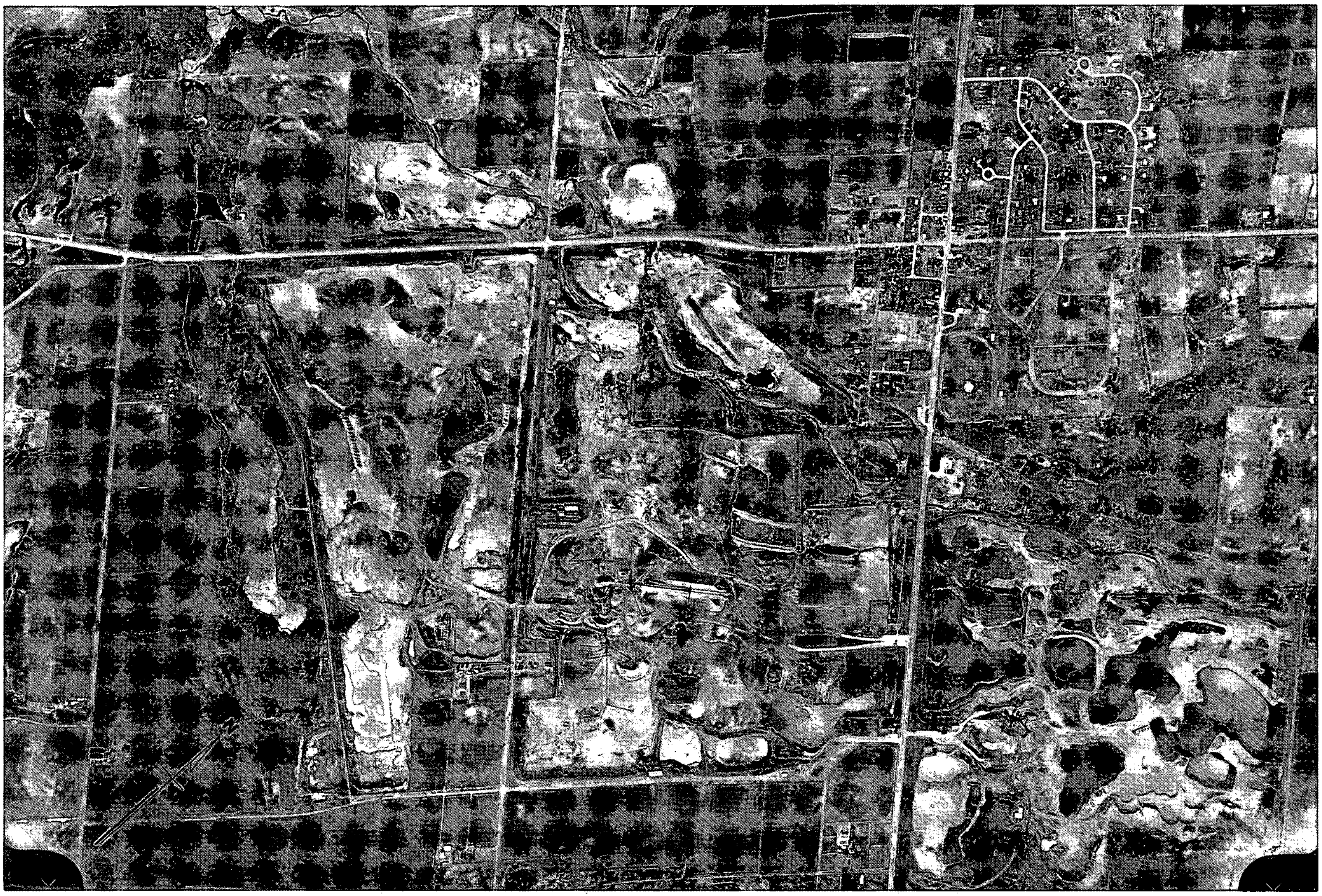


Photo 13. This 1980 airphoto of the same area near Caledon (Map 7) shows the extent of landscape disruption due to aggregate extraction.
Northway-Gestalt Corporation

major highway, within an hour's drive of more than 4 million people. The location, which made the aggregate resources so valuable, also provides numerous land-use alternatives for the future. This potential profitability ensures that stress will be short-lived and that these land parcels will rapidly acquire socially desirable ultimate land uses. Recent Ontario government action (modification of regulations), which imposes a high financial penalty for disturbed or unrehabilitated lands, will accelerate the trend.

Until recently it would be fair to say that in Caledon there has been little evidence that land affected by aggregate extraction is being returned to other productive uses. There was no planning collaboration among the various aggregate companies. Provincial licensing of operations seemed to override or preclude comprehensive planning by local authorities. Clearly, the future appearance and land-use activities of this part of Ontario were to a considerable extent at the mercy of decisions made by non-resident aggregate producers.

More recently, a residents' association has been formed to fight further expansion in the township. However, the more enlightened planning legislation, the watershed planning concerns of the Credit Valley Conservation Authority, a Provincial Government demand for upgrading aggregate operation site plans, the co-operative efforts by aggregate producers, and the healthier attitudes on all sides suggest that the rehabilitation programs of Caledon could be a "showplace for Canada" (B. Black, Caledon Township Planning Director, June 1982, personal communication).

It is clear that when mining operations are on this extensive and intensive scale, multi-land-use planning has to be employed. High- and low-density residential developments, active and passive recreational opportunities, agriculture, ecologically sensitive areas, and environmental protection are all land uses or issues that demand consideration in a broader way than the site-by-site approaches of the past. There is no reason why surface alterations, consequent on aggregate extraction, should not lead to a landscape suitable for a variety of future uses, but this will only occur as a result of much more sensitive, integrated, and positive planning approaches.

The Niagara Escarpment and quarrying impact: species and landscape preservation

Surface mining inevitably involves some change in a landscape – on a minimum level perhaps only a lowering of elevation. But in some cases the resulting landscape will be sufficiently different such that the pre-existing land use can never be reinstated. A good example is where resources occur below the water table or where a prominent landform of aesthetic value exists. In these situations perhaps the decision should be more circumspect than where the interim aggregate removal operation can be replaced by the pre-existing land use.

Although the National and Provincial Parks are protected (except in national emergencies) from

Photo 14. In some instances, the most significant natural areas can be included in an "environmentally protected area" as at this site near Kitchener, Ontario.
A.G. McLellan

mining activity, not all highly regarded landscapes in Canada are similarly shielded. Unique or spectacular landscapes often owe their origin to glacial or geological circumstances and the material they are composed of is frequently prized as aggregate sources, e.g. the Fonthill Kame and the Niagara Escarpment in Ontario. The uniqueness or unavailability of alternative less significant resources, the degree of public concern, and the many other factors affecting such landscapes all make mining approvals much more difficult in such cases, and rightly so.

These were some of the issues facing the Ontario government about the Niagara Escarpment, an outstanding landscape in a fairly mundane area of southern Ontario. Its proximity to large urban markets and the quality of its Lockport Dolomite caprock assured its profitability to aggregate producers. To the public, however, the location of cottage properties, ski hills, and other recreational facilities among such attractive natural landscapes gave these unique areas a high priority for recreation. Often lifestyle preferences (some formalized as in the establishment of hiking trails such as the Bruce Trail between Niagara Falls and Tobermory) result in immediate opposition to pits and quarries and their disruptive effects. The inevitable conflicts resulted in provincial legislative constraints which, although first imposed in 1969, continue to evolve and are not yet final at the time of writing in 1983.

It is clear that many stressful situations such as in the Niagara Escarpment exist throughout Canada and demand more inspection, expertise, and a wider viewpoint than are available in the local townships affected.

A similar situation could arise in relation to endangered species. For example, unrestricted access to aggregate resources might threaten the habitats and breeding grounds provided by marshlands for plant and animal species. The design of aggregate operations should in any case be sensitive to such issues. But, where unique landscapes or endangered species are at risk, it must be accepted that some properties will have to remain inviolable in their entirety. Even the best rehabilitation program will not provide perfect restoration (as in the National Academy of Sciences definition). In such situations the wise course of action may be complete protection, thus ensuring no stress occurs, and senior levels of government may have to provide leadership and, if outright purchase seems the only option, the necessary funds as well.

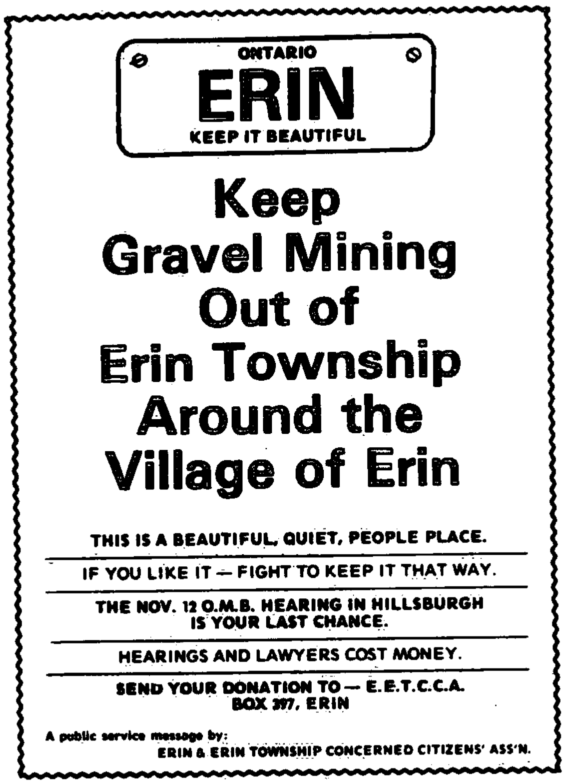
CANADIAN EXPERIENCE AND LEARNING FROM EXPERIENCE – THE LEGISLATIVE RESPONSES

The contentious debates of the 1960s and 1970s showed clearly that without some understanding of the extent of provincial aggregate resources, provincial governments would be unable to establish rational policies to guide development of the aggregate extraction industry. Almost all provinces now have established aggregate mapping and inventory programs. In Saskatchewan, Manitoba, Alberta, and Ontario specific attempts are being made to link these programs with the development of strategic land-use policies and the avoidance of ill advised sterilization.

Pre-1970 period

Before 1970 there were in Canada virtually no controls at the provincial or federal level that could have been used to constrain the stressful impacts of pit and quarry activities. The adverse impacts of pit and quarry operations on local communities and the growing concern for environmental issues initiated a process of change. The issues tended to be seen as local and some of the first major efforts occurred in rural townships, which had recently suffered a considerable expansion of pit and quarry activity and at the same time had experienced an influx of city dwellers seeking refuge from the stresses and expense of urban life. The growth of mining activities and the increase of traffic, noise, dirt, and environmental disruptions caused by pit and quarry operations dismayed these ex-urbanites. Their response was naturally very negative (Figure 5). Township councils sympathized with local residents' demands, and, recognizing the limited tax benefits of pits and quarries (generally aggregate operations are taxed at a rate only slightly higher than farms) and the increased costs they involve (e.g. in road maintenance), were quick to pass restrictive by-laws (major site setbacks, hours of operation, etc.) or

FIGURE 5.
Grassroots opposition
to aggregate extraction



ONTARIO
ERIN
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The Erin Advocate Erin, Ontario

indeed prohibit the opening of new operations. This negative response provoked aggregate producers and their associations to appeal to provincial governments to establish some rational planning control.

Provincial responses to pits and quarries in the 1970s – British Columbia and Ontario

At the same time as these issues were surfacing, the provincial governments had started creating portfolios responsible for general environmental matters, prompted by the change in public priorities. Provinces differed in their approaches. A wide variety of environmental regulations were promulgated related to the protection of fauna and flora and their habitats, surface and groundwater quality, pollution and the use of chemical substances, the emission of noise and dust, etc. These occasionally infringed on regulations specifically covering the aggregate industry.

Legislation established more stringent standards for pre-planning inventory, for more sensitive operational methods, and for the planning of after-use purposes. The means of achieving these standards included the requirement of a provincially issued licence, increased monitoring and inspection, the setting of penalties, bonds, and security deposits, and the creation of referral systems among the various government ministries and agencies responsible. Research to support these initiatives was undertaken, although in many instances it may not have been rapid or extensive enough to satisfy public demand for action.

In British Columbia it was found that in 1973, with a production of 31 million tonnes, sand and gravel were quantitatively the Province's most important mineral (they were even imported from Alberta and Washington). The government undertook an inter-agency study (under the aegis of the Division of Economics and Planning of the Department of Mines and Petroleum Resources) to "(1) analyze the long term land use aspect of the industry, (2) consider appropriate royalties and taxes; and (3) investigate provincial sand and gravel reserves" (Silvertson and Carson, 1974).

Some pertinent conclusions to the stress on land issues were:

1. Sand and gravel consumption per capita in this Province will likely grow from 13.7 t in 1973 to about 20 t in 1990. Thus, total demand will grow from 31.8 million tonnes in 1973 to 72.6 million tonnes in 1990. In the Lower Mainland, demand will grow from 14.2 million tonnes in 1973 to 29 million tonnes in 1990.
2. Sand and gravel reserves in the Lower Mainland are abundant but severely constrained by urban sprawl, environmental considerations, and municipal and provincial zoning laws. In addition, marginal reserves are made submarginal by relatively high royalties.
3. Information on sand and gravel reserves in the province and Lower Mainland is inadequate. It is not known exactly where the reserves are, who owns the land, and to what use the land is being put or will be put.
4. Environmental protection regulations are far from uniform, even in the Lower Mainland, and are not applied consistently. Some municipalities have severe restrictions on operators and some are lax in enforcement if not in law. The provincial law applies only on Crown lands and where no municipal law exists. It has not been adequately enforced because of lack of personnel. The public may be getting too much environmental protection in some localities and too little in others (Silvertson and Carson, 1974).

In Ontario, considerable government activity began in the late 1960s and has continuously improved the quality of planning of the aggregate industry. This has been described in full by Reynolds (1979), and summarized by Yundt and Messerschmidt (1979) thus:

> *"In the late 1960's unrest between the aggregate industry and residents of high production municipalities threatened the availability of aggregate resources. At the request of the aggregate industry, the Ontario Provincial Government examined the situation and in 1971 passed The Pits and Quarries Control Act. The intent of the Act was to regulate the operation of pits and quarries and provide for their rehabilitation.*
>
> *Four years later, in 1975, the inadequacies of the Act prompted the establishment of the Ontario Mineral Aggregate Working Party to examine the situation and suggest changes. Despite considerable improvements brought about by the Pits and Quarries Control Act, 1971, difficulties such as resource protection still existed. The Working Party was a new concept to the Ontario Ministry of Natural Resources because it was composed of representatives of all groups concerned with the mineral aggregate question – various government ministries, regional and municipal councillors and staff, industry and special interest groups. Secondly, the Working Party incorporated a public participation program into its policy recommendations.*
>
> *New legislation, to be known as The Aggregate Act, was given first reading in the Ontario Legislature on June 14, 1979 and is expected to be passed before the end of 1979. It will replace the present Pits and Quarries Control Act. Also, policy guidelines are being formulated to aid municipalities in the preparation of official plans and zoning by-laws in an effort to designate and protect mineral aggregate resources for the future.*
>
> *Rehabilitation of pits and quarries continues to be a high priority item, as evidenced by the research being undertaken and funded by the Province. Efforts are also continuing in resource inventory and in public education, in an effort to promote acceptance of the aggregate industry. The management of aggregate resources in Ontario has progressed substantially in the past ten years, but a sustained effort in management and control must continue"* (Yundt and Messerschmidt, 1979).

It should be pointed out that as of January, 1983, the impending legislation has not yet been approved.

The earlier Act had the advantage of imposing standardization and more acceptable extraction and rehabilitation procedures on producers, e.g. for the first time a security deposit had to be made of 2 cents/ton (2.2¢/t) up to 100 000 tons (90 718 t) or $500/acre ($1 235.53/ha), whichever is greater. Cosmetic landscaping, berm and tree screening were encouraged. Perhaps the most significant aspect of the Act was that it demanded for the first time that operators create and implement a site plan that showed present conditions and surrounding land uses, how the operation will proceed and how it will affect the site and adjacent lands, and how the land will be rehabilitated and its future use. Without an acceptable statement on these issues, the Minister can refuse to grant a licence to extract, even if zoning by-laws and all other planning requirements are complied with.

The process is a demanding and sophisticated one. Operators now have to prepare pre-planning inventories, respond to social and environmental issues, comprehensively design operations to render them as inoffensive as possible, and ensure that a useful piece of real estate remains on cessation of operations. Most large operators are obliged to hire a team of experts to gather and utilize the appropriate information for the initiation of a new operation. (see Table 3)

By early 1978, all of the important aggregate-producing areas in the Province were covered by the legislation. The total number of licensed pits and quarries in the designated municipalities covered by the legislation was estimated to be 1 590. The vast majority of these sites existed before the passing of the 1971 Act or before their particular area was designated. They were

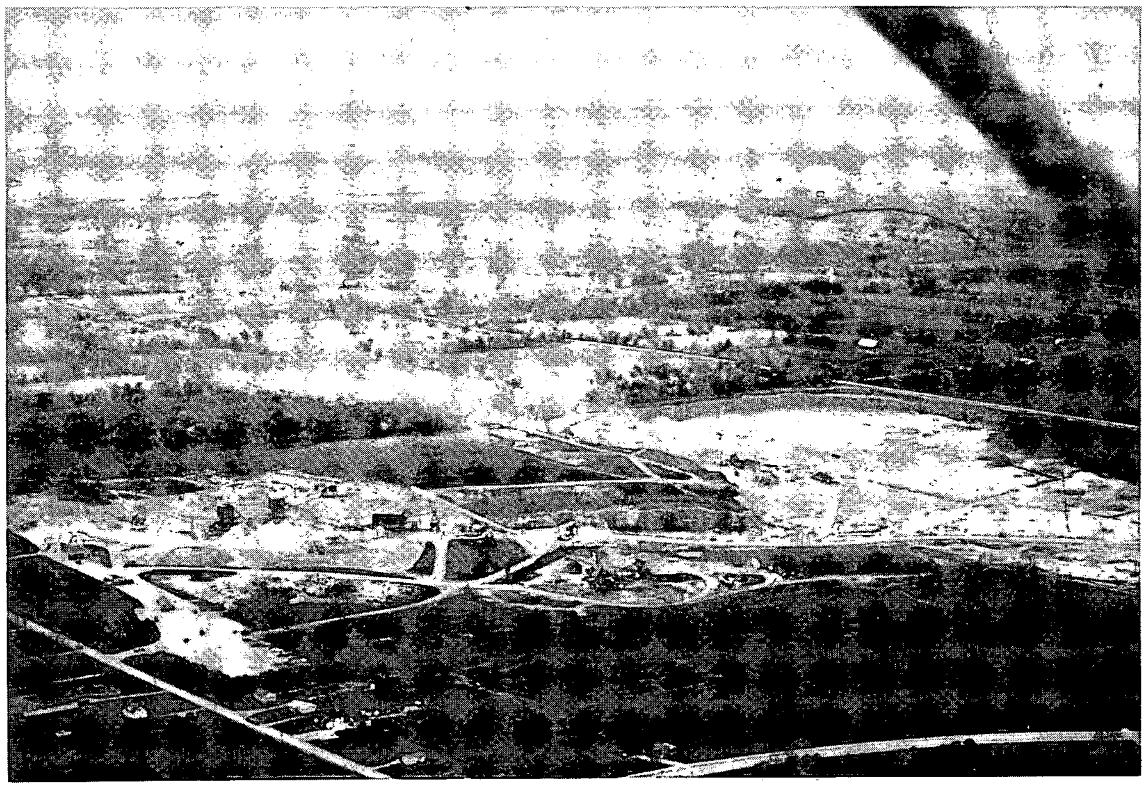


Photo 15. Impressive strides have been made at a few quarries even before government legislation. The Nelson Crushed Stone site has been a model for progressive rehabilitation in Ontario. Here, overburden and topsoil are stripped from one area and immediately replaced at an appropriate location undergoing rehabilitation elsewhere on the site.
A.G. McLellan

issued licences as it was not the intent of the legislation to put existing operators out of business. Since the Act came into effect, 40 applications for licences to operate new properties have been referred to the Ontario Municipal Board (Table 5).

A drawback to the licensing process is the length of time it takes for the necessary approvals. Two to 5 years and considerable sums of money are required to take an application before the Ontario Municipal Board.

TABLE 5.

Status of Ontario Municipal Board referrals

Decision to issue	15
Decision to refuse	10
No decision yet	7
Application withdrawn after referral to OMB	8
Total referrals	40

Other legislation affecting pits and quarries – Ontario

The Pits and Quarries Control Act is not the only piece of legislation affecting mineral aggregate extraction in Ontario. Matters such as safety, pollution, tree cutting, topsoil removal, and extraction on Crown land are controlled by various statutes and administered by different levels of government. Some of the legislation tends to overlap and conflict with the 1971 Act.

The Planning Act establishes Ontario's local planning system, under which municipalities control the way in which land is used and development takes place. Over the years the Province's involvement has been shifting from a supervisory role to one of ensuring that provincial concerns are looked after. The Planning Act, through zoning by-laws and official plans, has been used by municipal councils to prohibit extractive operations. Regulatory by-laws may also be passed by municipal councils under the Municipal Act to control such things as setbacks, blasting, and screening, many of the matters similarly found in the regulations to the Pits and Quarries Control Act.

Extraction of aggregate from Crown land is not controlled under the Pits and Quarries Control Act, but comes under the Mining Act. One of the most common complaints about the aggregate industry concerns transportation and the impact it has on neighbouring residents. One specific problem is with spillage from loaded dump trucks. Since January 1977 regulations under the Highway Traffic Act have required that dump trucks carrying mineral aggregate of a size smaller than 4 cm in diameter to be covered by a tarpaulin.

There are also other statutes that contain provisions that relate to pit and quarry operations, such as the Trees Act, the Environmental Protection Act, the Beach Protection Act, the Topsoil Preservation Act, 1977, etc.

Despite the fact that the new legislation has been delayed, the Ontario Government is empowered to change the old regulations when and as it sees fit. In January 1981 it was announced that as the security deposit of 2.2¢/t seemed ineffective in ensuring progressive rehabilitation (many operators viewed it merely as a penalty or tax on mining) it would be immediately increased to 8¢/t. The new Act, which will replace what is already the most sophisticated piece of Canadian legislation controlling the aggregate industry, demands new and upgraded site plans for all existing aggregate operations. The experience of the last 10 years has helped the Province to identify weaknesses, develop new approaches, and continue to accommodate the legislation to public and industrial concerns.

In general, the new Aggregates Act will clear up most of the definitional, administrative, and enforcement difficulties of its predecessor. Emphasis is placed on better rehabilitation, more municipal liaison, municipal remuneration, and power to suspend a licence. Pits and quarries on Crown land in designated areas will come under this new legislation.

One of the most welcome changes under the new Act concerns remuneration to municipalities. Over the years, local municipalities have maintained that they should be compensated for costs resulting from aggregate operations. The Working Party reviewed the problem and recommended that municipalities be compensated. The annual licence fee under the new Act will be 6¢/t with 4¢ going to the local municipality, 0.5¢ to the region or county, 0.5¢ to a program designed to eradicate the abandoned pit and quarry problem, and 1¢ to the Province (McLellan *et al.*, 1979).

The present economic recession has provided time to reassess the need for and nature of future regulatory controls. There is unlikely to be a rapid expansion of aggregate operations or of land disturbed in most of Canada in the near future as there was in Ontario from 1950 to 1975 (see Map 5, Uxbridge Township). In the west, however, problems may increase if expansion and growth continue. The best example to look at is probably Alberta. Here, despite the recent cancellation (1982) of mega-projects such as Syncrude, revenues derived from oil and natural gas still provide capital to stimulate development.

Overlapping legislation – Alberta

In all provinces there are numerous pieces of overlapping legislation that affect the aggregate industry. Nowhere has this been better documented than in a recent Alberta publication

(G.R. Shelley and Associates, 1977). Below are the various acts, with their major focus in parentheses.

The Sand and Gravel Act (owner retains rights of development and profit)

Department of the Environment Act (pollution control; environmental protection; water resource planning; prevention of deterioration of environmental quality through incompatible developments or land uses; and retaining the environment in its natural state or in a state suitable for recreation or the propagation of plant or animal life. Restricted Development Areas may be created to prevent the gravel resources in any area from being lost to future exploitation by the encroachment of incompatible land uses)

The Land Surface Conservation and Reclamation Act (surface disturbance and reclamation)

Clean Air Act (asphalt plants, air pollution, and dust)

Clean Water Act (pit de-watering and washing operations; discharge into and draining of water courses require permit)

Water Resources Act (water diversions, bank or shoreline changes)

Ground Water Control Act (well drilling)

Public Lands Act (licensing procedures for pits on Crown lands)

Agricultural Service Board Act (weed control, soil and water conservation control)

Weed Control Act (inspection and fines for weed control)

Soil Conservation Act (prevention of soil deterioration by wind, water, or other erosive powers, control of topsoil removal)

Alberta Heritage Act (historic site preservation)

Department of Transportation Act (gravel haulage routes)

The Municipal Government Act (acquisition of lands for municipal gravel pits, adverse impacts of gravel pits, abandoned pits)

The Planning Act (regulation of excavation or filling in of land or the removal of topsoil)

The Local Authorities Board Act (local by-laws under which a pit operates should the pit fall within new municipal boundaries)

Fisheries Act (Canada) (prohibits the depositing of deleterious substances in watercourses frequented by fish)

This maze of overlapping jurisdictions in Alberta is typical of other provinces. Although the situation is both understandable and probably necessary, it would be prudent if a single ministry, for example the Ministry of Natural Resources as in Ontario, should have final granting and monitoring authority for pits and quarries. Without one overriding ministerial authority, the approvals process becomes a confusing mosaic of negative and positive viewpoints, reflecting the specific individual mandates of each ministry or agency. If their comments were confined to constructive design improvements related to their own particular concerns, there would be less likelihood of intergovernmental conflicts and misunderstandings (McLellan, 1983).

In many parts of Canada it seems that we have tended to throw up a legislative smoke screen in response to demands for greater environmental constraints on development. Unattractive land uses such as pits and quarries, having little public sympathy, have been particular "beneficiaries" of this. Thus in Alberta, for example, there is little visible improvement in operation style, despite overlapping legislation and constraints imposed at provincial and municipal levels. At Carseland, 60 km east of Calgary, and at Cochrane 30 km to the west, extensive gravel deposits are extracted in ways that show little care or sensitivity. Random mining paths, numerous active, inactive, or abandoned vertical exposures, extensive stripped areas, and a total lack of peripheral screening (Photo 16) or progressive rehabilitation seem to be characteristic. In Québec a similar conclusion was reached by Boivin (1982): "The present legislation in Québec concerning mining and reclamation is inadequate to ensure the degree of public safety and environmental protection that is of prime concern in reclamation."

Clearly, to ensure the implementation of legislation, budgets must be adequate to establish an effective inspection system that includes powers to impose deterrent penalties.

Legislation – the local level

Local ordinances, namely restricted area bylaws and zoning constraints, are the major means used to prevent incompatible land uses becoming neighbours; most are designed to restrict the locations where pits and quarries may be developed. Some townships do have aggregate area zones but these usually reflect areas occupied by existing operations; new applications still normally require a rezoning application and amendments to official plans.

Many urban and rural municipalities also demand a specific development agreement, which commits the applicant to various procedures and may overcome local doubts about provincial controls. In Calgary, for example, the steps are as follows:

1) applicant files application with accompanying "technical package" prepared by consultants;
2) applicant requests Development Permit (where location is in the urban reserve lands of Calgary, gravel mining is a permitted use);
3) application is scrutinized by the City planning and engineering departments and, if they are satisfied, the latter requests the signing of a gravel mining agreement, which covers noise and dust

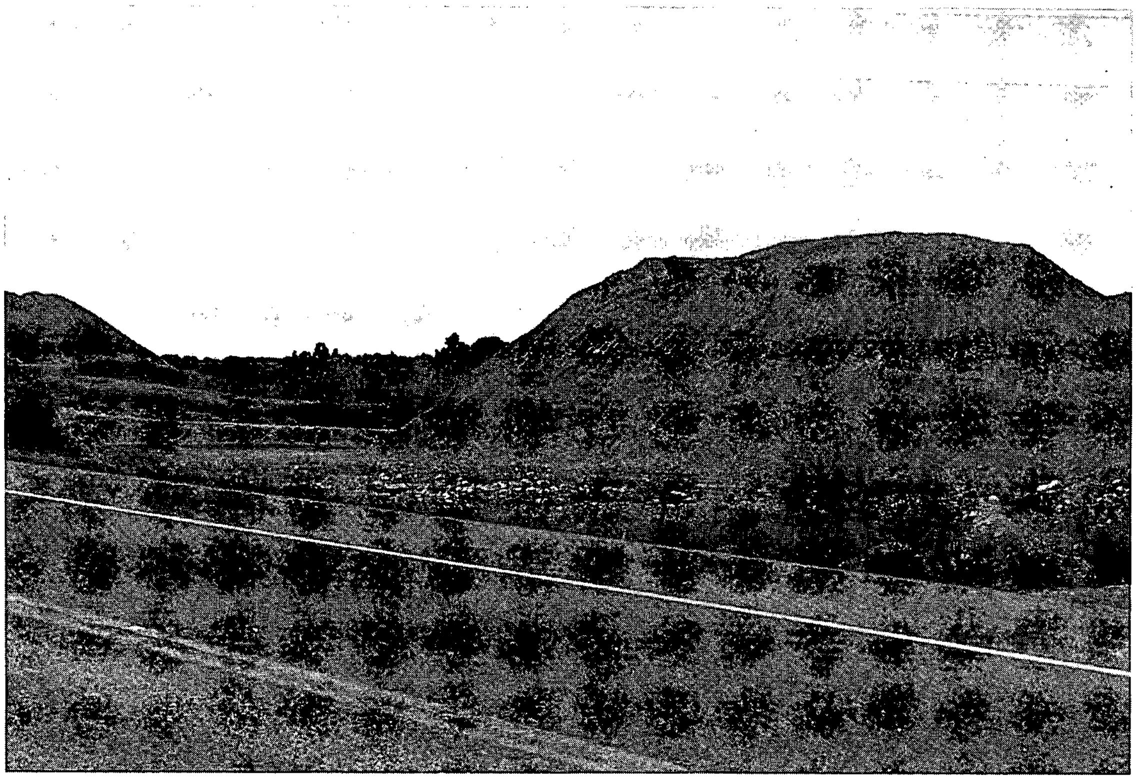


Photo 16. Negative public reaction to pits and quarries is often a result of the highly visible ravages of the landscape associated with such extraction activities. Provincial legislation does not seem to have improved this unattractive and obtrusive site near Calgary.
A.G. McLellan

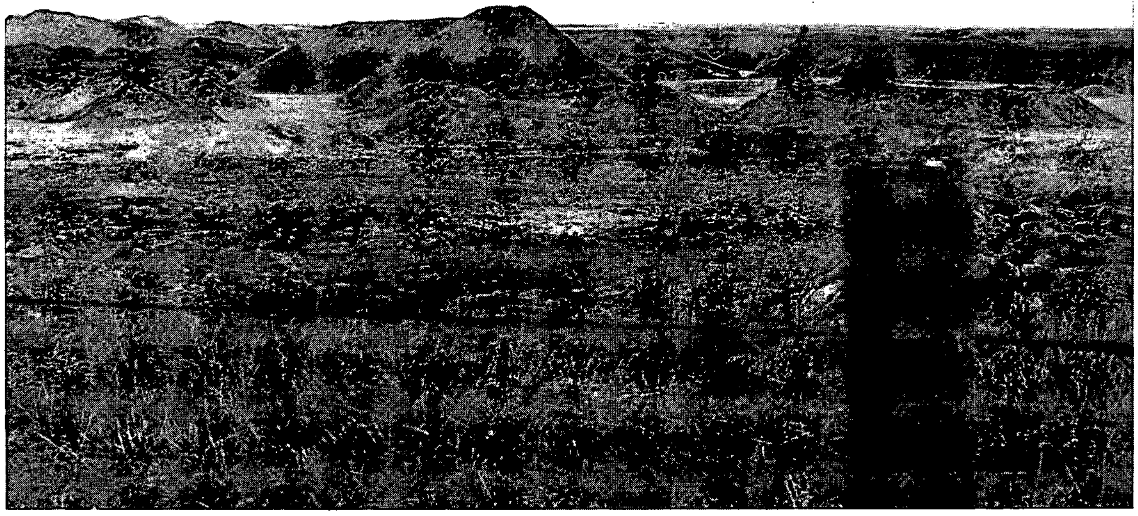


Photo 17. Extensive areas of land often lie in a devastated condition unavailable to other land uses for a considerable time. This site is located near Calgary at Carseland, Alberta.
A.G. McLellan

control, hours of operation, yearly phasing and reports on work progress, pit elevations, rehabilitation, etc.;

4) once the title is registered and a performance bond received, the operation can proceed.

The major conflicts in Calgary arise from increasing resident agitation about noise, dust, and hours of operation (subdivisions are being developed near the mining sites), and from differences between the City and aggregate producers about the amount of aggregate to be extracted and the duration of the operation approved under the permit. The City would like to restrict these and hold a review every 3–5 years (E.J. Grant, Engineering Development Co-ordinator, Urban Development Division, City of Calgary, personal communication).

A general rule is that where there is duplication of local or provincial ordinances, the more restrictive will apply. In Calgary, recent rapid urban growth has meant that urban fringe extraction sites require little more than grading, levelling, and topsoil spreading before they can be developed, but more distant sites show little effect of provincial or municipal ordinances (Photo 17).

The provincial dilemma – continuing regulatory conflicts

Provincial governments have to be careful to avoid displaying embarrassing differences within their own ranks. The scrutiny and comments of as many as half a dozen provincial ministries and agencies could lead to overlapping and contradictory decisions or requirements.

Provincial governments have the responsibility of acting in the best interests of all inhabitants of the province. This means: ensuring that aggregates are available at reasonable costs to the consumer; the designation and protection of valuable mineral sources through the local, regional, or county planning process; and taking into account disparities in availability. These provincial responsibilities can occasionally lead to conflicts with local authorities, which may not be sympathetic to provincial goals. Most provinces have insisted that ultimate authority be in one ministry. However, even here there may be problems, as in Ontario, where the "umbrella" Ministry of Natural Resources has responsibilities that are occasionally contradictory, e.g. for the preservation of parkland and natural areas and for resource exploitation.

Another major dilemma of provincial governments is the propensity of their independent ministries for establishing guidelines. Although the zeal and honesty of these ministries is unquestioned, a multitude of guidelines can cause considerable government embarrassment, the dissemination of misinformation, and the frustration of applicants for approvals or licences. What seems to happen is that with their individual and separate mandates in mind, ministries will investigate a known stress and recommend appropriate solutions. Regrettably, this is usually done independently of other ministries, without broad social and environmental input, and often without consideration of other policy decisions of the government. A good case in point is the situation of pits and quarries in the Ontario Ministry of the Environment (MOE).

The MOE has within its mandate concern for the pollution of surface and ground waters and air (dust and particle emissions) and noise. Clearly, on all these grounds the Ministry will be concerned with the stresses posed by pits and quarries. MOE intervention is at two different levels: by way of comments on Official Plans (and amendments) and on applications for pit and quarry licences under the Pits and Quarries Control Act. Over a period of several years, the Ministry, with the benefit of consultants' reports, discovered that interference (based on residents' complaints about blasting, plant processing, noise, and dust) occurs up to 2 000 m from the quarry operation. The same reports indicate that a 450-m separation distance (cf. the 50 or 100 m required under existing legislation) would reduce the complaints by approximately 32%. A separate study concluded that:

1) under certain weather conditions air blasts can shake a dwelling more than ground-borne vibrations at distances greater than 300 m;
2) shaking of dwellings is more annoying to occupants than the noise of blasts;
3) people within 305 m are "very annoyed" by blasts whereas those living 305–610 m away are "only annoyed".

By relating blasting to weather conditions (e.g. not during low cloud cover), reducing the weight of explosive per delay, changing the type of skimming and the amount of exposed detonating cord, aggravations can be ameliorated (Ontario Ministry of the Environment, 1981).

Occasionally the MOE has found itself at loggerheads with the Ministry of Natural Resources (MNR), which grants licences for pit and quarry operations, as in the case relating to the Regional Municipality of Ottawa Carlton (RMOC).

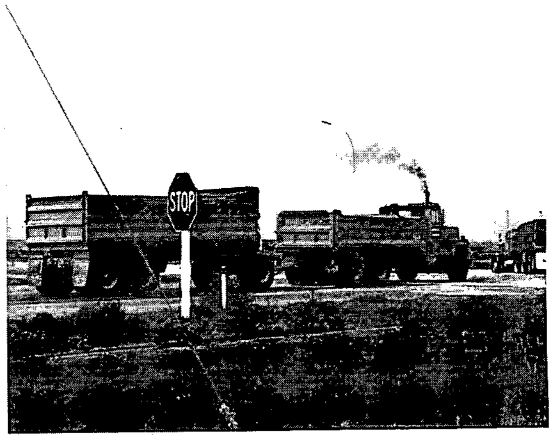


Photo 18. Many residents claim that ancillary effects of pits and quarries e.g. trucking, cause aggravation through the noise, dust, and safety hazards they pose. Covering of trucks with tarpaulins, paving access routes, using acceleration lanes, and controlling haul routes can alleviate some of the problems. These trucks on the Trans-Canada Highway east of Calgary have secure tarpaulin covering.
A.G. McLellan

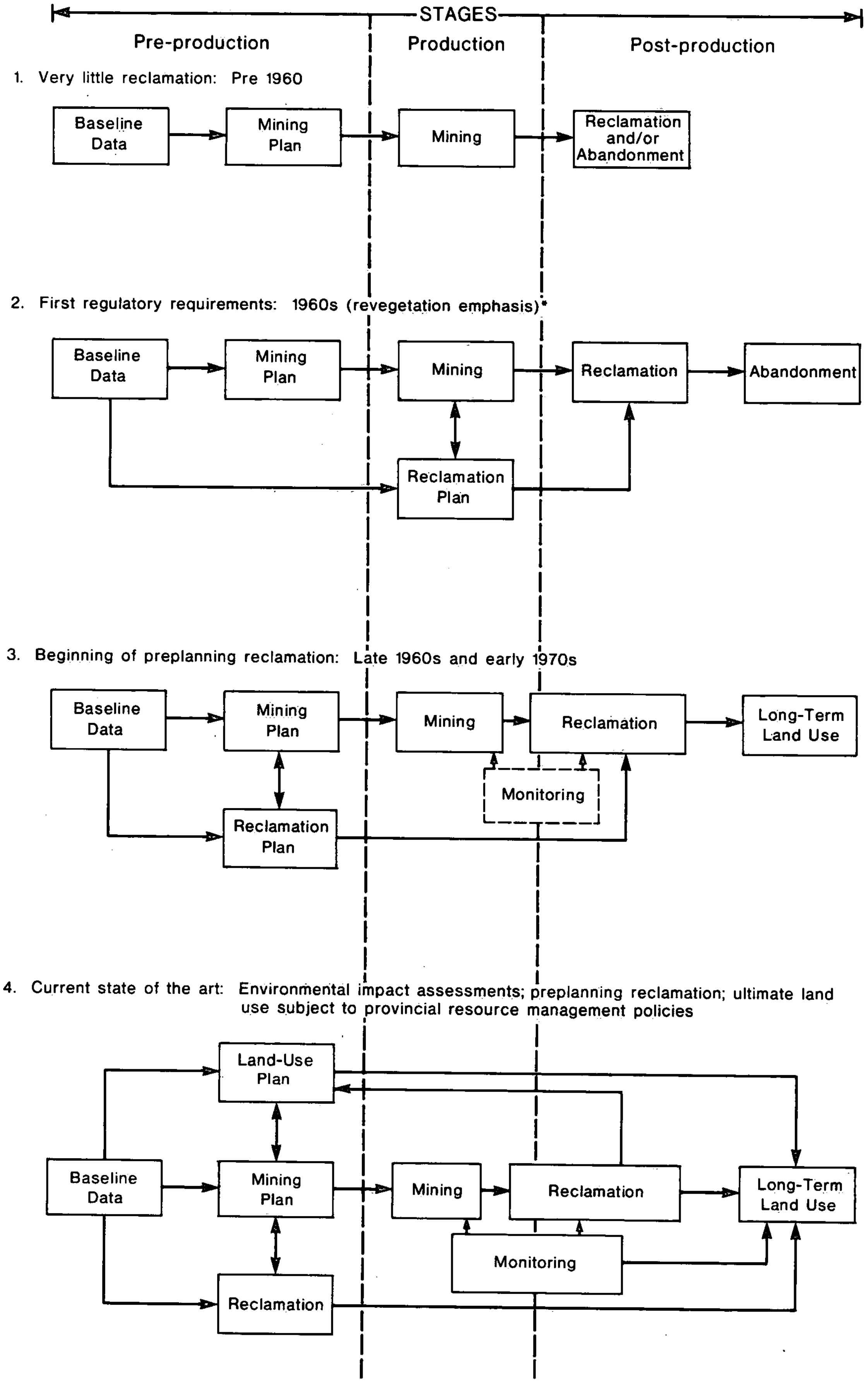
> *"MNR district staff have on occasion supported setbacks of this order. While commenting on one plan of subdivision MNR advised this Ministry that since the developer 'is willing to maintain a 1,500-foot [457-m] buffer zone, we feel that this setback is adequate and on that basis do not object to the proposed subdivision.' Similarly in another instance they indicated to the RMOC, their support of a MOE recommendation to notify prospective property purchasers of probable interference from noise, dust and/or vibration caused by the quarry operations. On the other hand, MNR staff find these distances excessively restrictive with regard to quarries locating adjacent to existing residential land uses"* (Ontario Ministry of Environment, 1981).

As a result of MOE's diverse experiences:

> *"It is therefore recommended that the following be applied when commenting upon new residential development adjacent to existing pit or quarry operations as well as new pits or quarries adjacent to residential land uses.*
>
> *i New residential development should not be allowed within 450 metres of the boundary up to which a quarry has been licenced to extract mineral resource unless an operating program, acceptable to the MOE has been included in an agreement with the municipality.*
>
> *ii Similarly quarry establishment or expansion should be opposed within 450 metres of residential areas unless an agreement as mentioned above can be obtained.*
>
> *iii For new residential development between 451 and 750 metres of an existing quarry, the subdivision agreement with the municipality should include an appropriate warning clause advising that quarry operations may (or will) cause some annoyance in the form of noise/dust/vibration although no structural damage is likely to occur. This notification shall be reflected in all subject agreements of Sale and Purchase (and lease agreements in the case of rental units), and shall be registered on Title. Furthermore, the notification shall not be removed without the prior consent of the Ministry of the Environment;*
>
> *iv For new residential development between 751 and 1,500 metres of an existing quarry, the subdivision agreement with the municipality should include an appropriate warning clause advising that quarry oper-*

FIGURE 6.

Schematic illustration of the historical evolution of approaches to mine reclamation



* There are some cases of this approach being adopted voluntarily prior to 1960

Reproduced from Marshall, 1983.

ations may sometimes be audible. This notification shall be reflected in all subject agreements of Sale and Purchase (and lease agreements in the case of rental units), and shall be registered on Title. Furthermore, the notification shall not be removed without the prior consent of the Ministry of the Environment.

v *A separation of 120 metres be maintained between pit operations and residential land uses unless an acceptable agreement, as in (i) has been entered into*" (Ontario Ministry of the Environment, 1981).

This complicated management and planning process question will continue to pose difficulties. It is becoming obvious that:

1) there should be shared control of planning and approval procedures at provincial and municipal levels;
2) licensing authority should remain with the senior level of government and should ultimately be vested in one ministry, although enforcement might be exercised at both levels;
3) local, county, and regional governments cannot continue to obstruct development by means of their planning powers and must show appreciation, in their official plans, for regional disparities of resource availability.

Further legislative difficulties among various levels of government

Marshall (1983) has tried to summarize the evolution of sophistication in regulatory requirements by the accompanying illustration (Figure 6). It shows the gradual addition of information/feedback links among 1) pre-planning inventory, operations, and rehabilitation site planning; 2) government monitoring and the aggregate mining operation; and 3) aggregate mining and the various factors in land-use planning.

Although this sequence is generally true of Canadian experience, in other aspects this rationalization is difficult to find. Firstly, each province has followed its own individual path in attempting to resolve environmental problems in general and pit and quarry land stress problems in particular. This, unfortunately, means that policy or legislative solutions found suitable in one province are not necessarily found nor applicable in another. Moreover, within each province conflicts persist between the various government levels.

It has already been pointed out that many local residents feel that local power in planning matters should not be eroded. They feel that the record of provincial control has not been impressive and they have resisted the imposition of authority from regional or provincial governments or from any of their ministerial branches or agencies. It has become apparent that unappealing development proposals will have to follow an extended planning process: starting at the local level – occasionally even with the individual resident – and proceeding through the township, municipality, and regional government levels and finally through the various provincial agencies. This is a lengthy and expensive process as well as a frustrating one. Individual levels of government have different priorities, which can lead to different decisions on what is or is not acceptable. In the last 2 years applicants for pit licences have been given contradictory advice from different levels of government on (a) wooded areas, (b) stream courses, (c) plant locations, (d) entrances and exits, (e) extent of environmentally significant areas, etc. It seems almost as if there is an implicit assumption that the developer will try to avoid doing the job properly, so that as many hurdles as possible have to be put in the way. Regardless of whether or not this assumption is true, there is no justification for systems of regulation and approval that overlap or contradict one another.

CONCLUSIONS

The Canadian experience with pits and quarries has not been easy. Much land has been used in a way that is detrimental to it ever being restored to its pre-mining land use. Given that pits and quarries are extensive land users, this is of grave concern. Unnecessary loss of land and/or its productive capacity are consequences of mining that are no longer necessary nor acceptable! The stressful impacts of pits and quarries make aggregate extraction incompatible with peaceful land uses such as recreation and residential areas. Planning must make strenuous efforts at reducing these stresses by keeping such uses apart.

Although it has proven difficult to present a precise comparative evaluation of the impact of pits and quarries across Canada and over time, several salient points emerge:

- Clearly, an enormous increase in the area disturbed by the aggregate extraction industry occurred during the boom development years of the 1960s and early 1970s. A similar expansion may occur at the end of the present recession. It will affect those provinces where development pressures are greatest and within provinces in those areas where growth and reconstruction are concentrated, e.g. resource areas and larger cities. Areas within 10–60 km of urban areas, often containing the most intensively used farmland, will feel the greatest pressures.
- The earlier expansion occurred during a period when aggregate producers were largely ignorant of techniques designed to minimize the land impact of surface mining. The results of this lack of knowledge were compounded by the problem of past abandonment and the undoubted conflicts created by previous pit and quarry operations. These conflicts had given rise to a greater demand for governmental enforcement of its legislation and an increased awareness of environmental issues; the period thus was characterized by hostility, conflict, and negative reactions.
- The hostile atmosphere and the difficulties faced by the aggregate producers stimulated provincial government action. Research was conducted and regulations were passed in order to improve the quality of aggregate operations. Much of this research has been pioneered in Ontario and the experience there will be informative for other provinces.
- Rehabilitation technology has improved to the point where the large-scale loss of farmland due to extractive operations (even if only temporary) need not occur and should not be tolerated. Nonetheless, it is clear that governments can still improve the collection of data, the monitoring of operations, and the effectiveness of rehabilitation techniques in the future.
- Where formerly there was conflict, a new spirit of compromise is developing. Aggregate reserves are being seen as vital to the future; plans are being made that recognize and make appropriate provisions for their use.
- Enlightened approaches by aggregate producers to their operations and to the return of land to a useful and often aesthetically pleasing condition, have encouraged governments to accept the industry as a responsible contributor to the Canadian economy and may slowly erode the negative public reaction.
- Planning authorities may wish to take a more active role in promoting aggregate mining in ways that best suit a local community's present and future needs. Constructive compromises hold the promise of supplying today's aggregate needs while at the same time retaining or even enhancing tomorrow's landscapes.
- Without energetic application and improvement in all of the above, and even with them, the impact of pits and quarries will continue to be stressful to many Canadians who consider this necessary industry an unwarranted intrusion into their community or lifestyle.

Photo 19. Butchart Gardens in Victoria, British Columbia was originally a limestone quarry. The supply of limestone was eventually exhausted and the quarry was considered an eyesore. Due largely to the efforts of Mrs. Butchart, the site was transformed into magnificent display gardens which have been open to the public for 70 years. Butchart Gardens receives more than one-half million visitors a year and is an outstanding example of how an attractive and valuable end-use can be established after extraction activity.
Canadian Government Office of Tourism

This text was reviewed by Ian B. Marshall of the Lands Directorate, Environment Canada, Ottawa, Ontario and by Dr. D. Hoffman, Director of the School of Urban and Regional Planning, University of Waterloo, Waterloo, Ontario.

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APPENDIX I

The Soil Conservation Society of America has suggested the following goals:

1) Encourage research and development in land reclamation technology.

   Every site to be reclaimed has its own special problems. New techniques must be developed and known practices applied to help solve all those special problems. Mined land must be restored in a way that preserves the natural resources and values that were there before, or even enhances those values, if that is practical. This means developing better methods of reconstructing the soil profile, using plant species that are right for the site, using the best methods of revegetating a disturbed area, improving water conservation, and developing special equipment if necessary. Laboratory work needs to produce improved and more reliable ways of characterizing the nature of soils on a commercial basis to ensure that the best reclamation practices are applied.

2) Encourage better planning before mining. Knowing precisely what existed before is requisite to restoring or improving the resource after mining. Pre-mining plans should include complete inventories of soil, water, overburden, plant communities, wildlife, and other natural resources. Plants used to stabilize the area should be adapted to the site and be appropriate to the planned use of the site. There will always be a need to develop or evaluate improved species for specific sites and land uses.

3) Encourage reclamation techniques that provide the greatest choice of alternative land uses.

   The widest possible choice of land uses later – that is what the proper reclamation technique should provide, given the physical and chemical make-up of the soil material. Future landowners would then have flexibility. For example, land suited to intensive agriculture should be returned to a condition where this or less intensive uses are possible, according to the needs of present and future generations. This approach would still allow community needs for recreation, housing sites, industrial development, or other uses to be met.

4) Encourage government agencies to work together.

   Mining and reclamation should be done in a reasoned, selective, and orderly manner without sacrificing the food and fibre base, quality of life in rural areas, or quality of the environment. This cannot be accomplished if governmental agencies at all levels do not work together in developing surface mine reclamation technology and programs.

5) Encourage an economically sound and stable mining industry.

   Everyone with a stake in the economy and concern for natural resources should encourage a healthy mining industry that has orderly operations. The healthier the industry, the greater its ability to carry out high-quality, long-term reclamation.

6) Encourage conservation and recycling of existing materials.

   Encouraging maximum use and re-use of mineral resources by the public and industry will reduce the amount of land requiring disturbance which will also be minimized if the maximum amount of mineral is extracted once a site is opened to mining.

7) Encourage legislators to keep reclamation laws current.

   Legislators at all levels must constantly review and revise legislation on reclamation of surface mined land so that it reflects the newest technology. If reclamation is to be improved, legislation – an important impetus to reclamation – must keep pace.

8) Encourage local input into mine planning and land-use decisions.

   Increasing local input in decision-making about mine site selection and affiliated industry would permit people to address the impact of mining on important farmland, unique and natural areas, fragile lands, and water resources.

9) Encourage public awareness of the cost of mining and reclamation.

   Reclamation is recognized as a part of the mining operation, and the costs associated with it should be borne by the ultimate consumer (Soil Conservation Society of America, 1980).

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DEGRADATION OF AGRICULTURAL LAND

Photo credit: D.R. Coote, Agriculture Canada

STRESSES ON LAND UNDER INTENSIVE AGRICULTURAL USE

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INTRODUCTION

Stresses on farmland under intensive agricultural use

Acceptable productivity of agricultural land is achieved only through the management of soils, crops, and water. This management includes tillage to control weeds and optimize soil conditions for seed propagation; the provision of plant nutrients through the use of manures, minerals extracted from the ground, and manufactured chemicals; and control of soil moisture through drainage, irrigation, and fallowing. Most of these management practices consume energy, but produce immediate benefits for the farmer. However, over extended periods of time negative effects are often manifested, which impose stresses on agricultural land and sometimes also on adjacent environments.

Negative effects arising from intensive agricultural land use in Canada fall into three broad categories: 1) loss of soil materials, including erosion by wind or water, and the oxidation of organic matter; 2) chemical changes in soils, including the development of salinity or acidity, and contamination with heavy metals; and 3) physical changes occurring when soils become compacted. Negative chemical and physical changes are also imposed on agricultural land by external processes such as atmospheric deposition of chemicals and soil disturbance during extraction of subsurface minerals (sand, gravel, coal, etc.), and when pipelines are installed. Soil degradation, whether caused by farming practices or other factors, ultimately affects the farm by reducing crop yields, requiring greater inputs of fertilizer and tillage energy, and increasing the risk of crop failure in years with poor weather conditions.

The stresses that are being placed on the agricultural land resource generally result in depletion of soil quality or quantity. Agriculture is one of the principal land uses in Canada, covering over 46 million hectares. Even small losses in the quality or quantity of the agricultural soil resource can therefore have a potentially significant impact on the environment and on future food supplies.

However, negative effects do not necessarily accompany all intensive agricultural land use. Farmland can be significantly improved by a combination of good soil and water management; use of manures, fertilizers, and lime; and selection of crops that do not expose or deplete the soil. Ideally, practices should be directed to the maintenance of a stable system that can persist indefinitely. Unfortunately, the continuing trend to more specialized agricultural systems and the greater impact on agricultural land made by other land uses have increased the likelihood of soil deterioration rather than improvement.

Relationship to other land uses

Stresses on agricultural land cannot be isolated from other land or its users. For example, water erosion causes streams to deteriorate through siltation and pollution, thereby affecting municipal and industrial water supplies, recreation, wildlife, fisheries, and even navigation (e.g. need for dredging of harbours). Wind erosion also deposits soil in streams, as well as filling the air with dust, damaging structures and machinery by abrasion, and smothering vegetation by drifting.

Loss of soil productivity through salinization, acidity, disturbance, or compaction can induce farmers to use a greater portion of their remaining land for less suited but potentially more profitable crops. This, in turn, may lead to more erosion as well as extending the area affected by the original problem. When land marginal for agriculture is cultivated, society as a whole suffers through loss of wildlife habitat and of forest and recreation land. Food costs and imports increase when production is shifted on to land that requires greater inputs of fertilizer and tillage energy to maintain yields. The maintenance of the quality of agricultural land is clearly of concern to most of society and not just to the agricultural community.

Importance of soil degradation to the national well-being

Although Canada is the second largest country in the world it does not have a large area of agricultural land. Almost half the land (48.2%) is totally unsuited to any form of agriculture because of the cold climate (Table 1). Another 28% of Canada's land has low temperatures, or is dry or rocky, to the extent that it has no agricultural potential except for very small

TABLE 1.
Extent of agricultural land in Canada

	Area (x10^6 ha)	Percentage of land area of Canada
Present use[+]:		
Cropped and fallow land	40.7	4.4
Improved pasture	4.4	0.5
Other improved land (buildings etc.)	1.0	0.1
Total improved land	46.1	5.0
Total land on farms	65.9	7.2
Class 1–4 agricultural capability soils[++]	81.7	8.9
Total area with climate suitable for agriculture[+++]	218.6	23.8
Total area with climate severely limited for agriculture by:		
— low temperatures	227.3	24.8
— dryness	29.3	3.2
Remaining area with no agricultural potential	442.9	48.2
Total area of Canada	918.1	100.0

[+] Statistics Canada, 1982.

[++] Shields and Nowland, 1975; includes estimate for British Columbia from British Columbia Ministry of Agriculture, 1979.

[+++] Clayton *et al.*, 1977.

pockets of good soil. In the rest of the country (23.8%), the feasibility of productive agriculture is determined primarily by the soils. Less than 9% of Canada's land area has soil capable of being cultivated and only half that area is being used for cultivated crops (about 41 million hectares). The balance is pasture, forest, recreation land, transportation corridors, and industrial and urban land.

Soils with good physical and chemical properties that are located in areas with climatic conditions suitable for a wide range of agricultural crops are a severely limited resource. They occur only in the Lower Mainland of British Columbia, the most southerly part of Manitoba, southern Ontario, the Montreal Plains, and the Annapolis Valley of Nova Scotia. It is only in southern Ontario that some economically important crops such as soybeans can be grown with any reliability. However, recent advances in plant breeding may make it possible to grow this crop successfully in southern Manitoba and Quebec.

Lands capable of growing soft tree fruits, such as peaches, are very scarce. Only areas of southern Ontario influenced by the local climate of the Great Lakes, such as the Niagara Peninsula and southern Kent and Essex counties, are suitable. The only other part of Canada suited to these crops is the Okanagan and its adjacent valleys in British Columbia, where irrigation is necessary for a crop to be produced. Irrigation has also made it possible for a substantial area of southern Alberta to be used for crops like corn, sugar beet, and vegetables, which would otherwise be limited to the climatically suitable areas already mentioned.

Considering the severely restricted area of Canada's high-capability soils in the most productive climatic zones, it is evident that the maintenance of the quality of these soils is of the utmost importance to the country as a whole. For example, Canada imports approximately one-third of the soybeans consumed, at a significant cost to its balance of trade. Lands capable of growing soybeans are among those most stressed by processes such as soil erosion, compaction, and acidification. Hence, any loss of productivity on these lands will add to the national debt and increase our reliance on other countries' policies and productivity. Similar arguments can be made for crops such as grain corn and fruit. In the latter case, we even import almost 50% of those fruits that can be grown in Canada.

Exports of wheat, other grains, and oilseeds, primarily from the Prairie Provinces, constitute one of Canada's principal sources of revenue and are a major reason for our continuing international trade surplus. However, much of the land on which these crops are grown has been providing nutrients from the slow decay of inherited organic matter, which accumulated in native prairie soils over thousands of years. Today that source of nutrients is becoming depleted and greater quantities of fertilizer are being used to maintain yields. The soils are also showing the effects of continued erosion, which has accelerated the loss of organic matter, and of the expansion of salinity into previously nonsaline areas. The maintenance and growth of grain exports is therefore closely linked to the maintenance of soil quality through organic matter management, reduction of erosion, and halting the spread of salinity.

History of soil degradation in Canada

The occurrence of most types of soil degradation in Canada has only been recognized recently. Wind erosion, however, has a documented history going back to the early days of settlement on the western prairies (Anderson, 1975). Wind erosion was noted as a problem in much of the southern prairies even before the "dust bowl" days. It was aggravated by the increasing popularity of summerfallowing, a practice that keeps the soil bare of vegetation by repeated tillage throughout every second or third summer. Summerfallowing helps build up soil moisture and nutrients (from organic matter oxidation) between crops, thereby increasing yields in the cropped years. Crop failures during the dry period of 1917–1920 led to severe erosion and economic hardship, which continued for almost 20 years. Thousands of farms were abandoned during this period. The federal Department of Agriculture, Experimental Farms Service, was strengthened in 1935 by the Prairie Farm Rehabilitation Act (PFRA). With the addition of demonstration facilities for experimental farms, practices such as strip cropping, planting crops in furrows across the prevailing wind, trash tillage instead of plowing, and planting windbreaks were encouraged (Thompson, 1953). Large areas of badly eroded abandoned land were taken over and seeded for permanent community pastures under the PFRA. The PFRA also organized Agricultural Improvement Associations, which brought farmers together to exchange information and work out solutions to their common problems.

Until recently the problem of wind erosion was thought to be almost completely controlled. A relaxation of attitudes has led to a decline in the maintenance of windbreaks and strip cropping systems so that the soil has again become vulnerable to wind erosion.

No other type of soil problem has been documented in Canada to the same extent as wind erosion. Water erosion, for example, although persisting since the land was first cleared, has been noted only in the Maritimes to have significantly affected crop production, mostly in the last two decades. The vigorous activity against soil erosion in the United States during the 1930s and 1940s had some influence in Canada, principally in Ontario; however, there was no major infusion of manpower and money in Canada comparable to that which accompanied the establishment of the Soil Conservation Service in the United States. The climatic conditions and nature of the farming systems of eastern Canada did not give rise to the dramatic soil erosion problems documented to the south. Enthusiasm waned with time, and most of the attempts at terracing and contour cropping initiated by a few enlighted Canadian farmers were eventually abandoned.

A small number of plots were established at research stations, under the jurisdiction of various governments and universities, to monitor soil erosion. Such plots were located first at Ottawa, Ontario, and Edmonton, Alberta, followed by plots at Guelph, Ontario, Saint-Coeur-de-Marie and Cap-aux-Corbeau, Quebec, and Charlottetown, Prince Edward Island. All these experiments have since been discontinued. Recently, however, a new interest in water erosion has developed, and sites at Beaverlodge, Alberta, and Fort St. John, British Columbia, in the Peace River region, and at Truro, Nova Scotia, have been established. Saskatchewan supported a watershed-based erosion control program in the 1950s in drainage basins between Prince Albert and Yorkton; grassed waterways, diversions, and strip cropping were established with government support. The program was discontinued in the early 1970s but was reinstated in 1981 in response to local demand. At present the most concerted effort against water erosion is being made in New Brunswick where, following years of neglect, the problem in potato fields is being addressed by construction of diversion terraces and grassed waterways.

Few major control measures have been initiated to deal with other soil degradation problems in Canada. Salinity, for example, although long known by farmers as a local problem, and in irrigation districts as a canal leakage problem, was first linked to agricultural management in the publications that followed preliminary research carried out in the 1960s. It is now considered one of the most pressing problems for agriculture in the Prairie Provinces, and is receiving much attention in both provincial and federal research and extension programs.

Similarly, soil acidification, which appears to be increasing as a result of the combined effects of nitrogen fertilizers and acid rain, has only been discussed widely during the last 10 years, even though the processes have been active for generations. Soil compaction, as a result of untimely, frequent, and often excessive tillage, is another example with a similarly brief history of general discussion.

Agriculture in Canada has been maintained at a highly competitive level through advances in crop breeding, fertilizers, pesticides, and machinery. However, the soil has often been abused as a result of these technological developments and their continued intensive use. In a world suddenly aware of the limited supply of energy, and with populations continuing to increase exponentially, the realization of a limited capacity to produce food is finally beginning to dawn on society as a whole. As never before, agricultural soils are being seen as a scarce and precious resource; as never before, they must be used wisely if they are to be conserved for future generations.

PROCESSES OF AGRICULTURAL LAND DEGRADATION AND THEIR IMPACT

The following discussion of the processes of degradation of agricultural land and their impact is divided into three broad sections: 1) loss of soil materials, 2) chemical deterioration of agricultural land, and 3) physical deterioration of agricultural land. The first of these includes soil erosion and the oxidation of organic matter; the second includes salinity, acidity, and contamination; and the third includes compaction and disturbance. Although there are some common trends and relationships among the processes described in this section, they are fairly distinct and generally result from different causes. It is therefore important that they be understood individually if a balanced appreciation is to be gained of the total problem of soil deterioration affecting agriculture.

Loss of soil materials

Erosion by water

Processes

Erosion of soil by water occurs, to a limited degree, even on well-vegetated, undisturbed land. It has produced some of the world's most productive alluvial soils. However, when the soil is exposed to water without the protection of vegetation, erosion is accelerated and particles are washed for distances ranging from a few centimetres to many kilometres. It is the dramatic erosion events that generally cause public concern, but even gradual movement over relatively short distances within a farmer's field can ultimately reduce soil productivity.

The main factors determining the rate and extent of soil erosion by water are: 1) the soil's susceptibility to disaggregation by raindrops or running water, which is a function of particle size distribution, organic matter content, permeability, degree of aggregation, and structural stability; 2) the intensity of rainfall or runoff; 3) the degree and length of slope, which determine the velocity and concentration of runoff; 4) the presence of frozen layers in the soil profile; and 5) the vegetation cover or residue, which protects the soil from raindrop impact and retards runoff and soil movement.

Silty soils low in organic matter tend to be those most easily eroded by water. Clay soils with weak aggregation can also be very susceptible, especially when saturated, as occurs when internal soil water drainage is restricted by compact or frozen soil layers. Rain drops break up exposed soil aggregates and soil particles are carried across the surface by runoff. If the soil is frozen beneath the surface, a condition often found in Canada in spring, infiltration is negligible and runoff rates are high. Soils plowed or cultivated the previous fall are also left unprotected by vegetation when spring rains begin. At first, runoff moves as a thin layer of water over most of the surface, causing sheet erosion. Rill erosion occurs when the runoff is concentrated into small visible channels (Photo 1). Eventually these channels deepen into gullies, causing operating problems for machinery and a lasting reduction in soil productivity (Photo 2).

Soil erosion by water removes or transports nutrients needed for crop growth. It causes sorting and redistribution of soil particles, often resulting in the removal of organic matter and the very fine-grained mineral fractions. These are the most valuable soil constituents, having the greatest plant nutrient retention and supply capacity. Soil erosion reduces the volume of topsoil, resulting in reduced water-holding capacity, poor root development, and uneven crop growth. It also results in siltation of natural surface drainage routes, which causes smothering of seedlings in spring and crusting of surfaces when the deposited soil dries out.

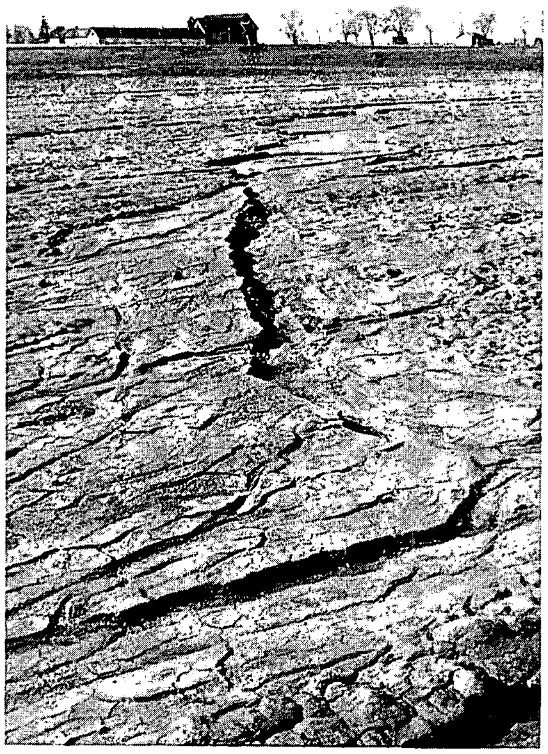


Photo 1. This rill erosion in eastern Ontario was the result of spring runoff on soil intensively tilled the previous fall.
D.R. Coote, Agriculture Canada

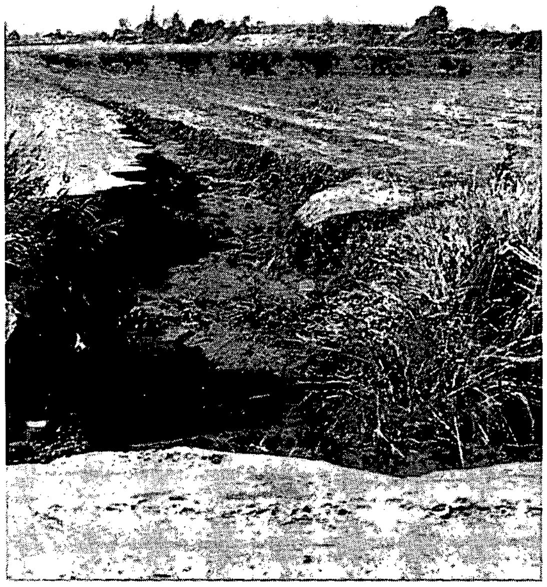


Photo 2. This eastern Ontario gulley was caused by heavy rain runoff early in the growing season. It might have been avoided by seeding across the slope, and by establishing a grassed waterway with an erosion-resistant outlet.
K.D. Switzer-Howse, Agriculture Canada

The annual rate at which soil forms in Canada is estimated to be between about 0.25 t/ha and just over 1 t/ha. Yet annual erosion rates of 20–25 t/ha are quite common in agricultural land that is suffering rill and gully erosion.

Soil erosion causes considerable environmental deterioration. The eroded particles transport attached pollutants, such as phosphorus and the persistent pesticides, to streams, rivers, and lakes. There they reduce water quality for fish, wildlife, recreation, and municipal supplies. The sediment itself is also damaging to aquatic environments, where it reduces light penetration and blankets fish spawning grounds.

Location and extent

Soil erosion by water is found in all regions of Canada. It is particularly serious, however, in the potato fields of Prince Edward Island and New Brunswick, in the corn belt of southern Quebec and Ontario, in the escarpment area of

Manitoba, in the Peace River region of Alberta and British Columbia, and in the Lower Mainland of British Columbia.

Soil erosion by water has been recognized as a problem in the Atlantic Provinces for many years. Soils used for potato production have long been affected in New Brunswick and Prince Edward Island. Recently, however, the expansion of corn as a silage crop has increased the area of land subject to water erosion. Conditions that contribute to soil erosion in Atlantic Canada are undulating-to-rolling topography, slowly permeable subsoil horizons in many soils, high fall and winter precipitation, and frequent freeze–thaw cycles in spring. Soils on which potatoes are grown are generally left in a bare and loose condition after harvest and over winter, and monoculture (no crop rotation) is common. Stone removal to facilitate mechanical potato harvesting and fence-row removal to accommodate larger machinery have further increased the problem as infiltration rates have been reduced and the length of sloping fields has been increased. Where corn is grown, the short wide-spaced stubble left after silage harvest provides little protection for the soil. Both these crops are associated with serious sheet, rill, and gully erosion. Given the limited extent of soils with high capability for agriculture in the Atlantic Provinces, this loss of soil is affecting a valuable and scarce resource.

Soil erosion rates have been measured in Prince Edward Island on one of the principal cultivated soil types. Over a 5-year period (1973–1977), measured annual soil losses ranged from only 0.2 t/ha on both 7 and 12% slopes under grass sod to 19.6 t/ha on a 12% slope with potatoes grown up and down the slope. Accompanying these soil losses were considerable reductions in organic matter and nutrient contents of the surface soil, leaving the sites more susceptible to erosion in subsequent years (Himelman and Stewart, 1979).

No measured soil loss data are available for New Brunswick, but it has been estimated that culivated land is eroding at an average annual rate of about 42 t/ha (Stewart, 1976). In the potato belt of New Brunswick more than half the soils with agricultural potential have slopes of 5% or more, which is sufficient to lead to soil erosion even under good management. Recent visual estimates indicate that at least one-third of the potato land is severely affected by erosion.

In Nova Scotia the assessment of soil erosion by water is again hampered by lack of data. A small study recently investigated 2 years of soil erosion in a corn field on a 9% slope. Measured annual soil loss averaged about 26 t/ha; the actual loss was thought to be considerably higher but was not known because the sampling techniques allowed some fine sediment to wash away unmeasured (Kolstee, 1979).

Water erosion rates have been measured in Quebec near Lac Saint-Jean and on the north shore of the St. Lawrence east of Quebec City. At the Lac Saint-Jean site, average annual erosion varied from less than 1 kg/ha under hay to 56.6 t/ha on a fallowed loam soil graded to a uniform 10% slope (Dubé, 1975). At the north-shore site on a sandy-gravelly loam soil with a slope of 15%, annual soil losses over 10 years ranged from 60 kg/ha under pasture to over 28 t/ha under bare fallow. On potato fields planted across the slope, annual soil losses of only 3.3 t/ha were recorded, while average losses of 6.0 t/ha were observed from potatoes planted up and down the slope. On average, 41% of the mean annual soil losses from different crops at this site occurred during the spring snowmelt period (Dubé and Mailloux, 1969).

The eastern Ontario area has relatively severe spring snowmelt conditions, i.e. considerable snowmelt, plus spring rains, on soils still frozen beneath the surface. Research undertaken in the 1950s showed that spring runoff from monoculture corn fields on one soil type (Rideau clay) was responsible for average annual soil erosion rates varying from 0 to 49 t/ha (Ripley *et al.*, 1961). The greatest loss was from corn grown up and down a 10% slope. One summer rain storm accounted for a loss of over 145 t/ha. Most of the annual total loss, however, occurred during the snowmelt period. The practices that controlled these soil losses were found to be crop rotation with oats and alfalfa, the use of manure, and cropping across the slope. With changes in the nature of farming systems taking place in this area, i.e. from livestock with forage rotations to cash cropping, it is clear that crop rotation and manuring are less likely to be practical. This leaves farmers with only the cross-slope planting option and recent developments in reduced tillage to reduce erosion rates.

In southern Ontario, where total rainfall energy (combined effect of rainfall intensity and quantity) is the highest in Canada, soil under continuous corn on fairly level land is estimated to erode at rates up to 12 t/ha annually, while corn in rotation with hay is not expected to exceed 7 t/ha. Pasture generally erodes at less than 1 t/ha annually (Van Vliet *et al.*, 1978). In a field study in southwestern Ontario, continuous corn on a 7% slope had an average annual soil loss of 19 t/ha over a 10-year period. In rotation with hay and oats, annual losses from the corn crop were just over 1 t/ha (Ketcheson and Webber, 1978).

The long-term shift to the production of corn at the expense of hay and small-grains crops is continuing across the entire agricultural portion of the Ontario – Quebec region as new varieties suited to the available heat units of the cooler areas are made available. The same is happening with soybeans, but as yet only in Ontario. Fall plowing is extensively practised in these areas to avoid spring seeding delays. Fence-rows have been removed, and woodlots and densely vegetated areas around streams have been cleared and cultivated to facilitate the use of large machinery. Fine and medium textured soils with inadequate protective cover are being exposed to raindrop impact and snowmelt runoff.

Water quality is of particular concern in southern Ontario because of proximity to the Great Lakes. The significance of erosion to water quality depends on the degree of transmission of the eroded soil material to streams. This "delivery ratio" ranges from about 10 to 30%. Most sediment is delivered to streams in February, March, and April. Water quality problems are compounded by the extensive network of municipal drainage ditches, which provide individual farmers with improved drainage outlets but also act as conduits for eroded soil. They often erode and slump, contributing further to stream sedimentation problems.

Infrequent but intense summer storms occurring in the relatively low-rainfall areas of the Prairie Provinces are a significant cause of local water erosion. The problem is characterized by sheet erosion of knolls, and rilling and gullying near road culverts. The greatest effects are observed in the southern part of the region where rainfall intensities are highest. Rolling and sloping lands west of the Red River Valley in southern Manitoba are particularly susceptible. As storms tend to be localized and brief, there are insufficient data on which to predict them. Management practices tend to ignore these events and so erosion can be severe where they occur. In a study near Edmonton (Toogood, 1963), over 4 t/ha of soil were lost in less than 1 h compared with a 10-year average annual loss of 2 t/ha on summerfallowed plots. Erosion from summerfallow averaged more than twice that from wheat in a wheat–fallow system, and 40 times more than wheat in a 5-year rotation with oats, barley, and hay. In another semi-arid study area at Swift Current, Saskatchewan, summerfallow was shown to lose four to eight times more soil during snowmelt than was lost from stubble fields (Nicholaichuk and Read, 1978).

Soil erosion by water is also associated with annual rainfall and snowmelt runoff in the more humid part of the agricultural area of the Great Plains, particularly in the lower foothills of Alberta, the Peace River region, and in east-central Saskatchewan (Prince Albert to Yorkton). Although summerfallow is less frequently used in these areas, a water erosion problem is common in the spring months when there is minimal protection of the soil.

Water erosion is a recognized problem in the lower Fraser Valley of British Columbia and to a lesser extent in parts of the Okanagan and

Kootenay valleys, where intensive cultivation for wide-row crops such as corn, potatoes, and grapes is practised. Rainfall occurs mainly during the winter months, contributing to the erosion of cultivated soils left bare of vegetation over winter. Precipitation in the interior valleys is generally low and irrigation is necessary for most crop production. Many of the soils have developed on silty lacustrine materials, which are highly susceptible to erosion under cultivation and irrigation. At present no quantitative data exist to determine the rates of soil loss occurring in the cultivated valley soils of British Columbia.

Trends

Water erosion continues to increase in extent and severity in eastern Canada as a result of land-use changes. It is also increasing in certain areas of western Canada, such as the Peace River region, where extensive land clearing is still taking place.

In eastern Canada there has been a steady increase in the area of corn as a result of new shorter season varieties. Since the mid-1960s, considerable changes have taken place in the Maritimes, where silage corn has replaced some hay and small grains. However, it is in Ontario and Quebec that the greatest area has been converted to corn production—almost 3/4 million additional hectares between 1966 and 1979, most of this being grain corn. Ontario has also more than doubled its soybean production to over 1/4 million hectares in the same period. As these crops are frequently grown in a monoculture system by cash crop farmers with no livestock to justify a hay rotation, it is clear that continuation of these trends will increase soil erosion in eastern Canada. Corn and soybean breeding programs continue to produce varieties with shorter growing seasons, so the spread eastwards of these crops is highly probable.

Most of the change in Ontario has occurred in the eastern counties, where large areas of productive clay soil are still being drained. With Canada still importing so much corn and soya, it is highly probable that the trend to more intensive use of this area for these crops will continue, and with it will be an increase in water erosion.

Trends in the Prairie Provinces are for a slight reduction in summerfallow area, with more frequent stubble-cropping (seeding grain crops in successive years), especially in Manitoba and Alberta. Together with improved minimum tillage methods, which maintain surface crop residues, the trend to less summerfallow should decrease water erosion risk. On the other hand, southern Manitoba has experienced a considerable increase in corn area in recent years, and soybeans are now being grown on a limited basis. Should variety improvements and demand continue to the point where the fine textured soils of southern Manitoba become major corn and soybean lands, the water erosion problem in this area will intensify.

On the west coast, water erosion is likely to continue as a result of the demand for land. Farmers are cultivating less suitable soils, often on fairly steep slopes, for crops such as strawberries and raspberries, because the productive flood plain soils are being used for corn and vegetables. Land prices are also high for better soils because of urban, recreational, and industrial competition. These trends are likely to continue.

An example from Prince Edward Island

For an example of a water erosion problem, its quantification and possible control, one can consider the results of a study in Prince Edward Island. The situation here also has much in common with other parts of the Atlantic Provinces.

Stewart and Himelman (1975) and Himelman and Stewart (1979) noted the discolouration of stream water by suspended sediments after even low-intensity storms, and serious visible erosion during snowmelt periods. Gullies up to 1 m in depth were common in long, sloping fields in the spring following harvesting of a row crop, e.g. corn or potatoes. They also noted that between 1966 and 1972, the years prior to establishing their study, farm size in Prince Edward Island increased by 10%, and a shift toward more cash cropping had led to fence-row removal and field size enlargement. These changes aggravated the erosion problem on typically undulating, low organic matter, sandy loam soils in the Province. Stewart and Himelman set up a series of study plots on both 7 and 12% slopes, on one of the dominant cropped soils. With these plots they collected and measured runoff and sediment from four cropping practices—potatoes grown up and down the prevailing slope, potatoes grown across the slope, a grass sod, and a bare fallow soil surface. After 5 years some important conclusions were reached from this work:

1) Soil erosion losses from the bare fallow area were consistently more than twice those from potatoes grown up and down the slope, and up to 200 times that from sod. The average annual rates of soil loss on the fallow areas ranged from 18.7 t/ha on the 7% slope to 41.1 t/ha on the 12% slope. Changing to potatoes grown across the slope reduced soil loss by 86% on the 12% slope and by 66% on the 7% slope.
2) Stewart and Himelman also found that amounts equivalent to 5% of the nitrogen, 3% of the phosphorus, and 46% of the potassium applied as fertilizer to the potatoes grown up and down the slope were lost in runoff and erosion. When calcium and magnesium losses were included, the value of this loss from the potatoes on the two slopes averaged 33% of the value of the fertilizers and lime applied.
3) Data collected in this study showed that the most serious period of erosion occurred during April, and was largely caused by snowmelt. The investigators suggested that winter cover, obtained by seeding small grains (e.g. rye) in the fall, should be considered as a first step in reducing erosion during the snowmelt period. Greater use of rotations, reduction of fallow, and avoiding steep slopes for crops like potatoes and corn, were all considered necessary if continued economic crop production was to be expected from these potentially erodible soils.

As a result of this study, agricultural research and extension programs in Prince Edward Island have since included soil erosion as an important element. The problems are far from solved, but their recognition and understanding are valuable in gaining acceptance for the erosion control practices that must eventually be widely adopted.

Erosion by wind

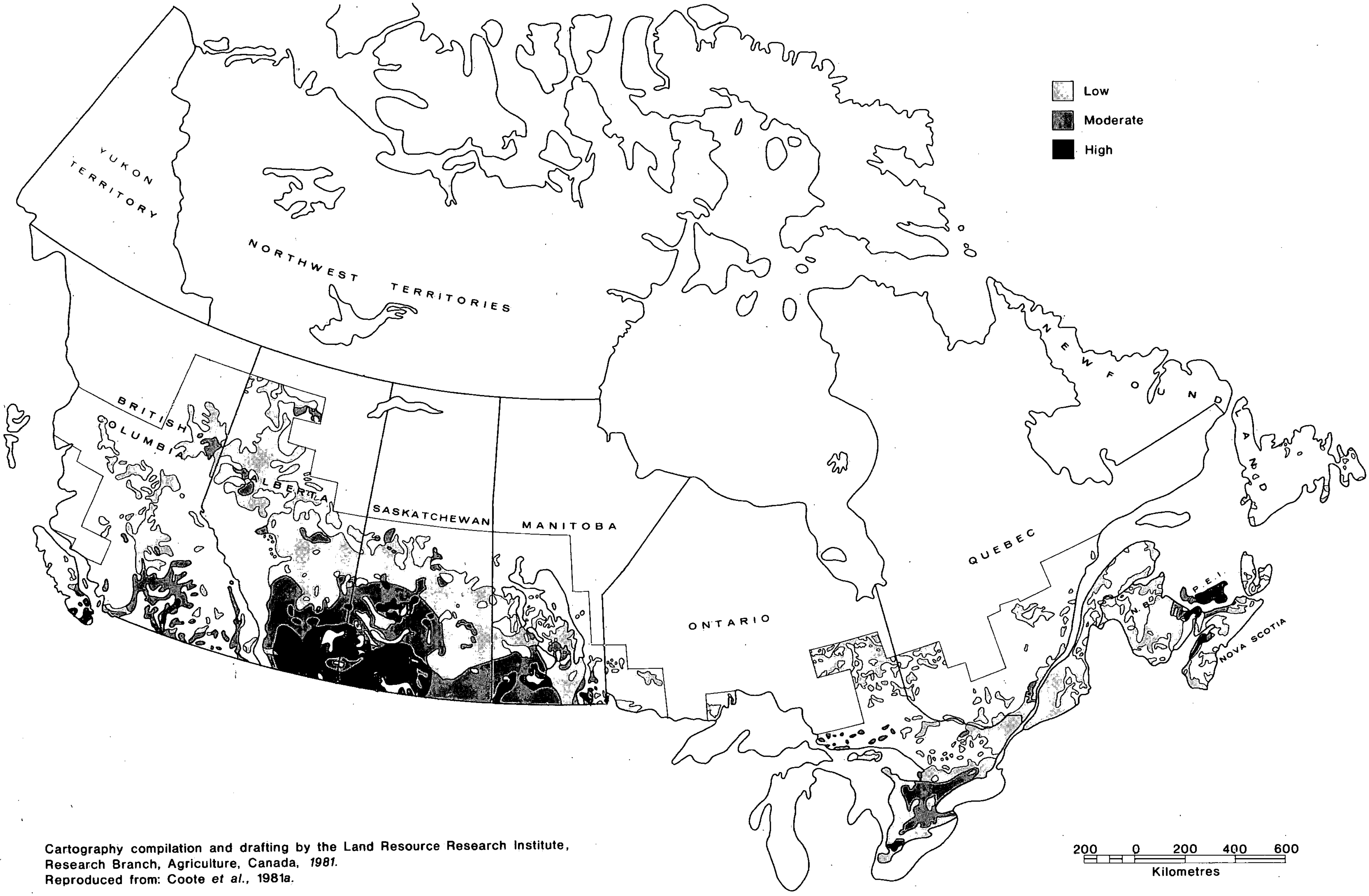
Processes

Wind erosion, like water erosion, removes the most valuable constituents of the soil first, taking the nutrients with them. The main factors determining the rate and severity of wind erosion are: 1) the resistance of soil particles to being moved along the ground by the drag of the wind, which is determined by the size of the soil particles and their aggregates, and their moisture content; 2) the velocity of the wind, which depends partly on the shelter provided by windbreaks and crops; 3) the roughness of the soil surface, which determines the drag of the wind at the surface itself; and 4) the plants or crop residues on the soil surface, which protect it from the wind (Chepil and Woodruff, 1963).

Fine sandy soils are most susceptible to erosion by wind, because a large portion of the particles are between 0.2 and 0.84 mm in diameter, the size range most easily blown by wind. Smaller soil particles generally cluster into aggregates held together by chemical and physical binding forces, enhanced by the presence of organic matter. If these aggregates are in the erodible size range, they too will add to the soil's erodibility. Thus almost all soil types will erode in strong winds if they are sufficiently dry. Even damp soils can become dry at the surface quite rapidly through the combined effects of strong dry winds and sunshine. Once soil movement is initiated, particles bounce along the surface,

MAP 1.

Relative wind erosion risk



Cartography compilation and drafting by the Land Resource Research Institute, Research Branch, Agriculture, Canada, *1981*.
Reproduced from: Coote *et al.*, 1981*a*.

displacing other particles so that they too are set in motion.

Windbreaks or vegetated strips of land, oriented across the prevailing wind direction, will reduce wind speeds for a considerable distance downwind. They also trap drifting soil particles. The more erodible the soil types, the closer should be the spacing of the crop strips or windbreaks, so as not to allow the wind to gather speed to an eroding level before the next barrier is reached. Ridges plowed across the wind direction, as well as large soil clods brought up from below the surface by chisel cultivators, can help reduce wind erosion in an emergency. The most effective control measure, however, is the maintenance of a mulch of stubble, straw, or other crop residues on the surface, which prevents the initiation of soil movement.

Location and extent

The risk of wind erosion has been predicted across Canada on the basis of soil types (textures), average wind speeds, and average soil moisture conditions (Map 1). Wind erosion will be dependent on the way in which the soil is protected as well as on the coincidence, at any particular location and time, of high winds and dry surface soil conditions.

Wind erosion in the Atlantic Provinces is less of a problem than elsewhere in Canada because of higher precipitation, broader distribution of forage crops, and extensive areas of forest. Prince Edward Island has the greatest potential for wind erosion because of the sandy soils, characteristic high winds, and relatively large percentages of land area that are cultivated. Wind erosion is still considered to be a minor problem there, but drifting soil and billowing dust are occasionally observed. Much the same situation exists in the scattered sandy soils of Quebec and eastern Ontario. The occurrence of blowing soil is usually limited to areas where monoculture corn or potatoes are grown, and fences and hedgerows have been removed to increase field size. These are obstructions to efficient use of large machinery, but they are highly effective in reducing wind velocities at the soil surface.

Wind erosion has become a problem in southwestern Ontario (Baldwin and Acton, 1978). The main risk period is in late winter when the snow has melted or has been removed by wind, exposing plow-furrow ridges after frost action has desiccated and crumbled the soil clods. Soil blowing can also be a problem during and after cultivation in unusually dry springs. It occurs particularly where fences and hedgerows have been removed, and where excessive cultivation has been practised for some time so that soils are low in organic matter, and structure and aggregation are weak. Sandy soils used for corn and potatoes seem to be most susceptible, although even clay soils are sometimes eroded by wind when conditions are right.

The most susceptible wind erosion area is southeast Alberta and southwest Saskatchewan, where high wind speeds and dry soils combine to provide the greatest risk. This area is also subjected to the warm, dry Chinook winds which blow out of the mountains causing erosion in the winter months. No data are available to estimate the total tonnage of soil that eroded during the worst period of drifting during the dust bowl days. However, some areas were known to have been stripped entirely of topsoil—a loss of about 2 000 t/ha. The PFRA community pasture program, established to rehabilitate the worst affected of these areas, covers over 800 000 ha (Anderson, 1975).

Estimates made in 1960 indicate that about 1 million hectares in Saskatchewan and Alberta were moderately to severely eroded, with another 2.7 million less seriously eroded, almost all of which was caused by wind (Johnson, 1961). In Manitoba, a further million hectares of moderately to severely eroded land, and 1.5 million hectares of slightly to moderately eroded land, were estimated to have been damaged by either wind or water or both. Scattered areas throughout the Red River Valley have suffered from wind erosion to the point that less fertile subsoil material is now brought up in tillage operations (Jenkins, 1968). Almost 20% of the improved farmland of the Prairie Provinces therefore appears to have been eroded by wind.

Generally speaking, the years following the worst of the dust bowl have been less hazardous and farmers have become complacent. Wind erosion control practices have been neglected and in recent years problems have re-appeared (Toogood, 1977). Drifting in the springs of 1976 and 1981 was particularly serious.

In the less arid areas of the Prairie Provinces, wind erosion is of less concern because of the slightly higher precipitation, lower wind speeds, more extensive continuous and forage cropping (i.e. less summerfallow), and more varied and wind-retardant vegetation (trees and shrubs).

Irrigated land in the high-risk zone around Lethbridge, Alberta, is also susceptible to wind erosion during the winter months. Row crops such as corn, potatoes, and sugar beet, grown under irrigation in this area, leave fields poorly protected after harvest and in the spring, unless special care is taken to maintain adequate residue cover on the soil.

Wind erosion does not appear to be a widespread problem in the Cordilleran region. The eolian origin of some of the soils of the interior plateau, however, renders them susceptible to drifting, which can also occur in outwash sands and lacustrine silts when they are exposed and dry. Intensive cultivation in some such soils in the valleys of southern British Columbia has led to intermittent wind erosion and even occasional dune formation.

Trends

Many of the trends relating to water erosion apply also to wind erosion. Minimum tillage and stubble-cropping trends in the prairies will tend to reduce the wind erosion risk in that part of the country. Field enlargement, fence and hedgerow removal, and the shift to more intensive monoculture cash cropping are increasing the risk in the east. An example of this trend is the increasing area of corn and soybeans being planted on land formerly used for hay and small grains in eastern Ontario. Another trend more directly relevant to wind erosion has been the shift from tobacco to corn on some sandy soils of southern Ontario. Under tobacco cropping, a rye winter cover crop and extensive use of manure are common. Windbreaks are also widely used. Where some marginal operations have shifted from tobacco to corn production, the soil is left with less protection over winter and wind erosion is now a concern.

A major uncertainty in predicting wind erosion in those areas that have suffered most in the past is the possibility of a prolonged climatic change to drier conditions. This would inevitably lead to an increase in summerfallowing and reduced yields and thus to more wind erosion. Some of the drier areas will probably always need some summerfallowing if they are to continue to grow grains and oilseed crops. However, snow-trapping methods (which reduce the loss of snow cover into ditches, sloughs, and windbreaks and retain it for soil moisture replenishment), together with increased use of fertilizer and better markets for the crop, have led many farmers in the less moisture-deficient soil zones (Black and Dark Brown soils) to reduce their summerfallow area. This will only be maintained if weather conditions remain reasonably favourable. A series of very dry years will convince farmers of the need for summerfallow as an "insurance" against yet another dry year.

Some examples from the Prairies

It is almost impossible to measure the extent or severity of wind erosion, and visual observations must generally be relied on to indicate the occurrence of the problem. A few recent examples are provided here.

During the spring of 1981 the prairies suffered very considerable wind erosion. The region from Calgary, Alberta, north to Saskatoon, Saskatchewan, and east to Brandon, Manitoba, suffered most. Road ditches filled with drifting soil and seedlings were smothered or damaged by abrasion. Under the small grains–oilseeds–sum-

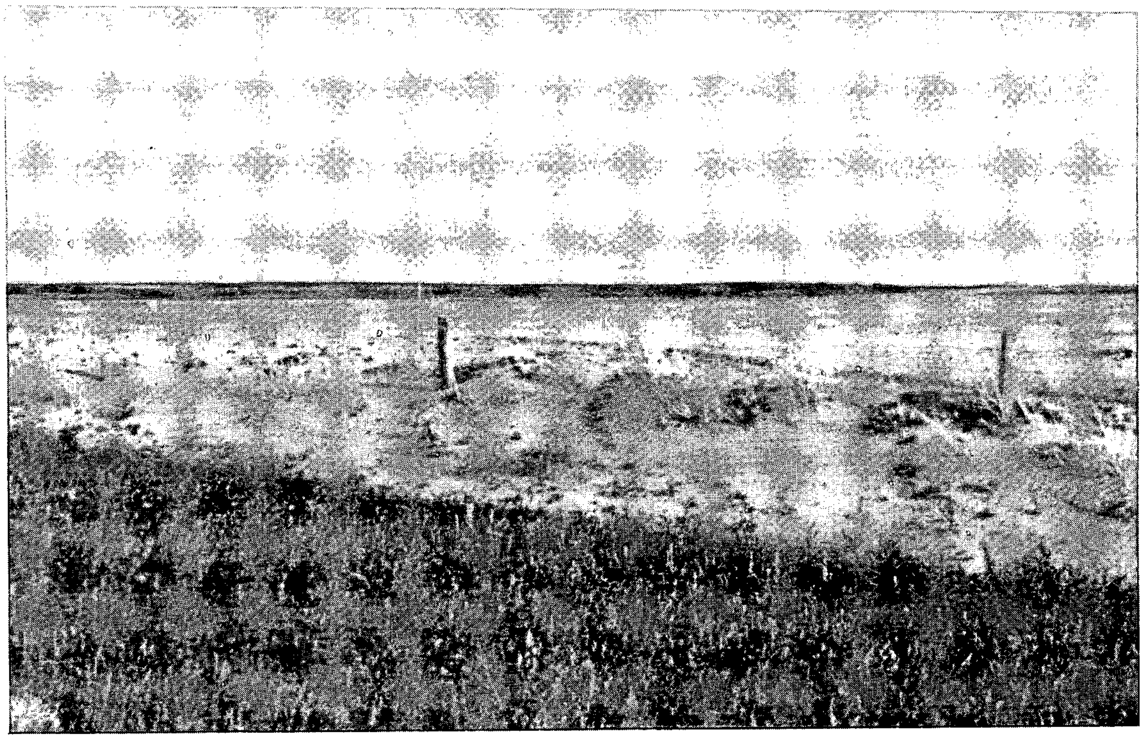


Photo 3. In this photo from southern Saskatchewan, soil has drifted into a fence-row from the field beyond. Productivity is permanently reduced when wind erosion like this persists.
D.R. Coote, Agriculture Canada

merfallow farming system (i.e. in the western part of this area) it was the summerfallow fields that suffered most and were the source of the drifting soil. Photo 3 shows drifted soil deposited in a fence-row in southern Saskatchewan. Very poor growth can be seen in the field beyond the fence-row, the source of the drifted soil. This drifting occurred in the spring of 1981 following the summerfallow year. The new crop was almost a complete failure.

Further east, in southwest Manitoba, a large field of fine sandy deltaic soil material was seeded with corn in the same spring. As the soil surface dried out, the fine sand started to blow, causing almost complete destruction of the seedling corn (Photo 4). This is an example of the use of a soil highly susceptible to wind erosion for a crop that, because of its slow germination and widely spaced rows, provides inadequate cover and protection during its early stages. The crop might have survived to a size where it would have protected the soil if the weather had been wetter. The outcome, however, was the most likely one, so the lesson to be learned is that the best protection for such soils is to avoid tilled crops altogether and grow forages, which essentially eliminate the wind erosion risk, or use recommended strip cropping spacings with adequate trash cover.

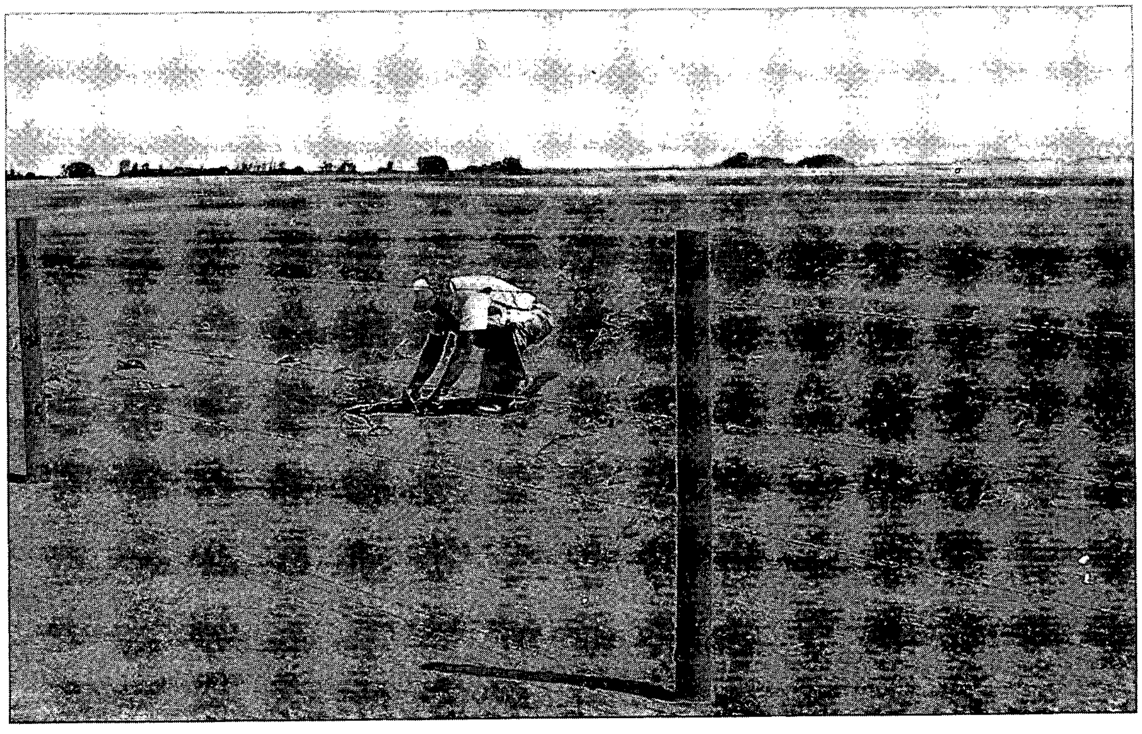


Photo 4. These young corn plants in southern Manitoba have been severely damaged by the abrasive action of wind-blown sand. The large open fields provide inadequate protection against soil drifting.
D.R. Coote, Agriculture Canada

In 1982, a year with relatively few wind erosion problems, Jenkins (1982) was successful in measuring the soil that drifted into a road ditch adjacent to a southern Manitoba field seeded the day before some strong winds were experienced. Calculations placed the drifted soil volume at almost 4 000 m^3 from an area of 32 ha, a loss of approximately 160 t/ha. Although this did not include the fine dust blown beyond the road ditch, it was still more than 14 times the annual soil loss considered "tolerable" by soil conservationists.

This information is being used by Manitoba soils specialists to impress upon farmers the losses they may suffer from even minor wind erosion, and to encourage them to adopt practices that will reduce the problem.

Loss of soil organic matter

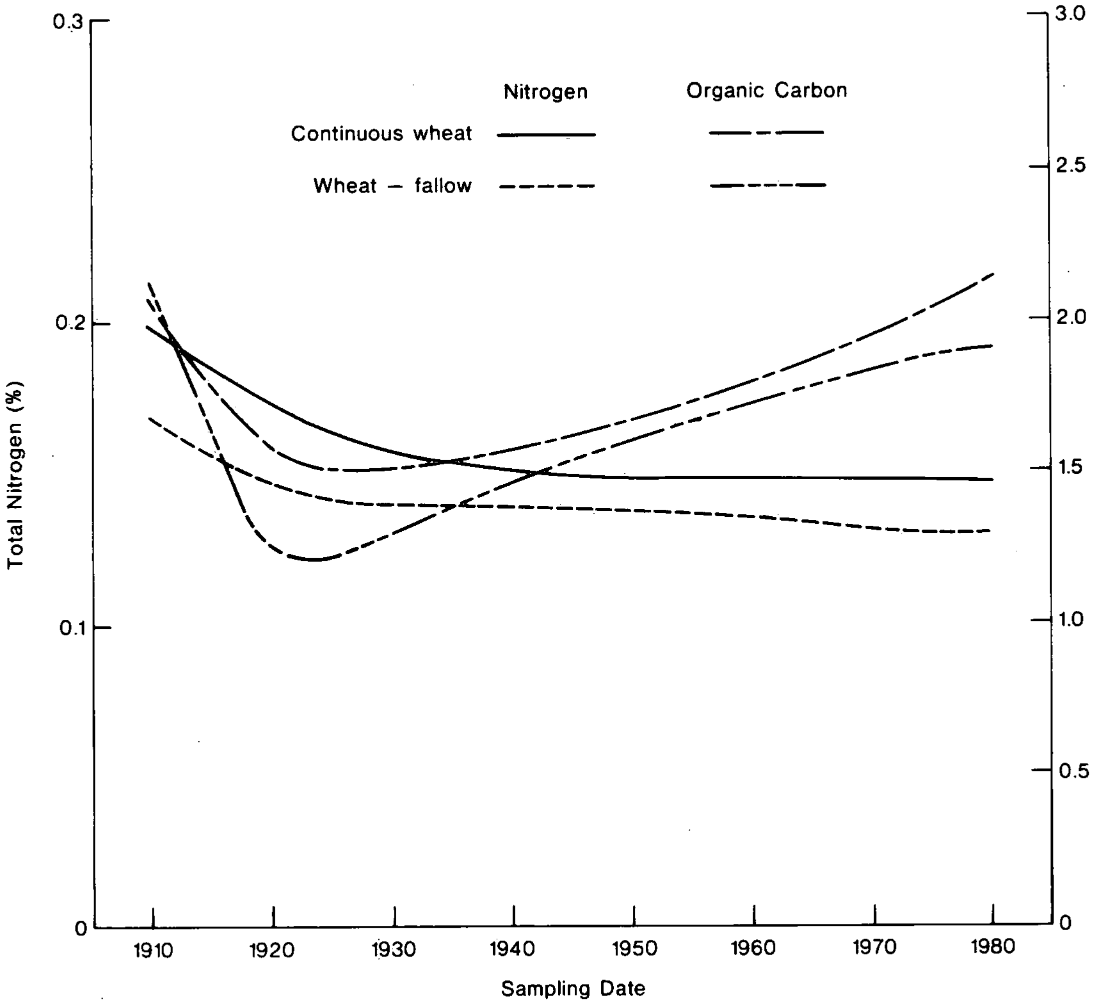
Processes

Soils start to lose some of their native inherited organic matter content immediately they are cleared, plowed, and tilled. The principal and most important process is one of aeration, which activates soil micro-organisms. The increased microbiological oxidation of carbon to carbon dioxide leaves the soil depleted of the most readily decomposed organic fractions. It also releases mineral nutrients, mainly nitrogen, for crop uptake or leaching by excess water. In land cleared of forest, a great deal of organic material in the form of trees, roots, and leaf litter is also burned to make way for cultivation. Erosion is also an important mechanism of organic matter loss.

Organic matter and organic nitrogen in soils exist according to a balance between input from plant residues and loss by oxidation (Martel and Paul, 1974). This is determined by the crop grown, residue management, type and frequency of cultivation, fertilizer and manuring practices used, and climate. Thus, for every set of crop rotation and management conditions, there will eventually be a characteristic organic nitrogen content for the soil type and climatic conditions at any given site. However, the equilibrium level of organic matter, although almost always below that which existed in the virgin soil, will depend on its nitrogen content. Figure 1 shows how soil nitrogen levels have declined in Alberta research plots under different cropping practices (Freyman *et al.*, 1982). It also

FIGURE 1.

Soil organic matter and nitrogen levels at Lethbridge, Alberta under continuous wheat and a wheat — fallow rotation over a 70-year period



From data of Freyman *et al.*, 1982.

TABLE 2.

Levels of organic matter in surface soils of Ontario and Quebec, and of nitrogen in soils of Quebec, as influenced by cropping practice

Soil type	Undisturbed	Continuous sod	Rotation	Continuous corn	Reference
		Percentage organic matter (no. of years)			
Ontario					
Clay loam	—	8.1 (50)	4.9 (5)[+]	3.7 (5)	Bolton and Webber, 1952
Clay	7.6	4.5 (8)	4.9 (8)[++]	4.0 (8)	Webber, 1961
Loam	6.5	4.4 (10)	4.1 (10)[++]	3.1 (10)	Webber, 1964
		Percentage organic matter/percentage nitrogen (no. of years)			
Quebec					
Clay loam	11.4/0.28	6.5/0.30 (25)	6.3/0.23 (30)[+++]	—	Martel and Deschênes, 1976
Clay	—	—	6.3/0.25 (10)[+++]	4.1/0.17 (8)	Martel and MacKenzie, 1980
Sandy loam	7.3/0.20	—	6.3/0.22 (30)[+++]	—	Martel and Deschênes, 1976

[+] Corn–corn–oats–hay–hay.

[++] Corn–oats–hay–hay.

[+++] Cereal–hay–hay–hay.

shows that total organic matter (organic carbon) in these plots has returned to near original levels, probably as a result of returning straw to the soil and replacing some tillage practices with herbicides. The data presented in Table 2 suggest that in eastern Canada both organic nitrogen and organic matter are declining under intensive cultivation.

Oxidation rates vary with soil types, cropping practices, and the length of time under cultivation. Research conducted over many years has shown that loss of organic carbon and nitrogen is most rapid in the first 5–6 years after cultivation; other studies have found little change in the rate of loss over time.

Over-grazing and burning also have an impact on soil organic matter loss. One study of over-grazing of range lands showed that the soil microclimate changed to that of a drier soil; that is, an over-grazed Black soil can assume the colour, pH, moisture, temperature, and organic matter content characteristic of a Dark Brown soil (Johnston *et al.*, 1971). This change, however, does not apply in all cases, as other studies have shown increases in soil organic matter under heavy grazing of some prairie grasses (Smoliak *et al.*, 1972). Burning of straw and stubble is still practised in some parts of the prairies, mainly to make tillage easier and allow soils to warm up earlier in the spring. The length of time that this practice can be continued before soil structure problems develop is not known.

Organic matter loss also results from intensive cropping of some irrigated soils. However, incorporation of crop residues such as corn leaves and stalks and sugar beet tops, and the use of manure where available, can arrest and even reverse this decline (Dubetz *et al.*, 1975).

The organic matter content of mineral soils is a major factor in maintaining soil structure; a loss of structure resulting from a decline in organic matter renders soils more susceptible to water and wind erosion and compaction. Moreover, organic matter is a major source of soil nitrogen and micro-nutrients, and gives the soil improved nutrient retention and water-holding capacities.

Location and extent

Loss of organic matter from cultivated soils appears to be a widespread problem throughout Canada, being dependent on the initial organic content of the soils and the effects of different cropping practices.

In soils of the prairies, native soil organic matter levels tend to be fairly high. Black Chernozemic soils have undisturbed organic matter levels that can be as high as 15%, but are more typically 5–10%; in Dark Brown and Brown soils they may be expected to be 3–7%. Organic matter is mineralized after cultivation and releases nitrogen and other nutrients that can be used by crops. It has been estimated that, on average, soils of the prairie region have lost 45% of their original organic matter since cultivation started around the turn of the century, and that this loss amounts to about 700 million tonnes of organic matter (McGill *et al.*, 1981). Summerfallow is a major reason for these high losses. Where precipitation is high enough, continuous fertilized cropping with small grains maintains a higher level of organic matter than that under summerfallow rotations (see Figure 1). Crop rotations incorporating a forage legume, or the use of manure, can reduce or even prevent the net loss of organic matter from a cultivated soil.

In the more humid regions of Canada, soil organic matter is also being lost as a result of frequent, and often excessive, tillage. In several studies of Quebec and Ontario soils, it was found that organic matter levels were highest in undisturbed land, were lower under continuous hay and rotations of hay with corn or cereal grains, and were lowest under continuous corn. Reductions of 50% or greater were noted (Webber, 1961 and 1964; Martel and MacKenzie, 1980). Other studies have shown that the organic matter content will equilibrate at a higher level if manure or other organic material is added to the soil (Sowden and Atkinson, 1968).

Loss of organic matter is often accompanied by reductions in soil aggregation, as evidenced by size and strength analyses of water-stable aggregates. Soil aggregation is directly related to soil resistance to erosion and compaction. Reductions of 40–60% in water-stable aggregation indices were reported under continuous corn compared with a 4-year corn–oats–hay–hay rotation on various soils in southern Ontario (Ketcheson, 1980). Fifty years of continuous sod on one of these soils left water-stable aggregation 60% higher than under rotation (Bolton and Webber, 1952). Three cultivated soils in southern Quebec used for a grains–forage rotation had water-stable aggregation indices ranging from half to one-fifth the values in the same soils in the undisturbed state (Martel and Deschênes, 1976). Both water-stable and dry aggregates increased dramatically with time over a 25-year period of continuous sod on both a clay loam and a sandy loam soil in Quebec; water-stable aggregation in the clay loam soil dropped an order of magnitude under continuous corn compared with that under a 5-year rotation (Martel and MacKenzie, 1980).

Similar results have been noted in the Atlantic Provinces, but soils in this region tend to have lower natural organic matter contents than elsewhere. Intensive tillage (especially for crops such as corn, tobacco, and potatoes) together with high erosion rates have reduced organic matter levels in Prince Edward Island to the point where serious deterioration of soil structure must soon be expected (Veinot, 1978). This will reduce yields and increase runoff and erosion. Observations made in New Brunswick suggest a similar situation to that in Maine, U.S.A., where soil organic matter and aggregation have been decreased by intensive tillage for potatoes, and runoff and erosion have increased (Saini and Grant, 1980). Very little information exists on soil organic matter losses in British Columbia. Intensive tillage is common in the soils of the lower Fraser, Okanagan, Kootenay, and other valleys in the southern part of the Province, where vegetables, corn, grapes, and other fruit are grown. There is a high probability of organic matter loss under these conditions. As well, the dry rangelands of the interior are subject to organic matter loss when they are over-grazed.

Trends

Organic matter levels are usually found to decline most rapidly when soils are first cultivated. The rate of loss then often slows down as an equilibrium level characteristic of the soil type, climate, and cropping practices is approached. Data from the Prairie Provinces indicate continued losses although the equilibrium levels are close to being reached (McGill *et al.*, 1981). More intensive and productive agricultural systems tend to produce an equilibrium organic matter content higher than that under summerfallow rotations. Thus the trend toward more stubble-cropping (i.e. less summerfallow), which has already been observed in Alberta and Manitoba, should be beneficial for soil organic matter levels in the Prairie Provinces. This trend is likely to continue under pressure to increase grain exports.

As monoculture row cropping for corn, soybeans, potatoes, and similar intensive crops becomes increasingly widespread in eastern Canada, organic matter levels will continue to decline over much of the land affected, until new equilibria are reached. The tendency to reduce mixed farming, leading to fewer livestock and fewer rotations based on hay and small grains, means that a large portion of the land now used for monoculture row crops has previously been used for hay and much of it has received manure. Organic matter levels were therefore fairly high when the land use changed, but the new equilibria will almost certainly be lower than those established over the last half century.

An example from Manitoba

As an example of the loss of soil organic matter, research at the University of Manitoba provides a valuable record of differences resulting from a number of alternative cropping systems. The results of 37 years of cropping a Black Chernozemic soil under a range of cropping intensities and fallowing frequencies were reported by Ridley and Hedlin (1968).

The study showed that all the rotation and fertilizer treatments that had been used resulted in a decline in organic matter content compared with the level of about 10% at the time the experiment was started. Unfortunately, there was no continuous grass treatment, which might have shown whether the original content could have been maintained by an agricultural use closely resembling the native prairie condition. Nevertheless, the highest value of organic matter after 37 years was 7.6% under continuous cropping for wheat with 8.9 t/ha of manure added annually. Even without manure, the organic matter content for continuous wheat was 7.2%, which was higher than any other treatment. At the other end of the scale, an alternating wheat–summerfallow system led to an organic matter level of 3.7%, which was only slightly higher, 4.1%, when manure was used. At 6.8 and 6.3% respectively, continuous oats and barley maintained almost as high an organic matter content as continuous wheat. Seeding alfalfa or grass prior to the summerfallow year of a fallow–3-year wheat system, and plowing this under as a green manure the following spring, led to a considerable improvement in organic matter (5.8% for alfalfa, 6.3% for grass) compared with the use of the more common bare summerfallow in the same cropping sequence (4.7%).

Yields of grain were higher in years following fallow, probably because of the availability of mineralized nutrients derived from declining soil organic matter reserves, and the additional soil moisture stored in the summerfallowed soil. However, Ridley and Hedlin (1968) found that total production over the period of the cropping sequence was far higher for continuous cropping than in any system in which no crop was grown in some years, even where no manure or fertilizer was used.

This study also included continuous corn, a cropping practice more common in eastern Canada. The organic matter content after 37 years was 5%, which was higher than any of the systems that incorporated bare summerfallow but was still the lowest of any of the non-summerfallow treatments. The 5% was half of the soil's original organic matter level, a loss comparable to that observed in eastern Canada under continuous corn.

Clearly, cropping systems that leave the soil free of vegetation and well aerated for extended periods lead to lower levels of soil organic matter. These lower levels provide less nutrient storage, lower resistance to erosion, and less structural stability than soils maintained in grassland or forage-based rotations. Rebuilding soil quality takes many years. By the time changes in cropping practices are made, lasting damage to the soil resource may have occurred.

Loss of organic soils

Processes

Organic (peat) soils are developed from material derived from dead and decaying plant residues. They form in bogs and marshes where water stands all year and the sediments have low oxygen levels. As plant and animal material dies and settles to the bottom, it decomposes only very slowly due to the anaerobic conditions. The rate of accumulation exceeds the rate of decomposition so that an organic soil develops.

The process of organic soil formation is reversed if conditions are drastically changed by drainage and cultivation for agriculture. The soil is aerated and decomposition rates accelerate; at the same time replenishment is reduced. The loss of buoyancy and shrinkage that occurs following drainage, and the compaction caused by machinery, also lead to a reduction in total volume of material. These processes constitute what is known as "subsidence". Organic soils are often also very susceptible to erosion by both wind and water. The material is very light when dry and is easily blown if left unprotected by crop cover, residues, or windbreaks. Runoff and poor drainage practices can also erode organic soil materials into outlet drains.

Loss of organic soils can be minimized by maintaining water tables as high as possible and by flooding during the winter months. This requires fairly expensive and sophisticated drainage systems, usually employing pumps to alter water table levels. Recent research has shown that soil subsidence rates may be reduced by the inhibition of bacterial and enzyme activity through which oxidation occurs. Studies in Newfoundland and Quebec have demonstrated that copper, originally added as fertilizer supplement to correct for deficiencies in some organic soils, has the effect of inhibiting oxidation of carbon, and thus reduces subsidence rates (Mathur *et al.*, 1979). Further research is underway to examine the practicality of applying copper to organic soils as a means of reducing subsidence from biochemical oxidation.

Depending on tillage and moisture conditions, and type of organic material, the total subsidence rate is high in the first few years after drainage and then declines. In some cases organic soils are also lost by deliberate or accidental burning.

Location and extent

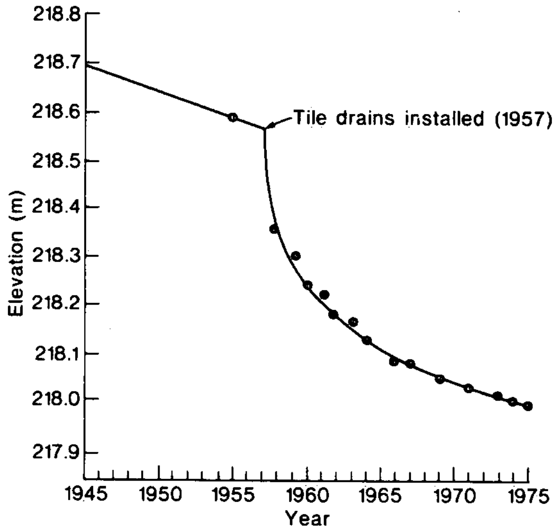
The area of organic soils in Canada is estimated to be at least 90 million hectares (Clayton *et al.*, 1977). However, only a very small proportion has a climate suitable for agriculture. Where the organic soil materials are rich in nutrients and reasonably well decomposed, and the climate is favourable, they are generally used for high-value crops such as onions, carrots, lettuce, and other vegetables (Photo 5). The principal areas of such use are in Quebec south and east of Montreal (about 7 000 ha, 90% of which is in the area directly south of Montreal), in Ontario north of Toronto (about 3 300 ha) and in the southwest near Lake Erie (about 2 200 ha), and in the lower Fraser Valley of British Columbia (about 1 800 ha). Other very small areas of organic soils used for vegetables and larger areas used for field crops and hay are found in each of the Atlantic Provinces, in eastern Ontario, in southern Manitoba to the north and east of the prairie grassland soils, and in the Lower Mainland and interior of British Columbia. No precise area figures are available for these organic deposits.

Photo 5. Intensive use is made of this productive organic soil in southwestern Ontario by growing vegetables such as the radishes shown in this photo. Without windbreaks, these large flat fields are susceptible to wind erosion when not protected by a crop.
Agriculture Canada

All cultivated organic soils have been drained, and are subsiding as a consequence of oxidation, shrinkage, and compaction. In Quebec an estimate of subsidence in an organic soil area cultivated for vegetable production was 2.1 cm/year over the first 38 years of cultivation. Based on this rate, it was predicted that the soil would be no longer usable after another 44 years (Millette, 1976). Although this may have underestimated the useful life of the soil, because of the more rapid rate of subsidence that occurs during the first year or two after drainage, it is interesting to note that the Holland Marsh in Ontario is expected, by some extension specialists, to last about the same length of time.

Post-drainage subsidence rates were measured at about 3.3 cm/year in the Holland Marsh between 1959 and 1962, following drainage and pump improvements made in 1957 (Irwin, 1977). Between 1967 and 1976, they were estimated to be about 1.1 cm/year, which was the same as the estimated rate prior to drainage improvements. Figure 2 shows the surface elevation of the organic soil from 1945 to 1975. After the drainage improvements the rate of subsidence increased drastically, levelling off after a period of about 10 years to the rate prior to the drainage improvement. In the year immediately following the new drainage works, the soil subsided at least 20 cm.

FIGURE 2.
Observed organic soil subsidence at Holland Marsh, Ontario



Reproduced from Irwin, 1976 (by permission of the author).

Estimates of subsidence rates are not available for organic soils in other areas of Canada. It has been suspected that loss rates may be higher in cultivated organic soils in the lower Fraser Valley and Vancouver Island in British Columbia because of the absence of prolonged periods when these soils are frozen. Prolonged freezing, common in organic soils elsewhere in Canada, slows the decomposition of the soil material.

Relatively small areas of organic soils are still being cleared for cultivation in many parts of Canada. In some cases, however, the organic materials are considered undesirable and are burned to expose the mineral soil below. This practice has been used extensively in eastern Manitoba (Michalski, 1977). In areas intended for cereal grains or hay, the organic material is often considered a hindrance as it creates problems of trafficability and nutrient immobilization.

Trends

Organic soils are being used in all regions of Canada. Proper maintenance and control of water tables are important factors in extending the longevity of these soils, but this requires carefully engineered and expensive dikes, ditches, and drainage and pump systems, which are seldom available. The tendency has generally been to drain the area to the greatest extent practicable. Pumps can effectively allow resaturation of these soils with the benefit of reducing subsidence and oxidation rates.

At present there is little evidence of a move toward the improvement of water table control in organic soils. However, development of chemical inhibitors such as copper, to reduce enzyme activity and oxidation, holds promise for future reduction in loss rates of organic soils.

Some organic soils that have been used for many years, or that were initially shallow, are reaching a depth where tillage operations are mixing mineral soil from below with the organic material. These soils are then generally used for field crops such as corn. As organic soils used for vegetables reach this stage of depletion, they too are likely to be turned over to field crop production. The soils best suited to vegetable production will thus have been lost. Only very limited reserves of new organic soils in the favourable climatic zones are available for development. Production costs will rise, and yields and quality will fall, as less well-suited soils are used. This could also lead to increased dependence on imports from other countries for Canada's basic food needs.

An example from Quebec

The organic soils of southwestern Quebec are an important vegetable growing area, with about 6.5 million hectares in production and an estimated farm gate value of vegetables produced in 1979 of about $17 million. This was 36% of Quebec's total vegetable production (Bureau de la statistique du Québec, 1980). The Agriculture Canada Research Station at St-Jean, Quebec, which is located in this important organic soil area, has monitored surface elevations of drained organic soils to estimate the amount and rate of subsidence being experienced (Millette, 1976; Millette *et al.*, 1980).

Topographic surveys taken in 1974 and 1978 were compared with one completed in 1936. The loss of elevation varied from field to field, depending on the cropping practices and water management. One area, which had had a fairly uniform 30-cm depth of well-decomposed organic soil overlying sphagnum peat in 1938, was found in 1974 to have depths of this layer varying from 20 to 46 cm, depending on the practices used. The area had been in hay from 1936 to 1946 and had then been used for different rotations of carrots, lettuce, onions, celery, and potatoes. Wooded windbreaks were planted around the area to protect it from wind erosion. Wooden drains were installed in 1937 at 38-m spacings, draining to a 60-cm deep open drain around the area. Additional tile drains were installed in 1972. Since 1951, irrigation water has been used to maintain a near constant water table and avoid overdrainage. The average subsidence on this area from 1936 to 1974 was found to be nearly 79 cm, or 2.1 cm annually.

Between 1974 and 1978, efforts were made to measure in more detail the loss of these soils. Planting oats, for example, was found to have reduced the average subsidence rate of the two fields in which this practice was used from 1.4 cm/year to zero, with an accumulation of about 0.1 cm/year. In three other fields, runoff from adjacent areas caused erosion such that the average loss rate exceeded 4.4 cm/year.

In a further study conducted in six commercially farmed organic soils in the region, Millette *et al.* (1982) found that subsidence rates varied from 1.0 to 7.0 cm/year. Both the highest and the lowest subsidence rates were in subsurface-drained fields with outlet controls, used for intensive vegetable production (mainly carrots) for more than 20 years. In nearby undrained wooded areas with the same soil types, they found that very little change in the soil surface had occurred, with all sites apparently increasing in elevation at the rate of about 1.0 cm/year.

As a result of these observations, several measures have recently been undertaken to reduce the loss of the organic soils at the Research Station. These include seeding oats on uncultivated areas, the construction of runoff diversions to prevent water erosion, and the installation of outlet controls on subsurface drains to maintain higher water tables. These and other measures can now be tested and improved and then encouraged among the farmers of the region while the search continues for better methods of subsidence control. With some estimates suggesting that these organic soils may not last for another 50 years at current rates of subsidence, the work of finding better methods to control this loss is clearly urgent.

Chemical deterioration of agricultural land

Soil salinization

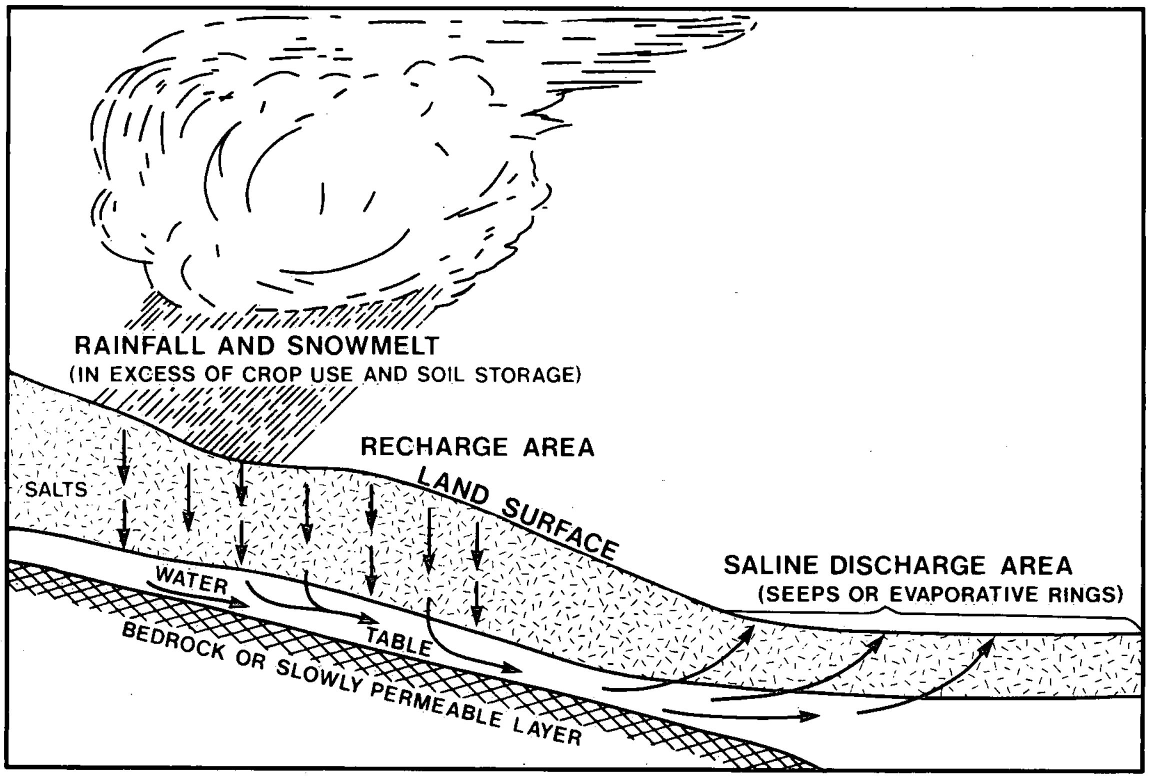
Processes

Soil salinization occurs when salts found in arid soils (from weathering of soil parent materials) are redistributed so as to bring them close to the surface, where they interfere with normal root growth and plant uptake of water and nutrients. The redistribution process results generally from the leaching of salts by water percolating through subsoils at one location, and then the accumulation of these salts at, or near, the surface of the soil in another area from which water evaporates. Figure 3 provides a schematic view of the process. In some locations, near leaky irrigation canals for example, the salts are not moved very far and may come from the subsoil immediately below the salinized area. In other locations, salts may travel longer distances from a recharge zone to a discharge zone. Flow may be from an upland area to a discharge site on the lower slopes or in a valley.

The process of salinization occurs without man's intervention and has, over the years, given rise to the salt flats and saline depressions common in most of the arid prairie region. A related process involving saline soil parent materials high in sodium content, sometimes associated with high water tables, has led to the development of the extensive areas of Solonetzic soils found in Alberta and Saskatchewan. The process of salinization that results from stresses placed on land by agriculture, however, is generally one where the naturally established groundwater levels and flow patterns are altered, leading to salt accumulation in a previously non-saline area or to the spread of an existing saline area.

Changes in the established patterns of shallow groundwater movement can result from the construction of roads, railways, irrigation canals, villages and towns. Perhaps the factor of greatest concern, however, because of its widespread nature, is the alteration of the hydrologic cycle brought about by replacing perennial native grasslands and wooded depressions in the prairies with annual grain crops having a lower net utilization of water. When summerfallow is also used, the amount of unused water that percolates deep into the soil is increased. Summerfallow retains only about 25% of the moisture it receives, the rest being lost to evaporation, run-

FIGURE 3.
Typical mechanism of dryland salinity development



Modified from Vander Pluym, *et al.*, 1981 (by permission of the author).

off, and seepage. Even where the summerfallow area is reduced and continuous cropping with wheat or barley is practised, consumptive use of water is only half to two-thirds of that under grassland. The shortfall is greatest in the spring when annual crops are not yet established. Alfalfa, on the other hand, has an even greater capability of extracting moisture than the grasses because of its deep rooting system. It can be assumed, however, that under native grassland there is very little groundwater recharge over much of the prairie region, as deep percolation of precipitation is limited even under grain crops (Staple *et al.*, 1960).

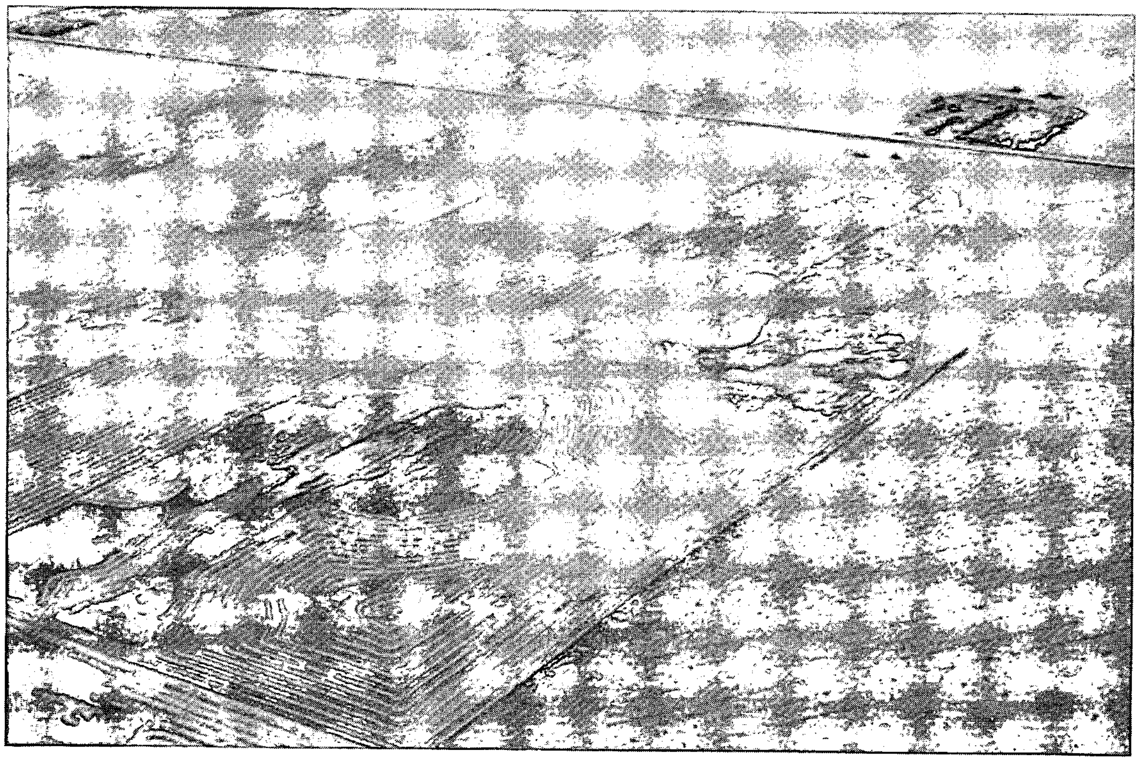


Photo 6. This aerial photo shows saline seeps in Alberta. Note the white surface salt deposits, weeds, and poor plant growth in the salt-affected area.
H. Vander Pluym, Alberta Agriculture

Over the years the flow of excess water, carrying dissolved salts when these are present in the subsoil, contributes to increased elevations of water tables—especially following periods of above average precipitation. The raised water tables result in areas where water moves to the surface by capillary action, evaporates, and the salts are retained by the soil. Many such areas are called "saline seeps" (Photo 6).

Henry and Ballantyne (1980) have distinguished four types of dryland saline seeps:

> Side-hill seeps, in which the entire salinization process occurs within a hillside, usually where soils are layered with different textures, with either bedrock or clay beneath to impede vertical water movement;
>
> Toe-slope seeps, in which the recharge area is in an adjacent range of hills;
>
> Regional seeps, in which groundwater flow occurs from hills to regional lowland;
>
> Evaporitic rings, which occur around sloughs or drainage channels.

High levels of salinity reduce germination and growth of most crops by interfering with water and nutrient transport mechanisms at the soil–root interface. The salts are usually sulphates, chlorides, carbonates, and bicarbonates of calcium, sodium, and magnesium. A soil is considered saline when the electrical conductivity of saturated water extracts of the surface soil exceed 4 mS/cm (millisiemens per centimetre). At this level of salinity many crops will still grow, but at 14 mS/cm only very tolerant native weeds can survive. Although there is a wide range of salinity tolerance among varieties of any particular crop, there is a general tendency for tolerance to be greatest in forages, lower in cereals and oilseeds, and least in vegetables. When more than 15% of the exchangeable bases is sodium these soils are known as saline-sodic or saline-alkali. Such soils usually have a very poor physical condition, depending on the amount of sodium present (Henry and Johnson, 1977).

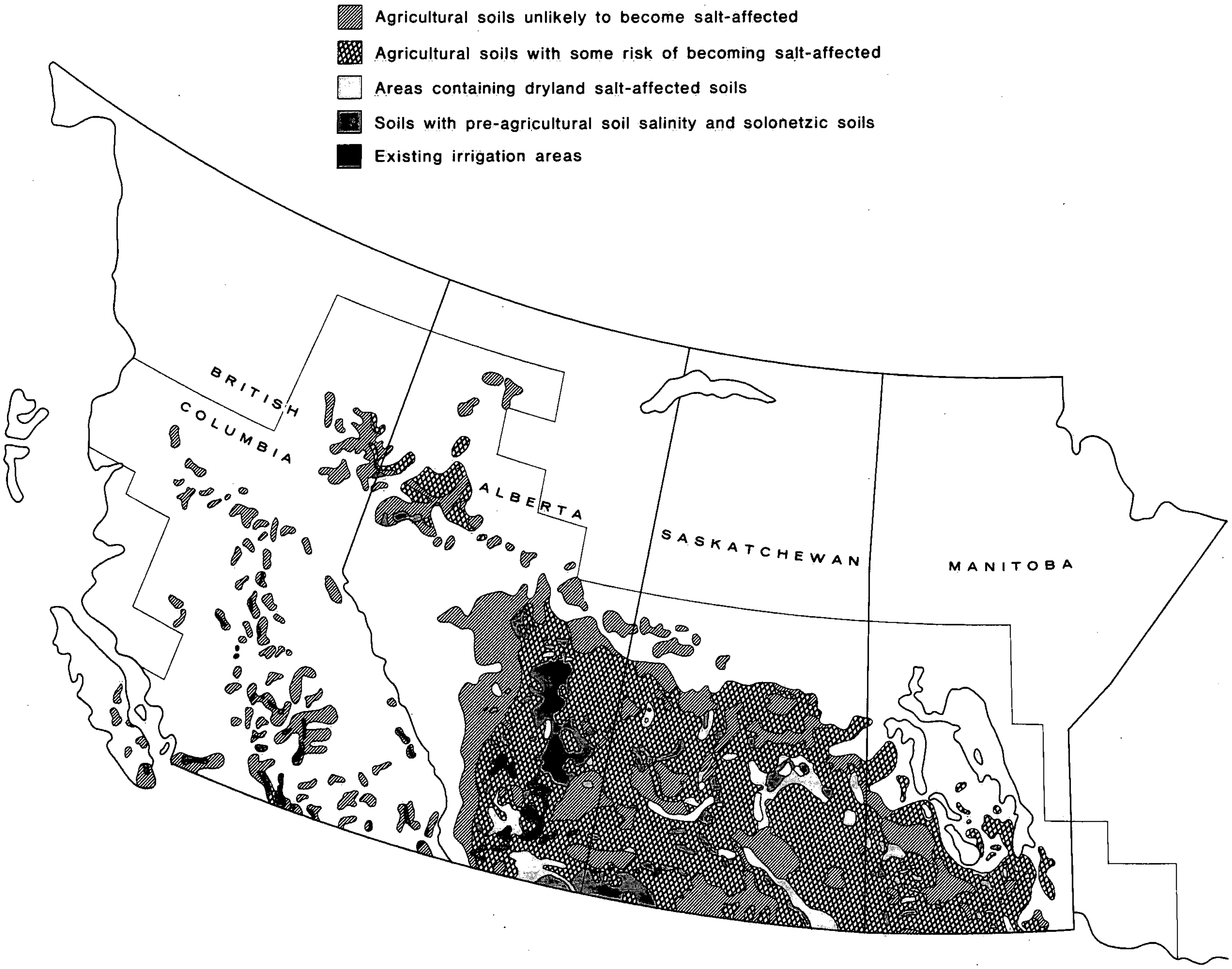
Salinity in irrigated areas commonly occurs when water tables are raised in the vicinity of canals because of leakage, or as a result of seepage from excessive water applications. As irrigation water raises water table levels it brings dissolved subsoil salts nearer the surface. When the water evaporates, the salt content of the remaining soil water increases until crop damage results and salt-tolerant weeds invade the area. Further evaporation results in the destruction of all vegetation, and eventually the formation of salt crusts.

Location and extent

Salinity only occurs to any significant extent in arid areas. Thus, with the exception of a small

MAP 2

Salt-affected soils and relative risk of soil salinization



Cartography compilation and drafting by the Land Resource Research Institute, Research Branch, Agriculture, Canada, *1981.*
Reproduced from: Coote *et al.*, 1981a.

number of sites in the interior of British Columbia, salinization is a problem of the Prairies. Most man-induced salinity occurs in very small areas (1–10 ha), but cumulatively they amount to an estimated 2.2 million hectares in dryland, and a further 100 000 ha in irrigated land (Vander Pluym *et al.*, 1981). The scattered nature of salinized areas is difficult to show on a map. Nevertheless, Map 2 shows where the largest concentrations of dryland salinity occur. The map also indicates the location of irrigated areas, but does not attempt to identify irrigation salinity. This is a widespread problem, however, affecting 15–25% of the irrigated land in Alberta and Saskatchewan. The older irrigation districts appear to be the most severely affected. There are no data on the amount of land salinized in British Columbia or Manitoba irrigation developments. Also shown on the map are those areas where pre-agricultural salinity is to be found, including the naturally saline Solonetzic soils. These latter have high sodium contents, causing dense subsurface horizons which impede drainage and root development.

Dryland saline seeps generally occur within about 2 km of the recharge area (Vander Pluym *et al.*, 1981), but there are some regional water movement systems that cover far greater distances. Farmers have observed dryland saline seeps develop and spread since the 1940s. On some farms so much land has gone out of production that additional land had to be purchased to keep the farm at an economic size. In Saskatchewan it is estimated that over 6.5% of the agricultural land is affected; in Manitoba about 4.6% and in Alberta about 1.0% is saline. These estimates include rangelands as well as cropped and summerfallowed land.

Trends

Future changes in soil salinity are far from clear. The severity of the problem at any given site varies from year to year depending on the amount of rainfall and snowmelt available to drive the system. Rates of salinization appear to increase following a series of wet years, and decline during dry periods. One study has suggested that dryland saline seepage, which has been spreading at the rate of about 10% annually, will soon enter a period of stabilization during which increases in affected areas will decline and eventually cease (Vander Pluym *et al.*, 1981). On the other hand, Sommerfeldt (1977) indicated that there is a strong likelihood that the process of groundwater salt movement, which has taken so many years to become established, will continue and perhaps increase in severity.

It has been noted that salinity in irrigated areas begins to appear about 10 years after a scheme goes into operation. Dryland salinity, however, appeared 35–40 years after the areas affected were first cultivated. The implication is that even in areas where the distance between source and seep is short, many years must pass before the changes in hydrology and salt content of the shallow groundwater create a saline seep condition.

In both Alberta and Manitoba over the last few decades there has been considerable reduction in summerfallowing, the cause of the most drastic alterations of water movement in dryland. In Saskatchewan, however, rates of summerfallowing continue with much less reduction. Even a considerable reduction in summerfallowing, and its replacement by continuous cropping with small grains, will not entirely eliminate the surplus water that feeds the salinization process. Greater use of alfalfa and other forages would have a positive effect in controlling the problem. In addition to lack of markets for the alfalfa and grasses, however, is the problem that these crops tend to leave the soil too dry for a succeeding grain crop, i.e. they have the opposite effect to that of summerfallow. Their widespread adoption is therefore unlikely, and so the continuation of conditions that contribute to dryland salinity seems assured, at least for the immediate future.

The situation in irrigated land is more encouraging. Great strides are being taken to increase the efficiency of water distribution and use throughout Alberta irrigated land (the largest irrigated area in Canada). Lining of canals to reduce leakage and increased use of sprinkler irrigation to reduce over-application of water are having a positive effect. Where necessary, subsurface drainage is also being installed to rehabilitate land that was becoming salinized. These techniques are also being established in other irrigated lands in western Canada. Irrigation salinity should not prove difficult to reduce. Dryland salinity, unfortunately, will provide a far greater challenge for many years to come.

An example from Alberta

There are very few salinizing areas that have been thoroughly characterized and investigated. One for which data are available is located near the town of Vulcan, Alberta, between Calgary and Lethbridge (Greenlee *et al.*, 1968). The area had been reported to have become progressively more saline over the period before the study began in 1965, and this was confirmed by comparison of air photos taken during the growing seasons of 1951 and 1962. Greenlee and his associates installed water table wells at three positions down the seepage slopes at each of four study sites. At one site, the wells were supplemented with three nests of four piezometers, which measure the pressure head of groundwater, at depths going down to the bedrock surface. On the slope above the saline seep, bedrock occurred at about 5 m below the soil surface; lower down the slope in the salinized area it was about 11 m deep. All the soils were loams, with subsoil textures varying from sandy loam to clay loam. Analysis of soil profiles indicated that soils lower down the slope had been saline at some earlier time during their development, but that a process of leaching and loss of salinity had long since been dominant. Re-salinization was now causing problems of high salt concentrations in the soil and declining productivity.

Piezometers and water table wells indicated that the area upslope from the seep was a recharge zone, i.e. that water entering the subsoil moved downwards and laterally away from the area. Salt contents of soil extracts and the groundwater in this area gave electrical conductivities of about 1.0 mS/cm, clearly non-saline. In the saline area, conductivities were greater than 20 mS/cm in the soil extracts from the surface to the lowest depth of sampling (about 1.1-m depth). The piezometers in this area showed that groundwater was rising to the surface. The groundwater had an electrical conductivity of about 7 mS/cm, indicating that the salts were accumulating in the soil.

To investigate the groundwater flow further, dye was added to the water in the wells at the top of the slope. The dye appeared later in wells and wet depressions (sloughs) farther down the slope. However, some of the wells and piezometers remained free of dye, indicating that the groundwater in the discharge zone was also coming from sources other than the upslope field area. Salt analysis, i.e. sodium content, strongly suggested that this water was coming from aquifers in the bedrock.

It is noteworthy that, at the time of this study, summerfallow was practised extensively in the Vulcan area. Other studies in this region (Van Schaik, 1974), clearly demonstrated that deep percolation of water occurred from time to time in a loamy soil under summerfallow. The inference was clear: that summerfallowing in the area of Vulcan appeared to be increasing groundwater levels and flows toward the lower slopes and that salts were moving with this water and being precipitated in the soils of the saline seep areas. Results such as these are now being used extensively by soils specialists across the prairies in an attempt to convince farmers that salinity is a side-effect of summerfallowing. Reducing summerfallow now may therefore have hidden future benefits by allowing the maintenance of soil quality through the avoidance of soil salinity.

Soil acidification

Processes

One of the dominant processes in soil formation is that of acidification, in which acids from the decomposition compounds of organic matter, and from the dissolution of carbon dioxide in water, enhance the rate of weathering of soil minerals. The process takes place in almost all soils, without the interference of man. In humid regions and in soils low in neutralizing minerals (such as limestone) the process proceeds faster than in soils of arid zones or where the soil has a high content of calcium or magnesium available to neutralize the acidity. Many soils are thus naturally acid. Farmers with such soils use powdered limestone (lime) as a neutralizing soil amendment on a regular basis to keep soil acidity at a level generally between pH 6.0 and pH 7.0, at which nutrient availability and crop growth are optimum (MacDonald, 1982).

Acidification is frequently accelerated, however, by man's activities. Chief among these is probably the use of fertilizers. Ammonium-based nitrogen fertilizers have the greatest acidifying affect, which is derived from the bacterial nitrification process that takes place in the soil after the fertilizer is applied. Ammonium is converted to nitrate, with the release of hydrogen ions that cause soil acidity. If the fertilizer material also contains sulphate, the acidifying effect is even greater. On average, nitrogen fertilizers need about three times the weight of nitrogen they contain as calcium carbonate (limestone) to neutralize the acidity. Some fertilizer materials have this calcium built in as part of the carrier (bulk) material.

The other main source of soil acidity contributed by man is that contained in rain and dry atmospheric deposition, which comes from air pollution. Coal burning, natural gas processing, vehicle exhaust gases, and a number of industrial emissions release sulphur and nitrogen compounds (mostly oxides) into the air, where they are dissolved in rain water to form acids. These are the components of "acid rain". Many of these gaseous emissions can be absorbed directly by the soil, causing further soil acidification (Hoyt *et al.*, 1981). Table 3 provides an indication of the relative importance of acid rain and fertilizer in causing soil acidity across Canada.

A third type of soil acidifying process is found in a few areas where sulphides occur in the soil, such as diked coastal flood plains and certain ancient marine sediments. Drainage and cultivation of these soils allows any sulphides present to oxidize to sulphates, with a drastic increase in acidity. Such occurrences are rare in Canada, being mainly in reclaimed coastal soils, in Nova Scotia, New Brunswick, and British Columbia.

Soil acidification is a problem of stress on agricultural land because it reduces the availability of plant nutrients such as nitrogen, phosphorus, calcium, potassium, and magnesium. At the same time it increases the availability of aluminum and manganese, sometimes to the point that plant toxicity occurs. Microbiological activity is also altered so that nitrification and nitrogen fixation are reduced, while certain fungal, ammonia-forming processes are favoured. Populations of earthworms and other soil fauna, which help aerate and mix the soil, are also adversely affected. Limestone must be added to acid soils to bring their pH back to the near-neutral range, from levels sometimes as low as pH 4 in severely acid soils. Except for certain special crops such as blueberries, which thrive in acid soils, acidity is a soil-degrading process resulting in reduced crop yields.

TABLE 3.
Representative annual contribution to soil acidity by atmospheric deposition (1977–1979) and fertilizer use (1974–1979)

Location	$CaCO_3$ equivalents required annually for neutralization (kg/ha)		
	Atmospheric[+]	Fertilizer[++]	Total
Atlantic Provinces	30	84	114
Quebec	35	51	86
Ontario	33	90	123
Manitoba	5	72	77
Saskatchewan	0	12	12
Alberta	2	51	53
British Columbia	5	66	71

[+] Based on estimated contribution of long-range transported acidity from precipitation calculated from Coote *et al.*, 1981*b*.

[++] Based on fertilizer sales data, Canadian Fertilizer Institute, assuming an average requirement at a ratio of 3:1 (calcium carbonate to nitrogen).

Soils vary in their susceptibility to increases in acidity (decreases in pH), which is related to their "buffering capacity". This is a measure of the amount of calcium and magnesium available to neutralize acidity before it develops in the soil. Acid sandy soils with low organic matter content generally have the lowest buffering capacity; neutral (and alkaline) clay soils high in organic matter have the highest. This is because organic matter and clay provide the soil with a large capacity to retain these neutralizing cations, and the pH is an indicator of the degree of depletion that has occurred.

Location and extent

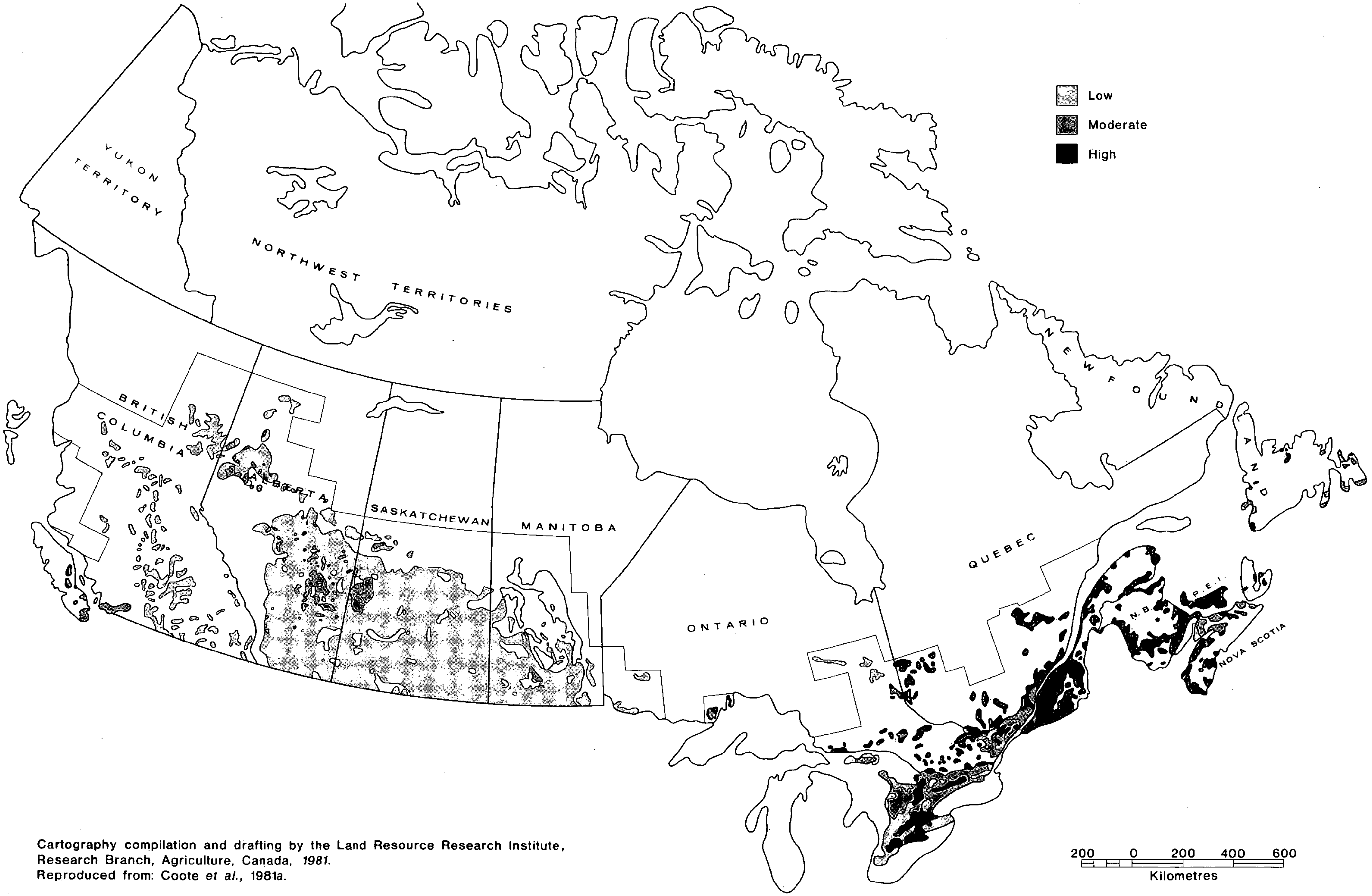
The susceptibility of soils across Canada to acidification is shown in Map 3. Naturally acid soils are found throughout eastern Canada. They are especially common in sandy materials and in those derived from the granitic rocks of the Pre-Cambrian Shield. Periodic liming of these soils has long been practised, but the use of nitrogen fertilizers and the increase in the acidity of rainfall in this region have made it necessary to use more lime than would otherwise have been required. However, in many of the acid soils of the Atlantic Provinces, pH values of 5.5 and lower are tolerated for potato production, as they help to control diseases such as potato scab.

Soils of southern Ontario have received very little lime in the past as most of the parent material is high in limestone. However, these soils have received some of the highest rates of nitrogen fertilizer in the country, mostly for corn production, and their surface-neutralizing capacity has become depleted. In addition, these soils are in the area of Canada subject to the greatest amount of acid rain, which has further depleted their surface reserves of bases (Coote *et al.*, 1981*b*). Although these soils have ample free calcium and magnesium carbonates at lower depths, acidity of the surface soil is increasing so that unfavourable conditions for root development are becoming more common. Furthermore, the subsoil lime is now often beyond the reach of young and shallow-rooted plants. The problem is most serious in sandy textured soils in the highly productive corn, vegetable, and potato-growing areas of southwest Ontario.

In the southern semi-arid prairies soil acidity is not a common problem, being restricted generally to the surface layer of some Solonetzic soils. Soil pH levels of 5.5–6.0 are of concern to prairie farmers who rely heavily on microbial mineralization of organic matter to supply a major portion of the nitrogen needs of the crop, a process that is inhibited by soil acidity. Farther north, in both Alberta and Saskatchewan, soil acidity is more common, being associated with soils of the sub-humid forested zones as well as with Solonetzic soils. There are over half a million hectares of agricultural soils in these two provinces with pH values below 5.5, and

MAP 3.

Relative risk of soil acidification



Cartography compilation and drafting by the Land Resource Research Institute,
Research Branch, Agriculture, Canada, *1981*.
Reproduced from: Coote *et al.*, 1981a.

another 1.8 million hectares between pH 5.5 and 6.0 (Hoyt *et al.*, 1981). Soil acidity is also being aggravated, but to a lesser degree than in eastern Canada, by fertilizer nitrogen use and atmospheric acidity. The latter is of particular concern immediately downwind of the gas-processing and tar-sands plants of Alberta. Lime is currently unavailable in the Prairie Provinces at a price that would allow its economic use on most farmland, so that the acidity, now often being recognized for the first time, is not yet being neutralized.

In British Columbia, most of the very acid agricultural soils (pH below 5.0) are found in the Lower Mainland and on Vancouver Island. The total area is small, however, there being only about 23 000 ha of these soils in the Province. Fertilizer use in orchards of the Okanagan Valley has produced localized acidity around individual trees, sometimes to pH values below 4.0. Lime use in southwest British Columbia has long been practised, but has only recently been extended into the Okanagan. Through the interior of British Columbia into the Peace River region, however, lime is generally not readily available.

Trends

The clear trend, confirmed by soil testing services across the country, is for the problem of soil acidification to increase in extent and severity. Nitrogen fertilizer use continues to increase, with only a slight moderation as a result of recent increases in cost. Acid rain levels do not appear to be decreasing, and could increase considerably in eastern Canada if greater use is made of coal as an energy source. In western Canada, increases in acid rain are likely only if there is an expansion of tar-sands processing and sulphur removal from natural gas.

Hoyt *et al.* (1981) projected, somewhat tenuously, that industrial sources could increase the acidity of Alberta soils to the extent that an additional 48 000 hectares would fall into the "acid" category (i.e. pH below 6.0) over the next 15 years. This is a small area compared with their prediction that over 1 million hectares in Alberta and the Peace River region of British Columbia will cross the "acid soil" threshold in the same period as a result of nitrogen fertilization.

For eastern Canada, Wang and Coote (1981) estimated that almost 30% of the agricultural soils, or about 3 million hectares, are at least moderately sensitive to acidification. This means that more than 10% of the exchangeable bases in these soils could be depleted by acid rain in a period of 25 years. Depending on the present pH of these soils, this loss of bases could lower the pH by up to half a unit, creating problems for the production of certain crops such as alfalfa, soybeans, and barley. Fertilizer use will affect these soils in much the same way as acid rain.

Liming practices in Quebec and the Atlantic Provinces are well established, and farmers may be able to control soil acidity by maintaining or increasing their current lime application practices. In the Lower Mainland of British Columbia and Vancouver Island the situation is similar. In the prairie and Peace River regions and in southern Ontario, present acidification will only be checked if new programs are established to make liming materials economically available.

Hoyt *et al.* (1981) have estimated that, at average prices to be expected if a viable liming industry were to be established in Alberta and Saskatchewan, farmers could recover the cost of lime in the first 2 years after application. With benefits expected to last 10–15 years after lime application, the idea appears highly feasible but has yet to be pursued. Until it is, soil acidity in this part of Canada can be expected to continue to increase in severity and area. Demonstration sites and subsidized introductory liming programs may be needed before the practice of liming becomes established in this region. In southern Ontario, lime sources are closer to the soils where the lime is needed and a marketing infrastructure exists that can be utilized once the demand for lime becomes clearly established. It is likely that this demand will materialize in the near future and soil acidity will be checked in this important area of agriculture soils.

An example from British Columbia

An interesting example of soil acidification is the situation that has developed in apple orchards in the Okanagan, Similkameen, and Kootenay valleys in British Columbia (King, 1972; Lau and Peters, 1980). The soils of these orchards all originally had neutral or slightly alkaline pH values (pH 7.0–7.6). In 1970 it was noticed that some trees being treated for what was assumed to be a simple case of boron deficiency were showing no response. As part of an investigation of the possible causes of this, soil samples were collected from around the affected trees and all samples were found to have pH levels below 5.0, which is very acid. The "boron deficiency" was attributed to manganese toxicity, caused by the increased solubility of manganese in acid soils.

Further investigation revealed that the increased acidity was nearly always found in the area within the drip line of the trees, i.e. under the leaf canopy. Irrigation water was distributed in almost all orchards as a uniform application to the whole area, including the soil between the trees where the pH was still neutral in most orchards. This ruled out the leaching of irrigation water as a cause of the acidity. Nitrogen fertilizers, however, were generally applied only under the trees. In one area studied, this was the case in all but 6 orchards, where it was spread uniformly over the whole area. Only in these 6 orchards was the pH similar in the area between the trees to that under them. At three of these sites the pH was near 5.5 (King, 1972). One of the fertilizer types commonly used was ammonium sulphate, which is known to be among the most acidifying fertilizers in general use.

The conclusion was inescapable: nitrogen fertilizer use on the apple trees over a number of years had acidified the soil to the point that at

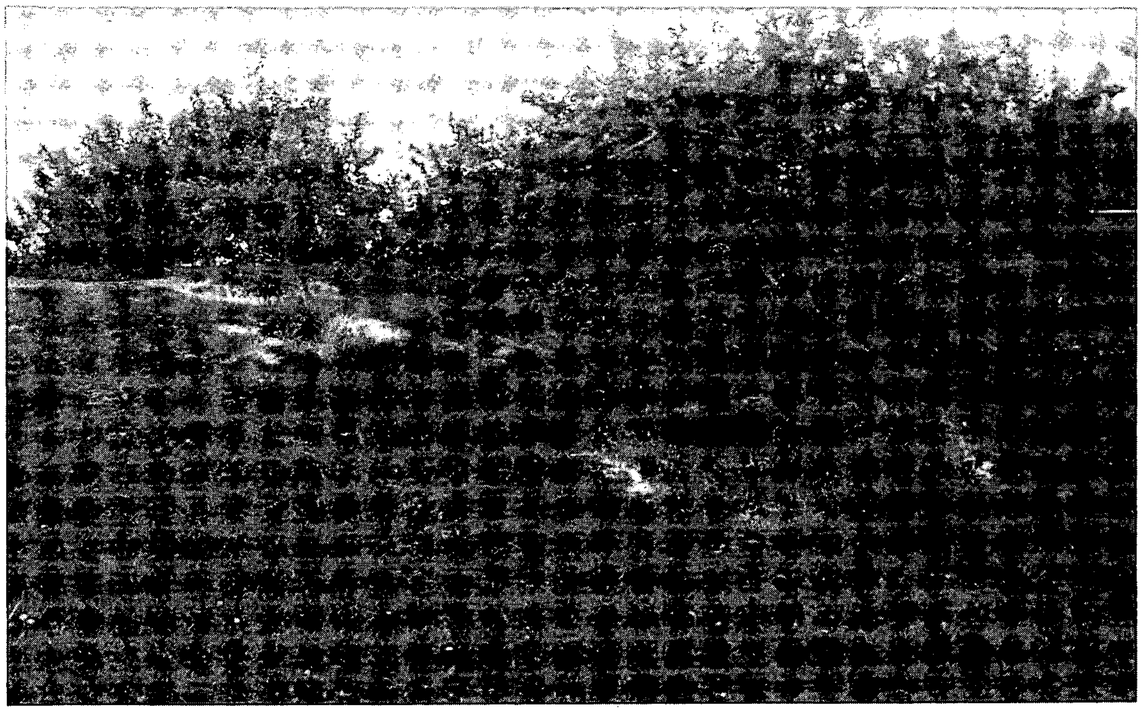


Photo 7. Fruit trees in the Okanagan Valley have been treated with lime applied to soil at the base of each tree to control soil acidity that develops when nitrogen fertilizers are used.
D.R. Coote, Agriculture Canada

least one nutrient imbalance had seriously affected many trees. Further investigation (Lau and Peters, 1980) has shown that the problem was most severe on the sandy soils, which are those least able to resist acidification because of their poor ability to retain the calcium and magnesium which neutralize acidity. Great variability was encountered in the soil pH values among these orchards, and this has been attributed to differences in the chemical composition of the soil parent materials, to the lime content of irrigation water, as well as to the soil texture and fertilizer use. Acid rain effects have been calculated from rainfall chemistry and are among the lowest in the country so that in this example, at least, acid rain does not appear to be contributing significantly to soil acidity.

Today, lime use in southern British Columbia orchards is being encouraged with considerable success (Photo 7). At the same time, the use of ammonium sulphate is being discouraged as a fertilizer material. King (1972) also suggested that non-acidifying nitrogen fertilizers such as calcium nitrate should be made available to apple growers in this area, but this has not yet occurred because of the high cost of this material.

Soil contamination

Processes

Soil contamination is sometimes called "soil pollution", and results from undesirable chemical additions to agricultural land. It includes the chemicals found in atmospheric fallout, as well as those from sewage and industrial sludge disposal, and pesticide residues. It can also include biological contamination.

Radioactive fallout and persistent residues of the now banned organochlorine pesticides are currently uncontrollable but appear to be declining to below tolerable levels. The rate of radioactive fallout (strontium 90, for example) peaked around 1965–1966, and is now declining by natural decay. Without a resumption of atmospheric testing of nuclear weapons, or a nuclear catastrophe, these levels should continue to decline. There is no known practical method by which present levels can be reduced, but crop uptake has been found to be within the limits required by health standards. As far as is known, radioactive wastes from generating stations are not currently being disposed of in a manner that affects agricultural land.

A great deal of information has been gathered on the fate of persistent organochlorine pesticides in soils. The use of the organochlorine insecticides aldrin, dieldrin, and DDT was phased out between 1969 and 1972, and the use of chlordane, heptachlor, and endosulfan has now been greatly restricted. Levels of these compounds are declining through biological decomposition. However, decomposition rates are affected by soils and climate, being higher in warmer, moister, and coarser textured soils than in cooler, drier, and heavier textured soils (Edwards, 1966; Frank *et al.*, 1974; Stewart and Chisholm, 1971).

Few herbicides persist in the soil at phytotoxic levels for more than a year at normal application rates. However, cool climates and clayey soils delay herbicide decomposition, and some herbicides, such as paraquat, are so tightly bound to soil clay particles that decay is almost halted, resulting in accumulation in the soil (Khan *et al.*, 1975).

The production of orchard and vegetable crops for extended periods on the same soil has resulted in accumulations of some residues of arsenic, lead, and copper, which were associated with the pesticides used before the organochlorine compounds came into prominence in the 1950s. Fortunately, considerable environmental awareness on the part of researchers and farmers, together with intensive evaluation processes before current pesticides are registered for use, has reduced the extent of soil contamination by residues.

Sewage sludge can be a valuable source of nitrogen and phosphorus for most crops, and is sometimes welcomed by farmers if provided at little or no cost. However, sewage sludge from industrial areas is often contaminated with heavy metals and toxic organic compounds. Studies in Ontario have shown that crop uptake and leaching losses of heavy metals are small (Webber *et al.*, 1978). This indicates that metals are accumulating in the soils to which sludge is applied. Of particular concern are cadmium, lead, chromium, nickel, copper, and zinc, all of which are retained by the soil following sludge applications (Bates, 1972). Continued incremental buildup can lead to eventual toxicity to plants and perhaps also to livestock or humans. Critical soil levels have been suggested but have not been finally decided (Ontario Ministry of Agriculture and Food, and Ontario Ministry of the Environment, 1981). Some sludges have already been declared unacceptable for land disposal because of cadmium content.

Soil contamination by metals and other chemicals is a continuing possibility from other sources. Emissions from industrial smoke-stacks and vehicle exhausts, and dust particles from open storage of industrial materials, are sources periodically encountered.

Biological contamination is a complex problem, which includes such organisms as the golden nematode of potatoes in Newfoundland and Vancouver Island, as well as a number of other soil-borne disease organisms such as clubroot in cabbage and root rot in cereals and tobacco. Animal parasites and diseases such as coccidiosis of poultry and anthrax in cattle can also be transmitted by contaminated soils. However, most parasitic and disease organisms survive for relatively short periods, and proper management of livestock and pastures can prevent reinfection.

Location and extent

Southern Ontario is the region of Canada most affected by soil contamination, although even there it is not yet a problem of great significance. There are considerable volumes of urban and industrial wastes for disposal, because of the strict sewage and effluent treatment standards designed to protect the Great Lakes. Consequently, much sewage sludge is being spread on farmland, a practice that is likely to increase as landfill sites become more scarce. This region also has the highest density of industrialization and urban population in Canada, resulting in high overall levels of waste production. Fuel consumption is also high, as are atmospheric emissions (e.g. lead). The intensive fruit and vegetable production in the area has also led to greater use of pesticides than in most other regions.

Approximately 11 100 ha of farmland in Ontario were used for sewage sludge disposal in 1975, all within 40 km of the city that produced the sludge (Webber *et al.*, 1978). In 1978, 34% of Ontario's sludge was disposed of in this manner, the remainder being mainly incinerated (41%) or landfilled (16%). With possible increases in the degree of phosphorus removal at sewage treatment plants (to meet the requirements of revised United States – Canada Great Lakes Water Quality Agreements), it is likely that the quantities of sludge to be disposed of will increase still further. Because land used for sludge disposal should not be re-treated with sludge for a number of years, to avoid heavy-metal buildup, the total area affected may be five to ten times greater than the area used in any particular year.

Many Ontario soils used in the past for orchards and vegetables (especially potatoes) have slightly elevated levels of arsenic, copper, mercury, or lead, or a combination of these, caused by past use of pesticides and vegetation killers to facilitate harvesting (Frank *et al.*, 1976). Sludge disposal on these soils may therefore be more hazardous than on others.

The entire area from southwestern Ontario to the Atlantic Provinces receives the heaviest deposition of atmospheric pollutants in Canada, as suggested by acid rain data (Coote *et al.*, 1981*b*). Frank *et al.* (1978), have shown that for at least one toxic industrial organic compound (PCB), the quantity deposited in rainfall on the soil was considerably greater than that leaving a number of small watersheds in drainage and runoff water. This suggests that the material was being retained in the soil and vegetation. Cumulative quantities, however, were not great enough to allow detection in soil samples. Another example of airborne pollution of soils is the nickel, copper, and zinc found downwind of nickel smelting operations in Ontario (Rutherford and Bray, 1979). Fluorine contamination has also been suspected downwind of aluminum smelters in the St. Lawrence Valley near Cornwall, Ontario, and in the Lac Saint-Jean region of Quebec.

Soils in the potato-growing areas of Prince Edward Island and New Brunswick have often received sodium arsenate when the crop was treated to kill surface growth prior to harvesting. Some arsenic residues can be found in the soil from the use of this material, which has now been discontinued.

The large area of eastern Canada used interchangeably for crops such as corn, soybeans, alfalfa, and small grains also suffers a problem with the carryover of herbicides such as atrazine. The atrazine is used on corn, but may damage the other succeeding crops. This is generally a temporary form of soil contamination, which can be avoided by careful selection of herbicides combined with proper attention to crop sequence.

There is less immediate concern for soil contamination in western Canada, other than by sulphur and by salts that have already been discussed. There is some sewage sludge disposal on agricultural land by the cities of Winnipeg, Yorkton, Regina, Saskatoon, and Calgary. Municipal wastewater is used for irrigation in a number of small communities throughout the prairies and the interior of British Columbia. No soil contamination problems have yet been identified in these areas. Soil contamination has occurred in isolated instances as a result of oil spills associated with wells and pipelines. Salt and potash mining also produces some downwind soil contamination from fine dust, especially where open storage piles are used.

In all parts of Canada where processing of fruit and vegetables occurs, wastes are produced that are frequently disposed of by irrigation. Many of these wastes contain very alkaline materials and soils have been temporarily damaged through their disposal. Soils can also suffer a type of contamination if they are used for the excessive disposal, or dumping, of manure. This is most common where livestock numbers are excessive in relation to the area available for waste disposal. Such problems have been encountered in the lower Fraser Valley of British Columbia, and in Quebec south and east of Montreal. Besides making the soil almost unworkable for several years, these manure dumps have badly polluted runoff water, which can easily pollute streams, lakes, and wells.

Trends

Trends in soil contamination are very difficult to discern. On the one hand there is a greater awareness of the dangers of pesticide residues; on the other hand there is an ever increasing quantity and variety of industrial compounds being manufactured, or appearing as by-products, that are finding their way into soils and the environment in general.

Atmospheric dispersion of wastes is receiving more and more attention because of its relationship with acid rain. If acid rain is successfully reduced by limiting atmospheric emissions of sulphur and nitrogen, it is probable that soil contaminants will be reduced correspondingly. Contaminated discharges to sewage systems, however, are difficult to trace and control. They inevitably lead to the contamination of sewage effluent, and the contaminating materials are often concentrated in the sludge during treatment for phosphorus removal. These sludges are landfilled, incinerated, or spread on the land. Landfill sites within easy reach of treatment plants are increasingly difficult to find; emissions from incineration simply change the route of contaminant movement, adding to atmospheric deposition and creating an ash disposal problem. For municipal officials, spreading sludges on agricultural land near urban centres is therefore becoming the most attractive alternative for disposal. This unfortunately may lead to added pressure on farmers to accept sludges of doubtful quality, resulting in greater soil contamination.

With the cost of pesticides and fertilizers increasing steadily, many farmers are adopting the "integrated" approach to pest control and the use of manures. With integrated pest management, the use of crop rotations and carefully timed pesticide applications minimizes the damage done by insects and weeds, and reduces the amount of pesticide used. Although current pesticide formulations are carefully tested, minimizing their use should further reduce the risk of soil contamination. The trend to wider and better use of manure for economic reasons will reduce the risk of this material being dumped on small areas of land simply as a disposal practice. Full utilization of manure as a fertilizer will increase soil quality, and reduce contamination by excess nutrients or salts.

An example from Ontario

As an example of the contamination of soils that can occur as a result of the disposal of sewage sludge on farmland, a brief review of some of the results of an extensive study by the University of Guelph for the Canadian and Ontario governments is presented here (Soon and Bates, 1981). The study considered the nutrient and heavy-metal content of three different types of sewage sludge obtained from a number of cities in southern Ontario. The effects of different sludge application rates on heavy metals in soils and crops were studied, together with similar studies on the major and minor crop nutrients.

The principal criterion on which sewage sludge applications are based in Ontario is usually nitrogen content (Ontario Ministry of Agriculture and Food, and Ontario Ministry of the Environment, 1981), with the intent of reducing the risk of nitrogen pollution of water supplies. Secondary criteria are the existing soil phosphorus levels and the ratios of nitrogen to the 11 heavy metals of most concern in sewage sludge. The latter provides for limits to the maximum total application of each metal. Traces of all heavy metals are found naturally in most soils and plants, but the maximum safe levels for livestock or human consumption are still uncertain. Two heavy metals that provide an indication of the difficulties encountered in determining allowable applications of sludge are considered in this example.

Cadmium is a heavy metal seen as particularly dangerous to man and animals. Soon and Bates (1981) found that with certain sludges there was a steady increase in cadmium in both soils and crops almost every year as applications continued. At the level of application at which the Ontario guidelines for cadmium applications were just exceeded, one type of sludge (aluminum treated) had increased the level of soil extractable cadmium i.e. available to plants, by about 300%. The concentrations of cadmium in corn plants increased by about half this amount. With a calcium treated sludge, on the other hand, there was very little change in soil extractable cadmium or crop uptake, even when the maximum guideline application level was exceeded.

In the case of nickel, however, it was a calcium flocculated sludge that resulted in the greatest increases in the extractable soil nickel levels—up to 6 times greater on one soil type at the application rate at which the recommended maximum application was exceeded, compared with about a two-fold increase with the aluminum sludge. Concentrations in corn plants were increased about 200% and 10% respectively.

As sludges decomposed, heavy metals were found to move only slightly in the soil, otherwise remaining near the surface where they were applied. However, from this location they could be lost to the surrounding environment through wind and water erosion. Recommendations have been made to reduce the risk of runoff and erosion of heavy metals and nutrients, such as not applying sewage sludge to steep slopes or near waterways.

Sewage sludges were demonstrated to be a valuable source of nitrogen, phosphorus, and other elements required by crops. However, it was also shown that the toxic heavy metals they often contain behave very differently in soils depending on the element itself, the type and origin of sludge, and the type of soil. Thus farmers should be wary of sewage sludges and should insist that the present guidelines, provisional as they are in some respects, are closely adhered to. Once contaminated, soils will retain heavy metals almost indefinitely, which may create future problems.

Physical deterioration of agricultural land

Soil compaction

Processes

Soils suffer compaction when their structure deteriorates and particles are re-arranged in such a way that the volume of the spaces around them is reduced. This can happen in several ways including: repeated loading of the soil by driving over it with heavy machinery; shattering clods (aggregates) and vibrating smaller particles into a denser packing arrangement by tillage machinery used at high speed, or with deliberate shattering action, e.g. rototillers; losing organic matter that binds soil particles into stable aggregates; and squeezing air out of the soil and collapsing the pore structure by working the soil when wet (Photo 8).

Soil compaction is detrimental for many reasons. It results in poor conditions for root growth; water and air cannot move freely in the soil to optimize the root environment. Roots cannot penetrate to deeper soil horizons in which additional moisture and nutrients are generally available, thus plants are more susceptible to stress during dry conditions.

Soil compaction reduces the rate at which water moves into and through the soil. This results in greater surface ponding (which damages many plants), surface runoff, and soil erosion. It has also been observed that water often fails to percolate to subsurface drains fast enough to provide the required drainage. Soil compaction increases the energy requirements for tillage, requiring larger tractors or narrower machinery, resulting in greater fuel and time costs. It is generally associated with the frequent tillage practices of continuous monoculture row cropping. Repeated tillage at the same depth causes the condition known as a "plow pan". This is a dense layer in the soil that generally forms immediately beneath the depth at which tillage, especially plowing, is done.

Soil compaction seems to be most severe in soils that are either coarse textured (sandy) or fine textured (clayey). This may be due to the better aggregation of soil particles into clumps (aggregates) in soils with a mixture of particle sizes (loams). Some research suggests that compaction is at least partly reduced by frost action in soils during the winter.

Location and extent

Soil compaction and structure deterioration are being investigated across Canada, but relatively few measured data are available to assess the extent of the problem. For example, in the Lower Mainland of British Columbia heavy textured (clay) soils with high water tables that are frequently worked in a wet condition are known to have been damaged by compaction. Water stands for long periods on the surface of some fields, even with subsurface drainage. However, no measurements have been made of the exact cause or severity of the problem, and no inventory has been made of its extent.

There is much the same lack of information in eastern Canada, although some data are available in southern Ontario, southern Quebec, and New Brunswick. Compared with corn grown in rotation, continuous corn in southwestern Ontario caused a reduction of air-filled pores in the soil of about 10% and an increase in bulk density, resulting in a need for more fertilizer to maintain yields (Bolton *et al.*, 1979; Bolton and McDonnell, 1982). In eastern Ontario, repeated tillage over a period of 35 years for both continuous corn and continuous small grains (oats, barley) has been shown to reduce water movement, increase soil density, and reduce air-filled pore space in at least four different soil types (Coote and Ramsey, 1983). Similar results have been found in studies in New Brunswick on land used for potatoes (Saini and Grant, 1980). Potato-harvesting equipment is particularly heavy and vibrates a great deal. Furthermore, many cultivated soils of the Atlantic Provinces have naturally dense subsoils, which provide a barrier to drainage and root development even without tillage compaction.

In southern Quebec soil compaction is creating difficulties for farmers growing corn and sugar beet on both clay and sandy textured soils. Increased soil density has reduced internal drainage so that ponding of rain on the soil surface damages the crop. It also leads to soils being tilled when wetter than optimum, compounding the problem. Compaction has increased the power requirement for tillage so that in some fields tractors that can usually pull a 6-furrow plow now only manage 3 furrows at a time.

Tillage at the right moisture content tends to break up soil compaction, at least in the topsoil layers. In cultivated orchards, on the other hand, the regular use of machinery and loaded trailers has caused considerable compaction at or just below the soil surface. Studies in Quebec indicate that the degree of compaction by this process has apparently been moderated somewhat by frost action and root development (Raghavan *et al.*, 1976). The same problem in orchard soils in British Columbia has reduced the infiltration of irrigation water, resulting in the need for cultivation to let water enter the soil.

Soils of the prairies are apparently not being compacted by normal tillage operations (Cameron *et al.*, 1981). In the sub-humid areas, such

Photo 8. The operator of this plow in southwestern Ontario has attempted to work around a depression in which water has ponded in the ruts. Working soil in this condition damages its structure, increases compaction, and adds to the problems of surface runoff and wet depressions.
C. Baldwin, Ontario Ministry of Agriculture and Food

as the Peace River region and central Saskatchewan, soil structure in cultivated soils is often weak and there is concern that spring tillage may aggravate a problem of crusted soil surfaces.

Trends

Soil compaction is closely related to the intensity and frequency of tillage. Any increase in these factors is likely to increase soil compaction, particularly where soil moisture conditions are such as to provide a high probability of tillage being done when the soil is wet. The clear trend to greater use of continuous monoculture row crops in eastern Canada indicates that the problem is almost certain to worsen. These soils are generally saturated in the spring following snowmelt, and with short available growing seasons farmers are always anxious to till as early as possible, often before the soil has dried sufficiently. Similarly, heavy harvesting equipment is often used late in the fall when soils are excessively wet. The expansion of crops like corn into marginal areas, using short-season varieties, will thus add to the soil compaction problem. This may be expected in the Atlantic Provinces and in southeastern Manitoba.

The compaction problem was documented by Bolton *et al.* (1979) in soils under continuous corn in southwestern Ontario, and led these authors to conclude that the outlook for this cropping practice was poor. They suggested that reduced efficiency in the use of fertilizers and declining soil tilth may eventually lead farmers away from continuous monoculture and back to crop rotations, which maintain favourable soil conditions.

It seems unlikely that a problem of soil compaction will develop in the prairies. There is a trend to decreasing tillage through reductions in summerfallow and greater acceptance of minimum or even zero-tillage (in which chemical weed control essentially eliminates conventional tillage) for many field crops. Reduced frequency of tillage will lead to less risk of compaction in most soils. The extension of field crops into the northern prairies will increase soil structure problems in these marginal areas. Much more research into the nature of soil structure deterioration will be necessary before the future extent of the problem can be forecast with any degree of certainty.

An example from New Brunswick

Research carried out by Saini and Hughes (1972) in New Brunswick provides an example of the impact of intensive continuous tillage on soil physical conditions. Three soils commonly used for potatoes were studied to determine effects on soil density, soil moisture content, rate of oxygen diffusion through the soil, and the yields of potatoes as a result of compaction by tillage and harvesting machinery. It was found that as the number of times a tractor passed over the soil increased from 0 (zero tillage) to 12 (excessive tillage), the soil bulk density increased by 18%. At the same time, soil moisture measurements indicated that the infiltration of water into the soil was reduced, with a corresponding increase in runoff. The rate of oxygen diffusion through the soil, which is important for root growth, was reduced by 13%. However, the greatest impact was on yield, which decreased by about 22% as a result of the increased soil compaction.

In a related study, Saini and Hughes (1972) showed that the ease with which a soil was compacted varied among soil types. Generally, however, it was greatest when the soil was wetter, and increased with the number of years that the soil had been used for continuous potato production.

Unfortunately, little information is available to indicate how compaction in New Brunswick might be reduced or avoided. Work has continued on the use of soil conditioners, e.g. shredded tree bark, to assist soils in resisting compaction during tillage and potato harvesting.

It is impossible to determine the direct impact of soil compaction on yields across New Brunswick. Annual variations in climate, adjustments made by farmers to fertilizer rates and tillage practices, and improvements in varieties all tend to mask the effect of soil quality, making the full impact of compaction difficult to detect.

Soil mixing and disturbance

Processes

Soil mixing and disturbance can arise for a number of reasons, but the most important are open surface mining and the installation of oil and gas pipelines. When these operations are in agricultural areas there is now generally an explicit requirement that the land be returned to a reasonable agricultural condition after the work is completed. Other forms of soil disturbance are common, many being associated with the permanent removal of land from agricultural production—highway construction is an example.

Surface mining is undertaken for the extraction of a variety of materials. Those most affecting agricultural land are coal, sand, and gravel. Extensive coal deposits underlie agricultural land in the prairies, and extraction of these reserves necessitates the disturbance of productive soils. In the case of the construction materials, it is economic pressure to use those deposits closest to urban areas that dictates the disturbance of agricultural land. Adequate supplies of sand, gravel, and stone can be found throughout the country in areas with little agricultural potential, but transportation costs generally lead to deposits in good agricultural areas being used first.

Extraction by surface mining usually follows stripping of the topsoil and subsoil to expose the underlying material. If topsoil is stockpiled separately from the rest of the mantle of overburden, it may be reused during reclamation. Often the extraction process requires turning over and mixing the overburden and placing it on adjacent areas previously mined. Even with topsoil separation, the nature of subsoil material is drastically altered from its original condition. Where salts are present, as is common in the prairies, seepage of groundwater after reclamation may well be saline. Surface topography is generally altered, leading to modifications of groundwater flow patterns. The process of strip mining often leaves a ridged land surface that requires further grading and levelling during preparation for reuse by agriculture.

For sand and gravel extraction and stone quarrying, pits are often open and used for long periods of time. There is little overburden or waste material to be used for filling, and topsoil reserves are often inadequate for reclamation. The drastic alterations in topography often leave few alternatives for reclamation other than recreation.

During the installation of a pipeline (see Photo 9), topsoil is generally stripped before subsoil is brought to the surface and stockpiled. When it is returned to the trench it is invariably mixed and the deeper and less weathered material ends up nearer the surface. After topsoil replacement, the surface and the modified column over the pipe often become compacted. Productivity is frequently lower than before disturbance. Sometimes the soil is more productive for certain crops when material high in calcium is brought closer to the surface. This has been shown to benefit yields on Solonetzic soils (saline and alkaline) in the prairies (de Jong and Button, 1973; Toogood, 1974). Alfalfa, a crop that does not tolerate acid soils, has also benefitted from higher pH values after pipeline construction in eastern Canada. Most changes in soil properties in non-prairie regions, however, lead to poorer yields of most crops for at least 5 years. Lower soil organic matter levels, less nitrogen and available phosphorus, and poorer soil structure (especially in fine textured soils) seem to be the main reasons for yield losses (Culley *et al.*, 1982).

Location and extent

Sand, gravel, and stone extraction make up the largest area of disturbed land in the agricultural areas of Canada. In eastern Canada it is estimated that at least 34 000 ha of land was disturbed for these purposes in 1977, of which over 28 000 ha was for sand and gravel (Marshall, 1982). About 60% of this area was in

Photo 9. Topsoil and subsoil are piled along a pipeline right-of-way across productive corn fields in eastern Ontario.
V. Kirkwood, Agriculture Canada

Ontario and 30% in Quebec. If unlicensed operations were included, however, Marshall estimated that the area in Ontario alone would increase by 8 000 ha. A study of a densely populated area of southern Ontario showed that only about one-third of the sites had received total or partial reclamation.

Areas of land disturbance for construction materials are estimated to be about 14 000 ha in British Columbia, 11 000 ha in Saskatchewan, and 9 000 ha in each of Alberta and Manitoba. In Manitoba, about 2 500 ha are within 50 km of Winnipeg (Marshall, 1982).

Strip mining for coal is the main type of mining activity affecting agricultural land. The provinces suffering the greatest impact are Alberta and Saskatchewan. In New Brunswick much of the area affected is either former cleared agricultural land or forested land with a reasonable agricultural potential. About 2 500 ha have been stripped in the agricultural areas of Alberta, about 5 000 ha in Saskatchewan and about 4 500 ha in New Brunswick. Rates of new strip mining, averaging about 150 ha annually in each of these provinces in 1979, are now being closely matched by reclamation rates (Marshall, 1982; Thirgood, 1978). Alberta has developed strict controls that require coal mining operations in the agricultural zone to rehabilitate mined land for reuse by agriculture when mining is completed. The time during which the land is being strip mined and preliminary reclamation is being carried out is generally about 5 years. A further 5 years seems to be needed before reclaimed land is returned to an acceptably productive agricultural state.

Pipelines have been extensively installed across western Canada, and eastwards into Quebec. Main pipelines extend for over 5 000 km in the Prairie Provinces alone. Few problems of stress on agricultural land in the prairie region have arisen. In humid soils, however, damage to soil productivity is common along the work-area of the pipe, and often across the entire right-of-way (18–30 m wide). Culley *et al.* (1981, 1982) have reported substantial yield reductions in Ontario that were still detectable 5 years after installation in land used for row crops. The greater soil damage in eastern Canada compared with the prairies appears to be due to wetter conditions encountered during construction and less intense or deep freezing. Furthermore, row crops like corn and soybeans are more sensitive to poor soil conditions than the small grains grown in western Canada. Fine textured (clayey) soils also appear to be damaged by pipeline installation more easily than coarse textured (sandy) soils.

Trends

There has been a renewed interest in coal as a fuel for electricity generation and industrial purposes, and this interest will probably continue. Coal deposits most economically accessible will most probably be exploited first, and this means disturbing large areas of prairie farmland. About 80% of Alberta's shallow coal deposits are in the agricultural region and about 65% of these lands are class 1–4 for agriculture. One projection made in 1980 has suggested that within 25 years approximately 5 670 ha of this land will be mined each year to meet the demand for coal (Hermans and Goettel, 1980). If this estimate is valid, it must be presumed that similar increases in coal mining activity in agricultural, or potentially agricultural, areas could occur in Saskatchewan and New Brunswick.

Pipeline installation is currently active in eastern Ontario, much of it affecting good farmland. Extensions of pipelines eastwards to the Atlantic coasts of both New Brunswick and Nova Scotia are either underway or planned. Many of the soils affected have dense subsoil materials that will degrade topsoil when the inevitable mixing takes place. Poor drainage and wet weather will almost certainly result in much of the work being done under adverse soil moisture conditions. Even with great care, many soils in the rights-of-way of these pipelines will be compacted and will yield poorly for a number of years following construction. Continued pipeline installation in western Canada is certain, but serious soil problems are not expected in the southern agricultural zones. However, agricultural land in the more humid northern areas will probably be adversely affected.

An example from Ontario and Quebec

Studies carried out on the Sarnia, Ontario, to Montreal, Quebec, oil pipeline exemplify the characterization of the impacts of soil disturbance and mixing during pipeline construction (Culley *et al.*, 1981; 1982). The 76-cm diameter pipeline was installed at a depth of 1.2 m between September 1975 and March 1976 through a wide range of soil types and in a variety of weather conditions. Disturbed soil was used for many different crops after construction was completed.

In general, the effect of pipeline installation was found to be greater over the trench than in the adjacent work area. Soil bulk (dry) densities in a clay loam soil area were increased by about 10% over the right-of-way compared with the undisturbed field; hydraulic conductivity of the soil decreased by an average of 38%. Total soil porosity was also decreased. In the same area, resistance to penetration of the soil was increased 67% over the trench and 50% over the rest of the work area compared with the undisturbed field. These compaction problems were not observed in a sandy soil area.

Soil organic matter was reduced at the soil surface by the pipeline installation as a result of mixing low organic matter subsoil with the topsoil. The mixing, on dilution, was calculated to be equivalent to 20–50% of the topsoil being replaced by subsoil. As a result of this mixing, nutrients in the topsoil were lower in the work area compared with the undisturbed soil. The soil pH, on the other hand, was improved by this mixing because of the higher lime content of the subsoil. This had a positive effect on yields of alfalfa, a crop that needs a non-acid soil for good development, which grew as well after pipeline construction as before. Most other crops did poorly, however. The greatest effect was seen in the first years after construction in the clay soils, where yield reductions of up to 50% were measured. After 5 years, crop yields had improved considerably, but the row cropped areas (corn, soybeans) were still not yielding as well as in the adjacent undisturbed fields.

Culley *et al.* (1981) found that the amount of damage done to agricultural land during the installation of this pipeline was less when the work was done under dry conditions. Adverse effects were also reduced when work was done when the soil was frozen to a depth of at least 20 cm.

The direct effect of pipeline construction on the soil is only one example of the impact of land disturbance on agricultural areas. Mining activities, and transportation and energy corridors not only physically disturb the land, but also dissect land holdings, interfere with farm operations, and make sound management decisions more difficult for the farmer.

ECONOMIC IMPACT OF LAND DEGRADATION

Land values

Many farmers are well aware of the economic effect of land deterioration. The dust bowl resulted in millions of hectares being simply abandoned because of erosion and the associated economic hardships. Land that is seriously eroded or salinized becomes virtually worthless. Farmers are sometimes eligible for tax assessment adjustments to allow for serious deterioration; for example, Saskatchewan assessments are updated periodically and deductions are made for salinization.

Vander Pluym *et al.* (1981) estimated that western Canadian dryland with a market value of $1 500/ha in good condition would have been worth only $200/ha after salinization. Although irrigated land was worth little more than dryland when both were saline, it averaged about $2 300/ha in good condition. They estimated that the total loss of land values from salinization in western Canada could already have been about $3 000 million at 1981 values.

Most of the erosion currently being observed in tilled land in all parts of Canada is occurring at a rate far exceeding that at which new soil material is forming from the weathering of the parent materials. This causes a steady loss of volume of soil organic matter and fine weathered mineral particles, the value of which has yet to be determined. With prairie agriculture still so dependent on native organic matter to feed crops, the loss of 45% of the organic matter reserves of cultivated land (McGill *et al.*, 1981) must, inevitably, have reduced the value of this land compared with land kept in grasses or other forages for extended periods.

Little information is available on land-value changes that might result from land degradation in eastern Canada. Fertilizer is generally used for all field crops, so organic matter nutrient supplies are not normally an important consideration. Land seriously eroded and compacted, however, will be less attractive to the farm buyer than well-maintained land. Nonetheless, other factors such as proximity to urban centres, slope, depth to bedrock, and soil drainage still tend to dominate land values in the eastern provinces.

Productivity

Although deterioration of land does not always reflect directly on land values, it has a marked effect on soil productivity or the cost of maintaining productivity. A few examples can be used to indicate the extent of these costs.

Erosion removes plant nutrients, which have to be replaced either immediately or at some future date when yields would decline without large fertilizer applications. The potato-growing areas of New Brunswick have soils so impoverished that exceedingly heavy use of fertilizers is necessary for continued production.

Stewart and Himelman (1975) estimated the loss of nutrients by erosion on potato land in Prince Edward Island at $28/ha. Farrell (1982) estimated soil loss from sloping fields in southern British Columbia to be worth $25–30/ha in fertilizer nutrients. However, if the value of the total soil volume of major and minor nutrients is included, these estimates are certainly low. Eventually, the loss must be taken into account even of plant nutrients that do not appear to be scarce. The final value may reach $10–20/t—an order of magnitude greater than the above estimates. The long-term effect of lost soil material in relation to physical support for plants, and nutrient and moisture holding capacities, must also be considered. However, it is difficult to place a dollar value on these factors.

Arsenault (1979) estimated that to protect the sloping potato fields in New Brunswick from erosion with the use of variable grade parallel diversions, with grassed waterways for outlets, would cost $125–$185/ha. This cost would be recovered in fertilizer retention alone in about 5 years.

Estimates have recently been made of the costs of soil erosion to agriculture in Ontario (Wall and Driver, 1982). An intensive county by county evaluation placed the total loss due to erosion at $68 million per year, of which 40% was attributable to yield reduction, 45% to soil nutrient removal, and 12% to pesticide losses. In addition, it was estimated that eroded soil cost farmers $6 million annually in ditch and outlet drainage maintenance.

Jenkins (1982) measured the amount of soil blown by wind into a road ditch in Manitoba in the spring of 1982. Analyses of available nutrients showed that the minimum value of this drifted soil was over $12 000, or about $390/ha. If the total content of nutrients in both the drifted soil and the fine dust that was blown beyond the road ditch were included, it is probable that the long-term value of this loss would have been far greater.

The Prairie Farm Rehabilitation Administration (1982) has recently attempted to calculate the probable annual and cumulative benefits of soil conservation measures which can: a) halt the spread of soil salinity; b) reduce soil erosion by 50% (wind and water); and c) reduce leaching and denitrification losses of nitrogen by reducing the summerfallow area by 5.5 million hectares. The annual benefits of achieving these levels of soil conservation were estimated to be $26 million, $3 million, and $41 million, respectively, with a cumulative benefit of $3 224 million by the year 2000.

Vander Pluym *et al.* (1981) estimated the loss in productivity of prairie soils due to salinization at $51.5 million annually in lost returns from cultivated dry land, $16 million annually from rangelands, and $15 million annually from irrigated land. They further estimated that the multiplier effect of this loss throughout the economy of western Canada would bring the total to a staggering $186 million annually.

Costs of reclamation of a dryland saline seep are hard to estimate as each site requires different treatment. It has already been shown that summerfallow can often be eliminated at no cost, and possibly a benefit, in terms of total returns. If drying up saline areas is achieved at the same time, the benefits are significantly increased. If ditching and drainage is possible to remove surface water and prevent a seep, this may well pay for itself in 2–3 years (Vander Pluym *et al.*, 1981). Growing forages in salinizing areas may also pay for itself, but the problems generated by lack of markets, handling, storage, etc. make this an attractive option only for livestock farmers.

Hoyt *et al.* (1981) estimated that the loss of productivity due to soil acidification in Alberta could reach $85 million annually by 1985 if control measures are not taken. They calculated that lime could be made available to farmers at a cost of about $30–40/t, and that this could be recovered in about 2 years by increased yields. On the west coast and in eastern Canada lime is already available. Nevertheless, it costs farmers about $20/t and may be needed at an annual rate of about 500 kg/ha, thus adding to production costs.

Compaction in eastern Canada is known to be increasing tillage and fertilizer costs, and decreasing yields of crops such as potatoes, soybeans, and corn. Few data are yet available to estimate the cost in terms of lost productivity or added energy and fertilizer costs. Nevertheless, these costs are inevitable if monoculture cash cropping is to continue. On the other hand, the greater use of rotations based on less profitable crops such as forage and small grains, in order to avoid compaction (or erosion) problems, may be economically disastrous for many farmers.

Soil deterioration is, to a large extent, a reflection of the agricultural economy. Farmers see little to be gained in conserving for a future they may not be able to stay in business long enough to see. They are often forced to watch their land deteriorate because of short-term economic pressures. Furthermore, there is a trend for less land to be passed from parents to children and some farmers may have less incentive to conserve for future generations. Ultimately, it is society as a whole that will pay the costs, of either land degradation or its prevention, in increased food prices.

Environmental costs

The environmental costs associated with man's activities are almost impossible to calculate. Briefly, the following are some of the environmental conditions that may be adversely affected by the deterioration of agricultural land.

Water quality is often seriously impaired by sediment carried into streams and lakes following erosion. Wind erosion is included in this process because much wind-blown soil is either deposited directly in water bodies or washed out of dried-up streams and ditches during peak spring flows. Sediment has a direct impact on fish by damaging spawning grounds. Eroded soil carries nutrients and sometimes toxic chemicals. Many will cause eutrophication or contaminate natural waters. Drift of sprayed pesticides, or runoff and erosion shortly after their application, cause fish kills in adjacent streams and lakes.

Salinization, by mobilizing salts previously fairly static in the subsoil, can result in increased discharges of salts to streams and drainage channels. The problem will generally be most noticeable in areas where reclamation drainage or irrigation is being carried out to remove excess salts from the soil.

Acidification of soils increases the solubility of aluminum, manganese, and iron. In acid soils themselves, these can reach toxic levels for crop plants. These elements can also damage aquatic ecosystems if leached to streams and drainage systems. This is a major cause for concern about acid rain, especially in naturally poorly buffered soils and where lime is not normally used.

Deteriorating agricultural soils may result in excessive application of fertilizers and cultivation of marginal land in order to maintain production. If this occurs on a large scale, wildlife habitat may be seriously encroached on or damaged by sediment and chemicals.

The dollar values of these and other environmental impacts of the stress suffered by agricultural land are impossible to calculate. It must therefore be hoped that education and awareness will provide the necessary stimuli for farmers and policy makers to reduce the side effects of degradation of agricultural land.

LEGISLATION AND POLICY OPTIONS FOR THE CONTROL OF LAND DEGRADATION

Traditionally, farmers have been subjected to a minimum of legislative controls on land use in Canada. There are therefore few legislated instruments by which farm practices may be modified for the well-being of the population as a whole. There are some exceptions however:

> Alberta has an emergency clause in a Soil Conservation Act (1980) under which farmers can be directed to carry out emergency measures, such as chisel plowing to bring clods to the surface to arrest soil drifting. Action under this statute has seldom been taken, but the threat is sufficient to make farmers respond during periods of severe wind erosion.
>
> Saskatchewan has recently developed a Drainage Control Act (1981) under which farmers are required to obtain permits before land is drained. By issuing or refusing permits, provincial officials hope to avoid situations in which soil erosion or salinization might otherwise occur.
>
> Manitoba has The Fires Prevention Act (1970) under which farmers can be restricted from burning organic soils. (The purpose of the controls, however, is more to reduce the risk of forest fires and traffic accidents than to preserve the soil resource.)
>
> Under the Habitat Protection provisions of the federal Fisheries Act (1976–77), action can be taken against farmers for allowing sediment from soil erosion to damage fish habitat. In the Atlantic Provinces and parts of British Columbia this Act is enforced by federal officials; elsewhere it is a provincial responsibility to administer these provisions.
>
> Most provinces have enacted environmental legislation which might relate to control of sediment from soil erosion. It has generally proved difficult to apply such legislation to agricultural situations.
>
> Pest control products are controlled under federal legislation, the result of which is the ability to remove compounds from the market rapidly if problems of toxicity or soil pollution are identified.
>
> Most provinces control the disposal of sewage sludge, and some have prepared guidelines in an attempt to avoid harmful accumulations of contaminants in soils.

Although these examples do not cover all the possible measures that might be taken under existing legislation, they do provide an indication of the kind of limited options available to those who wish to enforce changes in farming practices.

Incentives contained within production and marketing policies at both the federal and provincial levels are likely to be of greater effectiveness than legislated controls. For example, the Lower Inventories for Tomorrow (LIFT) program in 1970–1971 had a significant (and probably negative) effect on prairie farmland by increasing the area of summerfallow. Grain, oilseeds, and forage areas can be altered as a result of changing marketing quotas, relative freight rates, import restrictions, crop insurance programs, etc.

Grants and incentives for erosion control measures can help promote soil conservation. Under the Prairie Farm Rehabilitation Act (PFRA) (1970), for example, trees are made available to farmers wishing to establish windbreaks. Ontario has a "Farm Productivity Incentive Program" under which farmers can obtain cash grants for erosion control measures such as terraces and grassed waterways. Most provinces have some kind of financial assistance program to aid farmers willing to undertake these measures.

One positive long-term benefit for agricultural land nationally would be a program or policy to encourage the rotation of crops, especially if forages were included in the rotations. This might be realized if marketing, transportation, and processing arrangements were altered so as to re-establish a system of livestock production on mixed farms, rather than the cash cropping and intensive livestock specializations that are becoming so common. Also more livestock manure would be returned to the soil from which the nutrients were originally removed, and organic matter levels would be better maintained. This is one of few long-term options for the reduction of soil degradation and for the better maintenance of our agricultural land resource.

Another approach of less direct, but possibly more lasting, benefit is that of increasing the awareness among farming and urban populations of the nature and severity of land degradation and its impact on future generations. Furthermore, if the public at large better understood the economic constraints that continue to force farmers to exploit their land to the limit, they would probably be willing to support more conservation-oriented farm management, even at the cost of higher food prices. It must be hoped that ultimately some combination of measures, such as those briefly mentioned above, will bring about a halt to the deterioration of our farmland. Without a concerted national effort, however, this hope may never be fulfilled.

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DEGRADATION OF FOREST LAND

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FORESTRY PRACTICES AND STRESS ON CANADIAN FOREST LAND

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CHANGES IN CANADIAN FOREST LAND USE

The pattern of disturbance

The forests of Canada are in a dynamic state. The processes of succession following disturbance are repeated time and time again as new disturbances occur in the landscape. Historically, the major disturbance has been fire. Only in certain forests that are hard to burn, such as shade-tolerant hardwood forests in Eastern Canada, high-elevation forests, or the West Coast rain forest, has succession developed into climax forests. Climax forests are stable forest communities in equilibrium with their environments, which will not change appreciably unless radically disturbed. These forests cover extensive areas with old, mature and over-mature or decadent trees. Elsewhere the forest is a mosaic of different age classes, reflecting historical disturbances.

The historical role of fire in forests has been studied in great detail and has been the subject of many symposia and conferences. Attitudes towards fire have changed. Although it can cause widespread damage, it can also have many beneficial effects and is widely used as a management tool in forestry, e.g. to prepare land for natural or artificial reforestation, to prevent dangerous accumulations of fuel on the forest floor, to control certain insects and diseases etc. (Canadian Forestry Service, 1977; United States Department of the Interior, 1979; United States Forest Service, 1981).

Before the white man came to Canada, Indians used fire to maintain grasslands, clear land for corn planting, drive game, encourage the growth of blueberries, and for many other purposes. Early explorers noted the occurrence of vast forest fires. Gales and hurricanes blew down extensive areas of forests; insect epidemics periodically killed large areas of timber; and for centuries the spruce budworm has repeatedly killed balsam fir forests (Lortie, 1979). In some areas of Canada this cycle of change was frequent–as often as every 20 to 30 years in areas of severe forest hazard. Elsewhere the cycle was less frequent, every 400 or 800 years, as in the West Coast forests or some New England forests (Lorimer, 1977). Before the white man came there was a dynamic equilibrium between the disturbances and the recovery by forest succession.

The white man has changed and shifted this equilibrium by changing the rate and nature of the disturbances, but the recovery processes remain the same. The most dramatic changes have occurred where man has caused radical disturbances in forest ecosystems that historically were disturbed very infrequently, e.g. West Coast forests and tolerant hardwood forests. Most striking is the deliberate pattern of disturbance created by clear-cutting operations. These operations have a strong visual impact, but a full assessment of their stress on the land must examine the concepts involved and the changes in processes of recovery. Perhaps more serious than the impact of logging has been man's unintentional importation of exotic diseases and insects against which our forests had few defences. These include pathogens such as Dutch elm disease, chestnut blight, white pine blister-rust and weevil, balsam woolly aphid, larch sawfly, and beech bark disease. In extreme cases, these have virtually destroyed a valuable native species, e.g. the American chestnut.

Concepts of stability and equilibrium and their perception

Ideas or perceptions of change in forests are important because they influence public attitudes to forest management practices. Some ecologists compared the stability of a forest to a pendulum, which once moved will oscillate and return to equilibrium state. This concept was held by Clements and others who thought that an undisturbed forest is unchanging and a disturbed one proceeds through a well-defined series of stages, eventually reaching a single fixed state for a region (Odum, 1971). This "monoclimax" idea of a single equilibrium state, with a certain resistance and resilience to change, assumed a return to equilibrium along a well-defined pathway. This view regards disturbance as "bad" or "stressful" and equilibrium as "natural" and the ideal condition for a forest.

Recent studies of forest development since the last glaciation, about 10 000 years ago, have used pollen analyses to show that as climate changed, each forest community has not retained its integrity and a climatically determined equilibrium state. The forests are still changing by migration, i.e. population dispersal is taking place. The evidence suggests no single equilibrium state, or a single deterministic pattern of recovery for forests. Many forests require periodic disturbance for their natural maintenance, as for example do jack and lodgepole pines. Nature does not necessarily indicate when a forest is stable or in a desirable state (Botkin, 1980). It follows that it is not necessarily stressful for human intervention to create a type of forest that is new or "unnatural" by historical precedent. The new forest ecosystem will have a different structure and function and different fauna and flora, which may or may not be regarded as "better" or "worse" than a natural forest.

Another perception problem about stress of forests surrounds ideas about monocultures and the "stability" associated with species richness (a large number of species). Colinvaux (1978) has pointed out that the idea that complex biological systems are stable has a deep appeal to naturalists, for it fits the intuitive idea of nature working well. The complexity/stability idea is based on mathematical systems, information theory and feedback loops. He points out that systems models have shown there is no simple relationship between the complexity of a species list and stability in the lives of populations; indeed, often it is the reverse. Plants and animals in a food web do not conduct themselves as channels for food energy transfer in the same way as information transfers in electronic systems. Plants and animals work hard to secure food and stop others from getting it; they act as "road blocks" to transfers. There are no free-flowing feedback loops; feedback between one event and another is resisted or delayed. Changes in complex communities may reinforce stress. It is suggested that the idea that complex communities are more stable than simple ones is not valid and has done mischief by distracting people from real problems.

In reality Canadian forests comprise vast areas of relatively even-aged stands, often composed of only one of two dominant species occurring in a mosaic of age classes reflecting previous disturbance. The actual species combinations are related to regional climate, local site conditions, and the timing and nature of the disturbance. In essence, man competes with natural forces in the harvesting of timber before it is destroyed.

Problems of stress, or the negative impacts of forestry, are those associated with real losses in soil fertility; with the loss of species or of the quality or ages of tree species and associated plant and animal species; with the loss of unique or valuable habitat or of landscape values.

The history of the world has seen vast forest destruction, which is still going on. The deforestation of Mediterranean forests was associated

Photo 1. In 1926, horse drawn sleighs were used to haul logs to the riverside in Quebec.
PA-44055/Public Archives Canada

with erosion, loss of fertility and loss of tree and animal species. The forests were largely replaced by brush species (Thirgood, 1981; Hughes and Thirgood, 1982). The history of forest utilization in Canada is different.

The development of logging and concern over its impacts

Settlers in Canada regarded the vast forests as something to be removed in order to create farm land. The first cash crop was potash from trees. The removal of the forest has been complete in some areas; some counties in southern Ontario have less than 10% forest cover. Much forest land once cleared has since reverted naturally to forest as agricultural production became more concentrated. Since Confederation millions of hectares of farm land in eastern Canada have been abandoned; the forests of these areas today are usually of low quality and are badly managed or not managed at all (Lussier, 1982).

The rise of the white pine and spruce sawlog industry in eastern Canada in the 1800s was based on log export. The removal of logs was by horse to water (Hughson and Bond, 1965); only the best trees were removed–the forest remained. Roads were not constructed; most logging was done on snow. Today it is difficult to detect any signs of this logging in the forest, except for old pine stumps and changes in species composition. The impacts on the land were minimal. Similarly, on the west coast oxen and steam-donkey logging have left little impact. Generations of logging only the best trees in parts of eastern Canada, however, may have lessened the genetic quality of some species.

In the 1920s the pulp industry developed in eastern Canada, and until the 1950s, was based on horse skidding or horse sleighs and water transport. Clear-cutting started, but usually many small or unmerchantable trees were left. Road contruction was minimal and most logging operations were on snow. The impacts of these horse operations on the soil were minimal, but other effects are evident today in the changed age class structure of forest and in the change in composition of many stands from conifers to mixedwoods or hardwoods. There was almost no artifical reforestation.

On the West Coast, the 1920s–1930s was the era of steam railroads and steam skidders. They operated at low elevations on rich sites of very old high-value timber. This logging process was often followed by slashburning, leaving a legacy of young forests, sometimes poorly restocked, and old railroad grades, now overgrown with trees. The resilience of these rich ecosystems was great; there was little reforestation.

Impacts of logging operations became more obvious with the switch to mechanized operations based on truck hauling. Since World War II, vast networks of roads have been pushed into the virgin forests of Canada. Starting in the 1960s horses were replaced by rubber-tired skidders, full-tree harvesting started, clear-cut sizes increased, and logging operations changed to the 8–10 month period of least snow in the forest. Long-distance truck haulage required high quality roads. Pressures for heavy capital investment in equipment, an expanding market for smaller sized trees, the development of the market for chipped wood, improvements in sawmills such as chip-and-saw rigs which could utilize small trees, and an expanding economy with many new mills all combined to create a dramatic rise in the total area and size of clearcuts in Canada. Currently about 800 000 ha are cut annually. Large fires in the last century and earlier had created extensive forests of mature and over-mature timber, which are now ripe for harvest. In the west, logging operations reached higher up the mountains into new ecological zones.

By the end of the 1960s, parallel developments in the United States led to national concern there about the environmental impacts of clearcutting. Carelessness and disregard of environmental factors in forestry operations using heavy equipment gave rise to a flood of publications (Wood, 1971; Montgomery and Walker, 1973; Horwitz, 1974); and to Congressional (United States Congress, 1972) and Presidential (Seaton *et al.*, 1973) studies of the problem. In the United States much initial impetus for the national concern over forests was provided by the terraces cut into hillsides for the purposes of tree planting on the Bitteroot National Forest in Montana (United States Forest Service, 1970).

In Canada the 1970s were marked by similar, but not as intensive, concerns about logging impacts. Initially, the destruction of advance growth by skidders was of concern. Later the exporting of valuable nutrients out of the forest through the process of logging became an issue (Webber *et al.*, 1969; Weetman and Webber, 1972). Subsequently, the impacts of logging equipment and intensive management practices on erosion, water flows and fish populations, recreation, wildlife populations, and scenic values all became important. Numerous investigations and studies were made (C.D. Schultz & Co. Ltd., 1973; United States Forest Service, 1979*a*). At present, the scrutiny of forestry operations is often intense in areas of sensitive terrain. Corporate and government guidelines control operations (Toews and Brownlee, 1981*a*) and landscape design manuals are used to plan clear-cuts (Ontario Ministry Natural Resources, 1973; British Columbia Ministry of Forests, 1981). Today the amount of environmental control over logging operations is proportional to the degree of public interest and access to the area concerned. Controls are few on remote or small logging operations particularly where they are close to the economic margin.

In parts of northern Canada, the options for the manager are to let the timber burn or rot, or to allow the cheapest logging possible. Photo 2

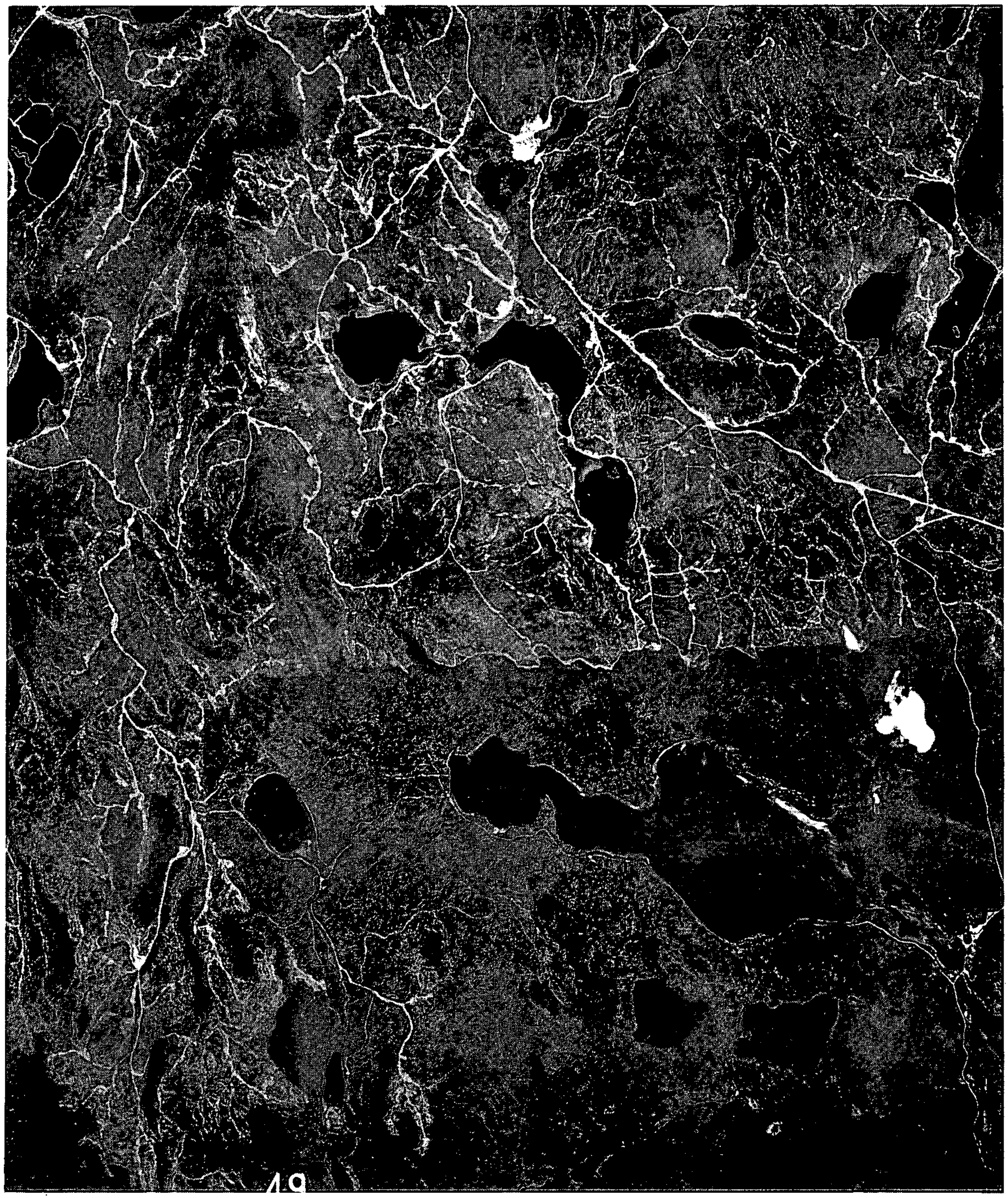

Photo 2. Unregulated logging operations using rubber-tired skidders and truck haul in the remote areas of the Quebec North Shore early 1970s; overmature, even-aged black spruce forest cut for pulpwood.

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shows the results of unregulated logging in northern Quebec.

For the small landowner, often a non-resident, cash returns may now be worth more than environmental values. Much of the timber in small woodlots is of low quality. Most concern and care occur on large-scale corporate operations under long term lease arrangements (Tree Farm Licences and Forest Management Agreements), which are subject to close public and provincial scrutiny.

Current national concerns about the stresses created by logging focus on the future economic impacts of the lack of regeneration. Of the 800 000 ha cut annually, less than one third receives any treatment and unstocked or poorly regenerated (backlog) areas are accumulating at an alarming rate at the same time that timber supply shortages are forecast (F.L.C. Reed & Associates, 1978; 1980; MacGregor, 1982). The national level of silviculture practice is very low (Weetman, 1981; 1982).

Locally, certain cuts and watersheds continue to become the focus of intense concern, particularly when fish or wildlife populations appear threatened or wilderness values appear endangered. Today any stresses associated with logging, either real or perceived, are assessed in both economic and environmental terms. Forests are the primary source of wealth for much of Canada. The current trend in leasing arrangements on provincial Crown lands (representing 90% within provincial boundaries of the commercial forest of Canada) is towards fostering managerial responsibility in the leaseholder.

Recent re-evaluation of forests as a potential source of energy have focused renewed attention on the impacts of intensive biomass[1] harvesting, particularly the nutrient exports. Most nutrients in trees are contained in the leaves and small branches which normally return to the soil, but which are removed in intensive biomass harvesting. Litter removal in European forests by peasants has historically caused declines in forest site fertility (Le Groupe Dryade, 1980; Freedman, 1981). It appears that such nutrient exports can result in declines in productivity where forest crops are harvested on very short rotations, in the 2–15 year range.

When do forestry practices cause negative or depletive stress on land?

The ecological evidence suggests that changes in the forest caused by removing mature stands are not necessarily detrimental simply because they are a change. Changes take place at two levels: the stand and the forest. Impacts on the stand are local. At the forest level they must be judged in relation to the land-use objectives. Table 1 shows a matrix of 38 variables, each of probable primary and secondary impacts, all at the stand or local level involving climate, water, soil, and fauna and flora. Only 5% of the 1 406 combinations are major direct impacts, either favourable or unfavourable to the functioning of the ecosystem.

To the extent that forestry duplicates the natural disturbances in forests, it can be argued that because they will inevitably occur the impact is neutral, at least at the stand level. One of the arguments for managed forests, in contrast to unregulated forest removals, is that the timing of the impacts is controlled. Under a fully regulated forest condition, with a balanced set of age classes, there is regulation of water yields, wildlife habitat and forage, and a degree of control over insect, disease, wildfire, and other losses. The benefits of this control are at the forest level; they are tangible and are the product of deliberate multiple-use forest management. Indeed, these benefits are the aim and the cornerstone of provincial forest land-use policies in Canada.

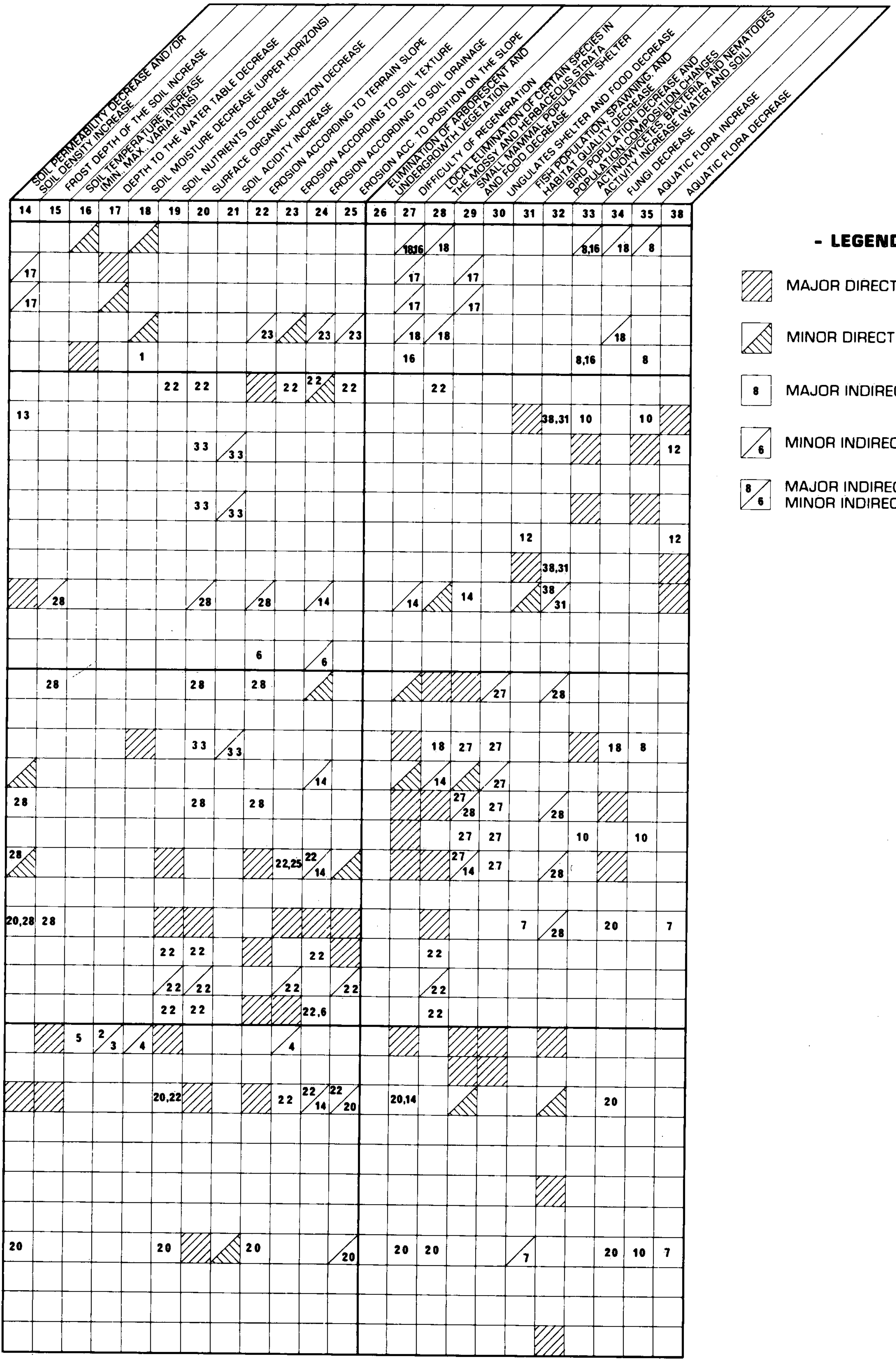
There are philosophical arguments about the desirability of opening up vast expanses of virgin forest to human use and abuse. Some people view the most desirable forest landscape as one that is little or not at all influenced by man, one that is subject to purely natural disturbances. This is a cornerstone of National Parks policy which states that "Natural resources within national parks will be given the highest degree of protection to ensure the perpetuation of a natural environment essentially unaltered by human activity." Further, "Natural resources within national parks will be protected and

TABLE 1.

Interrelationships of potential impacts of forest biomass harvesting.

PROBABLE SECONDARY IMPACTS / PROBABLE PRIMARY IMPACTS			AIR TEMPERATURE INCREASE (MIN., MAX., DAILY MEAN) 1	EVAPOTRANSPIRATION DECREASE 2	RAINFALL INCREASE 3	WIND (SPEED AND DURATION) INCREASE 4	INSOLATION INCREASE AND ALBEDO CHANGES 5	WATER FLOW INCREASE 6	WATER TURBIDITY INCREASE 7	WATER TEMPERATURE INCREASE (MIN., MAX., VARIATIONS) 8	CONDUCTIVITY INCREASE 9	WATER NUTRIENTS INCREASE 10	B.O.D. INCREASE 11	DISSOLVED OXYGEN DECREASE 12	SEDIMENTATION INCREASE 13	INFILTRATION RATE DECREASE 36	SURFACE WATERS INCREASE 37
I - II MACRO-, AND MICROCLIMATE	AIR TEMPERATURE INCREASE (MIN., MAX., DAILY MEAN)	1								◢		8		8			
	EVAPOTRANSPIRATION DECREASE	2						37								17	◢
	RAINFALL INCREASE	3						37								17	▨
	WIND (SPEED AND DURATION) INCREASE	4															
	INSOLATION INCREASE AND ALBEDO CHANGES	5	▨							▨		8		8			
III WATER	WATER FLOW INCREASE	6							22								
	WATER TURBIDITY INCREASE	7									10	▨		13	▨		
	WATER TEMPERATURE INCREASE (MIN., MAX., VARIATIONS)	8							33		10	◢	33	▨			
	CONDUCTIVITY INCREASE	9															
	WATER NUTRIENTS INCREASE	10							33		▨		33				
	B.O.D. INCREASE	11												▨			
	DISSOLVED OXYGEN DECREASE	12															
	SEDIMENTATION INCREASE	13												▨		14	
	INFILTRATION RATE DECREASE	36						37									▨
	SURFACE WATERS INCREASE	37						▨									
IV SOIL	SOIL PERMEABILITY DECREASE AND/OR SOIL DENSITY INCREASE	14														▨	36
	FROST DEPTH OF THE SOIL INCREASE	15															
	SOIL TEMPERATURE INCREASE (MIN., MAX., VARIATIONS)	16	▨							◢		33	33	8			
	DEPTH TO THE WATER TABLE DECREASE	17														▨	36
	SOIL MOISTURE DECREASE (UPPER HORIZONS)	18															
	SOIL NUTRIENTS DECREASE	19									10	▨					
	SURFACE ORGANIC HORIZON DECREASE	20						22,25	22			19				14	
	SOIL ACIDITY INCREASE	21									◢						
	EROSION ACCORDING TO TERRAIN SLOPE	22						▨	▨			7,19			7		
	EROSION ACCORDING TO SOIL TEXTURE	23						22,25	22								
	EROSION ACCORDING TO SOIL DRAINAGE	24						22	22								
	EROSION ACC. TO POSITION ON THE SLOPE	25						▨	22								
V - VI WILDLIFE, FLORA, AND VEGETATION	ELIMINATION OF ARBORESCENT AND UNDERGROWTH VEGETATION	26	5	▨	◢	▨	▨			5		19					3/2
	DIFFICULTY OF REGENERATION	27															
	LOCAL ELIMINATION OF CERTAIN SPECIES IN THE MOSSY AND HERBACEOUS STRATA	28						22	22							14	
	SMALL MAMAL POPULATION, SHELTER AND FOOD DECREASE	29															
	UNGULATES SHELTER AND FOOD DECREASE	30															
	FISH POPULATION, SPAWNING, AND HABITAT QUALITY DECREASE	31															
	BIRD POPULATION DECREASE AND POPULATION COMPOSITION CHANGES	32															
	ACTINOMYCETES, BACTERIA, AND NEMATODES ACTIVITY INCREASE (WATER AND SOIL)	33							◢		10/21	▨	▨	11			
	FUNGI DECREASE	34															
	AQUATIC FLORA INCREASE	35															
	AQUATIC FLORA DECREASE	38															

Source: Le Groupe Dryade, 1980.



- LEGEND -

- ▨ MAJOR DIRECT IMPACT
- ◸ MINOR DIRECT IMPACT
- 8 MAJOR INDIRECT IMPACT
- ⁄6 MINOR INDIRECT IMPACT
- 8⁄6 MAJOR INDIRECT IMPACT / MINOR INDIRECT IMPACT

managed with minimal interference to natural processes to ensure the perpetuation of naturally evolving land and water environments and their associated species" (Parks Canada, 1981). Such a policy does not recognize natural resources within national parks as potential crops for harvesting or production. "National parks are special areas which are protected by federal legislation from all forms of extractive resource use such as mining, forestry, agriculture, oil, gas and hydro electric development and sport hunting. In some new national parks, however, certain traditional resource uses by local residents may be allowed to continue. Such activities must not destroy or seriously impair the natural values for which the park was established...." (Parks Canada, 1981). Wood-Buffalo is the only national park where there is regulated commercial forest removal and Gros Morne is the only one allowing regulated domestic forest removal.

An example of the dynamic nature of forests is given by Temagami Forest Reserve in Ontario, established in 1901. The area had large stands of eastern white pine. Logging was permitted except on islands in the lakes and up to the skyline on the mainland (Skyline Reserve). In the following 80 years the cut areas have regenerated naturally, partly to pine and other species, while the islands and the skyline reserves are in various stages of transition from pine to other species such as maple and balsam fir (Armson, 1981). In this case logging has thus been an important factor in maintaining a high pine component in the forest. In earlier periods this maintenance was accomplished by fires that set back the succession to shade intolerant tree species and allowed seeding from the large fire-resistant pine. White pine has a reproduction pattern adapted to fire disturbance.

Present silvicultural prescriptions for forestry practices carefully consider the reproduction strategies of the trees and the evidence for previous disturbances in the stands–be it insects, disease, blowdown, fire, or cutting. This use of natural evidence to decide on cutting practice does not always produce a prescription to clear-cut a stand of trees. However, whenever the historical disturbance has been large-scale wild fires, producing even-aged stands composed of trees that have become mature about the same time, the ecological evidence will probably dictate clear-cutting, which is the logical prescription over large areas of Canada. It is fortuitous that this is the cheapest and often the only feasible way to remove the timber.

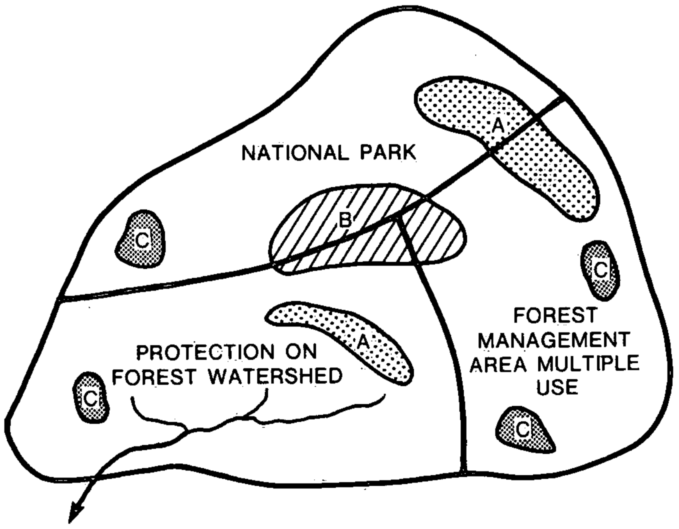
Earlier logging practice has given clear-cutting a bad reputation, which is not currently deserved (Smith, 1973). Early unregulated practices did remove all merchantable timber and in many cases the logging was followed by large-scale fires that had disastrous effects on subsequent regeneration both in the United States and Canada. Many cuts were too large to provide for adequate seed sources. This type of cutting still occurs in some places at the economic margin in the Canadian boreal forest, due to the problems associated with the removal of vast areas of over-mature timber at high logging costs and very low stumpage[2] return. Over much of Canada, clear-cutting is a prescribed harvesting treatment conducted under regulated and monitored conditions.

At the forest level the negative stresses due to forestry operations are those changes that are not in accord with the forest management objectives and plans for the area.

The negative stresses owing to forestry practices are largely perceived human values. For example, some environmentalists would not regard the destruction of large areas of mature timber in a national park by spruce budworm or mountain pine beetle as a stressful phenomenon. But the same destruction in a forest management area (for commercial harvesting) would threaten current and projected multiple-use benefits by eliminating valuable timber, upsetting the age class structure of the forest and projected harvests, producing ugly dead stands, and probably leading to major forest fires and loss of animal habitat. Remedial actions would be initiated, which in themselves would have some stress components, e.g. extensive chemical spraying or major road construction and loss of landscape values. Trade-offs of stress are involved. Figure 1 gives examples of perceived stress at the forest level.

FIGURE 1.

Relation of perceived positive or negative stress on forest land in relation to land-use objectives and perturbation at the forest level



Stress = change in ecosystem functioning due to disturbance

\+ = viewed as beneficial or complementary to objectives of land use

— = viewed as detrimental to objectives of land use

LAND USE AND OBJECTIVES

	Disturbance	National park (nature protection)	Forest management area (multiple use)	Protection area (water quality and quantity)
A	fire	+ (1)	— (3)	— (5)
B	insect caused mortality	+ (1)	— (3)	+ (1)
C	clearcut logging	— (2)	+ (4)	+ (6)

EXPLANATION

(1) A natural disturbance that has occurred historically and should be allowed to continue, it provides pioneer vegetation that favours wildlife populations.

(2) Logging has no historical precedent and may cause unnatural changes in ecosystem functioning and in forest-level functioning.

(3) Removal of forest by unregulated disturbances upsets planned age-class structures and threatens benefits from multiple-use forests.

(4) Controlled removal and replacement of timber regulates timber flow and other multiple-use benefits.

(5) Extensive fires in watershed protection forests will threaten water quality and peak flows.

(6) Small clearcuts or partial cuts have been shown to improve water yields at no sacrifice.

Recent examples of these situations are the severe mortality of balsam fir forests in Fundy National Park in New Brunswick and in the Cape Breton Highlands National Park of Nova Scotia. In Cape Breton, the highland area outside the Park was under multiple use but public pressure, prevented the Province from crop-protection spraying on provincial lands. There are similar problems and arguments about the mountain pine beetle damage in western Canada's national parks and adjacent commercial forest lands.

At the stand level, negative stresses due to forestry operations have a more apparent physical and biological reality. They are most closely related to the scale and placing of cut-overs and to the nature and degree of soil disturbance by road construction and forwarding equipment used to move logs from the stump to the roadside. As regulation and control of operations has tightened, controversy over logging and silviculture practices has declined.

Judgement about the nature and scale of the stress produced by forestry operations requires:

- recognition of the land management objectives and
- an understanding of the forest ecosystem dynamics, functioning, and recovery processes.

Stress in one forest may not be stress in another. Forests differ by climates and by sites, and public and individual values vary considerably about the philosophy, objectives, and ethics of land use.

An outline of the regional character of the stresses and specific issues and case histories will be used to demonstrate these points.

THE REGIONAL CHARACTER OF FOREST LAND-USE STRESS

Newfoundland

The island forests are boreal (Rowe, 1972), characterized by a harsh climate that excludes extensive agriculture (see Map 1). Settlement around the coast for three centuries has eliminated much of the coastal forest by repeated cutting and burning. The large interior forests of balsam fir and black spruce were first exploited for pulpwood in 1897. Now there are three major pulpmills and many small sawmill operations (Page *et al.*, 1974).

The ecological dynamics of the interior forests show that repeated burns or cutting and burning can lead to the development of *Kalmia* barrens or heathland conditions (Damman, 1964; Figure 2). Heaths are areas dominated by shrubs or ericaceous vegetation such as *Kalmia*, *Vaccinium*, and *Ledum* species, representing a real reduction in forest site fertility. Once established, they are difficult to reforest. There are now extensive areas of man-made, non-forest heath on the island, similar to the heaths or moors in Britain and Europe.

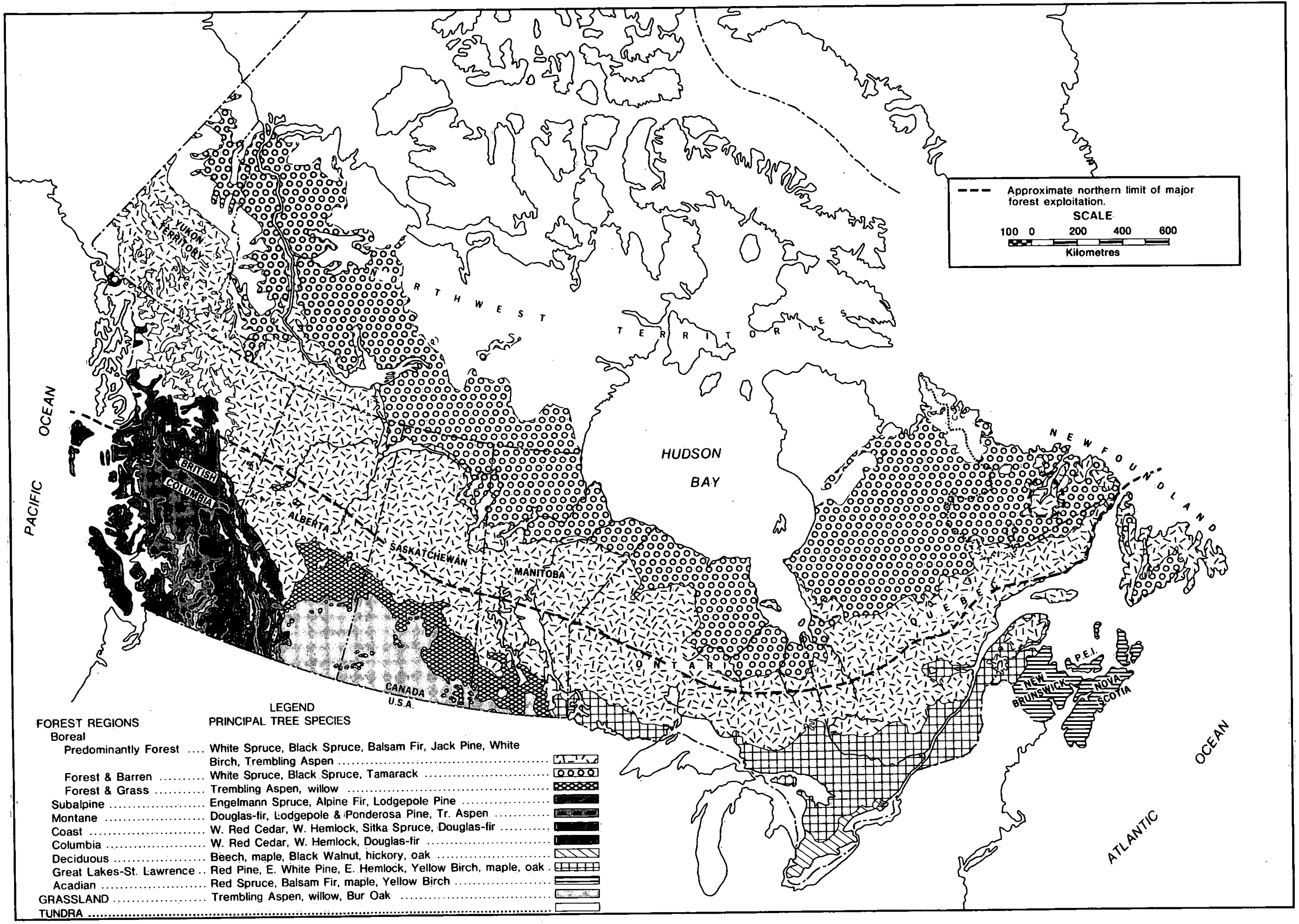
The natural regeneration of forests following logging and fire is often slow and difficult. Estimates are that 50% of such areas may not regenerate adequately to desirable species. Wood shortages are forecast and without remedial measures will worsen well into the next century. With federal help, however, the province and industry have initiated an extensive program of reforestation, stand treatment and salvage cutting to mitigate the expected decline in forest productivity.

The mature interior forests have been attacked by hemlock looper and, like the rest of the spruce–fir forest of eastern North America, are undergoing severe spruce budworm defoliation and subsequent mortality. Chemical spraying is used for crop protection. Studies have concluded there is no evidence that currently used insecticides cause persistent environmental damage affecting fish, fish food organisms, birds, or mammals (Hudak and Raske, 1981). The greatest impact of the infestations will be socio-economic, caused by unemployment resulting from a lack of future supplies of mature timber.

In Newfoundland, as elsewhere in Canada, mechanized logging operations developed in the 1960s. Two of the major corporations operate on large licensed areas with unique 99-year leases. There has been relatively little government regulation of logging practice. Studies of ground disturbance following skidder logging and of forest road construction have shown many stress problems (Case and Rowe, 1978; Case and Donelly, 1979). The following conclusions on skidder logging by Case and Donelly (1979) are characteristic of many unregulated skidder operations in the boreal forest.

> *"Skidder logging operations caused a variety of ground disturbance ranging from litter removal to deep exposure of the mineral soil. Types and extent of disturbance varied among locations depending on soil textural and drainage characteristics and on the season in which logging took place.*
>
> *Bulldozing caused deep exposure of mineral soil on 9.6% of the area of cutovers. In terms of the total land area cut over in Newfoundland this translates to 1 500–2 000 ha of productive site which is removed from forest production annually. The potential loss in allowable annual cut from bulldozing alone is 0.15 m³/ha/yr.*
>
> *Greatest mineral soil exposure was associated with short term extraction roads and skidtrails. Lesser amounts were attributable to landing and secondary and primary hauling road construction. Bulldozing disturbance on winter-logged areas was 50–60% less than on summer-logged areas.*
>
> *The problem of the effect of bulldozing on site quality is related both to bulldozing technology, i.e. the manner in which operators carry out construction, and to inadequately controlled operational layout. While some degree of soil disturbance through bulldozing is inevitable in logging, it can be reduced by educating both supervisors and operators in the efficient layout and construction of timber extraction networks.*
>
> *Disturbance on unbulldozed portions of cutovers occurred as scattered patches of exposed mineral soil, compaction and slash accumulations. Individual patches of exposed soil were small and not contiguous and thus did not pose an environmental problem.*
>
> *Greatest ground disturbance to unbulldozed areas resulted from summer and fall operations on poorly drained soils. Such operations caused site damage by remoulding the soils and compacting them thus disrupting natural drainage so that excess water was contained at the surface. Potential reductions in site productivity arising from such activity can be minimized through the proper selection of equipment and the timing of its use to ensure that poorly drained sites are logged during freeze-up periods.*
>
> *Compaction affected 30% of the unbulldozed portion of cutovers. Softwood regeneration on such areas tends to remain sparse and suppressed for much of the rotation period. In Newfoundland up to 4 000 ha/yr may be affected in this manner. In terms of productivity, potential reductions in allowable annual cut of up to 0.36 m³/ha/yr are possible.*
>
> *While heavy logging slash occupied 29% of the unbulldozed cutover and may cause patchiness in the developing stands, it did not appear to be a major barrier to natural tree establishment. However, dense slash may pose a problem to forest management aimed at artificially restocking cutovers and may require that some form of treatment be undertaken to facilitate silvicultural operations.*
>
> *In the final analysis skidder logging operations following conventional procedures create ground disturbances which could result in substantial site deterioration and reductions in long-term site productivity. Consequently, every effort must be made,*

MAP 1. Forest regions of Canada



LEGEND

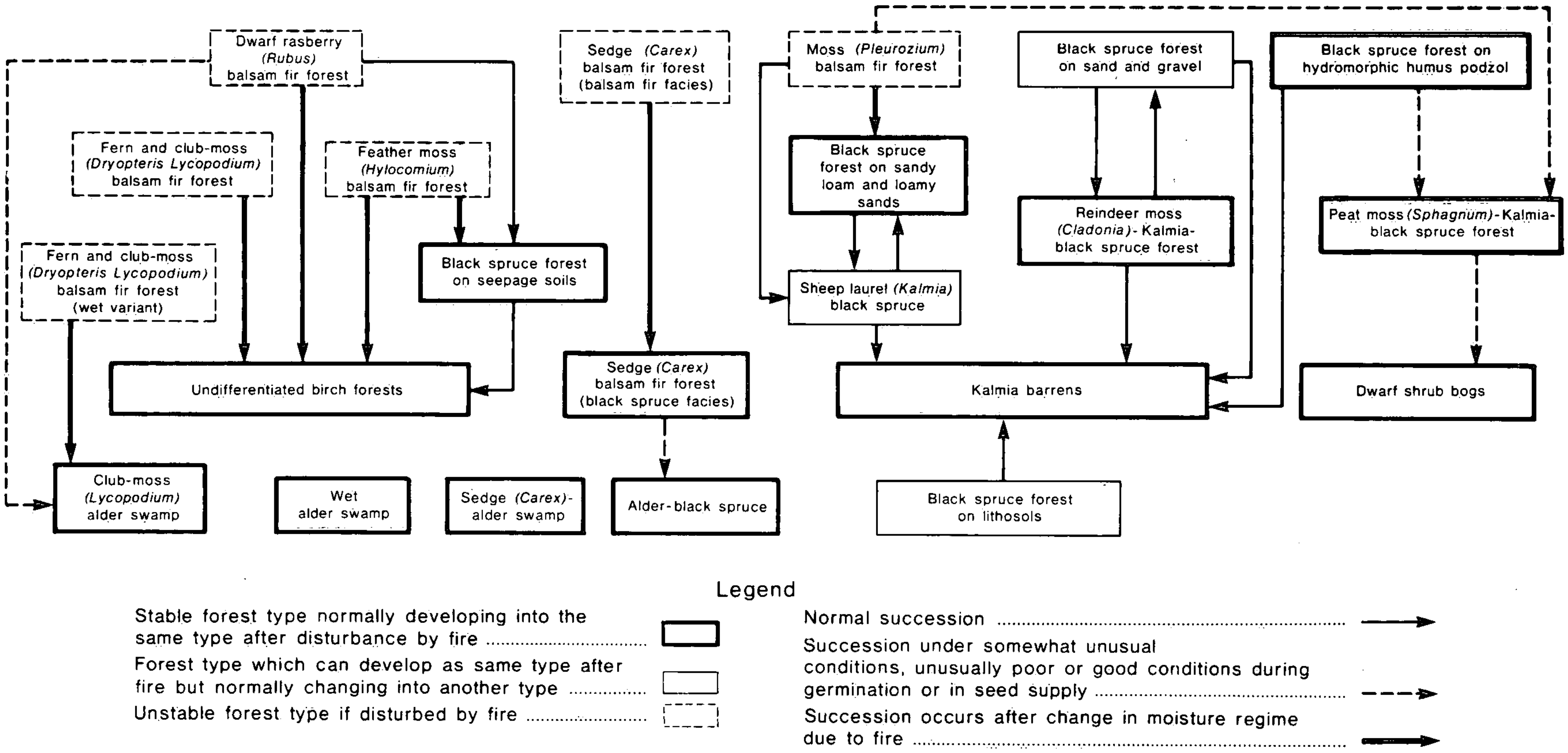
FOREST REGIONS	PRINCIPAL TREE SPECIES	
Boreal		
Predominantly Forest	White Spruce, Black Spruce, Balsam Fir, Jack Pine, White Birch, Trembling Aspen	╱╲
Forest & Barren	White Spruce, Black Spruce, Tamarack	○○○○
Forest & Grass	Trembling Aspen, willow	▩
Subalpine	Engelmann Spruce, Alpine Fir, Lodgepole Pine	■
Montane	Douglas-fir, Lodgepole & Ponderosa Pine, Tr. Aspen	▒
Coast	W. Red Cedar, W. Hemlock, Sitka Spruce, Douglas-fir	■
Columbia	W. Red Cedar, W. Hemlock, Douglas-fir	■
Deciduous	Beech, maple, Black Walnut, hickory, oak	▧
Great Lakes-St. Lawrence	Red Pine, E. White Pine, E. Hemlock, Yellow Birch, maple, oak	⊞
Acadian	Red Spruce, Balsam Fir, maple, Yellow Birch	☰
GRASSLAND	Trembling Aspen, willow, Bur Oak	░
TUNDRA		□

Source: Reproduced from Rowe, J.S., 1972. Forest Regions of Canada. with modifications by G.F. Weetman.

FIGURE 2.

Pathways of succession after fire and logging in interior Newfoundland forest types

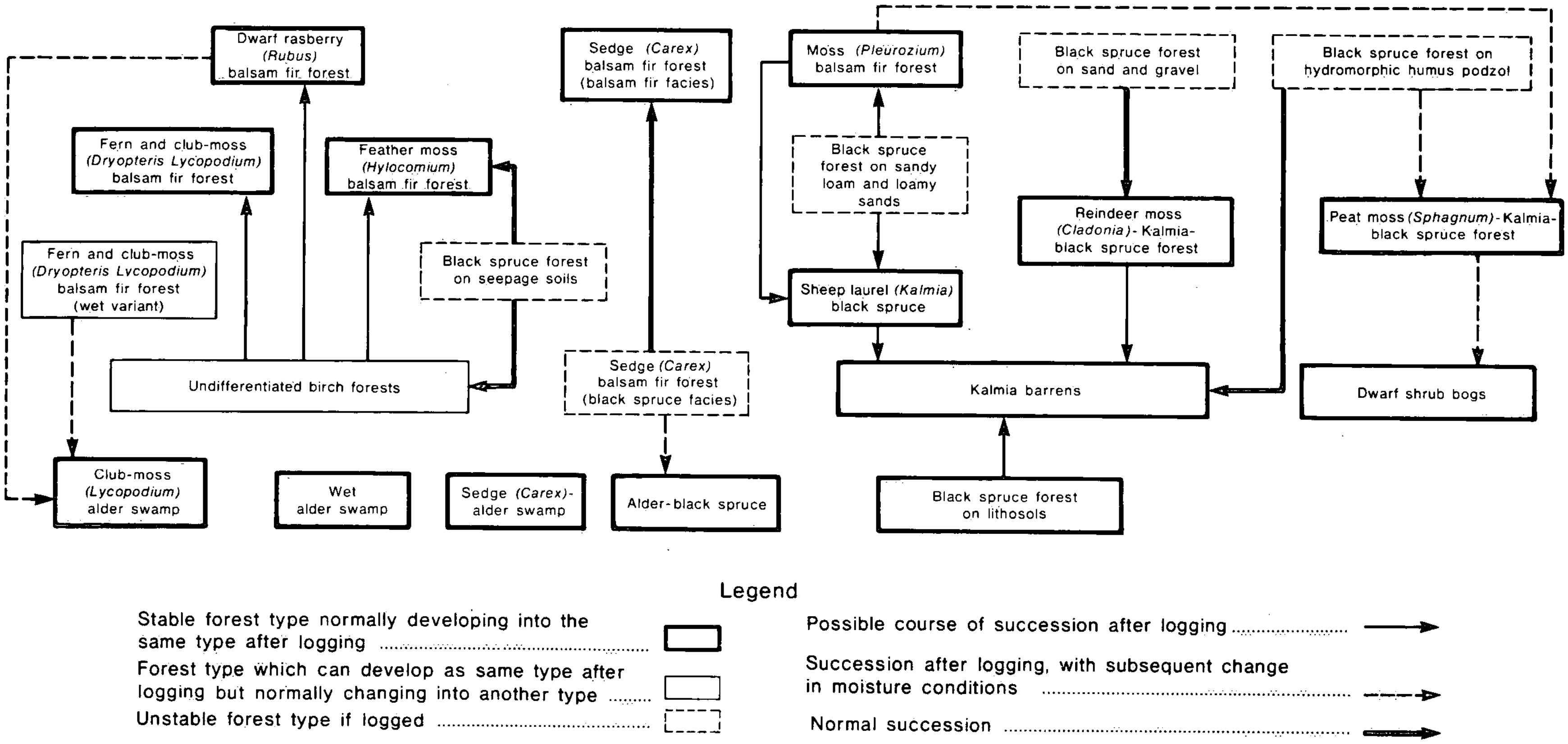
SUCCESSION AFTER FIRE *



Note the trend to *Kalmia* barrens or Heathland conditions.

* Any time of the year except after a fire in the fall of balsam fir seed year.

SUCCESSION AFTER LOGGING



Note the trend to *Kalmia* barrens or Heathland conditions.

Source: Damman, 1964.

Photo 3. Second growth balsam fir stand in central Newfoundland showing inadequate softwood regeneration on old tractor roads.
B. Case, Newfoundland Forest Research Centre, Canadian Forestry Service, St. John's, Newfoundland

> *especially under intensive forest management, to minimize impacts by reducing site damage at the operational stage in timber harvesting."*

Photos 3 and 4 show some of the effects of logging. Cut-overs often have unmerchantable hardwoods left that tend to change the species composition of the next crop from conifers to mixed or hardwood stands. This cover-type conversion, although not influencing the ecosystem functioning, does change habitat for wildlife and reduces future supplies of coniferous timber.

Table 2 lists the potential effects of resource road construction on aquatic and terrestrial environments. Photo 5 shows the visual effects of unregulated road construction for harvesting in Newfoundland. There are local or stand level stresses on the land. In addition, there are forest level stresses associated with increased human access to remote areas; poaching, fire hazards, and vandalism increase. On the positive side, road access facilitates fire control, forest recreation, hunting, and forest management.

Maritimes

The forests of Nova Scotia, New Brunswick, and Prince Edward Island are rich in species compared with those of Newfoundland and include large areas of both conifers and tolerant hardwoods. The Acadian forest (Map 1) has not only been subject to extensive exploitation for 150 years, but has also suffered severely from hurricanes, fires, insects and disease attack. By World War I, the sawmilling industry based on large old growth white pine and spruce had declined owing to depletion of the mature forests. Before the advent of the pulp industry in the 1930s cutting was partial, removing only the best trees–a negative practice from a genetic point of view. There was no reforestation or forest management, and other species tended to replace white pine.

Major portions of the forests of these provinces are in small ownerships, dating from the original settlement (approximately 25% of those in New Brunswick, 50% in Nova Scotia, 100% in Prince Edward Island). In the absence of any fiscal incentives for small woodlot management or of any control of logging practices, there has been a steady deterioration in the quality of forests in these ownerships. In contrast, the amount of forest has increased as a result of the abandonment of agricultural land, as occurred in New England (Spurr and Barnes, 1980).

As in most of Canada, there has been virtually no forest management in Nova Scotia until recently. Owing to a variety of causes, both man-made and natural, much of the forest is in poor condition. Goldsmith (1980) reviewed the history of depletion on 40 000 km^2 and concluded that the forest has deteriorated in terms of height, diameter, species composition, increase in heathland, nutrient depletion, and shortages of sawtimber and softwood for pulp.

About 52% of Prince Edward Island is forested, but most of the stands are immature and poor in quality.

In New Brunswick, with 48% of the Province in public ownership, problems of stress at the stand level largely concern road construction and the careless use of logging equipment. Nearly all the Province is fully accessible. There are now few horse logging operations in existence.

In the Maritimes, deterioration in stand quality and species composition of the hardwood forest continues as a result of high-grading practices[3], overmaturity and disease. Today most hardwood forests are of little value except for pulp. At the forest level, depletion of the mature timber softwood resource from combined harvesting and a continued spruce budworm epidemic has created a crisis in allowable cut.[4] This has led to such draconian measures in New Brunswick as cancelling all historic forest licences, reassignment of the Crown forest resource to licencees, and a moratorium on new mills.

Protection of mature softwood growing stock, primarily of balsam fir, from spruce budworm has required large-scale aerial spraying with chemicals for over 25 years. The use of DDT was stopped because of its residual effects. The "no control" option during epidemics normally leads to death of the spruce and fir forest stands (Hudak and Raske, 1981). Continued spraying is strongly disliked by much of the public and is accused of being associated with public health risks, although the evidence for this is very weak. The issues have been hotly debated and intensively studied, and they dominate forestry stress issues. A long-term policy is needed to reduce the need for spraying (Baskerville, 1976; 1978). Planned removal of budworm-susceptible mature stands is required to achieve a balance of age classes. However, such a policy is difficult to implement in mixed ownerships and requires much new road construction.

The replacement of spruce–fir and hardwood forests by new stands of budworm-resistant black spruce plantations (Marceau, 1981) has required large scale site preparation with 65-t Le Tourneau Tree Crushers, plows, and drag scarifiers. There appears to be no evidence for direct negative stress on land at the stand level caused by their use. Less road and landing construction in a grid network for future plantation maintenance greatly reduces the amount of bulldozing on cutovers.

Two other stress-related issues arising from large-scale reforestation programs are the long-term effects of replacing hardwoods by conifer monocultures and the use of herbicides. The monoculture issue has been discussed and debated for decades. The reality is that vast areas of Canada are under monocultures. Problems associated with second rotation decline in soil fertility in *radiata* pine afforestation in New Zealand or with spruce rotations in Germany (Smith, 1962) do not have ecological parallels in Canada. The actual area of plantations

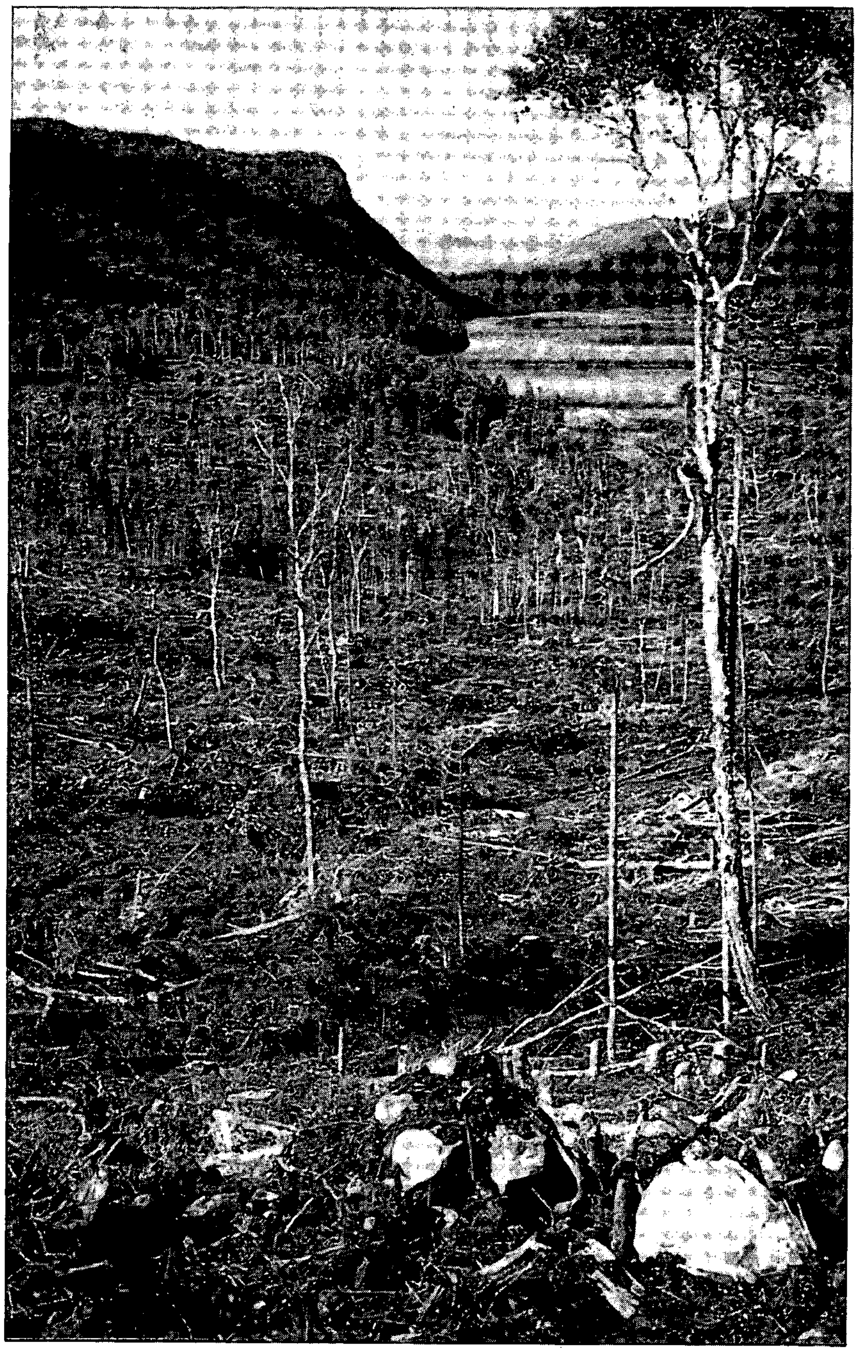


Photo 4. Ground disturbance and unmerchantable trees following skidder logging in Newfoundland.
B. Case, Newfoundland Forest Research Centre, Canadian Forestry Service, St. John's, Newfoundland

Photo 5. Bulldozing standing trees destroys valuable timber, reduces values, and creates future problems of access for harvesting.
B. Case, Newfoundland Forest Research Centre, Canadian Forestry Service, St. John's, Newfoundland

will be very small in comparison with the natural forests. There appears to be little need for concern about fertility reductions associated with spruce plantations.

Herbicide use is essential for successful establishment of conifer plantations and natural regeneration on rich sites, but its use is controversial. Public opposition to pesticide use hinders, and may render useless, much reforestation work in Canada. The stress issues in this paper are those concerning land values, i.e. vegetation, forest floor and soil, animals, and water; they have been exhaustively studied. Norris (1981) has recently reviewed the behaviour of herbicides and risks of their use. He indicates that data are available to determine the effects of oral exposure on animals that feed on sprayed vegetation, on soil organisms exposed to herbicides applied to soil (which disappear quickly from both forest floor and soil), and on aquatic organisms exposed to herbicides in water. Toxicity data for both acute and chronic effects are available. The major stress issue in herbicide use is now the perceived hazards to human health and to fish. Regulation of herbicide use is strict, and an independent group of experts in the United Kingdom has concluded that they pose virtually no danger to human health if the prescribed safety precautions and dosages are followed.

Some of the greatest stresses at the forest level may come from not using herbicides. However, alternatives to use of herbicides, such as prescribed burning and mechanical site preparation, may expose the forest stand to greater stress than the herbicides themselves.

Canadian Shield Forests–Quebec west to Saskatchewan

The vast area of the Canadian Shield (Map 2) is characterized by deep-to-shallow tills and waterlaid deposits, an outcome of the last glaciation 8 000 to 10 000 years ago. The whole area is underlain by ancient granite and gneiss rocks, which strongly influence the nature of the topography and soils. The forest is mainly boreal and the soils mainly podzols[5] (Map 3). Growing in a cold continental climate, the associated extensive and dense conifer forests have been subject to major fires and blowdown losses. Road construction is often difficult and costly. Growth rates and accumulated yields are not great and much harvesting has been, and still is, near the economic margin.

In contrast to the Acadian and St. Lawrence regions, there has been no major competition from agriculture for land use except in some clay belt areas in Ontario and Quebec.

The southern fringe of this area was logged for sawlogs before World War I. The major exploitation started in the 1920s for pulpwood. Today most of the area up to the northern economic limit of exploitation (Map 1) is under lease to major forest corporations.

Under horse logging, impacts on the land itself were minor; movement of wood to mills was by water. By the 1960s, concern was being expressed about excessive accumulations of bark and debris in rivers and lakes. About this time, truck hauling began to displace river driving, but there is still some major river transport. As aspen and birch are not suitable for river movement because of sinkage and are of less value for pulp, these species have traditionally been left uncut in pulpwood operations. This has led to the conversion of stands from softwoods to mixedwoods over large areas of boreal forests. From the viewpoint of economics and future wood supply, this has been a negative stress and the cause of much concern (Whitney and McClain, 1981). The boreal mixedwood forest is thus a successional mosaic of stratified stands, where cutting has favoured hardwood reproduction over softwoods.

There has been relatively little reforestation on the annual cutover of about 500 000 ha in this region. Softwood growth has often been slow to establish, uneven in size, and often covered by brush. The succession and dynamics of fire-origin forests, to which the tree species are adapted by the presence of full or partially serotinous cones[6] in jack pine and black spruce, are not the same after logging. Fires prepare seedbeds, destroy competition, provide seed supply by heating cones and breaking resin bonds of the scale, and provide shaded spots in the forest floor where seedlings can establish themselves by leaving standing dead timber. Harvesting does not usually do these things well, if at all. The lack of softwood regeneration in the boreal forest has been, and is, the cause of much concern (Canadian Forestry Association, 1977) and has led to renewed efforts and pleas for more reforestation. Appraisals and analyses of the situation (Armson, 1976) and the necessary remedial silvicultural measures (COGEF, 1975) have led to drastic changes in licensing procedures and payments for silviculture practice. The industrial licencees are increasingly responsible, under legal agreements, for the conduct of remedial silviculture on their agreement areas.

This stress on the forest is probably the most important and long lasting of all the man-made stresses on the forest. It is a problem of national

TABLE 2.

The effects of resource road construction on aquatic and terrestrial environments

Construction phase	Effect	Cause
Right-of-way clearing	Reduced site productivity; loss of productive land	Excess removal of vegetation on fragile sites; excessively wide rights-of-way.
	Destruction of habitats of low density bird and animal species	Removal of vegetation in or near unique habitats.
	Barriers to fish migration	Tree felled into the watercourse.
Right-of-way stripping	Reduced site productivity	Excess removal of topsoil; stripping rather than brush-matting in wet areas.
	Loss of productive land	Destruction of the organic mantle by bulldozing in areas of marginal growth; landslides due to removal of vegetation in areas having shallow soils over bedrock, and on sandy sites.
	Loss of usable timber	Blowdown caused by damage to the root systems of standing trees along the edge of the right-of-way; bulldozing of standing trees; burial of trees under piles of debris.
	Barriers to fish migration	Bulldozing of trees and debris into the watercourses; increased siltation of the watercourses.
	Increased stream siltation	Entry of eroded soils into the watercourse due to inadequate width of buffer zone and extending push-lanes into the watercourse.
Stream crossings	Increased stream siltation	Bed and bank erosion caused by improper culvert alignments and increased velocities due to restricted stream flows; roadbed wash-outs resulting from lack of riprapping or winged abutments.
	Barriers to fish migration	Increased velocities under bridges through culverts; improper placement of culverts causing a "waterfall" effect; culverts obstructed by debris; oversized culverts, which cause decreases in water depth.
	Loss of fish spawning area	Undersized and debris-clogged culverts causing "ponding" effect upstream; increased water velocities causing increased siltation downstream.
	Loss of productive land, and wildlife and waterfowl habitat	Undersized and debris-clogged culverts causing "ponding" and flooding upstream.
Drainage facilities	Loss of productive soil	Erosion of cut banks by high water velocities in long ditches.
	Loss of productive land, and wildlife and waterfowl habitat	Flooding due to inadequate drainage facilities; destruction of organic mantles in marshes and bog areas by altering natural drainage patterns.
	Increased siltation	Ditch run-outs which enter directly into the watercourse.

	Reduced water quality	Toxic materials entering the watercourse through drainage systems, either as a result of inadequate dyking or accidental spills.
Borrow pits, cut-banks, fills, crushing operations	Increased siltation of the watercourse	Inadequate buffer zone resulting in siltation due to run-off from exposed soil surfaces; pumping waste water and pit water directly into the watercourse.
	Loss of spawning and rearing areas	Removal of aggregate material directly from the watercourse.
	Reduced site productivity	Erosion causing removal of fine soil particles containing nutrients.
	Loss of productive land and wildlife habitat	Removal of vegetation, organic mantle and topsoil by bulldozing.
	Loss of waterfowl habitat	Filling marsh areas.
Roadways adjacent to watercourses	Increased siltation	Inadequate buffer zones resulting in siltation due to run-off from exposed soils.
	Increased water temperature	Removal of vegetation increasing quantity of solar energy received by the watercourse.
	Oxygen depletion	Decay of organic matter entering watercourse.
	Decreased food supply for fish	Removal of vegetation resulting in a loss of leaf fall which supplies nutrients and terrestrial insect drop to the watercourse.
Roadways near sensitive or unique wildlife, bird, and waterfowl habitats	Loss of habitat; increased feeding pressure; division of herds and flocks; displacement of birds and animals.	Traffic disturbance to animal and bird populations; interruption of migration patterns, and nesting/calving areas.
Support and maintenance facilities	Destruction of fish, wildlife, and waterfowl habitat	Fuel and oil spills in the watercourses; misuse of dust and ice control agents; misuse of pesticides.

Source: Case and Rowe, 1978.

scale and will influence the condition of the forests and the well-being of Canadians for generations.

The change from fire removal to human removal of mature timber, plus the increasing areas of young forest created by man, has dramatically changed the ungulate populations in the boreal forest (McNicol and Timmermann, 1981). White tailed deer have expanded their range northwards, caribou have retreated northwards, and moose populations have increased (Maps 4 and 5).

Foresters are now treating more cut-overs with scarification equipment to destroy plants competing with tree seedlings, and prepare seedbeds by disturbing the humus layer with mechanical equipment. Prescribed burning is also used to remove logging debris, to prepare sites for planting, and to reduce fire hazard. These treatments, if carefully prescribed, can be beneficial to both wildlife and timber.

At the stand level, concern over the direct impacts of mechanized harvesting, other than road construction, in the boreal forest has centred on:

- size and shape of clear-cuts
- destruction of advance growth
- mechanical rutting, disturbance, and compaction of the forest floor
- removal of nutrients, leading to loss of fertility
- destruction of wilderness values

These concerns are considered in more detail later.

Watershed and scenic values have not been so important as in Western Canada. In the boreal landscape the terrain is often very broken and covered with a mosaic of forest types; cuts can be blended and the visual absorptive capacity (VAC) of the landscape to disturbance is high. The terrain is usually not mountainous and is remote from population centres. Because of flies and the network of lakes and rivers, most recreation and cottage construction is along waterways. Protests over cutting in recreation areas have led to the use of buffer strips along roadsides and water. In some cases partial cutting has been required near waterways, rather than clear-cutting, so that views up to the skyline from the water can remain undisturbed. Landscape design manuals and guides for cutting and logging practices (Hough, Stansbury & Associates Ltd., 1973) for eastern forests concentrate on these problems.

In the boreal forest there are many sensitive sites, such as rocky sites with shallow soils, which may have been burned by large fires, creating even-aged stands. In the harvesting of this age class of timber special consideration is required to prevent destruction of the soil, i.e. areas reserved from cutting, small strip or block cuts, partial cuts, care in skidding, winter logging, etc. Some areas may be so susceptible to damage as to preclude their being logged.

A particular problem in boreal forests is organic terrain; usually mature black spruce forests grow on deep organic soils. Historically such areas were logged when frozen. Today, summer logging with skidders or tractors produces deep ruts, which become waterfilled and overgrown with sedges and reeds and inhibit spruce regeneration. Recent developments in the use of large, very low-pressure rubber tires hold promise of eliminating this problem. Skidders thus equipped are faster, more stable, more productive, and have little effect on the soil (Mellgnen, 1980).

Great Lakes–St. Lawrence Region–Ontario and Quebec

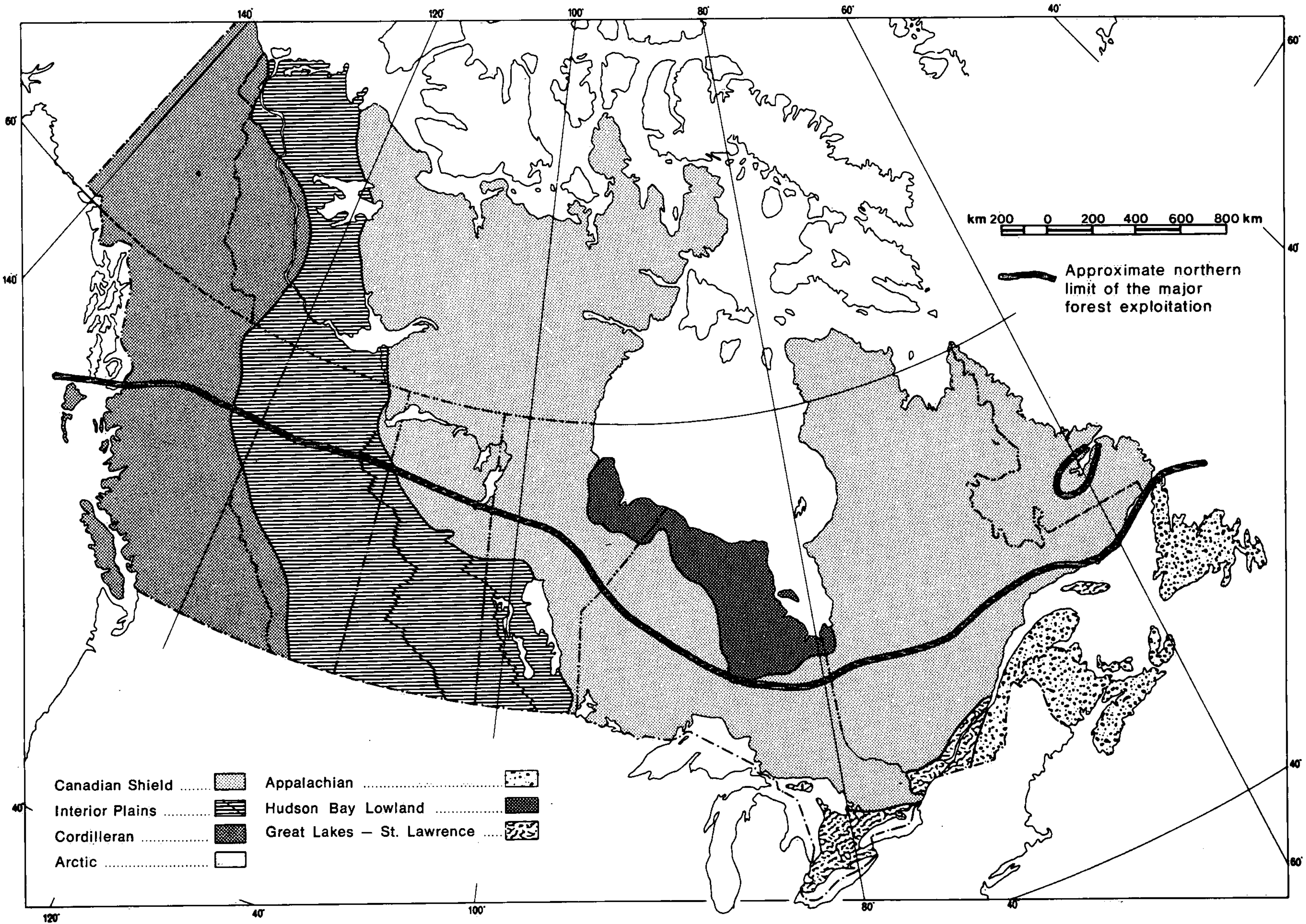
This area south of the boreal forest is characterized by much conversion of forest land to agriculture and the abundance of tolerant hardwood forests composed of maple, beech, hemlock, yellow birch, and also originally containing much white pine. The most southerly hardwood forests of Canada, the Deciduous Region (Map 1), have been largely replaced by agriculture–only remnants remain.

The forests of this region have high amenity values which have been perceived to be threatened by logging. These values are highest near cities, in public recreation areas and in farm woodlots.

Much of the land is privately owned. There is relatively little control of cutting practices on private lands, and taxation systems do not favour forest conservation. Tree farming is not recognized as a bona fide farm operation for property assessment purposes in Ontario (Puttock, 1982), although a 50%-rebate on land taxes is available for registered managed woodlots.

The negative stress of unregulated cutting and logging practices on small private forest holdings is of great concern (Université Laval,

MAP 2.
Major physiographic regions



Source: Reproduced from Rowe, J.S. 1972. Forest Regions of Canada with modifications by G.F. Weetman.

1981). It is a problem of national scale in the United States, where most of the forests are privately owned. In Canada, private ownership of forest land is mainly in the settled parts of Ontario, Quebec and the Maritimes (Map 6). The stresses present are those of high-grading best quality trees from holdings, the destruction of woodlots, stand conversion to low quality forests, destruction of the resource base for the hardwood furniture industry, loss of habitat for wildlife, and loss of scenic values. Many of these values are non-quantifiable. Their losses occur in the forest most visible and accessible to the inhabitants of Eastern Canada. For products of real monetary value, small-scale private forestry is considered unprofitable because of the small scale and the inherent time lags. Because of the non-quantifiable values involved, the application of current economic theory, specifically that of investments based on cost/benefit analyses, is considered absurd in such forest management (Lussier, 1981). State subsidies and regulations are required for the successful integration of forest land uses on such lands. Although there are enlightened provincial programs to encourage better management of small private forest holdings, the money and staff available to implement these are too limited to cope with the problem.

Because of this situation, Canadians living in such cities as Ottawa, Montreal, Toronto, Hamilton, Windsor, and Fredericton are surrounded by privately owned forests, most of which have been and still are very badly managed.

A problem that has been severe in the lower St. Lawrence valley in Quebec is that of rural unemployment and associated social problems. With the collapse of the agricultural-based life style, rural residents and the government have turned to state subsidized silviculture in the degraded forests as a way to alleviate unemployment and improve the condition of the woodlots.

The mix of problems associated with decline in economic viability of agriculture on marginal lands, and of woodlot and associated Crown forest lands, has led to many studies of forest land use planning (Hills *et al.*, 1970; Jurdant *et al.*, 1972). Although the stresses on the land, the forests and the people are well documented, solutions are not readily apparent. The forestry problems are compounded by low-priced timber available from Crown forests, absentee property owners, land speculation, population migration to cities, and lack of resources to implement adequately existing government policies on private land forestry.

Provincial park forest policy in this region has been criticized. Many of the parks in Ontario and Quebec have been logged for a 100 years.

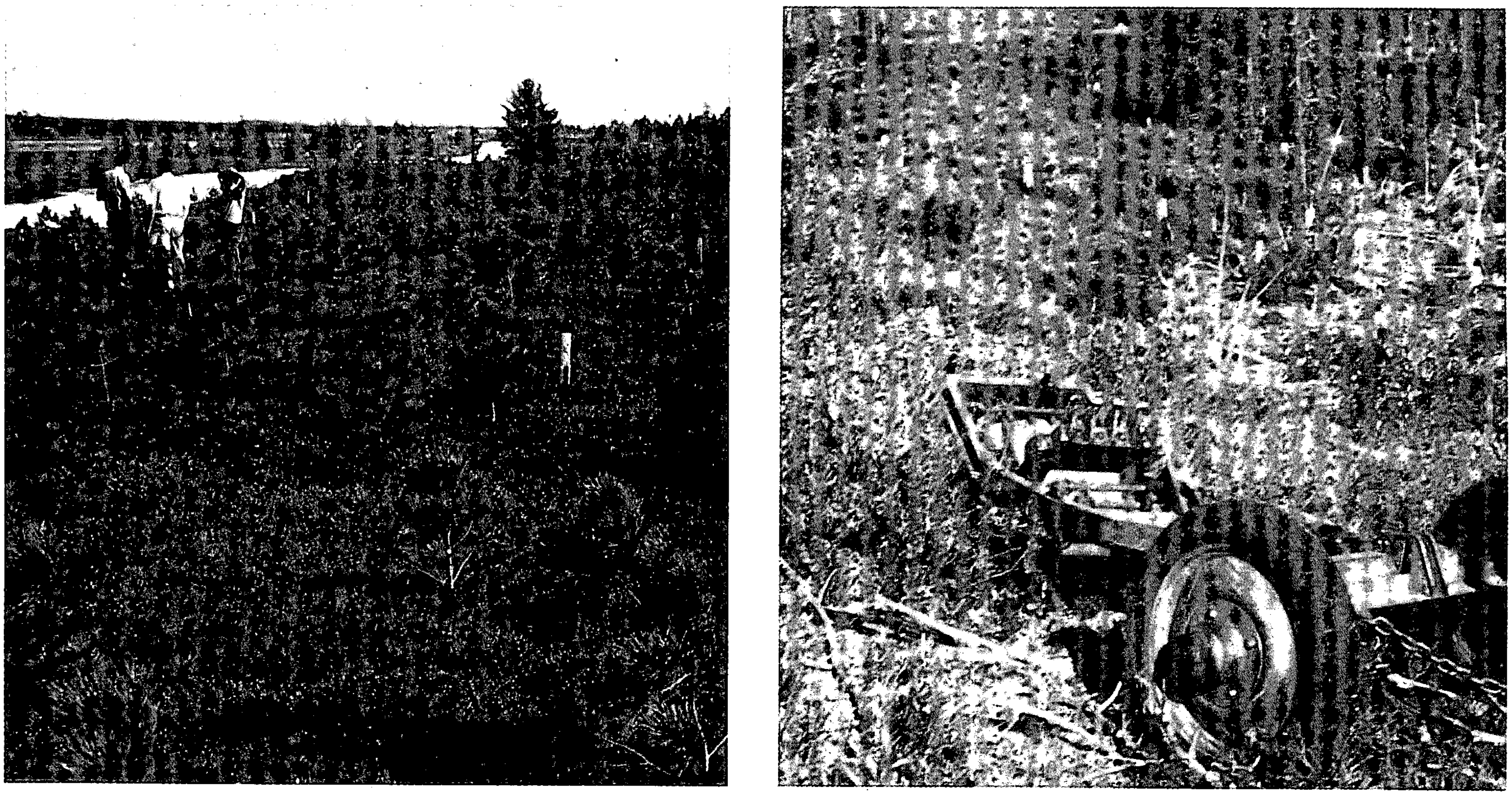


Photo 6. Reforestation of *Kalmia* heathlands produced by cutting and burning is difficult; physical removal of the heath is usually required. Site fertility is reduced.
G.F. Weetman

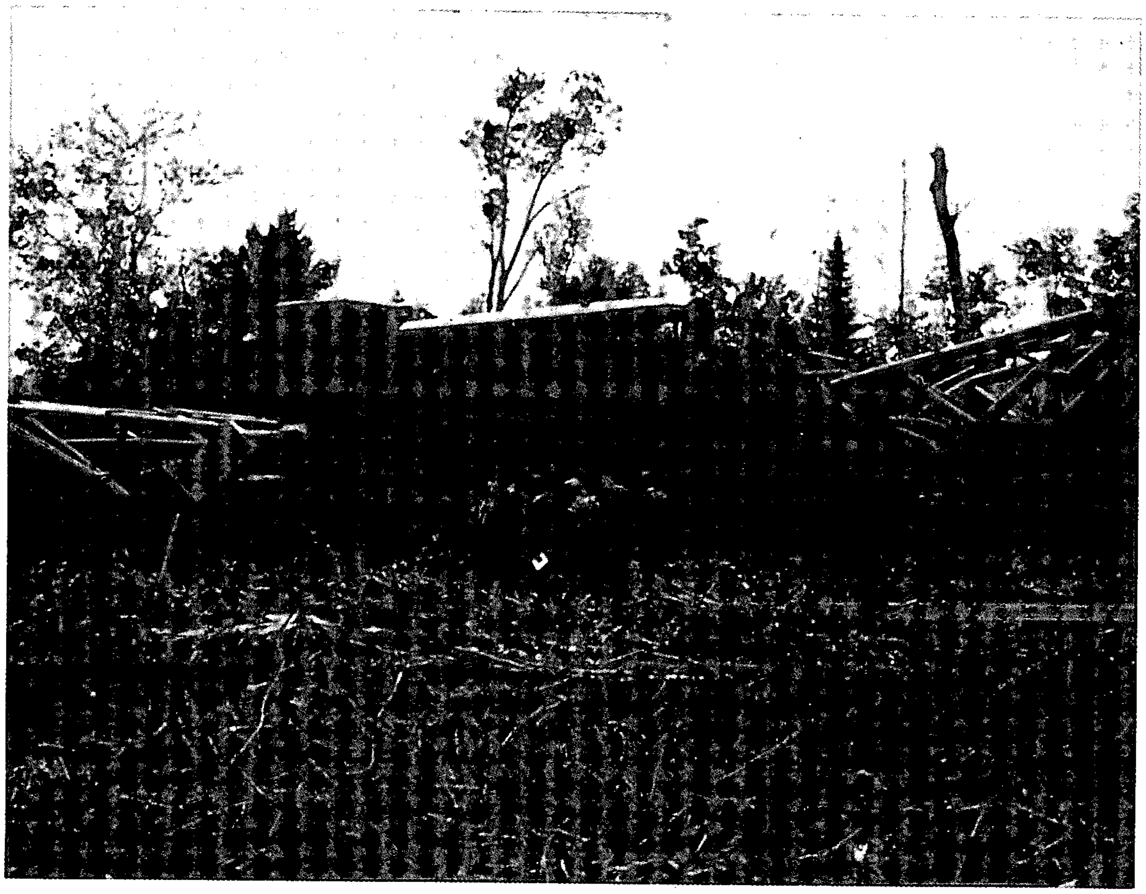


Photo 7. Sixty-five ton Le Tourneau Tree Crusher used for preparing planting sites in New Brunswick.
G.F. Weetman

Here the stress issue is whether logging operations are compatible with public perception of the parks' objectives. Resolution of this issue has involved land-use zoning of parks, restriction of logging to non-tourist periods, and use of partial cutting systems such as selection cutting[7] in tolerant hardwoods (e.g. Algonquin Park, Ontario) and shelterwood systems[8] in white pine management.

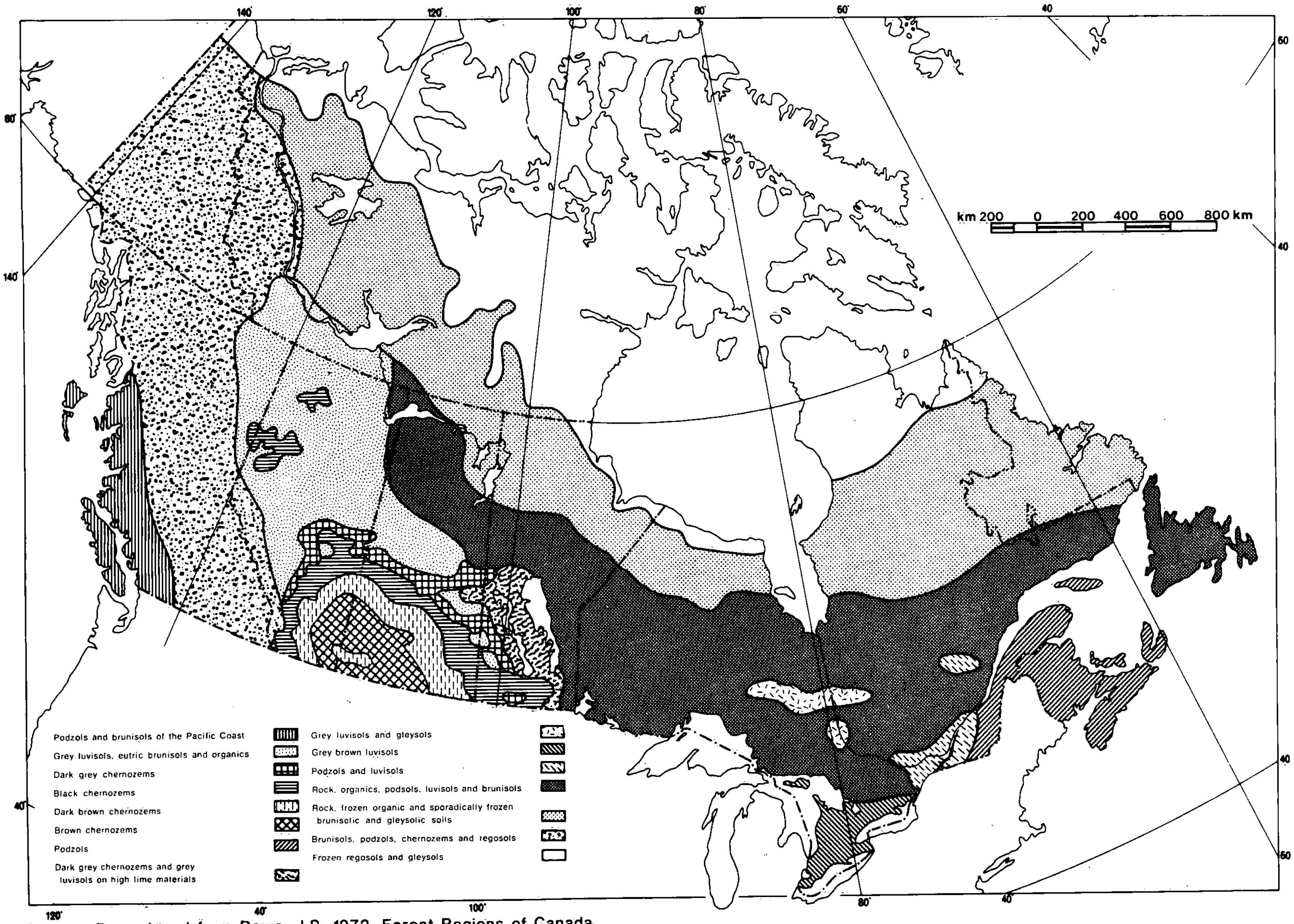
Prairie boreal and aspen parklands–Manitoba, Saskatchewan, and Alberta

Stresses on forest land by logging have only recently started to attract attention in most of this region (Environment Council of Alberta, 1979). The issues are similar, but the areas are great, the population sparse, the forest historically repeatedly burned, and the major clearcutting associated with the pulpwood industry relatively recent.

The lands south and west of the Canadian Shield of the Interior Plains (Maps 1–3) are characterized by deep soils, little rock exposure, few lakes, unbroken terrain, and forests dominated by white and black spruce, jack pine, and aspen. In such flat landscapes, with deep soils,

MAP 3.

Major soil zones and regions



Source: Reproduced from Rowe, J.S. 1972. Forest Regions of Canada.

logging impacts are much less evident and sensitive sites much fewer.

In the foothills of the Rocky Mountains of Alberta these conditions change. This is an area of scenic beauty, of rapidly expanding coal, oil, and natural gas developments, and of public forest recreation. The competition and stresses associated with multiple use of these public forest lands have become severe. Oil and gas exploration has criss-crossed the area with cleared seismic lines and the forest industry has established major road networks and has clear-cut harvested on a large scale. Increased forest protection has now been initiated.

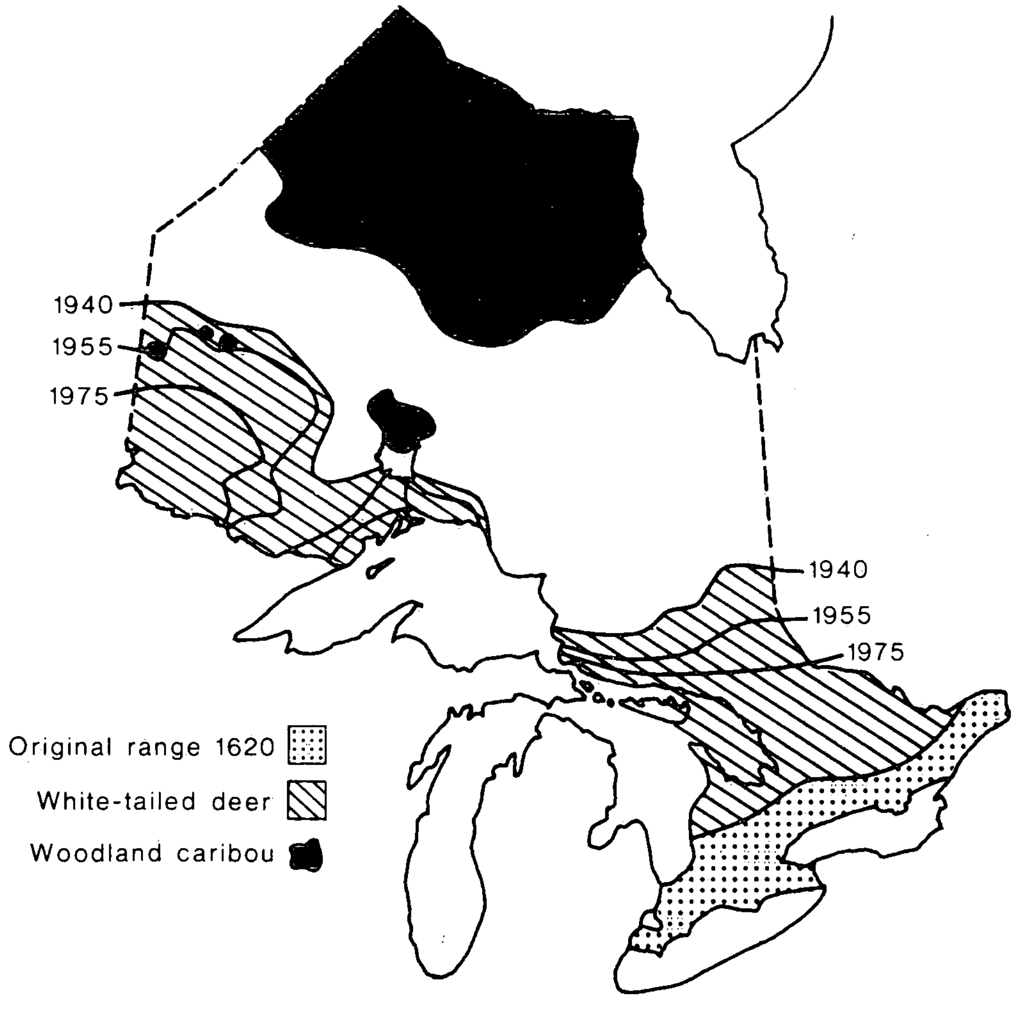
The logging stresses are difficult to separate from other land uses. A major study of the environmental effects of harvesting in the Edson and Grande Prairie regions (C.D. Shultz & Co. Ltd., 1973) identified environmental damage caused by forest road construction as far greater than that associated with all other phases of harvesting. Watershed protection of the headwaters of the rivers flowing into the region is of prime importance. The central issue is the influence of tree removal on total water yield and seasonal stream flow. The processes involved are interception of precipitation by the tree canopy, the rate of evapotranspiration, and the rate of snow melt. The size of cut in relation to snow accumulation and melt is of concern. Studies have proven that real water yield increases are possible as a result of cutting. Anderson *et al.* (1976) stated that maximum first year increases after clear-cutting, partial clear-cutting, and selection cutting were 46, 20, and 10 area-cm respectively. (To allow meaningful comparisons between watersheds of different size, streamflow amount is often converted to units of uniform depth over the watershed, called area-centimeters.) An approximate upper limit is 4.5 mm annually for each 1% reduction in forest cover, but most are half this amount (Golding, 1981).

The importance of watershed values has led to the preparation of guidelines for minimizing the degree of ground disturbance, use of buffer strips along streams, and block and strip cutting (Table 3).

A feature of the region is the dramatic change in landscape between Jasper and Banff National Parks, now dominated by closed forests where logging and mining are not permitted, and the forest areas east of the parks, which are now radically disturbed by man. Much of the forest in Banff and Jasper National Parks is composed of even-aged, subclimax stands of lodgepole pine that in the absence of fire will be gradually converted to white and Englemann spruce. Meanwhile, as these lodgepole pine stands mature, they become centres of mountain pine beetle infesta-

MAP 4.

Changes in the white-tailed deer distribution from 1620 to 1975 and the present woodland caribou distribution in Ontario



Source: Smith and Borczon, 1977 and Bergerud, 1978 *in* McNicol and Timmermann, 1981.

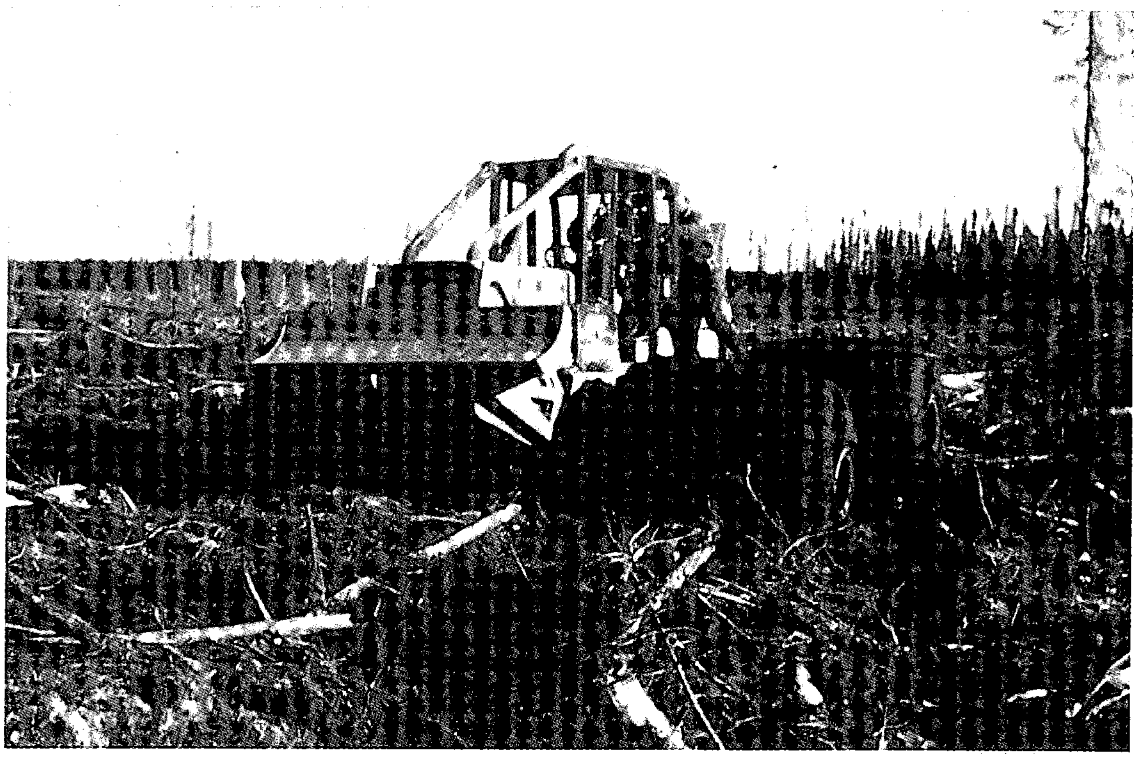


Photo 8. Ruts caused by skidders on organic terrain in the boreal forest can be avoided by wide tired skidders.
E. Heidersdorf

tions that spread to commercial forests adjacent to the parks. The changes wrought by logging are obvious to the public, and highlight the contrast with the "natural landscape" and fauna of the national parks. The access provided by forest roads for tourists and hunters is a form of stress that is perceived quite differently by different segments of society.

Mountain forests

Interior–British Columbia and Alberta

The interior mountains of British Columbia and Alberta have a very wide range of climates, from desert to alpine to boreal. All this area has short growing seasons with a continental climate. The forest regions (Rowe, 1972) are the Montane, Columbia, and Subalpine. The common feature of this region has been the historic occurrence of extensive fires and insect epidemics leading to heavily disturbed forests, except at high elevations.

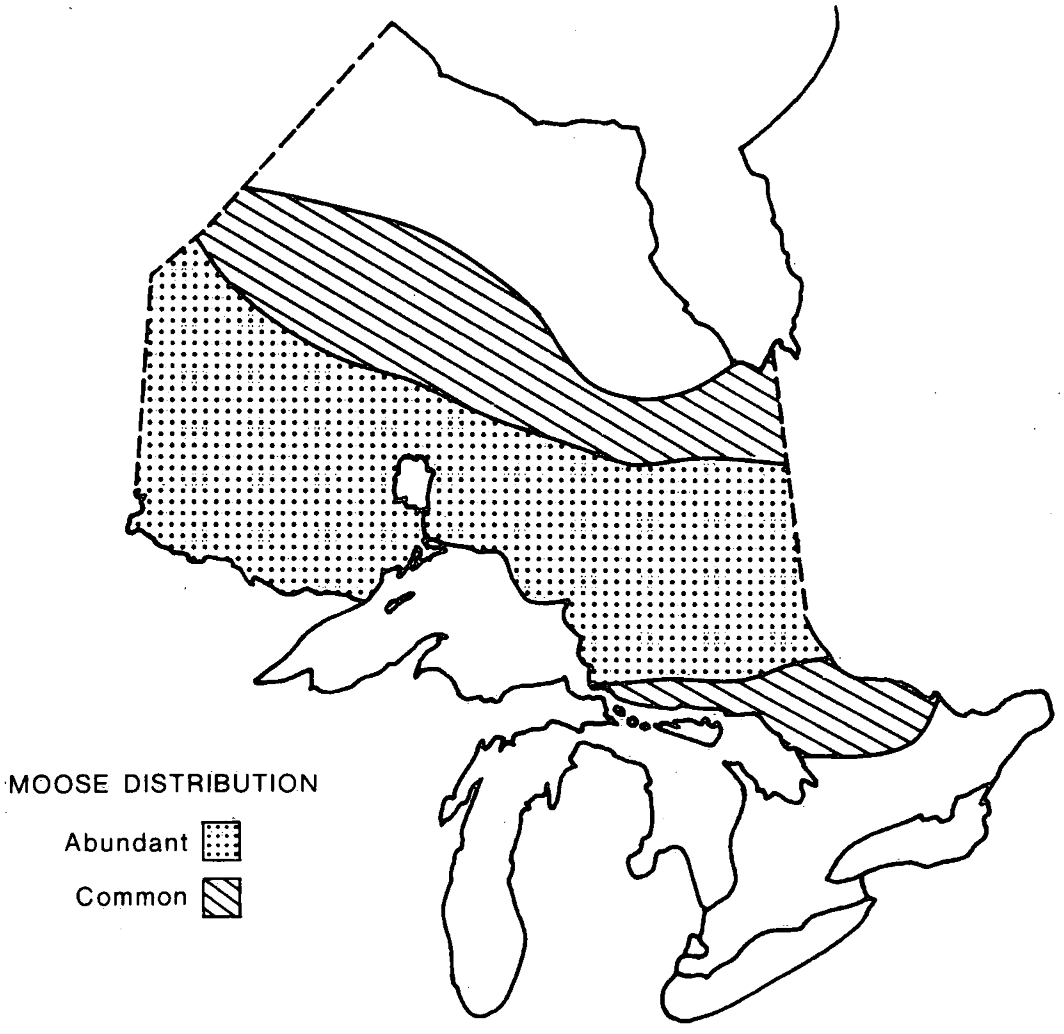
The rolling and mountainous terrain, the use of water for irrigation, the seasonal shifts of ungulate populations, the use of valleys for farming and ranching, and expanding tourism have together produced very severe land-use conflicts.

The area is dominated by logging for sawlogs, not for pulpwood as elsewhere in Canada. Truck hauling is required and roads must be pushed up steep mountains. Low elevation forests were exploited long ago.

The negative stress issues centre on:

1. Habitat protection for ungulates, especially low-elevation winter habitat and high-elevation mature forest, in particular for the Kootenay caribou herd.
2. Watershed protection in irrigation areas such as the Okanagan.
3. Maintenance of lands for wilderness areas in uncut valleys.
4. Erosion and carelessness associated with mountain logging roads and use of skidders.
5. Size, shape, and orientation of clear-cut areas for landscape values.
6. Fish habitat protection.
7. The designation of environmentally sensitive forests on mountain slopes (environmental protection areas).
8. Whether logging should be permitted in provincial parks (as occurs in eastern Canada).
9. Lack of regeneration on many sites, particularly high elevation sites.
10. Scale of salvage operations in beetle-killed timber.

MAP 5.
Moose distribution in Ontario



Source: Cumming, 1972 *in* McNicol and Timmermann, 1981.

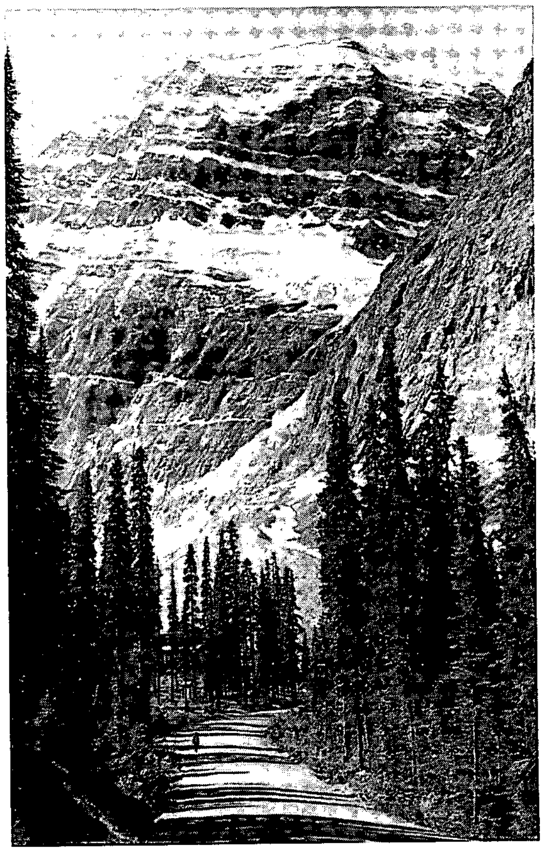


Photo 9. Jasper National Park, Alberta.
NFB-Phototheque-ONF - Photo by Nelson Marrifield

This area has a low resident population, primarily involved in logging, ranching, and tourism. The economic viability of the region is dependent on a successful interpretation of land uses over much of the area. Non-resident visitors often favour single use zoning, usually for recreation or wilderness. As the conflicts multiply, the need for large-scale biophysical surveys as a scientific basis for rational land use becomes more apparent.

Coastal British Columbia

In contrast to interior forests and to elsewhere in Canada, coastal forests have historically had a very low frequency of major fires. Major hurricanes are rare and the forests, dominated by tolerant conifers such as western and mountain hemlock, pacific silver fir, grand fir, and western red cedar, have reached great ages and sizes. Forests 200–600 years old are usual in unlogged areas. The appearance is of a very uniform cover of large evergreen trees.

Disturbance of this forest by fire or logging produces a dramatically different appearance: fire produces large standing dead trees; logging produces large accumulations of slash and large stumps. Slash burning following logging produces a picture of apparent devastation. These radical changes in appearance result from the contrast between the clear-cut areas and the uniform green cover of old growth forests. These landscapes have a low visual absorptive capacity (VAC). The visual problem has been mitigated by using landscape design manuals to modify cut size, shape, and location to meet visual quality objectives (VQOs) (United States Forest Service, 1979*b*). The amount of slash burning has been greatly reduced following the development of site-specific guidelines for its use (Klinka, 1977).

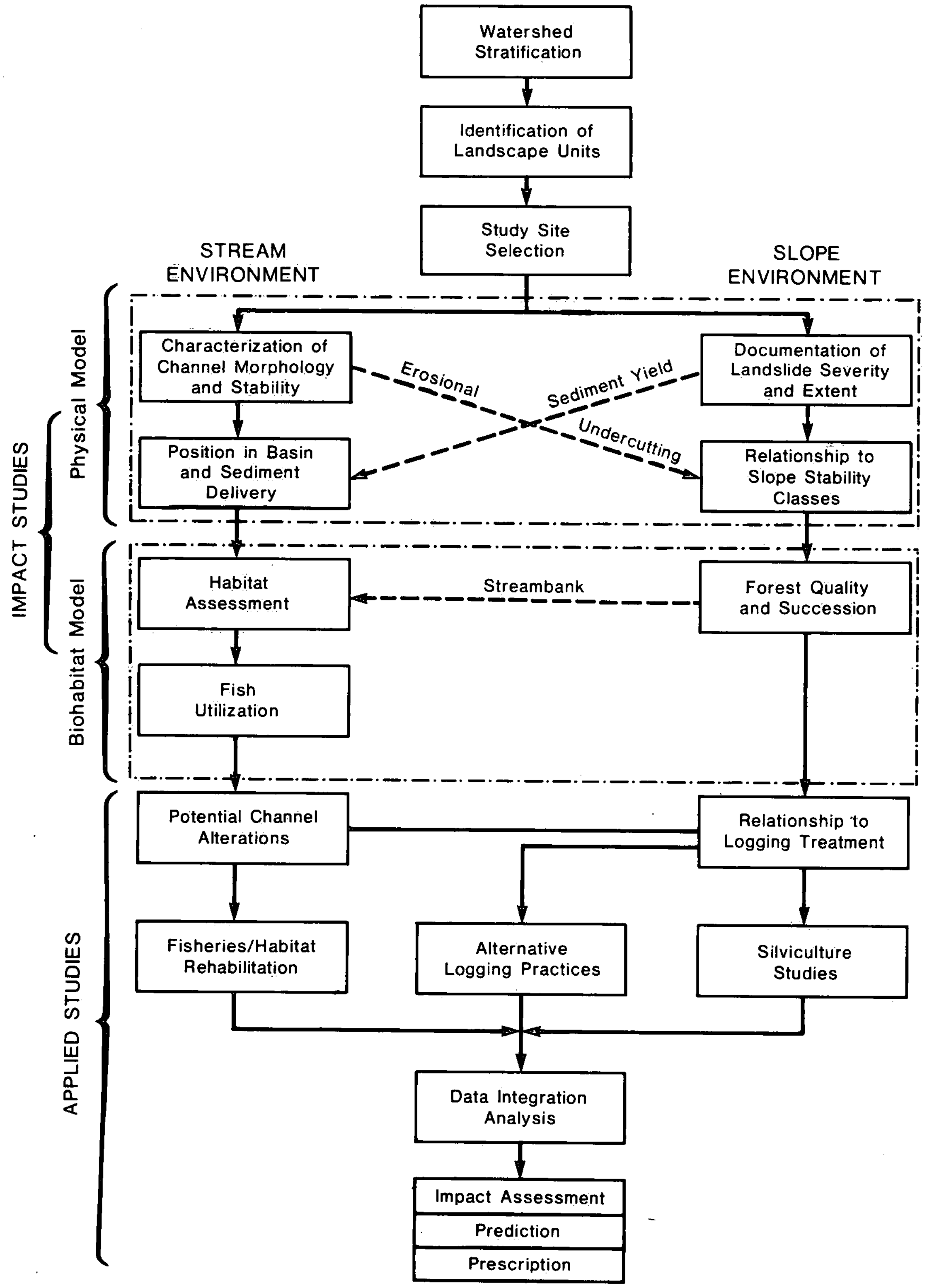
Because the forests are old and the growing conditions are good, large volumes of merchantable timber have accumulated even at high elevations and on steep slopes. Logging operations penetrate high up the slopes and valleys of the coastal mountains, necessitating expensive and difficult road construction. All this construction, plus the clear-cuts are highly visible. Erosion, landslides, and excessive and careless road construction have occurred; fish habitat has been destroyed by landslides or organic debris in rivers and streams (Toews and Moore, 1982). Many studies and reports have been done, both for the coast and the interior (United States Forest Service, 1979*a*; Finnis *et al.*, 1973). Control of logging practice is rigorous, mostly by the use of guidelines jointly prepared by government and industry.

Specific concerns have focused strongly on loss of fish habitat, particularly salmon. The conflict in jurisdiction between salmon habitat, which is under federal administration, and logging practices on Crown lands, which are under provincial administration has attracted much attention. Slope stability and mass wasting (or slumping) problems associated with logging on steep slopes on the Queen Charlotte Islands is an example of the jurisdictional conflict (Poulin, 1981). Figure 3 illustrates the study components of fish–forestry interactions.

In high-elevation coastal forests associated with yellow cedar, mountain hemlock, and pacific silver fir, as well as with deep snow accumulations and short growing seasons, lack of regeneration following clear-cut logging is of much concern (Reuter, 1973). Very old forests can only be harvested economically by clear-cutting in this area, advanced fir growth[9] is often of

FIGURE 3.

Study components of fish-forestry interactions in the Queen Charlotte Islands, British Columbia



Source: Poulin, 1981.

poor quality and there is little experience in planting high-elevation species.

Restrictions on the size of clear-cuts and the elimination of the practice of progressive clear-cuts, in which mature timber was removed quickly over large areas, have been imposed. Figure 4 illustrates potentially adverse interactions between timber management practices and factors associated with site deterioration. Although regeneration, protection, and stand treatment practices have less impact than harvesting and roads, they have been of concern to managers dealing with water quality objectives (see Figure 5).

Procedures for the evaluation of potential adverse resource impacts on water quality objectives have been given in detail (United States Forest Service, 1980). Table 4 lists the potential adverse resource impacts on water quality of most silviculture activities. It is:

> *"a simple table with silvicultural activities listed in one column and the potentially adverse resource impacts resulting from each silvicultural activity listed in the second column. The list of potential impacts associated with particular silvicultural activities is suggested for initial consideration but may need to be revised according to local conditions.*
>
> *Silvicultural activities listed are:*
>
> *1. Methods of cutting*
>
> *2. Felling*
>
> *3. Yarding methods*
>
> *4. Road and access system*
>
> *5. Fuel management methods*
>
> *6. Site preparation*
>
> *7. Other activities*
>
> *Adverse resource impacts include:*
>
> *1. Aerial drift and application of chemicals*
>
> *2. Bare soil*
>
> *3. Channel gradient changes*
>
> *4. Compaction*
>
> *5. Debris in channel*
>
> *6. Excess water*
>
> *7. Onsite chemical balance changes*
>
> *8. Slope configuration changes*
>
> *9. Streamside shading changes*
>
> *10. Vegetative change*
>
> *11. Water concentration*
>
> *Table 4 can be used in two ways –*
>
> *1. In the formulation of the silvicultural activity plan.*
>
> *2. In the process of determining what variables are affected by what controls when running the handbook simulations."*

(United States Forest Service, 1980).

It is also important to recognize that the effects of logging may not always be harmful to fish. Some warming and enriching of the waters with nutrients may enhance the productivity of very cold mountain streams.

TABLE 3.
Guidelines for minimizing ground disturbance of logging operations on watersheds

---

Planning for watershed protection identifies potential problems and determines practices for avoiding them. The first factor to be considered is minimizing the total area or degree of ground disturbance.

1. Use staggered settings to reduce the area of continuous clear-cuts and prevent buildup of runoff water.
2. Minimize length of road and the amount of earthwork in road construction.
3. Choose that method of logging most appropriate to the conditions. Recognize that tractor logging causes more disturbance than high-lead logging, followed by skyline logging, and finally helicopter logging.
4. Carefully plan skid-road locations.
5. Carefully select sites for landings.
6. Consider whether slash burning is necessary, recognizing that severe burns expose mineral soil to erosive forces and cause higher nutrient inputs to streams.
7. Consider the windthrow potential in establishing setting boundaries.
8. Carefully plan road drainage and determine culvert size to carry peak flows.
9. Plan to leave buffer strips of trees between streams and adjacent roads and landings.
10. Assess the erosion potential of streams and stream banks considering the natural debris present in the stream and the probable input of logging debris.
11. Plan operations so that road construction and drainage facilities are completed before the wet season.
12. Plan for post-logging road maintenance.
13. Provide field supervision that will be adequate to ensure that specifications laid down in the logging plan will be observed.

Source: Golding, 1981.

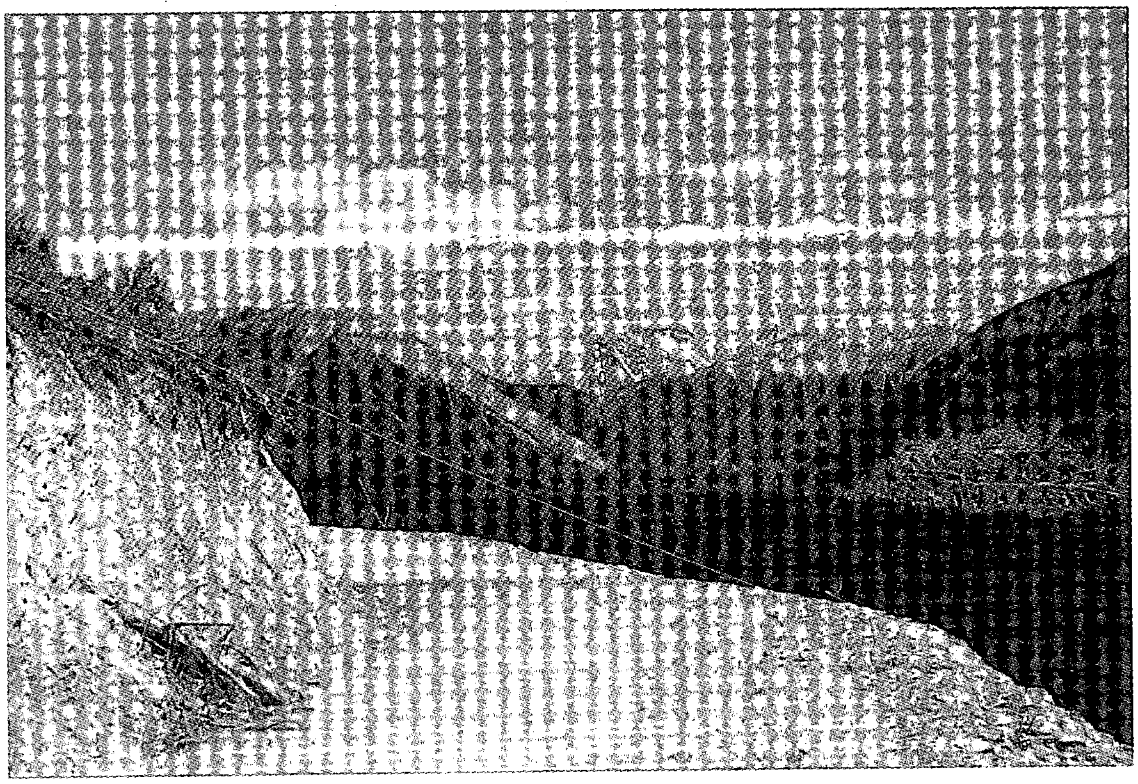


Photo 10. This photo shows a high-elevation forest road and clearcuts with tractor skid roads. East Kootenays, British Columbia.
R. Smith, PFRC, Victoria

North of 60° and northern Quebec

Forests in the northern territories are nearly all non-commercial in size and volume (see Maps 1, 2 and 3; Forest and Barren). Only in the areas close to the MacKenzie River and Ungava Bay do boreal forests, mostly composed of white and black spruce, reach commercial volumes. The white spruce from valley bottom sites in the Yukon has been used mainly for sawlog production. In Alaska, forest exploitation has been more extensive. White spruce trees average 18–24 m tall and 25–36 cm in diameter. The biology of these high latitude forests is well known (Zasada *et al.*, 1977).

There are two main stress features: lack of regeneration of white spruce and amount of fire protection. The first is an almost universal feature of white spruce. On rich valley sites, vegetation competition makes both natural regeneration and planting slow and difficult. Fire protection issues are concerned with identifying the desirable level of effort necessary to control or extinguish natural wildfires. The fire ecology of this region is well known; fire is a natural phenomenon, usually originating from lightning. When the economic value of the timber is low, fire control policies are determined, first, by what future benefits or disbenefits may result from balanced or unbalanced forest age class structures in the next century and, second, by the relationships between fire, vegetation, soil, barren-ground caribou, and fur bearers. Lichens growing on the ground and on trees are the caribou's winter food and comprise 60% of the winter forage. Forest fires can destroy this vital winter habitat (Scotter, 1971). Fire control policy has been to let many fires burn unless special habitat, timber values, or human settlements are in danger.

It appears unlikely that the forests of this region will be subject to much large scale exploitation. Owing to the recent financial failures or poor economic performance of northern pulpmills in Canada, new mills are unlikely to attract investors (Mathias, 1971; Loomis, 1979). Isolation, lack of amenities, hostile climate, and distance from markets are the determining factors. It is probable that the vast area of northern forests in Canada will remain in a virgin state, periodically burned by fire.

SPECIFIC ISSUES

In the section to follow on specific forestry issues, there is no discussion of the use of pesticides and herbicides, which today are important issues in many parts of Canada. The author recognizes that these are significant concerns. However, because of the large body of literature already in existence, and the large number of reports presently in preparation on these subjects, they are not documented in this section.

Harvesting and site fertility

In contrast to agricultural lands, forest lands recycle nutrients by litterfall (the fall of leaves, twigs and flowers). The cycles of nutrient elements in closed forests are quite "tight", i.e. there is little leakage of nutrients from the system into streams and groundwaters. Most of the streams flowing from northern forests are poor in nutrients, or what is termed "oligotrophic" (infertile). Concern about nutrient cycling in forests goes back to pioneer German studies. These noted declines in the fertility of spruce and pine forests following the removal of needles from the forest floor. Peasants, as a historic right, used the needles as litter for animals and to fertilize their gardens (Weetman and Webber, 1972). European forests subject only to removal of tree trunks over 100–200 year periods have been shown not to lose fertility; the wood and bark contain few nutrients. These infrequent removals of nutrients are made up by inputs into the forest ecosystem from dust, precipitation, and soil weathering. This type of "tree length" logging was the only type of logging in Europe and North America until recently. Starting in the 1960s attempts were made to mechanize harvesting, which sometimes involved removing the entire aboveground portions of trees to the roadside for removal of limbs—"whole tree" logging. This type of logging removes all the leaves and branches and represents a major nutrient export from the site as they are nutrient rich. Calculations of the nutrient budgets of forests treated by whole-tree logging suggested that inputs could balance exports on long cycles (50–100 years) between cutting (see Table 5), but not on shorter cycles. Whole-tree logging is not recommended on poor forest sites with low nutrient reserves.

Currently, there is very little full-tree harvesting in Canada—only 5% of the total wood cut east of Saskatchewan in 1978 was by full-tree methods (Canadian Pulp and Paper Association, 1981). About 0.8 million hectares are cut annually in Canada, about 0.6 million east of Saskatchewan. The area of full-tree logging is probably about 30 000 ha annually, nearly all of which is on long rotations. Biomass energy plantations are in an experimental stage, mainly in Eastern Ontario; their economic viability is yet to be proven. They do require energy inputs in the form of cultivation, herbicides, and fertilizers.

Site depletion by nutrient exports in harvesting trees does not now seem to be of major concern, provided full-tree harvesting is restricted to good sites.

Following the OPEC oil crisis in the mid-70s, attention was given to forests as a supply of natural energy. Under the federal Energy From The Forest (ENFOR) program numerous

TABLE 4.
Silvicultural and related activities and associated potential adverse resource impacts on water quality

Activities	Potential adverse resource impacts
Methods of cutting:	
Clearcutting	Excess water Streamside shading changes Vegetative change
Seed tree cutting	
Selection cutting	
Shelterwood cutting	
Felling	Debris in channel Vegetative change
Yarding methods:	
Hand pulpwooding	Compaction
Animal skidding	Bare soil Compaction Water concentration
Tractor skidding	
Cable yarding — high lead	Bare soil Water concentration
Cable yarding — skyline	Bare soil Slope configuration changes
Cable yarding — balloon	Bare soil
Aerial skidding	Onsite chemical balance changes
Mechanized logging (feller, buncher, etc.)	Bare soil Compaction Water concentration
Road and access system:	
Construction and maintenance	Aerial drift and application of chemicals (dust) Bare soil Channel gradient changes Compaction Debris in channel Slope configuration changes Vegetative change
Fuel management methods:	
Burying slash	Bare soil Compaction Slope configuration changes
Firelines and fuel breaks	Bare soil Compaction Slope configuration changes Water concentration
Broadcast burning	Aerial drift and application of chemicals (ash) Bare soil Compaction Debris in channel Excess water Onsite chemical balance changes Vegetative change Water concentration
Hand piling and burning	
Machine piling and burning	
Prescribed underburning	
Jackpot or spot burning	
Yarding unmerchantable material	Bare soil Compaction Debris in channel
Lop and scatter	Debris in channel
Rolling chopper	Compaction Onsite chemical balance changes Vegetative change
Chip and spread	Compaction Debris in channel Onsite chemical balance changes
Masticate	

TABLE 4. (*continued*)
Silvicultural and related activities and associated potential adverse resource impacts on water quality

Activities	Potential adverse resource impacts
Site preparation:	
Dozer stripping	Bare soil Compaction Excess water Slope configuration changes Vegetative change Water concentration
Terracing	Bare soil Compaction Excess water Slope configuration changes
Machine scalping	Bare soil Compaction
Bedding	Bare soil Water concentration
Plowing Disking	Bare soil Debris in channel Slope configuration changes Vegetative change Water concentration
Drags	Bare soil Compaction Vegetative change Water concentration
Drainage	Bare soil Water concentration
Chemical treatment	Aerial drift and application of chemicals Debris in channels Vegetative change
Other activities:	
Mechanized planting	Compaction Water concentration
Release from plant competition—	
Fire	See broadcast burning
Chemical	Aerial drift and application of chemicals
Mechanical	Compaction Water concentration
Thinning and cleaning—	
Hand	Debris in channel Vegetative change
Mechanized	Compaction Debris in channel Vegetative change
Fertilization Seeding with treated seeds	Aerial drift and application of chemicals Onsite chemical balance changes Vegetative change

Source: United States Forest Service, 1980.

Photo 11. Removal of all the above-ground portions of trees increases export of nutrients compared to removal of only the trunks. Such exports may reduce site fertility on sites poor in nutrients, such as jack pine-lichen sites in the boreal forest.
G.F. Weetman

studies were done to calculate the total biomass reserves in forests. New calculations were made based on biomass harvesting to maximize energy production. In theory this could be done on short (2–15 year) cutting cycles in stands grown especially for energy production (energy plantations). Trees that reproduce from stump sprouts or can be propagated by cuttings, such as some poplars and willows, are now being grown. These plantations are largely restricted to cultivated soils and have the characteristics of agricultural crops. Intensive short rotation cropping with high nutrient exports will require repeated fertilizer applications to maintain soil fertility (Freedman, 1981).

Historically, in both Europe and parts of North America, forest crops for wood fuel and charcoal were grown by repeated cutting of coppice forests,[10] such as those composed of oak, a species that sprouts from stumps. This practice stopped with availability of fossil fuels but might return to parts of Europe and North

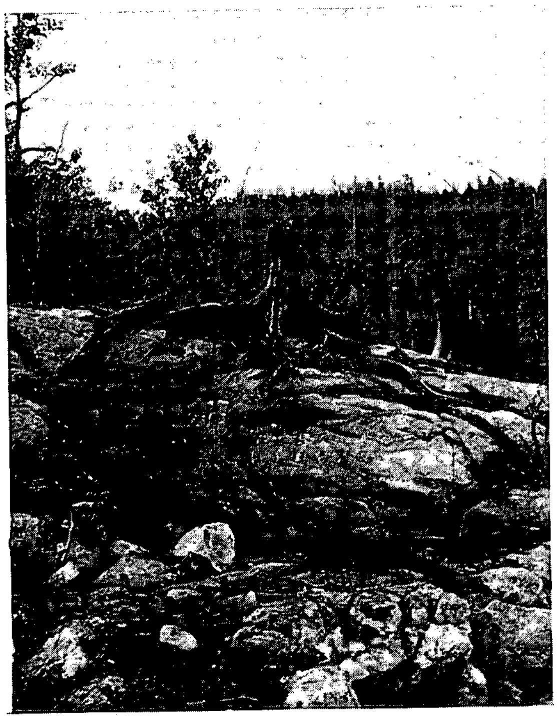
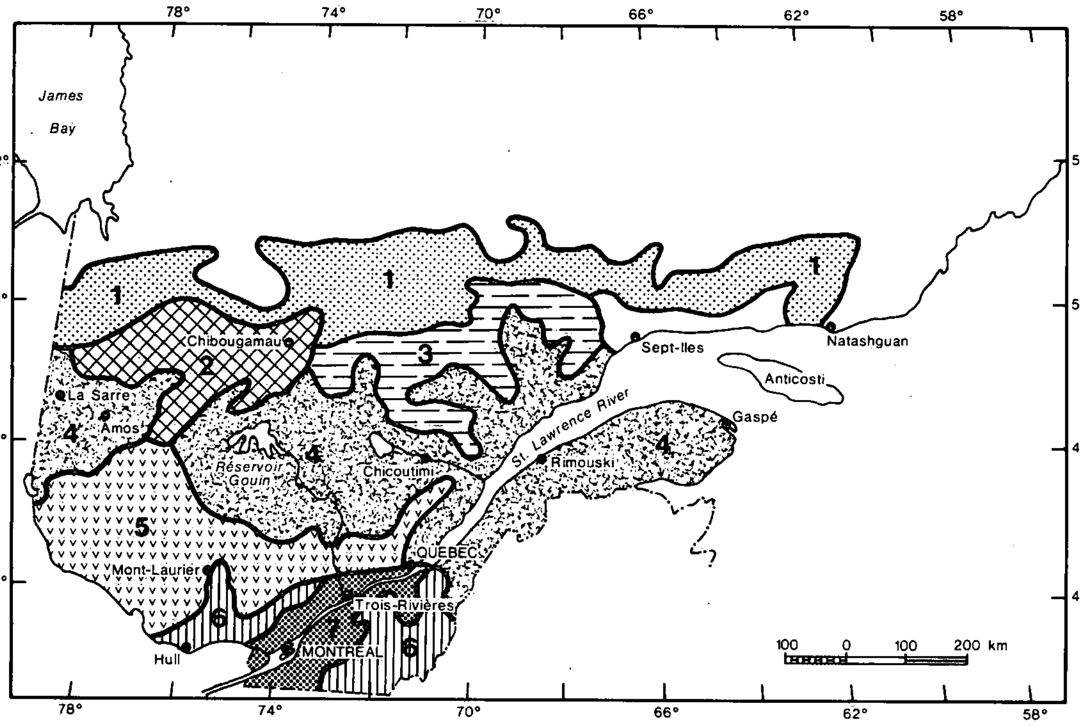


Photo 12. Large and severe forest fires following logging can reduce site fertility by removing the forest humus on shallow soils.
G.F. Weetman

MAP 6.

Overview of Quebec's main forest problems



Subdivision of Quebec into forestry problem areas:

░ Zone 1 – Forest is not economically accessible.

▩ Zone 2 – Over-exploitation, supply shortfalls, natural regeneration often inadequate.

☰ Zone 3 – Thin soil. Following development, frequent regeneration problems on rocky ground.

▒ Zone 4 – Lack of mature forests. Heavy infestation of spruce budworm. Too great density of softwood in natural regeneration. Gradual invasion of non-commercial hardwood.

∨ Zone 5 – Heavy infestation of budworm, continued deterioration of quality stands.

▥ Zone 6 – Combination of problems encountered in zones 4 and 5. Heavy invasion of forest pests in best sites.

▓ Zone 7 – Primarily agricultural zone, however with many farm woodlots which are often badly managed.

Source: Lussier, 1982.

America if non-renewable energy sources become too expensive. Most of the wood cut in the world is used for fuel: 1 500 million people in developing countries derive at least 90% of their energy requirements from wood and charcoal (National Academy of Sciences, 1980; Barney, 1981).

Of greater concern is depletion of site fertility on low fertility sites by the use of slash fires, which burn off the humus layer containing the bulk of the available nutrient supply. Such sites are common on mountain sides with rocky or very shallow soils. This deliberate slash burning was common in British Columbia but is now forbidden although natural and man-caused wildfires still occur. Historically, extensive wildfires have occurred on such poor sites in the Canadian boreal forest, often following logging which produced hazardous slash accumulations. The recovery of fertility is slow. Examples are the fires of the late 1930s in the Chic-Choc Mountains of the Gaspe Peninsula in Quebec. Severe wildfires in high-elevation black spruce forests have resulted in poorly regenerated forests whose fertility is mainly in a thin lichen cover.

Wildfires following logging have been very common. They have been particularly detrimental when they occurred in young stands before seed production. Barrens and heathlands in Newfoundland (Damman, 1964), Nova Scotia (Wall, 1977), and Quebec are examples of real declines in forest productivity associated with fires following logging.

The most direct impact of logging on site fertility is by removal of the upper soil horizons, either directly by bulldozing or by subsequent soil erosion. During winter-logging operations on snow, prevalent until the 1960s, there was little disturbance of the forest floor. Most of the fertility of Canadian forests, in terms of nutrient reserve, is concentrated in the top 10–20 cm of organic forest floor and underlying mineral soil. The actual percentage of the cutover that has exposure of mineral soil (EMS) is usually very small when rubber-tired skidders, cable skidders, or balloon systems are used for logging.

Photo 13. Severe forest fire in 1955 at Baie Comeau, Quebec.
G.F. Weetman

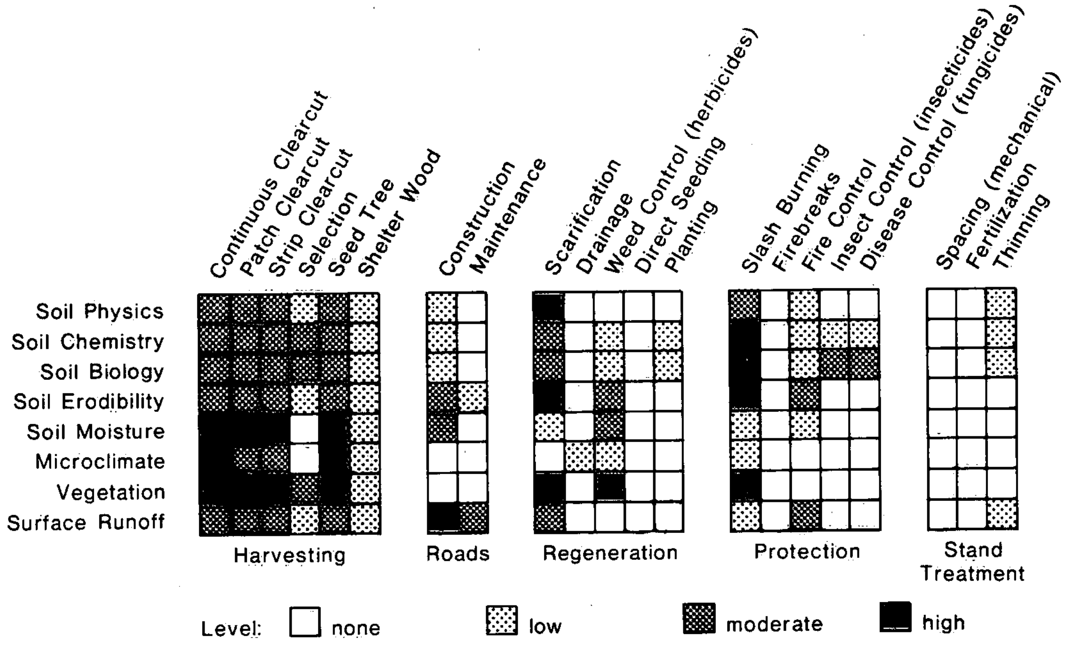
The EMS values range from 5 to 20% (Sidle, 1980). When bulldozers are used for skidding, EMS values can reach over 70%. In practice these problems with tractor skidding tend to occur on slopes of 25% and greater where rubber-tired skidders cannot operate safely. Loggers often cannot afford the capital investment of cable skidding equipment. Cable skidding is increasingly required on steep slopes, but many mountain forests have been and still are logged with bulldozers. This form of logging results in skidroads cut into the hillside at a slight bias to the contour, producing a series of terraces.

The removal of the forest litter layer exposes the soil to erosion by rain; the crumb structure of the soil breaks down and fine particles of soil plug the pore spaces in the underlying soil, reducing the rate at which it can absorb water. 'Splash erosion' can wash sediment down hill. Soil compaction by bulldozers reduces the large pores in the soil and increases its density. Studies of seedling growth on skid trails have shown reduced growth (Smith and Wass, 1980; Adams and Froehlich, 1981). Soil compaction is most likely to be a problem on fine-textured soils, as in the Ontario Clay Belt and in areas without frozen soil such as the southern British Columbia mountains. For most of Canada annual freezing and thawing cycles of the soil tend to reduce compaction.

Provided the forest floor remains in place, there is little evidence for real fertility loss from conventional logging operations. The vigorous growth of cutover stands subject to apparently devastating unregulated logging earlier in the century attests to this. Most fertility loss can be avoided by limiting the amount of bulldozing and exposure of mineral soil on steep slopes. Provincial policy guidelines are in place to control mountain logging practice (Smith, 1973). To date, multidisciplinary reviews or environmental impact statements are not required for cutting permits except in special locations. On National Forest lands in the United States control of cutting practice has been much more rigorous (Spurr, 1981). Tables 6 and 7 give some of the 1972 and 1976 guidelines. Erosion control guides are available for road construction; these require revegetation of exposed soils with seed mixes, as is done on provincial highways (Carr, 1980).

FIGURE 4.

Potentially adverse interactions between timber management practices and site deterioration - related parameters



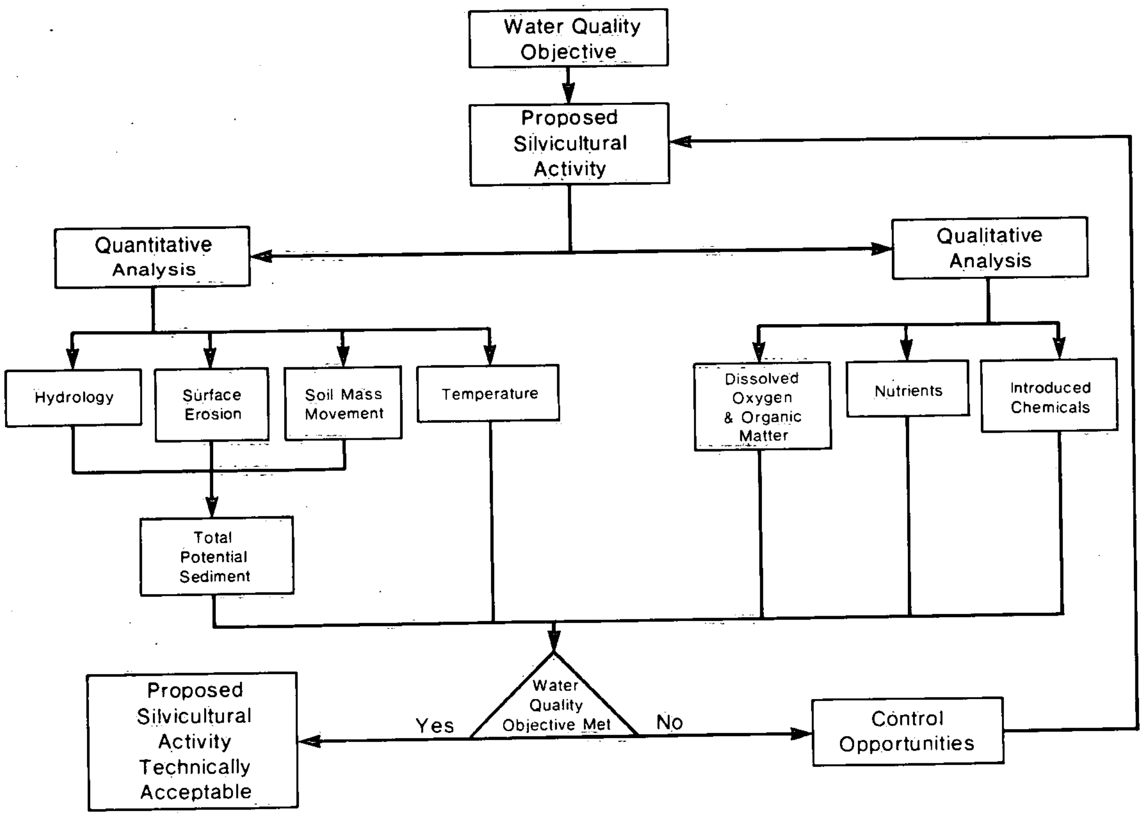
	Harvesting						Roads		Regeneration					Protection					Stand Treatment		
	Continuous Clearcut	Patch Clearcut	Strip Clearcut	Selection	Seed Tree	Shelter Wood	Construction	Maintenance	Scarification	Drainage	Weed Control (herbicides)	Direct Seeding	Planting	Slash Burning	Firebreaks	Fire Control	Insect Control (insecticides)	Disease Control (fungicides)	Spacing (mechanical)	Fertilization	Thinning
Soil Physics	▒	▒	▒	░	▒	░	░	□	■	□	□	□	□	▒	□	░	□	□	□	□	░
Soil Chemistry	▒	▒	▒	▒	▒	░	░	□	▒	□	░	□	░	■	□	░	░	░	□	□	░
Soil Biology	▒	▒	▒	▒	▒	░	░	□	▒	□	░	□	░	■	□	░	▒	▒	□	□	░
Soil Erodibility	▒	▒	▒	░	▒	░	▒	░	■	□	▒	□	□	■	□	▒	□	□	□	□	□
Soil Moisture	■	■	■	□	■	░	▒	□	░	□	▒	□	□	░	□	░	□	□	□	□	□
Microclimate	■	▒	▒	□	■	░	□	□	□	░	░	□	□	░	□	□	□	□	□	□	□
Vegetation	■	■	■	▒	■	░	□	□	■	□	■	□	□	■	□	□	□	□	□	□	□
Surface Runoff	▒	▒	▒	░	▒	░	■	▒	▒	□	□	□	□	░	□	▒	□	□	□	□	░

Level: □ none ░ low ▒ moderate ■ high

Source: Finnis *et al.,* 1973.

FIGURE 5.

The effect of a silvicultural activity on a water quality objective



Interrelationships among the quantitative, qualitative and control factors and their application to a proposed silvicultural activity.

Source: U.S. Forest Service, 1980.

Harvesting and regeneration

One of the least visible but probably the most long lasting and important negative stresses on land at the forest level is the regeneration problem on Canada's cut-over lands. The industry harvests about 800 000 ha annually, of which 200 000 ha are artifically planted or seeded. Some 200 000–300 000 ha regenerate reasonably well on their own, and the remaining area lies idle for a time or reverts to noncommercial weed trees and scrub (Environment Canada, 1981). The problem is long standing and of serious national concern (Weetman, 1977; Royal Bank of Canada, 1979). Biologically it is usually centred on the differences between a fire or insect disturbance (to which the trees are adapted) and a logging disturbance. Logging often does not create good seedbeds for new regeneration, due to lack of exposure of mineral soil. Mineral soil is a better seedbed than the litter layer, which tends to dry out. Logging may remove seed sources or not provide for release of seed from serotinous cones (as in jack and lodgepole pine), which need heat to break the resin bonds on the cone scales. Logging may not remove vegetative competition on rich sites or it may destroy established seedlings (advance growth) present before logging. Logging may leave residual trees that are of unwanted species (such as poplars) or of poor form, which subsequently dominate the new stand.

Silvicultural prescriptions to remedy these situations are site specific, i.e. they depend on the reproductive strategies of the tree species and

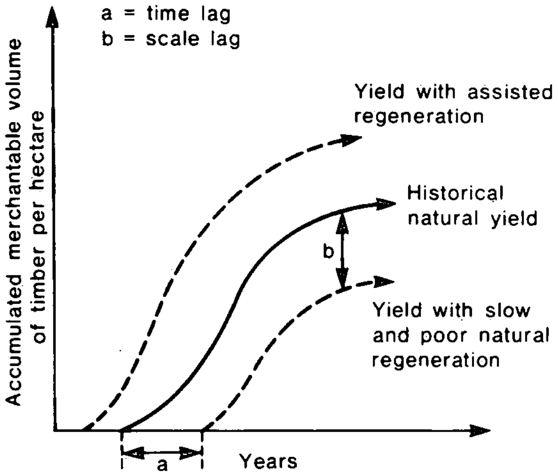
TABLE 5.
Nutrient removals with harvested biomass by intensive harvest techniques, expressed relative to total inputs, net fluxes, and soil pools
(All-aged stand of red spruce-balsam fir)

Category	Biomass	N	P	K	Ca	Mg
Harvest removals (kg/ha/100 yrs)						
a) conventional clear-cut	118 000	120	18.2	76	219	20.4
b) whole-tree clear-cut	153 000	239	35.2	133	337	36.9
Inputs (kg/ha/100 yrs)						
a) precipitation		600	40	170	720	170
b) weathering		0	60	500	1 800	500
c) N_2 fixation		1 000	—	—	—	—
Total inputs		1 600	100	670	2 520	670
Net flux (kg/ha/100 yrs)		700	30	-60	-700	-200
Soil pool (kg/ha)						
a) total, rooting zone (39 cm)		3 760	1 280	13 400	5 750	1 770
b) available, rooting zone		47	105	73	110	39
Conventional removal, % of total inputs		8	18	11	9	3.0
Whole-tree removal, % of total inputs		15	35	20	13	5.5
Conventional removal, % of net flux		17	61	-127	-31	-10
Whole-tree removal, % of net flux		34	117	-222	-48	-18
Conventional removal, % of total soil		3.2	1.4	0.6	3.8	1.2
Whole-tree removal, % of total soil		6.4	2.8	1.0	5.9	2.1
Conventional removal, % of available soil		255	17	105	199	52
Whole-tree removal, % of available soil		509	34	182	306	95

Source: Freedman, 1981.

the history and condition of the forest. Such prescriptions usually call for scarification (i.e. mechanical disturbance of the forest floor), direct seeding, planting, use of herbicides to control brush, and subsequent thinning to concentrate growth on fewer stems and reduce rotation ages. Figure 6 illustrates the effect of poor regeneration after logging on the timing and yield of the next timber crop.

FIGURE 6.
Technical changes in the yields of forest stands due to changes from historic natural yields



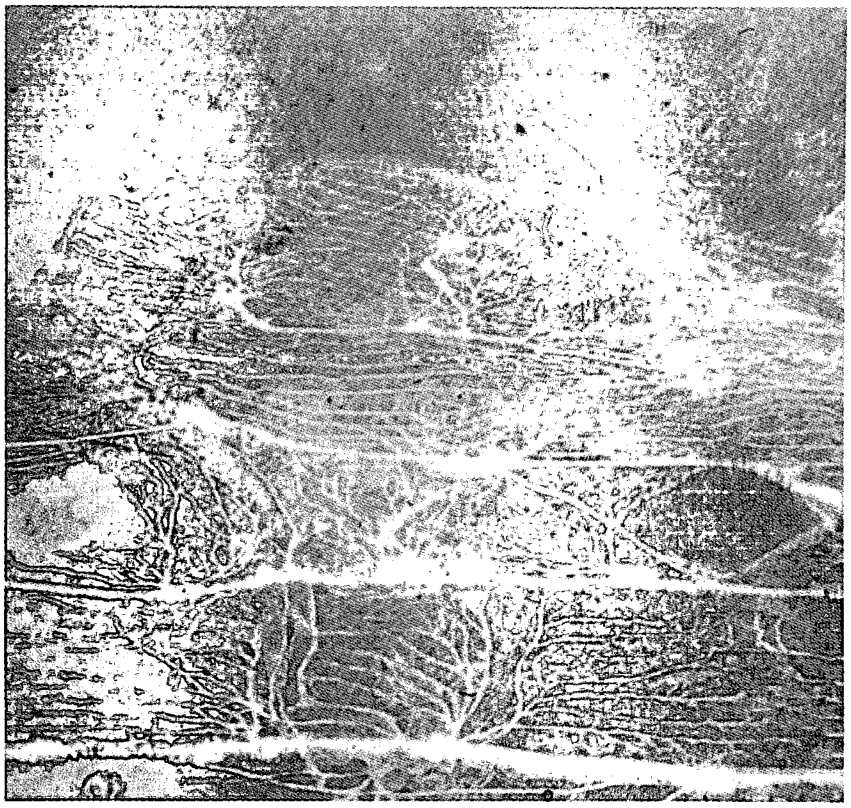


Photo 14. Physical removal of the forest humus layer and upper mineral soil by truck road and skid trail construction reduces site fertility.
P. van Heek, British Columbia Forest Service

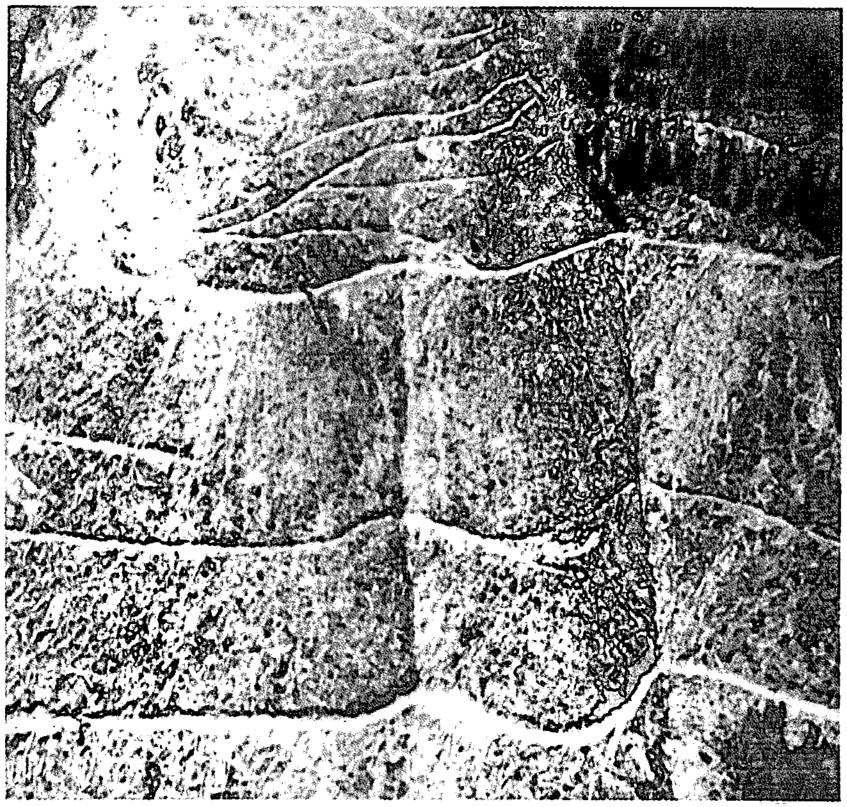


Photo 15. This photo shows the amount of soil disturbance by cable and tractor skidding systems in steep coastal mountains in British Columbia.
P. van Heek, British Columbia Forest Service

TABLE 6.
United States Guidelines on clear-cutting: Church Guidelines for Federal Lands 1972

1. Allowable harvest levels
    - a. Allowable harvest on Federal forest lands should be reviewed and adjusted periodically to assure that the lands on which they are based are available and suitable for timber production under these guidelines.
    - b. Increases in allowable harvest based on intensified management practices such as reforestation, thinning, tree improvement and the like should be made only upon demonstration that such practices justify increased allowable harvest, and there is assurance that such practices are satisfactorily funded for continuation to completion.
      If planned intensive measures are inadequately funded and thus cannot be accomplished on schedule, allowable harvest should be reduced accordingly.
2. Harvesting limitations
   Clear-cutting should not be used as a cutting method on Federal land areas where:
    - a. Soil, slope or other watershed conditions are fragile and subject to major injury.
    - b. There is no assurance that the area can be adequately restocked within five years after harvest.
    - c. Aesthetic values outweigh other considerations.
    - d. The method is preferred only because it will give the greatest dollar return or the greatest unit output.
3. Clear-cutting should be used only where:
    - a. It is determined to be silviculturally essential to accomplish the relevant forest management objectives.
    - b. The size of clear-cut block, patches or strips are kept at the minimum necessary to accomplish silvicultural and other multiple-use forest management objectives.
    - c. A multidisciplinary review has first been made of the potential environmental, biological, aesthetic, engineering and economic impacts on each sale area.
    - d. Clear-cut blocks, patches or strips are, in all cases, shaped and blended as much as possible with the natural terrain.
4. Timber sale contracts
   Federal timber sale contracts should contain requirements to assure that all possible measures are taken to minimize or avoid adverse environmental impacts of timber harvesting, even if such measures result in lower net returns to the Treasury.

Source: Spurr, 1981.

TABLE 7.
Extracts from the National Forest Management Act 1976

- soil, slope, or other watershed conditions will not be irreversibly damaged;
- there is assurance that such lands can be adequately restocked within 5 years after harvest;
- protection is provided for streams, streambanks, shorelines, lakes, wetlands, and other bodies of water from detrimental changes in water temperature, blockages of water courses, and deposits of sediment, where harvests are likely to seriously and adversely affect water conditions or fish habitat; and
- the harvesting system to be used is not selected primarily because it will give the greatest dollar return or the greatest unit output of timber.
- Individual cut blocks, patches, or strips will conform to the maximum size limits for areas to be cut in one harvest operation established by the regional plan according to geographic areas and forest types. This limit may be less than, but will not exceed 60 acres [24 ha] for the Douglas-fir forest type of California, Oregon and Washington; 80 acres [32 ha] for the southern yellow pine types of Alabama, Arkansas, Georgia, Florida, Louisiana, Mississippi, North Carolina, South Carolina, Oklahoma, and Texas; 100 acres [40 ha] for the hemlock Sitka spruce forest type of coastal Alaska; and 40 acres [16 ha] for all other forest types.

  The regulations permit larger cuts when silviculturally desirable to produce a better combination of benefits, when approved by the regional forester after 60 days public notice, or when timber must be salvaged because of fire, insect and disease attack or windstorm.

Source: Spurr, 1981.

The current rate of cutting (annual allowable cut or AAC) on provincial Crown forest land is the estimated level of harvest that can be maintained indefinitely under existing standards of management and utilization of the tree stands, i.e. sustained yield management. At present, the AAC is usually based on the historic natural yield of the forest. If the future yields are greater or less than this historic level, the AAC must be adjusted accordingly. The timing and size of the AAC depends on the age class structure of the forest in the sustained yield unit, i.e. the area of timber in each age class and the magnitude of its estimated yield at time of harvest.

Many management units in Canada have very unbalanced age class structures. Calculations of allowable cuts by provincial planners for sustained yield units have indicated deficits in the present or near-future timber supply for current sawmill and pulpmill capacity. Such calculations are made using whole-forest computer models that simulate growth of the forest for the next one or two rotations. Such models can examine the impact of improved regeneration and stand protection practices on future allowable cuts. These dynamic analyses of Canada's forest resources have produced an alarming picture of economic wood supplies and have in turn led to congresses (Canadian Pulp and Paper Association, 1980), symposia (National Forest Regeneration Conference, 1980), and study reports (F.L.C. Reed & Associates, 1978) aimed at developing measures to alleviate the situation.

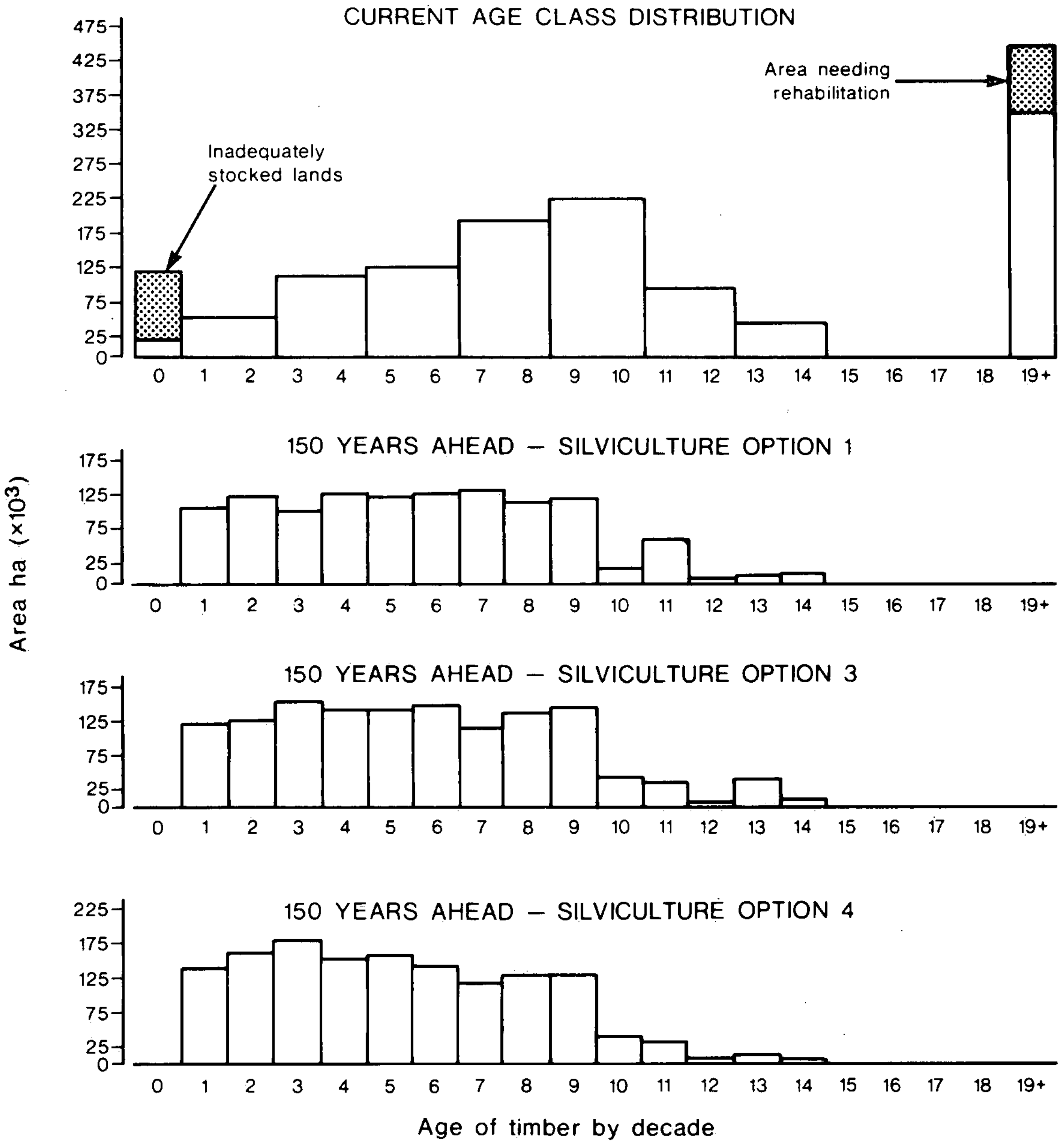
Although increased planting is part of the solution, other silvicultural measures such as site preparation, scarification, seeding, herbicide use, thinning, fertilization, and—most of all—control of location and timing of logging are all part of the strategic plans to improve the wood supply. The chief obstacle to implementing these plans adequately is lack of money.

The political nature (and the crux) of the problem is that the forests are publicly owned and provincial governments have been unable or unwilling to secure funding for this work at an appropriate scale.

The legal nature of the stress problem lies in the licensing system for timber. Licencees, usually large corporations, are not allowed to obtain equity in Crown timber. Regeneration work has to be paid for by the landowner (the province) by direct deductions from stumpage payments due (British Columbia) or by a contractual agreement (Ontario) or by a special forestry tax on timber (Quebec). Increasingly, the national trend has been to use these arrangements with the corporate licencee to secure funding and effective implementation of regeneration work. In return, licencees have demanded and obtained long-term tenures to licence areas, subject to forest management performance

FIGURE 7.

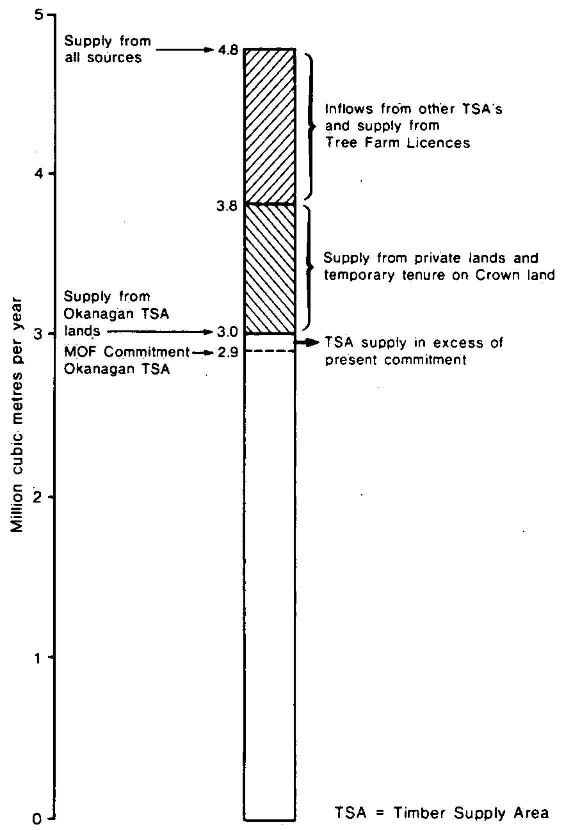
Age class distribution: beginning and end of decade 15



Source: Crown Zellerbach Ltd., 1980.

FIGURE 8.

Present sources of timber for mills located within the Okanagan Timber Supply Area



Source: Crown Zellerbach Ltd., 1980.

(Evergreen Principle). Corporate forest nurseries have been established. Corporate initiatives are now taken to convince governments of the necessity of spending more money on silviculture, noting that such work is self-financing, i.e. calculated increases in allowable cut, if taken now (Allowable Cut Effect), produce taxation revenues that more than pay for the silviculture.

A recent example of the national problem of wood supply is the Shuswap Okanagan Forest Association (SOFA) submission in British Columbia (Crown Zellerbach Canada Ltd., 1980). SOFA represents all the licencees on Crown land in the sustained yield unit.

The following figures of the SOFA example (Figures 7, 8, and 9) show the alleviation of the stress of insufficient wood supply, caused by a lack of regeneration. These figures are selected components of a computer analysis of the timber supply problem in the Shuswap Okanagan area of British Columbia. They show the results of an expanded silviculture program with 3 options (options 1, 3 and 4)—representing planting, rehabilitating old forest, and spacing (either singularly or in combination)—to improve stand yields and forest age classes 150 years in the future. The analysis indicates that present allowable cuts can be increased, with the tax benefits paying for the silviculture program.

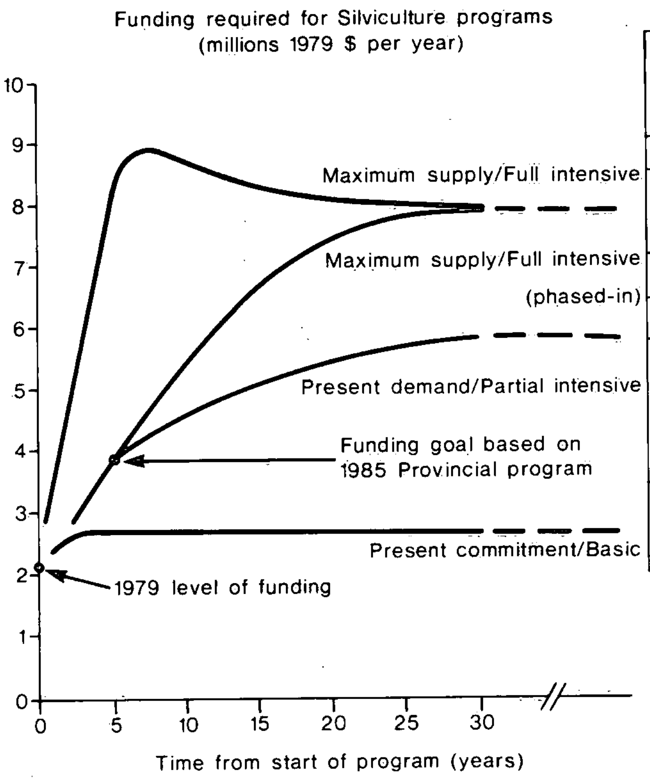
Figure 7 shows the current unbalanced age class structure of the forest. There are 375 000 ha of old forest (190 yrs +) ready for harvest, but the rate of harvest of this timber must be spread over time to allow the younger forest to become mature. There are 100 000 ha of inadequately stocked lands. Figure 8 shows the supply problem. There is a present cut of 4.8 × 10^6 m^3 but an allowable cut by the Ministry of Forests of only 2.9 × 10^6 m^3 from Crown lands within the Timber Supply Area (Figure 8).

The allowable rate of cut of the old timber could be increased if the growth rate of cutover stands could be accelerated by silvicultural practices. Using a computer model to simulate the growth of the forest, assumptions were made about increases in growth rates and yields possible due to planting and thinning programs on both new cut-over lands and lands not adequately stocked at present. The model indicated the relationship between increasing intensity of silvicultural practice and the indicated allowable annual harvest volume that is sustainable. The assumption is made that the silviculture program is possible and that yield increases will be attained.

Figure 9 shows the costs and benefits attainable. Because the rate of harvest is increased, stumpage revenues received by the province from the sale of the timber should pay for the funding required to pay for the silviculture pro-

FIGURE 9.

Costs and benefits for forest management options Okanagan Timber Supply Area



Sustainable level of benefits*

Annual Harvest Volume (million m³/yr.)	Direct Industrial Employment (man yrs.)	Annual Stumpage Revenue (millions 1979 $ per yr.)	Total Public Revenue (millions 1979 $ per yr.)
Short-term 3.9	4044	31	75
Med-term 4.2	4355	34	81
Long-term 5.0	5185	40	96
Maintain 3.8	3941	30	73
Short-term 2.9	3007	23	56
Med-term 2.9	3007	23	56
Long-term 2.5	1867	20	48

* NOTE:

1. Estimates of sustainable level of benefits from the Okanagan TSA do not include:
   - An expected real value increase in stumpage of 2% per year.
   - Additional employment and revenues generated by increasing funding for silviculture from 1979 levels.
   - Indirect employment which is approximately 3 times direct employment.
2. The annual stumpage revenue is $ 8.00/m³ based on actual appraisals in the Kamloops region during 1979. This revenue does not necessarily reflect future fluctuations between strong and weak markets.
3. Public revenue other than stumpage is based on studies by FLC Reed and Associates, December 1978 and studies by Crown Zellerbach Canada of forest industry revenues in the Okanagan area. These studies provide revenue estimates that represent normal operating experience over a 4-year cycle.

Source: Crown Zellerbach Ltd., 1980.

gram. Additional revenues accrue to the government because of the increased industrial employment. Figure 7 shows the more balanced age classes (i.e. roughly equivalent areas of timber by age class) that would be achieved 150 years from now.

These types of strategic analyses of timber supply suggest that major efforts to apply silviculture in needed areas on Canadian Crown lands are self-financing, provided an accelerated cut of mature trees is possible. Unfortunately, in some parts of Canada the supply of old timber is already exhausted, thus making funding of silviculture very difficult. In the case of the South Okanagan the silviculture program will not be approved until the assumed yield increases are shown to be attainable and feasible.

Although the solutions to the major national problem of regeneration seem to lie primarily in the realm of public forest policy and greater public expenditures on maintaining the resource, industry too must be prepared to invest in better forest management. The biological and technical aspects of the regeneration work, although formidable, do not really restrain further improvement in the renewal of the nation's forests. The legacy of previous forest exploitation in Canada has been forest ecosystems that function well biologically but not economically. Too rapid liquidation of mature forests, coupled with poor regeneration and replacement by stands of lower quality, resulted in a marked decline in the relative importance of the white pine and spruce sawtimber industries in eastern Canada. This loss of economic quality of forest caused by man is a form of negative stress on forest land that has had negative impacts on Canadian society, the appearance of the landscape, and some wildlife populations.

Harvesting and scenic values

Much of the Canadian forest landscape is composed of vast expanses of natural forest. The total area of man-made forests is negligible. The bulk of the Canadian population lives in cities and views the natural forest landscape as having important wilderness values. This perception of wilderness is associated with a forest undisturbed by human activity, or at least a disturbance not apparent to the observer. The importance and necessity of preserving wilderness has been intensively debated.

Public appreciation of the undisturbed forest landscape has led to a series of debates and confrontations over logging, particularly in provincial parks. Algonquin Park in Ontario, logged since its establishment last century, was placed under a Special Park Authority to regulate logging practice. In British Columbia logging in provincial parks is now under a moratorium.

Forest landscape management

Where forest lands are zoned for harvesting, forest landscape design principles are used to ensure that established visual quality objectives are met. The first step in this approach is to decide on the objectives. There are five visual quality objectives: preservation, retention, partial retention, modification, and maximum modification (Table 8). Implementation requires that the landscape sensitivity be determined by a landscape inventory. Forestry activities can then be designed to blend with landscape characteristics (Figure 10, Photos 16-20).

This formal analytical approach has been used successfully in many regions of North America, usually those with many visitors. Specific cutting guidelines are available for types of forest to meet visual quality objectives. For example, for tolerant hardwood[11] forests, like those in Algonquin Park in Ontario, specific recommendations on partial cutting are available (United States Forest Service, 1979*b*). Computer mapping systems are available for mapping landscapes (United States Forest Service, 1976*b*). For many parts of Canada, cutting permits are not granted on Crown lands unless the cutting plan has been approved by a landscape architect. In some areas 5- and 10-year cutting plans,

TABLE 8.

Relationship of landscape sensitivity and visual quality objectives

LANDSCAPE SENSITIVITY	VISUAL QUALITY OBJECTIVES (VQO's) and Associated Management Activities				
	PRESERVATION - No Activity	RETENTION - Activity not visually evident	PARTIAL RETENTION - Activity subordinate in Landscape	MODIFICATION - Activity dominates but borrows Line & Form	MAXIMUM MODIFICATION -Activity dominates, may be out of scale
HIGH	◄	—	►		
MEDIUM		◄	—	►	
LOW			◄	—	►

Source: British Columbia Ministry of Forests, 1981.

which are part of a broader land-use plan, are presented to the public for approval and comment.

Impacts of increased fire control

Since World War II, forest fire protection has expanded to cover all the commercial forests of Canada. The mean annual size of individual burns has declined in both the United States and Canada. As fire protection increased, so did concern about the prevention or reduction in the natural frequency of fires. Negative aspects of fire prevention measures include:

a) The build-up of hazardous fuel accumulations in some types of forests, leading to uncontrollable crown fires in place of natural low intensity ground fires (Wilson and Dell, 1971).

b) Replacement of fire-dependent coniferous forest types by more tolerant, but less valuable forest cover types. A reduction in the diversity of flora and fauna may be associated with the change (Day, 1979).

c) Impacts on wildlife populations, particularly fur bearers (Lym *et al.*, 1978; Bunnell, 1980).

d) Increases in insects and diseases in unburned stands (Alexander and Hawksworth, 1976).

The use of fire by aboriginal people has aroused interest and study by anthropologists (White, 1972). Lewis (1977) studied the ecology of Indian fires in Northern Alberta by interviewing older native people who were familiar with practices prior to province-wide forest fire protection after 1950. He found that in this section of the boreal forest, the Indians had employed very sophisticated approaches to, and understandings of, the dynamics of fire for the management of plant and animal resources. They used spring fires for maintenance of hay meadows and sloughs for grazing and trapping, to remove old unproductive forests, to kill trees for fall firewood collections, to clean-up and fireproof communities, to make and maintain trails, and for fire signals.

In this same area of Alberta, with a historically high frequency of fire, and thus predominantly young forests, widespread fire protection will allow such stands to mature and will provide for a major increase in allowable cut and the establishment of several new pulp mills in the next century when Alberta's oil resources are exhausted. Obviously there is a conflict between the objectives of fire protection for timber production and use of fire for maintaining wildlife habitat. Again, the negative aspects of the stress depend on the land management objectives and the compromises in multiple use.

For a park that is zoned for wilderness preservation, such as the 5 000-km^2 Quetico Provincial Park, Day (1979) in a study of the fire ecology has shown that a deliberate fire management plan is essential. Fire suppression and control have allowed the average fire rotation to increase progressively from 78 years before 1919 to 113 years in the 1920–1937 period and to 870 years for the 1940–1979 period. Fire-dependent species of the boreal forest such as jack pine, black spruce, aspen, and birch are being succeeded by balsam fir and tolerant hardwoods. The former may represent an uncontrollable fire threat after spruce budworm defoliation.

Recognition of the essential role of fire in Canadian forests has led to its deliberate use in forest management and to the revision of fire protection policies.

High-elevation forestry in the mountains

At elevations close to the timberline the growing seasons are short and seed production by conifers tends to be sporadic and not abundant. Deep winter snow, strong winds, and ice damage also slow tree growth. Many forest areas are classed as non-commercial or protection forest, but there are extensive areas in British Columbia and Alberta at 1 200–2 000 m in elevation where owing to the absence of fires there exist large volumes of standing timber of great age. These occur in the Engelmann spruce – subalpine fir zone in the interior and in the mountain hemlock zone on the coast (Krajina, 1969).

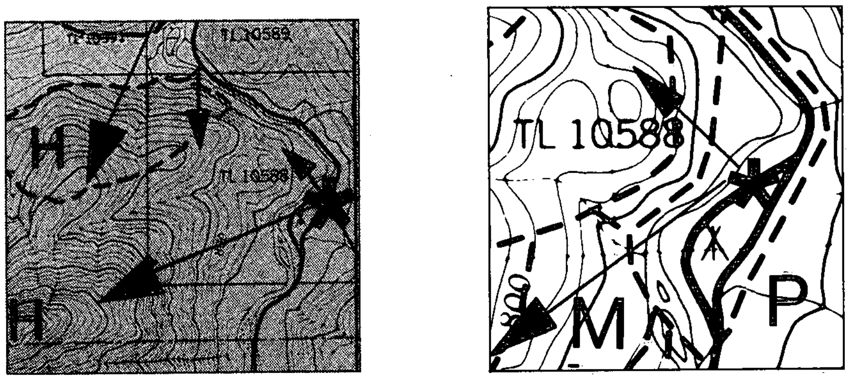
The stress problems associated with clear-cutting these high elevation forests are their subsequent slow regeneration and unsightly appearance. Forests in these zones currently supply 60% of the timber cut on the coasts of British Columbia and are the major reserve of sawtimber in the interior. Partial cutting of ancient mountain hemlock, yellow cedar, and amabilis fir stands is not feasible because of the steepness of the terrain, the large size of the trees, and the high logging costs. Many of these stands are uneven-aged in structure and could be subject to light periodic selection harvests. However, there is no technology to do this type of logging, although attempts are being made to manufacture a cyclocrane–a balloon with engines to lift trees directly off steep mountainsides.

Reproduction of mountain hemlock forest depends largely on advance growth of amabilis fir, often 50–100 years old at the time of cutting. Such old small trees grow well following cutting, but may have trunk rot caused by Indian paint fungus (Herring and Etheridge, 1976). Natural regeneration of hemlock and yellow cedar is often very slow owing to lack of seedbeds or seed. Plantations at this elevation have not been very successful. Slash burning on these sites is now not permitted.

Similarly in the interior, vast areas of old Engelmann spruce and subalpine fir forest

FIGURE 10.

Alleviation of visual stress in the landscape by landscape design



Step 1:
Landscape Inventory
Mapping of the visible landscape, its features and sensitivities, for the purpose of overall planning.

Step 2:
Detailed Landscape Analysis
Mapping of further landscape detail and selecting visual quality objectives that will determine landscape management decisions.

Step 3:
Design and Layout
Development of designs which blend with landscape characteristics and meet the selected visual quality objectives.

Step 4:
Logging and Silvicultural Practices
Implementation of road building, logging and silvicultural practices which complement the visual quality objectives and the corresponding designs.

Step 5:
Follow-up
Asking questions: did this management activity leave an acceptable landscape? Did special measures reach desired results? Should examples be published?

Source: British Columbia Ministry of Forests, 1981.

largely depend on subalpine fir advance growth for reproduction. Engelmann spruce plantations have not been successful and natural regeneration is very slow. Partial cutting has been recommended but is difficult to conduct (Alexander, 1974).

The stress problem for the forest manager concerns the rate of clear-cutting and the size of clear-cuts. In interior forests the habitat for mountain caribou may also be a factor. If such forests cannot be regenerated within a reasonable time (20–30 years), then the sustainability of harvest levels may be questionable.

One option that can be taken, and that has been taken for boreal forests in remote locations, is to engage knowingly and deliberately in "timber mining", i.e. harvesting the timber rather than let it be destroyed by natural means. Under such a policy, no future cuts would be foreseen for two or three centuries; timber exploitation becomes a tool for forced economic growth. However, the economic record of such a policy has been poor (Mathias, 1971; Loomis, 1979).

Timber mining also poses an ethical problem in forest land use. The issues involved in the removal of non-renewable, large old-growth timber have been debated at length. In the United States national forests, an "even-flow" policy is followed to provide for a steady removal of the trees over two to three centuries to ensure that future generations will be able to see the forests. Such a policy is not yet in place in Canada.

Although extensive areas of these high-elevation forests will be left unlogged in parks, environmental protection areas, and ecological reserves, questions about the necessity, speed, and nature of logging in these sensitive ecological zones are still being debated.

Wildlife impacts

The removal of mature timber over very large areas both destroys and creates habitat and food for wildlife. The diversity of forests and wildlife precludes specific analyses of the influence of each forestry management practice on each wildlife species. Impact can be assessed in terms of the change in resources required by wildlife following removal of tree cover. The resources are energy, nutrients, water, temporary shelter, habitation, escape cover, and space (Bunnell and Eastman, 1976). Changes caused by logging are illustrated in Figures 11–14.

The resources required by wildlife must be found within the home range or territory of each species. Any forestry activity that destroys some of these resources will cause stress on that species. The territories affected can be both horizontal and vertical, i.e. upward into tree crowns, and can vary widely in size. Assessment of the impact or stress must thus consider the species, its territory and habits, and its required resources.

In theory, each stress factor could be assessed for each of the grouped forest management practices: felling, site preparation, stand establishment, stand tending, stand protection, and general management considerations such as rotation length, annual allowable cut, landscape pattern, and road building. However, the number of interactions and assessments of impacts would become enormous as more and more wildlife species are considered. Specific responses of a species to specific practices will vary with different forest types.

With the adoption of multiple use management and a mandate to maintain a diversity of wildlife populations and certain specific populations of some species, assessment of these interactions and impacts has become essential. Particular attention has been paid to fish populations, large ungulates (moose, deer, elk, sheep, goats and caribou), predators (wolves, coyotes, black and grizzly bears), and the important fur bearing animals (lynx, marten, beaver, and muskrats). Bird populations also require attention.

Roads built into previously inaccessible areas, providing access for hunters and poachers, have had some severe effects on such animals as mountain goats and grizzly bears, which cannot sustain harvest rates beyond 5%.

One of the most contentious issues has been fish habitat protection. Forest harvesting impacts are given in Figures 15 and 16 for the freshwater environment and the estuarine and near-shore marine environments. In contrast to terre-

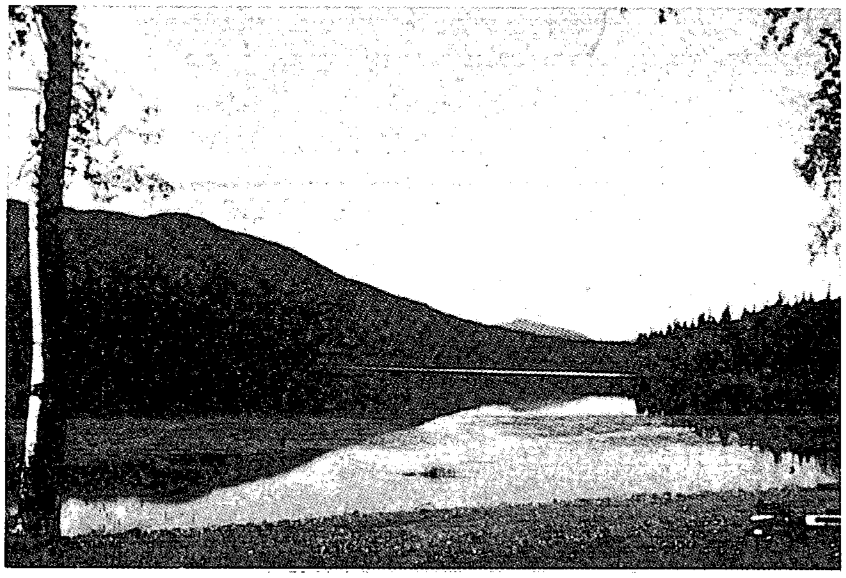


Photo 16. PRESERVATION

The Preservation VQO allows activities, such as maintenance of minimal facilities (recreation sites, trails), that enhance natural wildland values. Alterations beyond this, such as logging, are not acceptable.

In the managed forest, preservation may apply to relatively small areas where landscape values are high and outweigh other natural resource values, e.g. some land/water interfaces, special features of visual, historical, geological, biological or educational importance, areas of value for recreation.

This photo shows an important land/water interface. Kerry Lake, Prince George Region.
P. van Heek - © 1981 British Columbia Ministry of Forests

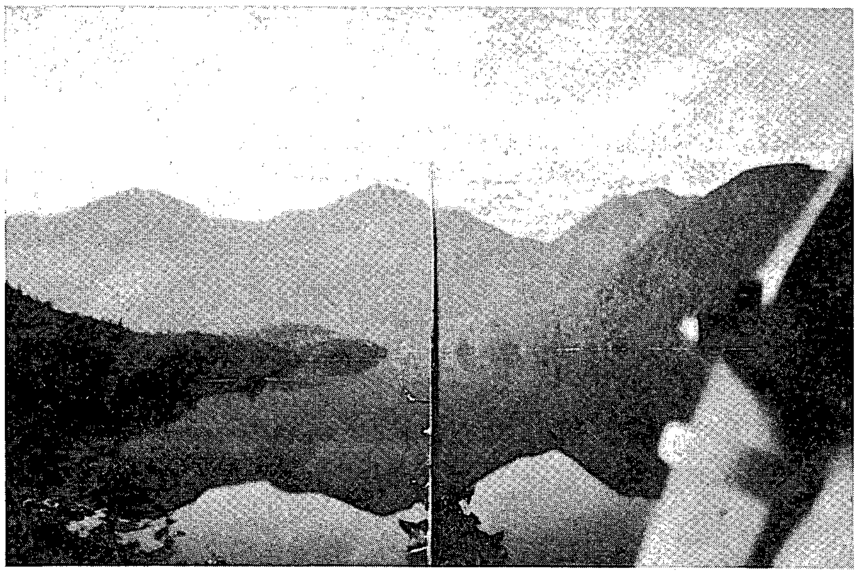


Photo 17. RETENTION

The Retention VQO requires that management activities or alterations not be visually apparent. The goal is to repeat the line, form, colour and texture of the characteristic landscape.

In the managed forest, retention may apply to areas where landscape values are high and where changes may be discernible but not clearly visible, e.g. land/water interfaces, vistas, views and focal areas.

Kennedy Lake, Vancouver Region. Logging on the ridge, or saddle, is not evident to the casual viewer.
P. van Heek - © 1981 British Columbia Ministry of Forests

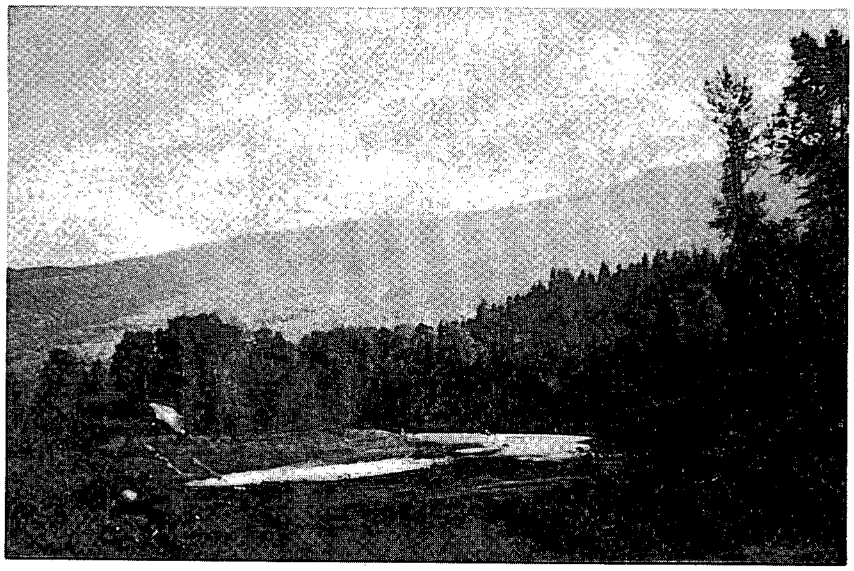


Photo 18. PARTIAL RETENTION

The Partial Retention VQO requires that alterations remain visually subordinate to the characteristic landscape. Repetition of the line, form, colour and texture is important to ensure a blending with the dominant elements.

In the managed forest partial retention may apply to areas where landscapes are of aesthetic importance and where management activities generally can match the landscape character and do not cause an obvious intrusion, e.g. where landscapes can absorb change. Sicamous, Kamloops Region.
P. van Heek - © 1981 British Columbia Ministry of Forests

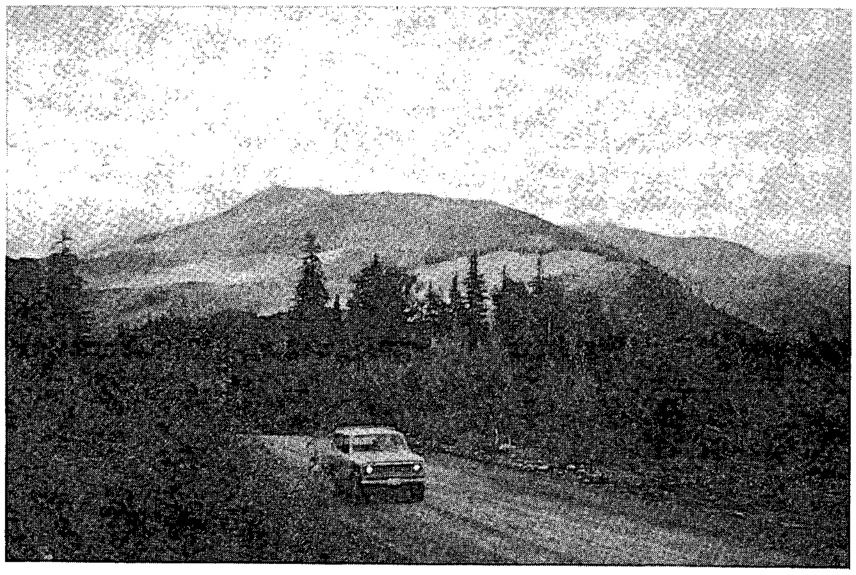


Photo 19. MODIFICATION

The Modification VQO allows alterations to dominate the original characteristic landscape. However, alterations must borrow from natural line and form to such an extent and on such a scale that they are comparable to natural occurrences.

In the managed forest modification may apply to areas where landscapes are more common and where management activities can blend with existing dominant lines, shapes and forms; it applies in particular to first-pass forest development. Nass Valley, Prince Rupert Region.
P. van Heek - © 1981 British Columbia Ministry of Forests

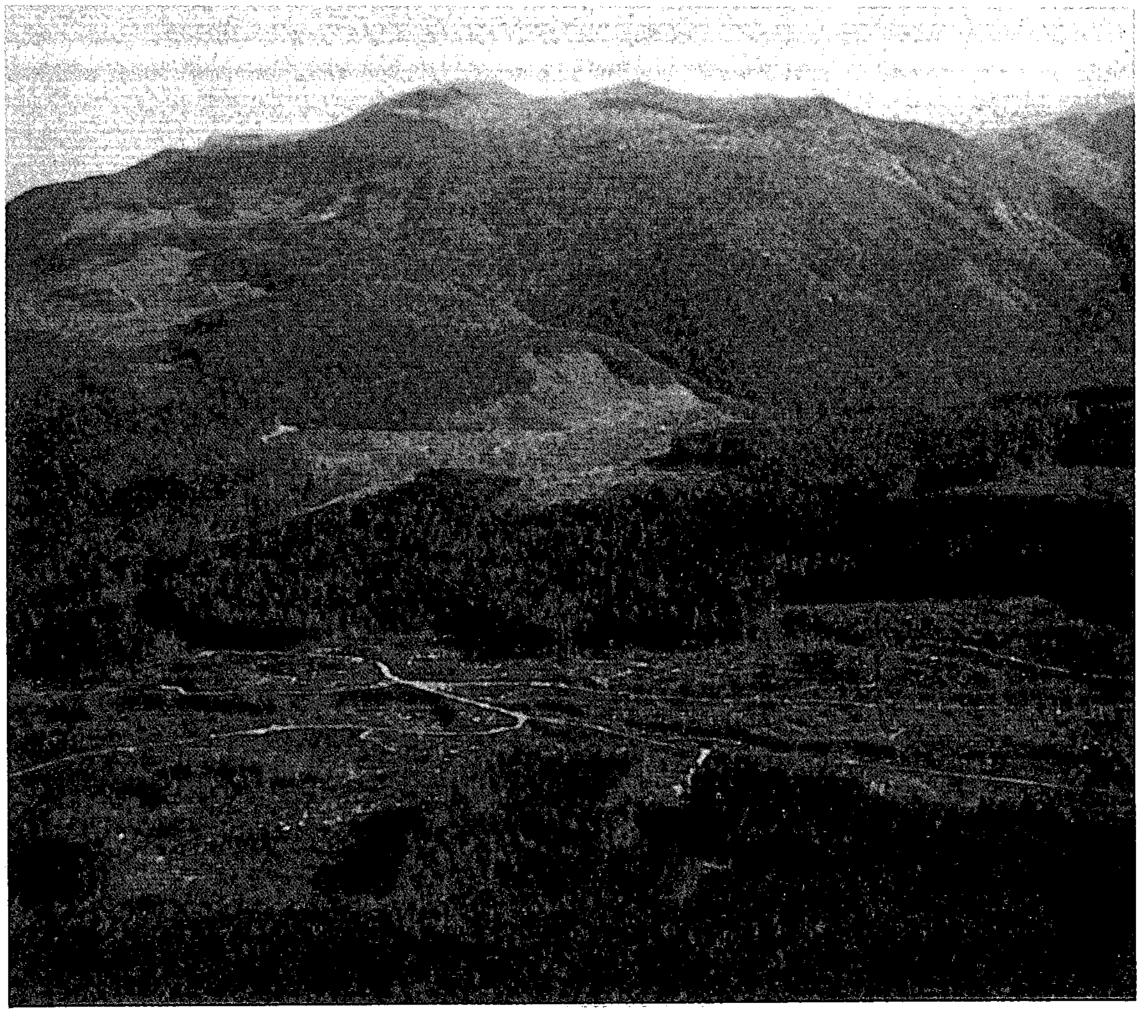


Photo 20. MAXIMUM MODIFICATION

The Maximum Modification VQO permits a dominant change to the original landscape, particularly in the foreground and middleground. Alterations may be out of scale or show detail quite different from natural occurrences.

In the managed forest maximum modification may apply to areas where landscapes are common and where resource use activities dominate the landscape; at close range changes to the landscape may be out of scale, but from a distance changes should appear to be natural occurrences; this VQO also applies in particular to natural disaster areas, e.g. fires, insect infestations, windthrow. Vancouver Region.

P. van Heek - © 1981 British Columbia Ministry of Forests

Photo 21. Regulated block cutting in even-aged lodgepole pine and Engelmann spruce forest. Okanagan, British Columbia.

G.F. Weetman

strial ecosystems, aquatic ecosystems respond very rapidly to change. Fish populations are very sensitive to temperature, pollutants and silt, all of which can be radically altered by logging practices. Some of the fish populations most affected by these practices are sole, flounder, ling, cod, rockfish, perch, salmon and herring. In addition, log sorting, storage, and transport in water influence not only fish but shrimp, lobster, crab, oysters, clams, starfish, sea-urchins, sea cucumbers, rock weed, eel grass, kelp, anemones, algae and vascular plants. Conflicts about the water transport of logs have been severe, including protests from recreational boaters. The handling and transporting of logs has altered the estuarine and marine ecosystems through grounding; scouring; bottom compaction; chafing; deposition of bark, branches, and sunken logs; formation of hydrogen sulfide; reduction of dissolved oxygen; and wash-scouring by towboat propellers.

Resolution of the numerous conflicts and stresses has been by very careful planning of logging, much consultation between user groups and levels of government, and changes to log sorting and storage on land.

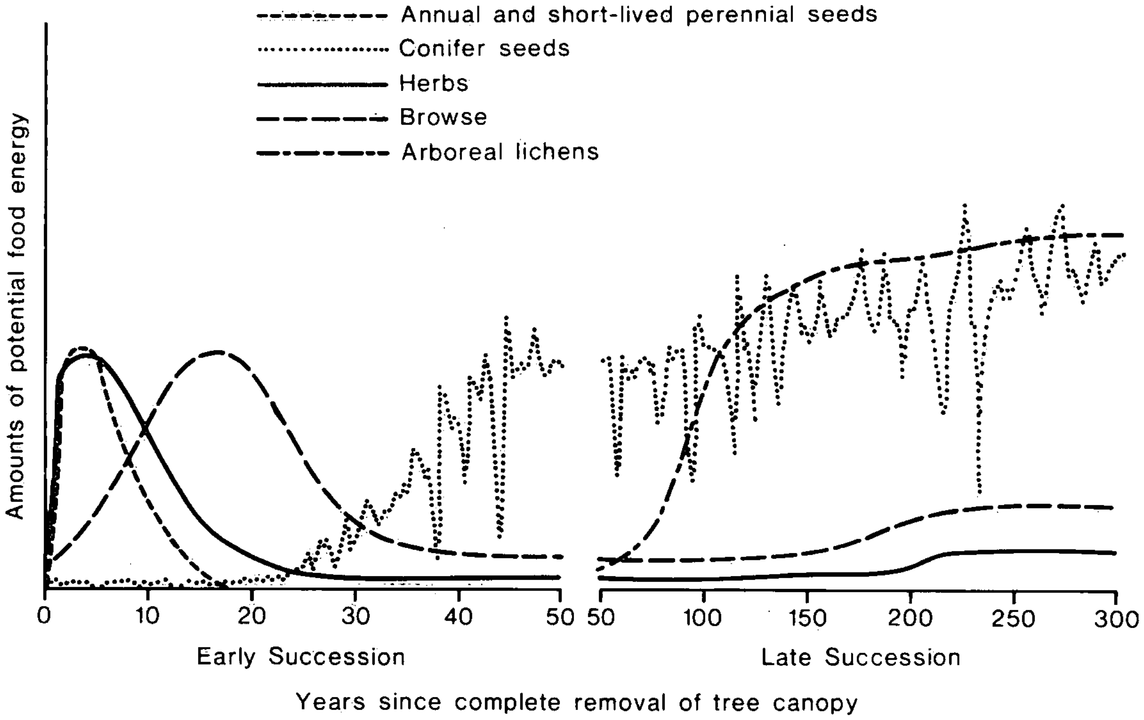
Ecological reserves

The recognition of the value, usually non-quantifible, of setting aside representative samples of ecosystems and of unique and endangered ecosystems in Canada's forests did not surface until the 1960s. Between 1965 and 1973, funding was made available under the International Biological Program (IBP) to select and describe potential sites for ecological reserves in all habitats across Canada. Policies and recommendations were made for forested natural areas that, while harbouring valuable species, would also serve as benchmarks in evaluating landscape change (Weetman and Cayford, 1972; Moir, 1972).

Provincial responses to the need for ecological reserves varied: 8 of the 10 provinces passed special legislation to set aside reserves (Peterson, 1982). British Columbia was active under the leadership of Dr. Krajina—there are now over 100 reserves in the Province (Krajina, 1976). Federal administration of forests is limited to federally owned or administered land, such as national parks, military bases, forest experimental stations, Indian reserves, and lands north of 60° except in Quebec and Labrador. Parks Canada has set aside lands in national parks as Zone I—special preservation areas, Zone II—wilderness areas, Zone III—natural environment areas, Zone IV—outdoor recreation areas, and Zone V—park services areas. Some provincial parks have areas set aside areas as ecological reserves (Maini and Carlisle, 1973). More recently, under the international Man and the Biosphere Programme (MAB), biosphere reserves have been set aside in two locations in Canada: Mont St-Hilaire,

FIGURE 11.

The effects of tree removal on the potential food energy of wildlife

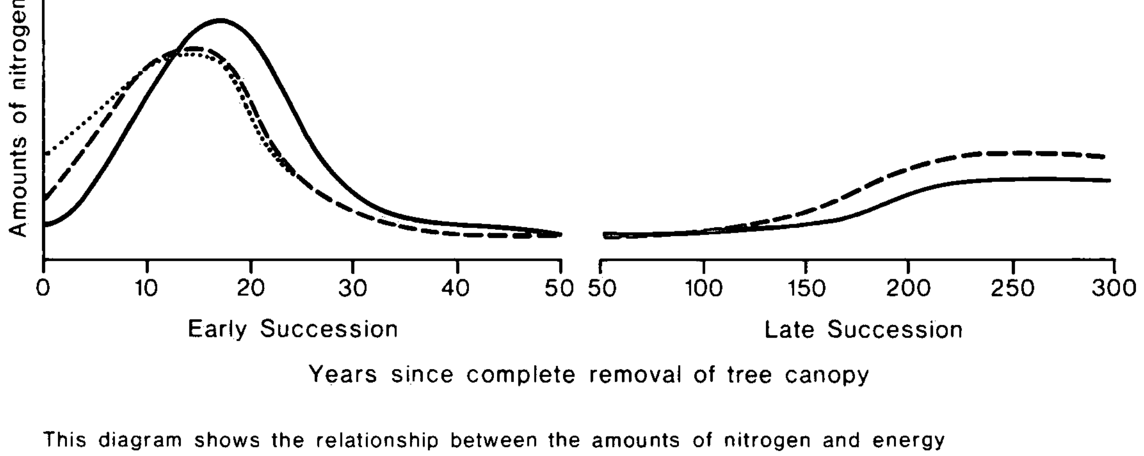


This diagram shows the relationship between the amount of potential food energy in different forms utilized by wildlife and the time since removal of the forest overstorey.

Source: Bunnell and Eastman, 1976.

FIGURE 12.

The effects of tree removal on the amounts of nitrogen and energy in browse



This diagram shows the relationship between the amounts of nitrogen and energy packaged in browse and the time since removal of the forest overstorey.

Source: Bunnell and Eastman, 1976.

Quebec, and Waterton Lakes National Park, Alberta (Francis, 1982). With concerns about the environment now overshadowed by economic concerns, the pace of establishment of new ecological reserves has slowed to a crawl, although most programs are still operating at the provincial level.

Canada has an enormous area of forest land and a great diversity of forests and climates. Ontario, for example, has identified 150 vegetation types that potentially ought to be represented within each site region as part of a nature reserve system. The emphasis so far has been on preserving special, rather than commonplace, ecosystems.

In order to assess the magnitude and nature of negative stress on forest land, ecological reserves can represent the required environmental baselines for judgement. The following reasoning is used:

- to make wise decisions in environmental management, one must understand ecosystem functioning and ecosystem reactions to change;
- to obtain such information one must have knowledge of undisturbed ecosystems as a baseline against which to measure man-made changes;
- relatively undisturbed natural areas form the basic research tool for establishment of such baselines;
- there is thus a need for a comprehensive natural area system to preserve and catalogue for use the full range of natural area types;
- if a network of environmental monitoring stations is tied to representative natural areas, the required baseline measurements should be met.

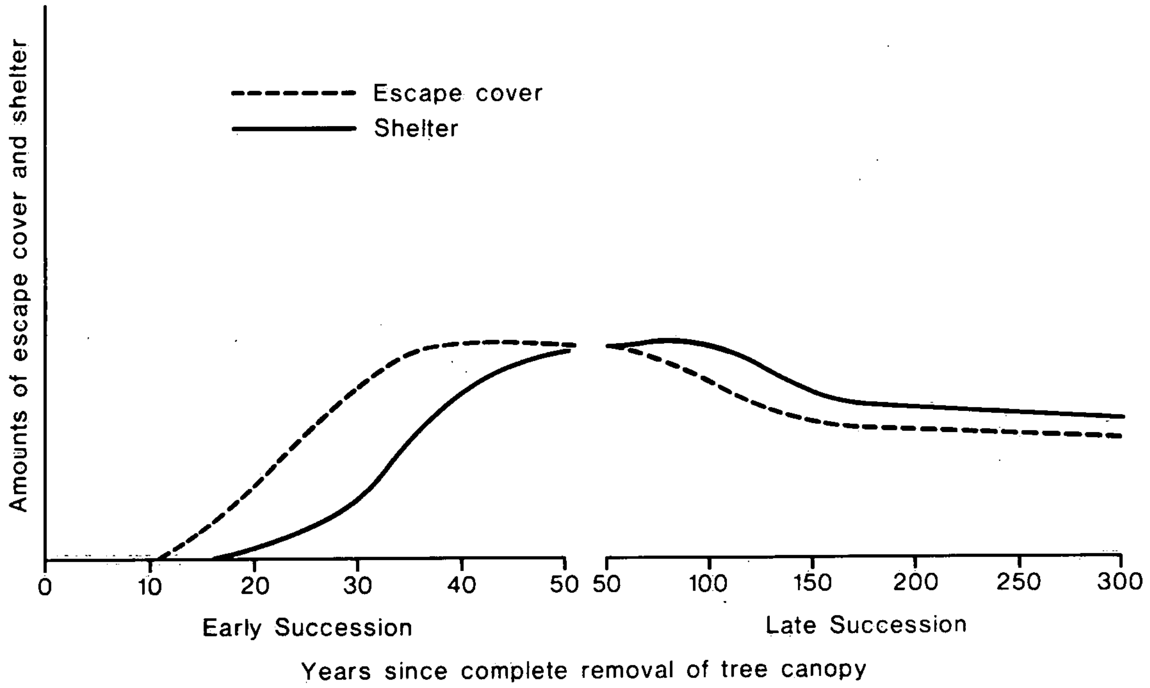
We are a long way from a comprehensive national system; perhaps we may never reach it, but it is a desirable goal.

REGULATION AND CONTROL OF FORESTRY PRACTICES

The control of forestry activities in Canada is almost exclusively a provincial responsibility. The provinces own 90% of the commercial forest lands. Large private ownership of forests often had its origin in a few old railroad grants. There is no federal legislation to control forestry practices on private lands and there is very little provincial enforcement of regulations governing forestry practices on private lands. As there is no regulation on smaller (1 000 ha or less) holdings and there are few fiscal incentives for sound environmental practices, some of the most destructive logging practices occur in the

FIGURE 13.

The effects of tree removal on the amounts of escape coverage and shelter for wildlife

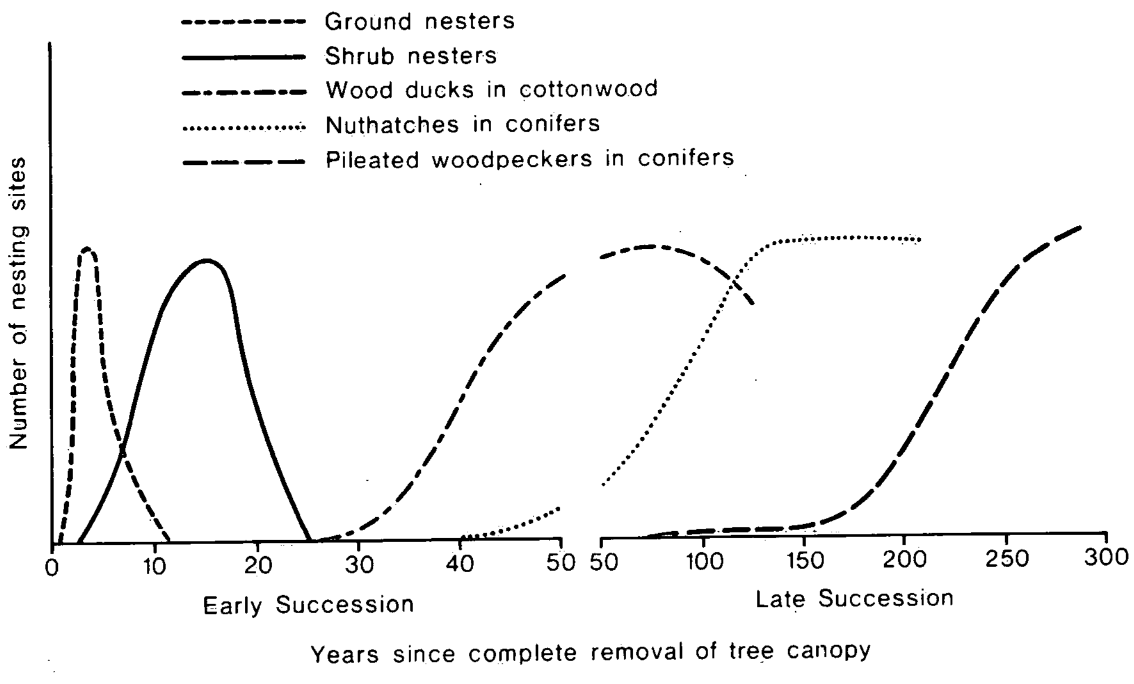


This diagram shows the relationship between the stand age and the capacity of the stand to provide shelter and escape cover to ungulates.

Source: Bunnell and Eastman, 1976.

FIGURE 14.

The effects of tree removal on the number of nesting sites for selected bird species



This diagram shows the relationship between the nesting sites for selected bird species and the time since removal of the forest overstorey.

Source: Bunnell and Eastman, 1976.

most accessible and visible private forests close to Canadian cities.

Federal regulation does cover migrating birds and fish. Under the terms of the British North America Act, the federal government has responsibility for the management and protection of all fish and related aquatic habitat, but in practice it has delegated the management of fresh water game fish to the provinces. The federal government has conducted biophysical land surveys on some provincial lands (Jurdant *et al.*, 1972), but such work is restricted mainly to federal lands north of 60° or to national parks.

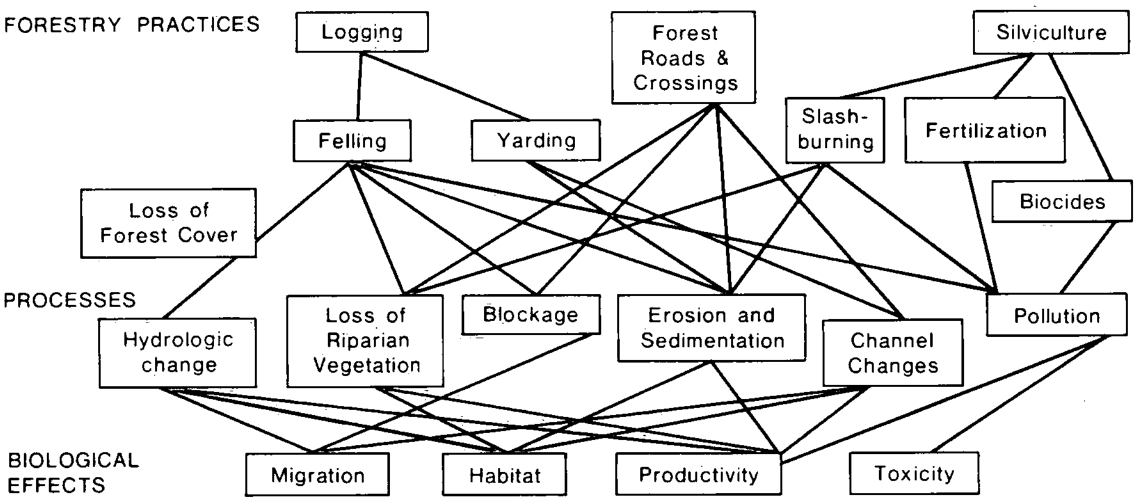
The federal government has provided considerable funding to assist in forest management since 1974. Currently this money is administered by Environment Canada and expenditures in 1982/83 on forest management and job creation related to it were roughly $110 million. A new 5-year forestry agreement between Nova Scotia and the federal government was signed in August 1982 and negotiations are in progress to develop new agreements with the other provinces.

At the provincial level the control of forest land use is regulated by various acts and administered by a mix of departments. In some provinces most of the regulatory control is vested in a single ministry of natural resources or its equivalent; in others there is separation of timber from wildlife, recreation, and environment. In contrast to the United States, it is difficult to bring lawsuits against government departments. Redress or protest against perceived wrongs in forest resource management must be largely by way of the political process or the media.

A large part of the provincial commercial forest lands are under long-term licence to major forest corporations. Although there were attempts in the 1950–1970 period to have the administration and implementation of all forest management practices, including both logging and silviculture, done by the government, the trend is now to assign this work to the corporate licencee. During the period 1950 to 1970, some provinces attempted to assume responsibility for the administration and management of forests, including logging and silviculture. The trend now is to assign this work to the corporate licencees. This is being done for two reasons. First, no provincial forest service can get enough people and money to manage adequately the vast areas under its control. Second, civil services have to work under constraints that make efficient management of many forestry operations difficult.

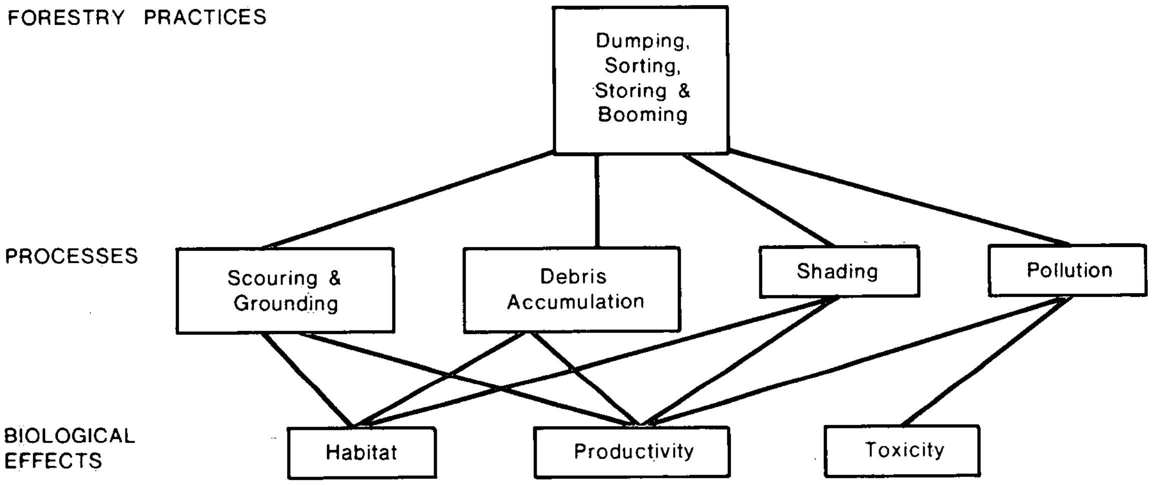
Planning and control of harvesting and silviculture activities on major areas of public lands in Canada must thus be by co-operation between the licencee (a major forest corporation) and the provincial government (forest resource management department or departments). Forest

FIGURE 15.
The impacts of forest harvesting on the freshwater environment



Source: Toews and Brownlee, 1981.

FIGURE 16.
The impacts of forestry on estuarine and nearshore environments



Source: Toews and Brownlee, 1981.

management and operating plans are approved for a 5-year or a 1-year period. Annual operating permits are required for each operation.

The mechanisms for provincial environmental controls on forestry operations vary. The following are the major ones; the literature references cite examples:

1. Folio approaches: A system of map overlays is used to identify important landscape, forest cover, and cultural and historical conditions. Operating permits are not issued until all possible conflicts have been resolved. Folios are expensive to prepare; the technique is mainly used for special interest areas (Bullen, 1978).

2. Referrals: All operating permits are referred to the appropriate departments of government before approvals are given. This is routine for any unusual or new type of operation.

3. Guidelines: Issued under the authority of the appropriate minister, guidelines on forestry operations have been issued following consultation with the industry and the public. Conformance with guidelines is monitored by industrial forestry associations, by the public, and by government employees (Young, 1977).

4. Ecological classification recommendations: Many of the provinces have systems and groups of specialists for classifying forest sites. Regional and district classification manuals contain site-specific recommendations for treatments and have considerable authority (Kabzems *et al.*, 1976).

5. Silviculture guides for species working groups: Some provinces have produced technical manuals that recommend or specify the appropriate cutting and other silvicultural treatments for each type of forests. These guides are prepared in consultation with forest research specialists (Bruce and Heeney, 1974).

6. Joint industry–government–public committees: In order to avoid confrontation over specific issues, such committees attempt to resolve the problems involved. Site visits to problem areas are usually made.

7. Forest land-use plans and public hearings: Formal documents specifying environmental impacts and alternate scenarios of land use are prepared by technical analysis and documentation, and followed by public hearings and voting. This procedure is mandatory in United States national forests and is carried out by certified silviculturalists (United States Forest Service, 1979*d*). Because of the expense this approach has not been used in Canada except for areas of real conflict or virgin watersheds proposed for logging.

8. Specialist Inter-agency Task Forces: Such groups are set up for "hot" issues to help resolve conflicts and determine best management practices (Poulin, 1981).

9. Consultant studies: When regional forest use conflicts become public issues the minister involved may call for a major consultant study of the whole problem under the direction of an inter-agency advisory committee (C.D. Schultz & Co. Ltd., 1973).

10. Legal challenges of licence renewal: These have been attempted on the grounds of inadequate forest management performance as required in the licence. A recent attempt to block Tree Farm Licence renewal in the Queen Charlotte Islands was not successful.

11. Royal Commissions: There have been many in Canada, usually called when policy changes are required. Although their recommendations have not always been implemented, they have often led to major changes in forest policy and administration.

SUMMARY STATEMENT

The negative stresses on forest land associated with forestry are at two levels—the forest, and the stand level.

The negative components at the forest level are defined as those changes in the forest that are not in conformity with the objectives of forest land management. Thus perceived effects from the same practice differ, depending on the objectives. Most disagreements and misunderstandings concern the objectives of land use, which are set by society and may require zoning land for single or multiple uses.

The baseline for measuring the negative stress at this level is the historic condition of the forest, recognizing it is in a dynamic condition and has been subject to many disturbances, in particular by fire and insects.

There is no easy answer to ethical, philosophical, and ecological arguments about the size and number of areas needed in Canada to be preserved from logging in order to allow natural disturbances to proceed unchecked; the debate continues. The economic value of the forest is immense. The tendency, except in the far North, is to control fire, insect, and disease disturbances, which results in changed forests. Under some circumstances, excessive protection can be seen as a form of negative stress in that it may lead to catastrophic wildfires, disease or insect outbreaks, or replacement of valuable forest cover types by less valuable ones.

To the extent that logging activities duplicate historical disturbances, they can be considered as neutral or non-stressful. There is evidence that logging and carefully prescribed use of fire, can indeed perform this role, offsetting the stress of protection and providing economic and ecological benefits associated with controlled disturbances and balanced mosaics of forests of varying ages and species. There appears to be little scientific evidence to support the idea that man-made or man-caused forests are inherently less ecologically stable or desirable than natural ones.

To the extent that unregulated logging practices, particularly if followed by fire, do not duplicate historical disturbances, then the regeneration of the forest may be, and often is, threatened. This form of stress, by reducing forest timber yields, has occurred and still occurs on a vast scale. The long-term quality, quantity, and availability of the nation's economic timber supplies are threatened and the economic and social consequences have been and are severe. This form of forest-level stress is the most serious impact of unregulated forestry practice. The biological solutions to forest renewal are largely available. Lack of people and money to practice better forestry is the chief inhibition to better forest management. This dearth may be exacerbated by tenure arrangements and disagreements between governments and industry, but these are not the sole cause of the problems. It is up to government, industry and labour to work together to improve the national picture of forest renewal.

At the stand level the negative stress associated with forestry activities is primarily due to the impacts of road construction and mineral soil exposure in logging. These are mainly soil fertility losses, fish habitat problems, and threats to watershed, scenic, and wilderness values. Timing and size of cut areas have impacts on wildlife habitat and populations that are species specific. This stand level of stress is more readily perceived but often of lesser total magnitude than the forest-level stresses.

The interactions among the forest ecosystem components at the stand level are complex but more readily quantifiable than forest-level problems. They are largely avoidable by carefully prescribed cutting methods, logging practices, road construction constraints, and silviculture operations. The occurrence of these negative impacts has attracted much public and regulatory attention. The frequency of the occurrences is declining, but is still high in remote forests and in logging operations on small private holdings. These latter areas do not represent a great area of Canada, but they are close to centres of populations and are subject to little regulation.

Forests in Canada are dynamic systems periodically subject to radical disturbances in most areas, even without human intervention. Recognition and understanding of the nature and direction of these changes allow for human intervention to provide a sustained flow of goods, services, and other intangible forest benefits. These can be in harmony with land-use objectives–a non-stressful situation. General scientific understanding of our forests is good, but much more site specific knowledge is needed and we have hardly begun to exploit the possibilities of genetic improvement. We also need to know much more about pest control. Despite this, the chief obstacles to practicing much better forestry are institutional constraints to implementing effectively what we already know.

Until recently, Canada had a surplus of wood and thus there was no pressure to practice better forest management. It was cheaper to travel a little farther for the wood or change standards of utilization than to invest in planting trees. A firm trying to practice good silviculture would have been at a strong competitive disadvantage. Now, however, both government and industry are concerned about the state of our forests. An honest effort is being made to improve forestry practices and although the level is still far lower than it ought to be, real expenditures on silviculture have more than doubled during the last few years. These and other improvements in forest management should help alleviate some of the stresses on Canada's forest lands.

This text was reviewed by Dr. I.C.M. Place, a private consultant who was formerly with the Policy and Economics Directorate, Canadian Forestry Service, Environment Canada, Ottawa, Ontario.

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GLOSSARY

[1] Biomass:	the total quantity, at a given time, of living organisms of one or more species per unit area (species biomass), or of all species in the plant community.
[2] Stumpage:	the price of timber as it stands uncut.
[3] High-grading practices:	removal of only the biggest and best trees.
[4] [Annual] allowable cut:	the estimated harvest of wood that can be maintained under existing standards of management and utilization.
[5] Podzols:	soils characterized by a surface layer of litter and humus over an ash-grey mineral (A2) layer from which nutrients have been leached. This layer in turn overlies a B horizon that is enriched by iron and organic compounds.
[6] Serotinous cones:	cones that remain on the tree for one or more years.
[7] Selection cutting:	the annual or periodic removal of trees (particularly the mature) individually or in small groups.
[8] Shelterwood system:	a silvicultural system in which the old crop is removed in two or more successive cuttings to provide a source of seed and protection for a new crop of tree seedlings.
[9] Advance growth:	young trees that become established naturally under the canopy or side shade of the main stand or overstorey trees.
[10] Coppice forests:	forests originating from shoots arising from the stumps and/or roots of trees that have been cut or harvested.
[11] Tolerant hardwoods:	broad-leaved trees that can endure heavy shade; in the Algonquin Park such forests are dominated by species such as sugar maple, beech, basswood, yellow birch and hemlock.

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LAWS ABOUT LAND

Photo credit: V. Neimanis, Environment Canada

LAND AS THE SUBJECT OF ENVIRONMENTAL LAW*

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* *The majority of research for this paper was completed by March 31, 1980 and may not reflect the state of the laws at the time of publication.*

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INTRODUCTION

At the time of Confederation, environmental management was not an issue, the resources were endless, and the people few. The immediate goal was to build a nation by fostering industry and promoting settlement. Pollution and other degradation of land, although not actively encouraged, were at least accepted as the natural consequences of the greater good: progress. For many of the Founding Fathers the environment was merely the setting for natural resources, the sources of much-needed revenue. If an individual had a complaint about his neighbour's activities, he was at liberty to go to the Courts to have his rights determined.

Today the preservation, maintenance, and restoration of land is seen as a value in itself, to be balanced against the revenue-producing activities that affect it. The law responds to and reflects this change in attitude. What may be termed "environmental law" is not, however, solely the responsibility of a single law-making authority. Instead, laws having environmental aspects have been and continue to be produced piecemeal in different jurisdictions at different times. To gain some understanding of Canadian environmental law in general, let alone that portion which deals with land, it is necessary to have a basic knowledge of the scheme whereby the law evolves and is applied.[1]

THE CONSTITUTIONAL SCHEME

The basic structure of government and law in Canada is to be found in The British North America Act[2] of 1867. Upon proclamation of the Constitution Act, 1982, this United Kingdom statute (together with its amendments) has been transferred to the exclusive legislative jurisdiction of the Canadian Parliament. This constitution, and various amending documents, gave Canada and the provinces the right to legislate for themselves according to their respective powers. The division of legislative responsibility, in so far as it concerns matters respecting the environment is as follows:

for the federal government - public property, regulation of trade and commerce, Sable Island, navigation and shipping, quarantine, sea coast and inland fisheries, lands reserved for Indians, criminal law, railways and other works and undertakings of an inter- or extra- provincial nature, works of multi-provincial or national importance, provision for uniformity of property and civil rights laws, agriculture, performance of British Empire treaty obligations,[3] and administration of any non-provincial territories;[4]

for the provincial government - public lands, municipal institutions, local works and undertakings, property and civil rights, punishment of provincial offences, matters of a local or private nature, agriculture, exploration for, development, conservation and management of non-renewable natural resources and forestry resources in the province, and development, conservation and management of sites and facilities in the province for the generation and production of electrical energy.[5]

All laws in force at the time of Confederation were to continue, including British statutes, Common Law, the Civil Code in Quebec, and colonial laws.[6] But Canada, as constituted, was still not a sovereign state; by virtue of the Colonial Laws Validity Act 1865[7], a law that was properly legislated in Canada might be void to the extent that it was repugnant to an Act, or order or regulations thereunder, of the British Parliament which applied to Canada. Only under the Statute of Westminster[8] in 1931 were Canadian legislators, both federal and provincial, freed of restrictions on their legislative authority, with the exception of the restriction on the power to alter the British North America Acts.[9] Fifty-one years later, under the terms of patriation of the constitution, this latter restriction was removed.

The wording of the constitution contemplates two specific kinds of legislative powers: exclusive and concurrent. Concurrent powers do not mean that an individual can choose one law he wishes to obey and ignore the other; the decision as to which has precedence lies elsewhere. With respect to concurrent jurisdiction over agriculture,[10] the Act empowers the provincial and the federal governments each to make laws affecting that subject within the province, but the provincial law is to be effective only in so far as it is not repugnant to any Act of Parliament. Thus the Act has expressly provided for federal paramountcy in this situation.

There are, however, classes of subjects within both federal and provincial exclusive jurisdictions that are broadly enough worded to encompass matters not specifically assigned to either. It is important to bear in mind that the draftsmen of 1867 could not be expected to be clairvoyant and that there are modern concerns not then considered, or even known, and therefore not specifically assigned by the Act. It has fallen to the law-makers to decide whether or not to legislate in respect of a given matter which, after all, must come under the legislative authority of at least one jurisdiction because the constitutional division of powers must be taken to be all-inclusive. When, as in the case of environmental protection, the area of legislative interest is not singular in itself but rather is a multitude of problems having various constitutional implications, the question of jurisdiction becomes much more complex.

Ultimately it is the Courts that determine if a piece of legislation is properly within the authority of the jurisdiction enacting it. But until the legitimacy of a particular law is questioned, it is possible that federal and provincial statutes may both deal with the same matter, each requiring that its provisions be obeyed. Since Confederation, the Courts have developed considerable jurisprudence to aid in the assessment of conflicting claims to legislative authority in reference to any given subject. Exclusiveness pertains to enumerated classes of subjects, but only to such matters as come "within" those classes.[11] A matter may, however, come partially within two or more classes and those classes might be assigned to different jurisdicitons. One point is quite clear: no jurisdiction may legislate with respect to a class of subjects within another's exclusive jurisdiction; such law, the primary objective of which is to effect control over a class of subjects outside its powers (albeit possibly cloaked in words purporting to bring the matter within one or more of its own powers[12]) would be invalid because it is ultra vires.[13]

Should an otherwise valid law of one jurisdiction affect only incidentally a class of subjects within the exclusive law-making authority of another jurisdiction, that law may be inapplicable only in so far as it encroaches on the other's powers. A municipal anti-pollution by-law has been found not to apply to a ship, although moored within municipal limits, because enforcement of the by-law would have affected the actual operation of the ship (its engines emitted the pollution), which was properly a federal responsibility with respect to navigation and shipping.[14] Had the ship merely been the site of the pollution, the cause bearing no relation to its function as a ship, the decision might have been different.[15]

There are situations in which a matter does not fall neatly into a definitive federal or provincial category and each jurisdiction is competent to legislate. But where their laws, made in this area of overlap, conflict, the federal law overrides, *i.e.* is paramount.[16] The provincial law is then ineffective but not invalid. Had the federal law never existed or ceased to exist, *e.g.* been repealed, the provincial law would be enforceable. There is some authority for the proposition that where both federal and provincial jurisdictions are competent to legislate, if the province sets the more stringent standards they will be valid and hence enforceable, although less stringent ones would not.[17] So too municipal standards that are stricter than the province's are enforceable, whereas less strict ones would not be valid. The effect is similar but here the municipality derives its powers and very existence from the province itself and does not have a constitutional right to them.[18]

Together the federal and provincial governments control the full range of legislative powers in relation to any matter, regardless of how those powers are divided between them. Despite the fact that one jurisdiction cannot delegate its legislative authority to the other,[19] co-operation and co-ordination is possible by means of delegation of administrative authority to a subordinate agency of the other jurisdiction.[20] Inter-delegation between the provinces, however, is virtually impossible because each province's legislative authority is confined by its territorial boundaries. Any attempt by one province to legislate beyond its own borders will be ultra vires.[21]

How any one province approaches a particular matter, *e.g.* environmental protection can be different from all the rest although in practice their laws are seldom totally dissimilar. As the likelihood of all provinces enacting identical environmental legislation is small, a feasible means of achieving uniformity is the passage of a federal statute effective across Canada. This might occur only if pollution was generally perceived to be such a nation-wide problem that it ceased to be a matter of a merely local nature and so fell within Parliament's residuary powers in relation to "Peace, Order and Good Government"[22], or some other federal head of power which was valid under the circumstances.

THE FORMS OF LAW

Law having environmental aspects may take a variety of forms in Canada; perhaps the most familiar one is the statute, *i.e.* Act. A statute is simply a written law, passed by either Parliament or a provincial legislature, to which Royal Assent has been given. If its provisions require that, in whole or in part, the statute is not to come into force until proclaimed, it is activated only on Cabinet order. Most statutes merely define the limits of that law, leaving in the hands of the Cabinet the subordinate authority to make regulations or orders relating to specified subjects. In reality, the Cabinet usually accepts as its own the regulations drafted by the civil servants in the appropriate department concerned with enforcing the statute. Thus while statutes may be made only by elected legislators, a large part of their law-making authority is in effect delegated to non-elected administrators.

Photo 1. Parliament Buildings, Ottawa.
NFB–PHOTOTHEQUE–ONF D. Siemienski

There are two other types of legislation that do not bear the name "statute", but which are in fact similar to it: by-laws and ordinances. A by-law is generally a piece of municipal legislation enacted by the Council of an incorporated municipality under the authority acquired from the province. An ordinance is a kind of enactment peculiar to the Territories, the legislative authority being vested in the Territorial Commissioner on the advice of his Council. Like provincial statutes, by-laws and ordinances are limited in operation to the territorial boundaries of their legislating authority. Less familiar perhaps, but equally classified as "law", is the Common Law. Demonstrative of the judicial tradition of attempting to ensure the cohesiveness and certainty of the law relative to any given matter, this system is founded on previous cases, precedent-setting decisions to be followed in the absence of legislation but usually only so long as they are not totally at odds with modern society's accepted norms. Under normal circumstances, however, the Courts have been inclined to defer to the legislatures to alter long standing Common Law rules through enactments reflecting contemporary society's standards. The Common Law applies to all of Canada except Quebec which has been constitutionally guaranteed its own comprehensive Civil Code for determining inter-personal legal duties.

Because each province and territory has its own judicial system and property and civil rights laws, decisions on the same factual situation may vary between jurisdictions. There may also be differences in statutory interpretation and variation of the Common Law from jurisdiction to jurisdiction. Hence a court in one need not recognize the decision from another, even if based on the same facts. But in practice, lower courts in one province or territory tend to accept higher court decisions in other provinces or territory (or for that matter in Britain) as having at least some weight even if those courts do not feel bound by them. A higher court decision made within the same jursidiction, however, is considered to be binding until overruled.

THE PURPOSE OF LAW

Broadly speaking there are five main purposes that law, especially statutory law, espouses: encouragement, prevention, regulation, compensation, and punishment. Common Law and the Civil Code tend to place emphasis on prevention and compensation. Statutes are usually not designed to serve one purpose alone, but are often multi-faceted; although each purpose is distinct there may be a blending of purposes within one statute to achieve a comprehensive scheme relating to its topic.

Encouragement can generally be read as meaning money. In other words, the government confers some economic or financial benefit on someone who undertakes a particular programme. A simple example is the establishment of research grants, subsidies, or even an entire government agency to help develop one or more technologies. A less direct method of encouragement is found in the provision for tax deductibility of up to one half of the capital cost of the acquisition of certain types of pollution control equipment in a fiscal year.[23]

Prevention can be accomplished by the establishment of precise standards or prohibitions, leaving it to the individual to comply. This is sometimes difficult to do where there is considerable variance among the situations to which the standards are meant to apply. Another, more flexible, method of prevention, which has been used to supplement the first, is to require, as in Ontario, that an assessment be made of the impact that a project will have should it be allowed to be undertaken.[24] In this way conditions suitable to each circumstance can be attached to the grant of approval, if given at all.

Prevention may also be achieved indirectly, the standards or prohibitions being focused on something other than the land itself. Laws governing land-clearance, *e.g.* forestry, may have the effect of preventing soil erosion. Protection of flora and fauna, *e.g.* endangered species, in a given area may effectively be protection for the land in that area because the quality of the soil normally determines the type of life it will support.

Regulation often has a twofold purpose. On the one hand, it may provide for the supervision and control over an activity to ensure that established standards are met. Such regulation allows for periodic inspection or review by officials, *e.g.* the Atomic Energy Control Board,[25] who may have the power to withdraw or refuse to renew the governmental permission necessary to operate. On the other hand, it may give the government a source of revenue, through licensing fees, to administer the law.

Compensation can be made available in three main ways. First, the law might state that, on proof of fault, the cost of the damage is recoverable from the wrongdoer. Second, the mere fact of the harm having occurred may be declared sufficient to make the person in charge of the cause of the harm strictly liable. Third, as under the Pesticide Residue Compensation Act[26], regardless of the question of whether anyone was at fault or in charge, compensation may be paid, once the injury is assessed, whether out of a specific fund or otherwise.

Punishment for statutory infractions is often included in legislation, be it federal, provincial, territorial, or municipal, to act (at least in theory) as a deterrent. Punishment can be by imposition of a fine or imprisonment or both, if so stated. The discretion regarding the extent of the penalty, subject to a maximum, is in most cases left with the Courts, but there can also be instances where the offence incurs a prescribed minimum penalty.

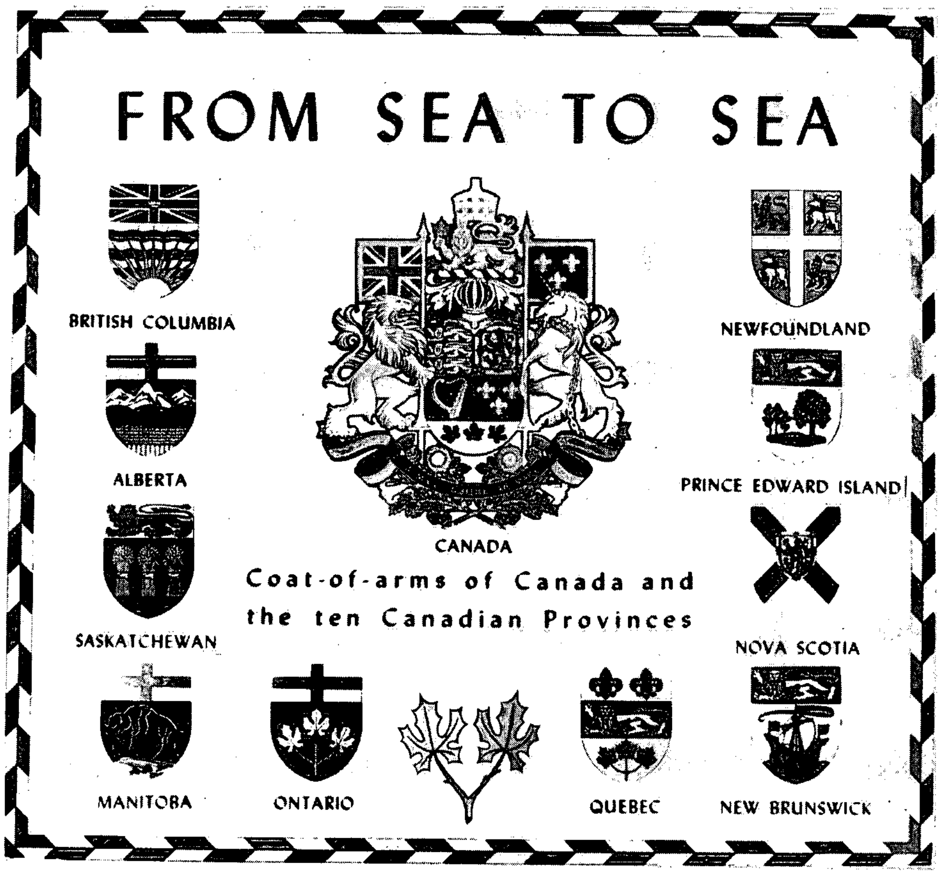

Photo 2. Canadian and Provincial Coat of Arms.
NFB–PHOTOTHEQUE–ONF

THE LEGAL CONCEPT OF LAND

Holding land, either by possession or ownership, has historically been the source of power under the British, and hence Canadian, system of government.[27] All land, even that in private hands, has traditionally been held at the pleasure of the Crown, which originally granted the land. This phenomenon, most apparent in feudal times, still remains true to a certain degree. The rule of the Crown prevails, exercised by the government of the day; it is this rationalization that provides a social order and stability. Formerly, land was not attributed a value in itself, but its value was determined in accordance with what it produced, *e.g.* crops, minerals, timber, and rents. In Canada, all lands came into the hands of the Crown by way of conquest and discovery, which were performed in the name of the sovereign. Although land ownership is at present almost absolute, the Crown still maintains an interest. This is apparent in the division of land grants into two distinct grants, the land *per se* and the mineral rights in the land. Unless the original conveyance from the Crown specifically included mineral rights, they were withheld and could be granted to someone other than the owner of the land. Even if the mineral rights were included in the grant, they remain severable from the ownership of the land. But bearing in mind the limitation with respect to mineral rights, both the Common Law and the Civil Code (Art. 414) recognize that the owner of the soil owns what is above and below it,[28] and with ownership goes the right to its use (Art. 406). This principle applies to both public ownership, *i.e.* Crown lands, and private ownership.

The right to use the land owned is also the right to have another's interference with use stopped. A problem arises when one landowner uses his land in such a fashion as to interfere with another proprietor's use of his own land. What place does legislation have in this situation? Currently, it is accepted that society, and consequently government, has an interest in protecting the environment and so can impose restrictions on a use of property that causes adverse alteration in land quality. But it has been stated in a recent Ontario decision that what is considered to be a contaminating activity, if its effects are confined to one's own land, is not to be interfered with lightly unless the wording of the legislation is precise in that meaning.[29] Proprietary rights can be seen as the essential distinguishing factor in the law's approach to environmental protection of land, as opposed to air and water. The latter two are fluid, not confined to a single location. Whereas a person may own the land that air and water touch, it is virtually impossible to exert absolute control over such air and water. Therefore a proprietor may be said to have the right to the use of air and water as an incident of holding land, but it is the Crown that has the dominant interest in their quality for the benefit of everyone's use.

The government may express an intention that certain lands are to be held for the benefit of people's use. These are Crown lands but are dedicated to the use of a particular class; parks, both national and provincial, are dedicated to public use, Indian reserves to the bands' use. Because the dedications are subject to the relevant enactments, there remains in the Crown the residuary right to expand, decrease, otherwise alter, or repossess the land for other purposes.[30] Thus the Crown remains the owner of such land, and a member of the class to whom the land is dedicated may have no legal standing to interfere with the government's exercise of its proprietary rights to degrade any part of that land. This is clearly the case at least in relation to Ontario park-land,[31] and, considering the similarity of the wording of such statutory dedications, the reasoning probably also extends to other jurisdictions.

The practical significance of the legal concept of land for the proprietor whose land has been

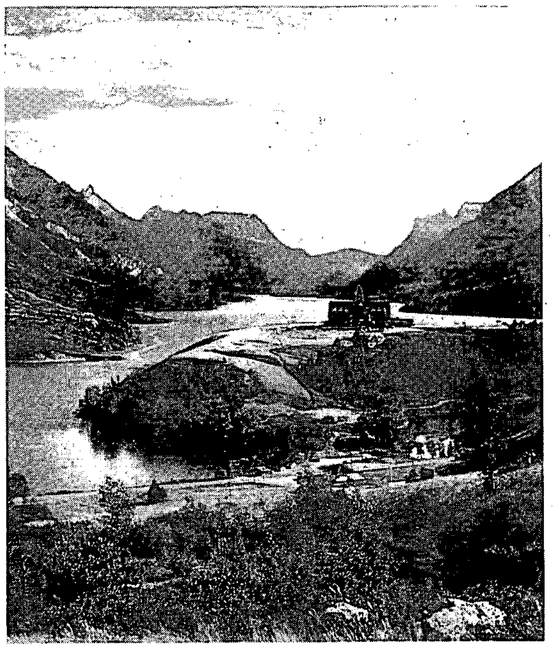

Photo 3. Land reserved for recreation: Waterton Lakes National Park.
NFB–PHOTOTHEQUE–ONF George Hunter

polluted lies in the assessment of the amount that he may recover for the damage sustained. Recovery depends on the extent to which the value of the land has been depreciated by the contamination. Even today the value is closely tied to the use to which the land is or can be put, and seldom to some aesthetic value. That is not to say that natural or decorative vegetation will not be given a replacement value, but vegetation is not land (with the possible exceptions of peat or sod-farming). The contamination complained of may be by land itself. For example, sand carried by man, water, or wind on to property on which a sensitive crop is growing is just as much pollution as any other damaging material. The question to be answered is to what degree is the land degraded, either temporarily or permanently? Residential or agricultural land that is contaminated so as to render it unfit for habitation or for the production of the crop indigenous to that area can be assessed in relation to the ordinary value for that purpose in that area, less its present depreciated value. The value to the owner must be present and real, not some future speculative value; it must relate to use. Sometimes that use is itself a degradation of the land, for example, a commerical sand-pit, which use is unique to that particular property. In that instance, the land damaged, for example by an oil spill, may be valued in accordance with the market value for that commodity damaged, and not with the value of surrounding lands used for a different purpose. The current market value of that particular land to its owner (so long as the use in question is not unlawful or immoral), is the standard for determining its value and hence the amount of its depreciation.

LEGISLATION RELATING TO LAND DEGRADATION

The following is by no means an exhaustive list of the statutes and ordinances (orders, regulations, and municipal by-laws are omitted) on the subject of land degradation; however it does present the more significant land quality provisions for the specified jurisdictions.

Canada

Atomic Energy Control Act, R.S.C. 1970, c. A-19.

This Act, administered by the Department of Energy, Mines and Resources, was legislated to control the production of atomic energy. By virtue of s.9, the administrative body created by the Act, the Atomic Energy Control Board, has wide powers that are to be used to ensure the safety of the industry. It has the specific authority to license operations and to regulate mining, production, importation, exportation, transportation, refinement, possession, ownership, use, or sale of prescribed atomic substances. Should an offence be committed contrary to the Act or those regulations, the offender is liable to fines up to $10 000 or ten years' imprisonment or both (s.19).

Clean Air Act, S.C. 1970-71-72, c. 47.

This Act, administered by the Department of the Environment, was designed to set up standards of contaminant emissions into the ambient air. The Cabinet is empowered to prescribe by Order national, maximum quantities of a contaminant that may be emitted by a specified class of stationary operations, if the concentrations produced by that class constitute a significant health danger or are in violation of international obligations (s.7). "Contaminant" is defined as "a solid, liquid, gas or odour or a combination of any of them" that causes air pollution (s.2). This definition makes the Act significant in relation to land degradation in its application to air-borne particulate matter and acid rain pollution. Emission standards, generally, are authorized with respect to works, undertakings, or businesses within the federal legislative powers (ss.10–18). Violation of any of these standards incurs liability to $200 000 fines (ss.9, 33). Inspectors designated under the Act (s.27) have the right to enter and examine operations to which the standards apply (ss.28–30). They may also order compliance with the standards or the cessation of operations, within the federal jurisdiction, causing the pollution (ss.16–17). But the inspection power is not limited to activities already under way; inspectors can require submission, for assessment, of plans and specifications of a federal work, undertaking, or business likely to emit air contaminants when operational. Should they determine that the potential emissions are unacceptable, they can order modification of the plans or prohibit their execution (s.15).

Environmental Contaminants Act, S.C. 1974-75, c. 72.

This Act, administered by the Department of the Environment, is meant to control substances posing a threat to the environment, *e.g.* PCBs. It provides the Minister with the power to gather data on and investigate a substance, alone or in concert with the Department of National Health and Welfare, and/or provincial governments (s.3). Persons who are engaged in the importation of the substance or in any commercial, manufacturing, or processing activity involving the substance, on notice from the Minister, may be required to disclose all their information about it or to conduct tests on it. Furthermore, once public notice is given, anyone who begins to manufacture or import the substance in quantities greater than 500 kg. must so inform the Minister (s.4(6)). If the Ministers of the Environment and of National Health and Welfare are satisfied that the substance presents a significant environmental danger, they may list it in the Act's Schedule of contaminants, either after consulation with the provincial governments concerned (s.5) or, in the case of an emergency, at once (s.7(3)). The Schedule may restrict, by quantity or region, the contaminant's use. Persons who import, manufacture, process, offer for sale, or knowingly use that substance in violation of the restrictions are guilty of an offence and liable to a fine of $100 000 or two years imprisonment(s.8). Inspectors designated to enforce the Act have powers of search and seizure of the substance (ss.10, 11), which is subject to forfeiture on a conviction (s.13). The permissible use, if any of a substance listed in the Schedule may be further restricted by regulations under the Act (s.18).

Government Organization Act, 1979, S.C. 1978-79, c. 3.

Part III of this Act, separately titled the Department of the Environment, made the Minister of this body responsible for all matters, not administered by other governmental divisions, relating to the preservation and enhancement of soil quality (s.5(a)).

Indian Act, R.S.C. 1970, c. I-6.

This Act, administered by the Department of Indian Affairs and Northern Development, controls the use of lands reserved for Indians. Anyone, other than a band member, wishing to occupy, use, or otherwise exercise any right on a reserve requires a Ministerial permit (s.28), as does anyone wanting to remove minerals, stone, sand, gravel, clay, or soil. Unauthorized removal is subject to a $500 fine or three months' imprisonment on conviction (s.93). Waste disposal on the reserve is to be in keeping with Departmental regulations (C.R.C. 1978, c. 960). Failure to comply may result in the permit being cancelled and clean-up measures being ordered, in additon to a $100 fine or three months' imprisonment or both. Land use may also be covered in band council by-laws which probably vary with each reserve (s.81).

Historic Sites and Monuments Act, R.S.C. 1970, c. H-6, as amended.

This Act, administered by the Department of the Environment, authorizes the Minister to provide for the administration, preservation and maintenance of historic sites established under the Act (s.3).

National Energy Board Act, R.S.C. 1970, c. N-6, as amended.

This Act, administered by the Department of Energy, Mines and Resources, deals with the location, construction, and operation of pipelines extending extra-provincially. The National Energy Board is the administrative agency empowered to certify these pipe-lines (ss.26, 27) and to require their repair, reconstruction, or alteration (s.39(1)). The Board, in addition to assessing the impact of each pipe-line application for certification, may make generally applicable regulations for the protection of property (s.39(2)) including soil quality (C.R.C. 1978, c. 1052, s.4 (b)). Violation of the regulations is a summary conviction offence (s.39(3)) and any damage caused must be compensated (s.64).

National Parks Act, R.S.C. 1970, c. N-13.

This Act, administered by the Department of the Environment, provides the public with recreational land in a near-natural state. The Cabinet may make regulations for the preservation, control and management of the parks (s.7(1)); for example, the control over waste disposal in any National Park has been delegated to its Superintendent (C.R.C. 1978, c. 1124, s.18). Contravention of the Act or regulations thereunder is an offence penalized by a $500 fine upon conviction (s.8(1)).

Nuclear Liability Act, R.S.C. 1970 (1st Supp.), c. 29.

This Act, administered by the Department of Energy, Mines and Resources, was legislated to provide for compensation for damage to property from fissionable or radioactive materials under the control of the operator of a licensed nuclear facility. Such operator is absolutely liable, without proof of fault or negligence (s.4), except if the incident causing the damage is the result of armed conflict (s.7). The Act authorizes the Atomic Energy Control Board to require operators to maintain insurance covering liability up to $75 000 000 (s.15).

Oil and Gas Production and Conservation Act, R.S.C. 1970, c. 0-4, as amended.

This Act, administered by the Departments of Indian Affairs and Northern Development and of Energy, Mines and Resources, regulates oil and gas exploration and development in the Yukon and the Northwest Territories, on federal Crown land, and in coastal waters not within provincial jurisdiction (s.3). The Cabinet is authorized to make regulations respecting exploration, drilling, production, processing, and transportation of oil and gas, and more particularly, respecting licensing of wells, preventing waste, confining oil and gas to its original stratum, and avoidance of land pollution (s.12 (a), (l), (n), (q)). Although committing waste is an offence, it may be proscecuted only with Ministerial consent (s.13). The Act empowers a Chief Conservation officer to investigate the commission of waste and to order an operation shut down to prevent pollution (s.14). Failure to comply with his order is in itself an offence (s.48(4)). On conviction for offences established by the Act, the offender may be ordered by the Court to obey the Act or orders enforcing its provisions (s.50).

Pest Control Products Act, R.S.C. 1970, c. P-10.

This Act, administered by the Department of Agriculture, requires the registration of pesticides and herbicides before they may be imported, sold, or transported between provinces (s.4). The Cabinet may make regulations concerning their manufacture and use (s.5(j)). One such regulation is the granting of discretion to the Minister to refuse registration to a control product if its use poses an unacceptable risk of harm to the environment (C.R.C. 1978, c. 1253, s.18(d)). Contravention of the Act or its regulations is liable to a fine or imprisonment for up to two years or both (s.10). Inspectors designated by the Minister have powers of search and seizure; the control product detained is to be forfeited on conviction of an offence under the Act (ss.6–9).

Pesticide Residue Compensation Act, R.S.C. 1970, c. P-11.

This Act, administered by the Department of Agriculture, is designed to compensate a farmer whose crop is contaminated by the use of a control product registered under the Pest Control Products Act and used in accordance with approved practices (s.3(1)). Whereas the Act does not contemplate compensation for damage to soil *per se*, compensation may be recoverable as long as the control product remains in the ground and contaminates crops thereon.

Territorial Lands Act, R.S.C. 1970, c. T-6.

This Act, administered by the Department of Indian Affairs and Northern Development, applies to Yukon and Northwest Territories land under the Crown's control (s.3). It allows the Cabinet, in consultation with the appropriate Territorial Council, to designate areas as land management zones and to make regulations respecting the protection, control, and use of the surface of the land in those zones (ss.31, 32). Use of the surface may be made the subject of a permit and failure to comply with conditions attached to its issuance, or other regulations, is an offence punishable by a $5 000 fine (s.33). In addition, the Cabinet has power to authorize an inquiry into questions affecting Territorial lands (s.19(h)). Pursuant to this power, the Berger Commisssion was formed to undertake what amounted to a comprehensive environmental impact assessment of the proposed Mackenzie Valley pipe-line route.

Alberta

Agricultural Chemicals Act, R.S.A. 1980, c. A-6.

This Act, administered by the Department of the Environment, controls fertilizers, pesticides, and soil supplements (s.2(a)). Regulations may require registration of substances as agricultural chemicals and restrict (or even prohibit) their use, sale, or supply, including the manner of their disposal (ss.10, 25). Whether or not such substances are specifically listed in the regulations as agricultural chemicals, if the Director of Pollution Controls believes that they cause or are likely to cause damage to land, he may issue a chemical control order requiring the person responsible to comply with specified controls including prohibition of their use. Inspectors have the right to check for compliance with the Act and regulations and may take soil samples for analysis (s.22). Conviction for infractions may result in a $1 000 fine or ninety days' imprisonment or both (s.26).

Alberta Environmental Research Trust Act, R.S.A. 1980, c. A-20.

This Act, administered by the Department of the Environment, provides for the funding of research relative to environmental improvement (s.3).

Beverage Container Act, R.S.A. 1980, c. B-4.

This Act, administered by the Department of the Environment, regulates disposal sites for beverage containers, requiring the operator to be approved or face a $1 000 fine on conviction (ss.2, 16, 18).

Clean Air Act, R.S.A. 1980, c. C-12.

This Act, administered by the Department of the Environment, is the provincial equivalent of the federal legislation of the same name, the offence section under this statute providing for a $5 000 fine (s.16). Conviction for non-compliance with a Ministerial stop order incurs penalties of a maximum fine of $10 000 per day or twelve months' imprisonment or both (s.14(4)).

Coal Conservation Act, R.S.A. 1980, c. C-14.

This Act is designed to assist in the control of pollution (s.4(e)). Before a coal mine or processing plant may be developed, operated, or abandoned, the issuance of a permit or licence must first be approved by the Minister of the Environment who may attach conditions thereto (ss.21, 23).

Department of the Environment Act, R.S.A. 1980, c. D-19.

This Act created the Department that is responsible for promoting the conservation of, management of, and pollution control over natural resources, including land (ss.1, 2, 8).

The Forest and Prairie Protection Act, R.S.A. 1980, c. F-14.

This Act, administered by the Department of Energy and Natural Resources, empowers the Minister, on the request from a Minister or agency having responsibility regarding pollution by the oil and gas industry, to compel able-bodied males to assist in clean-up operations (s.29).

The Hazardous Chemicals Act, R.S.A. 1980, c. H-3.

This Act, administered by the Department of the Environment is the provincial equivalent of the federal Environmental Contaminants Act; on conviction the penalty for contravention is a $1 000 fine or ninety days' imprisonment or both (s.14).

Photo 4. Land for energy: blasting for coal in Alberta.
NFB–PHOTOTHEQUE–ONF Larry Monk

Land Surface Conservation and Reclamation Act, R.S.A. 1980, c. L-3.

This Act, administered by the Department of the Environment, gives wide powers of regulation in respect of land degradation, including mining, pipe-lines, waste disposal or land-fill sites (ss.23, 24). The Minister may enter into an agreement with a land owner restricting its use (s.7), declare an area restricted, or expropriate its mineral rights so as to prevent degradation by exploration or mining (ss.10, 14). Anyone whose activities are likely to cause surface disturbance may be required to submit an environmental impact assessment of those activities on conservation, control of pollution, or preservation of the land (s.8). Before an approval to commence regulated surface disturbance activities may be granted, with or without conditions, plans and specifications of the operation must be submitted to the Minister (s.26). Unapproved activities are subject to stop and control orders (ss.9, 28). Land reclamation may proceed either voluntarily or by order. The Act provides for financial assistance to those wishing to restore land (s.12), but also authorizes reclamation orders in other situations where unacceptable degradation has occurred (ss.42–44). Should the reclamation order not be obeyed, the work may be done and paid for by the Minister, then charged to the responsible, non-complying party (s.46). If reclamation is required on an abandoned activity site, the operator of which is untraceable, or if the degradation was the result of natural causes, the cost of the remedial work may be paid by the government (s.48). The general penalty for contravening the Act or regulations is a $5 000 fine or three months' imprisonment on conviction (s.18).

Litter Act, R.S.A. 1980, c. L-19.

This Act, administered by the Department of the Environment, prohibits unauthorized littering of public or private land (ss.2–5). The Act may be enforced through its offence provisions or clean-up orders (ss.7, 9). Failure to comply with a clean-up order may result in the work being done and the costs recovered against the person who failed to comply (ss.11, 15).

The Oil and Gas Conservation Act, R.S.A. 1980, c. O-5.

This Act, administered by the Energy Resources Conservation Board, is the provincial equivalent of the federal Oil and Gas Production and Conservation Act. The penalties for contravention vary, but may amount to a $1 000 fine on conviction (s.99).

Pipeline Act, R.S.A. 1980, c. P-8.

This Act, administered by the Energy Resources Conservation Board, is the provincial equivalent of the federal National Energy Board Act. Clean-up provisions allow for containment and remedial operations to be undertaken when it appears that they will not otherwise be effected, the costs thereof being recoverable (s.37). Offences under the Act incur liability up to a $1 000 fine (s.53).

The Public Lands Act, R.S.A. 1980, c. P-30.

This Act, administered by the Department of Energy and Natural Resources, prohibits unauthorized accumulation of waste, occurrence of conditions endangering property, or creation of conditions on public lands likely to result in soil erosion (s.51). The Minister may order the person responsible to take remedial action and, if he fails to do so, cause it to be done, then recover the costs. Conviction of an offence gives rise to a maximum fine of $1 000 unless a specific penalty is otherwise prescribed (s.56).

Quarries Regulation Act, R.S.A. 1980, c. Q-1.

This Act, administered by the Energy Resources Conservation Board, regulates the operation of quarries including the prevention of damage to property therefrom (s.3). A quarry permit is required to carry on activities, which also are subject to inspection to check for compliance with the standards set (ss.5, 8, 9). Penalties for offences are a $100 fine for the first day of the infraction and a $50 fine per day if it continues (s.14).

Wilderness Areas Act, R.S.A. 1980, c. W-8.

This Act, administered by the Department of Recreation and Parks, forbids the unauthorized deposit of litter in a designated wilderness area and the damage or pollution of its lands (ss.8, 10). Fines up to $1 000 may be levied for a first offence (s.13).

British Columbia

Ministry of Environment Act, S.B.C. 1980, c. 30.

This Act, creating the Ministry, makes it responsible for the management, protection and conservation of land (s.4).

Ecological Reserves Act, R.S.B.C. 1979, c. 101.

This Act, administered by the Ministry of Lands, Parks and Housing, authorizes the Cabinet to establish reserves out of Crown land (ss.2–3) and to make regulations controlling the use of the land, including the dumping, deposit, or emission of any substances (s.7).

Environment and Land Use Act, R.S.B.C. 1979, c. 110.

This Act created the Environment and Land Use Committee to make recommedations to the Cabinet on matters of environmental preservation and land use (s.3). The Cabinet, having power to make orders and regulations respecting environment and land use (ss.6, 7), has set up mandatory environmental assessment procedures with regard to proposed land use of specified areas such as the Fraser Valley Estuary (B.C. Regulation 202/77).

Environment Management Act, S.B.C. 1981, c. 14.

This Act, administered by the Ministry of the Environment, provides for the management, protection and enhancement of land (s.2). An environmental impact assessment may be required for a proposed project (s.3). Where an activity has been declared by the Minister to have a detrimental impact, environmental protection orders may be issued to control or stop that activity (s.4). Where the Minister has declared an environmental emergency, he may require the compulsory assistance of any able-bodied adult to aid in preventing, lessening or controlling the hazard in question, *e.g.* an oil spill. The costs involved are recoverable from the person who caused the emergency situation (s.5). Failure to comply with an assessment request or protection order can be subject to a $100 000 fine, whereas giving false assessment information may result in a $100 000 fine on conviction (s.14).

Photo 5. Forest products harvested from the land: logging in British Columbia.
NFB–PHOTOTHEQUE–ONF Allan Katowitz

Land Act, R.S.B.C. 1979, c. 214, as amended.

This Act, administered by the Ministry of Land, Parks and Housing, prohibits unauthorized disposal of any substance on Crown land (s.62) subject to a $300 fine or sixty days' imprisonment or both (s.63).

Litter Act, R.S.B.C. 1979, c. 239.

This Act, administered by the Ministry of the Environment, forbids unauthorized littering or sewage disposal (ss.3, 4) on any land. Contravention of the Act or its regulations is made an offence punishable by a $500 fine or six months' imprisonment or both (s.6).

Pesticide Control Act, R.S.B.C. 1979, c. 322, as amended.

This Act, administered by the Ministry of the Environment, is the provincial equivalent of the federal Pest Control Products Act. Offences under this statute incur liability to a $2 000 fine or six months' imprisonment or both (s.22).

Pollution Control Act, R.S.B.C. 1979, c. 332, as amended.

This Act, administered by the Ministry of the Environment, gives the Director of Pollution Control wide powers to determine what constitutes a polluted condition with respect to land and to set standards. He is also empowered to issue cessation orders against polluters (s.13). The Act grants a right of access for inspection personnel to any land in pursuance of their duties (s.14, 18). Conviction of having contravened the Act or regulations gives rise to the possibility of a $10 000 fine or one year's imprisonment or both (s.25).

River-bank Protection Act, R.S.B.C. 1979, c. 369.

This Act, administered by the Ministry of Transportation and Highways, permits the Cabinet to carry out a project to prevent encroachment of any river upon its banks (s.11). Once interested landowners apply for protection-works to be built, Ministry engineers may prepare a report on the project, on which the decision to proceed may be based (s.2).

Soil Conservation Act, R.S.B.C. 1979, c. 391.

This Act, administered by the Ministry of Agriculture and Food, prohibits the unauthorized removal of soil from, or placement of fill on, land in a designated agricultural land reserve (s.2), the penalty for which is a $500 fine for each day the offence continues (s.9).

Manitoba

Clean Environment Act, S.M. 1972, c. 76, as amended.

This Act, administered by the Department of Mines, Resources and Environmental Management, forbids the contamination of soil beyond prescribed limits (s.4). No contaminating or potentially contaminating activity may be carried on without the approval of the Clean Environment Commission which has the power to order the contamination abated, controlled, stopped, and cleaned up. The Commission may have the contamination dealt with by someone else, when the responsible party fails to comply with an order, and will then recover the cost involved. The Minister may exercise emergency clean-up powers in situations calling for immediate action (s.14) or issue a stop order against the contaminating activity (s.16.1). Furthermore, the Minister or any person affected by the contamination has the right to apply for a Court injunction effective until the standards are met (s.16.2), such standards being, generally, determined under the Act or, specifically, under the regulations made by the Cabinet (s.18). The Act provides designated officers with inspection powers (s.16) and allows for fines to be levied up to $5 000 for offences (s.7). The Act also allows a municipality, with the approval of the Commissioner to undertake some degree of self-regulation in the form of abatement projects (s.15.1).

The Mining and Metallurgy Compensation Act, R.S.M., 1970, c. M190, as amended.

This Act, administered by the Department of Mines and Natural Resources, provides for the compensation of persons whose property suffers damage, *e.g.* from dust or waste, caused by mining, milling, smelting, or refining operations. The damage may be suffered directly or indirectly but must be incurred outside specified districts in order to be eligible (s.4(3)). Should the party responsible not enter into a voluntary settlement, the person whose interests were affected may have his claim determined by an arbitrator appointed under the Act (ss.5, 6).

The Pesticides and Fertilizers Control Act, S.M. 1976, c. 19.

This Act, administered by the Department of Agriculture, provides for licensing, regulation, and, if the Cabinet deems it necessary, prohibition of the use of fertilizers and of pesticides, *i.e.* registered under the federal Pest Control Products Act (s.4(4)). The Act gives inspectors powers to check for compliance and allows for the delegation of their powers to federal inspectors (s.4(1),(3)). On conviction offenders are subject to a $1 000 fine or six months' imprisonment or both (s.7).

New Brunswick

Clean Environment Act, R.S.N.B. 1973, c. C-6, as amended.

This Act, administered by the Department of the Environment, empowers the Minister to issue control orders limiting, stopping, or altering the manner of contamination of the environment, or instituting or varying any contamination control or elimination procedures or equipment (s.5). If a source of contamination is causing an immediate danger to property, the Minister may issue a stop order effective immediately (s.6). Designated inspectors have the right of access and testing in the course of their investigations (ss.23, 24). The Cabinet has regulatory power over what may be prescribed as a contaminant or waste, over standards and controls regarding sources of contaminants and waste, and over licensing of those sources (s.32). It may also enter into financial arrangements with municipalities to assist in control or prevention projects (s.15.1). The penalties vary according to the type of offender, but no one may be prosecuted for an offence unless the Minister has given his written consent (ss.33, 33.2).

Photo 6. Wildlife needing land for protection: Bald Eagle.
NFB–PHOTOTHEQUE–ONF Allan Katowitz

Ecological Reserves Act, S.N.B. 1975, c. E-1.1.

This Act, administered by the Department of Natural Resources, permits the Cabinet to establish reserves to preserve, among other things, areas containing unique or rare examples of pedological or geological phenomena (ss.3, 4). Any unauthorized activities that may alter any part of the terrain therein are forbidden (s.6), punishable as an offence by a $1 000 fine (s.14).

Highway Act, R.S.N.B. 1973, c. H-5

This Act, administered by the Department of Highways, allows the Minister to designate car dump sites (s.60). It requires that there be no unsightly deposit of junked cars on any land other than dump sites in accordance with the Act (s.61). Violators are subject to a $200 fine and clean-up orders upon conviction (s.62).

Pesticides Control Act, R.S.M.B. 1973, c. P-8.

This Act, administered by the Department of Agriculture and Rural Development, is the provincial equivalent of the federal Pest Control Products Act, to which it makes reference. The offence section establishes as penalties a $1 000 fine or one hundred days' imprisonment or both (s.30).

Quarriable Substances Act, R.S.N.B. 1973, c. Q-1.

This Act, administered by the Department of Natural Resources, prohibits the unauthorized removal of quarriable substances from designated shore areas or from Crown lands (s.6). The Cabinet has the right to make regulations concerning quarrying operations and to set terms and conditions of removal (s.20). Permits granted by the Minister are also subject to whatever terms and conditions he may attach (s.9). Failure to comply with the Act or regulations is punishable by a $100 fine for the first offence (s.18).

Unsightly Premises Act, R.S.N.B. 1973, c. U-2, as amended.

This Act, administered by the Department of Fisheries and Environment, forbids the accumulation of junk on lands within 500 feet of public thoroughfares (s.3). The Act empowers appointed inspectors to enter on lands to investigate contraventions of its provisions, the penalties varying with the nature of the offence (ss.6, 11–15).

Newfoundland

The Department of Consumer Affairs and Environment Act, S.N. 1973, No. 39, as amended.

This Act, establishing the Department, makes the Minister responsible for the protection and enhancement of soil quality (s.7(a) (i)). The Cabinet is authorized to make regulations concerning the constitution and prescription of pollution, the control of sewage or waste discharge on or into soil, the issuance of permits relating thereto, subject to terms and conditions, and the issuance of preventive or remedial orders (s.34(1)). The power of inspection is granted to officers appointed to check for compliance (s.35). Penalties for offences vary with the type of offender, but no prosecution may be undertaken without the Minister's written consent (ss.50, 51).

The Pesticides Control Act, R.S.N. 1970, c. 292, as amended.

This Act, administered by the Department of Consumer Affairs and Environment, is the provincial equivalent of the federal Pest Control Products Act. Contravention of provisions under this Act is subject to a $2 000 fine per day upon conviction (s.21).

The Quarry Materials Act, S.N. 1975-76, No. 45, as amended.

This Act, administered by the Department of Mines and Energy, is the equivalent of New Brunswick's Quarriable Substances Act. An offence is punishable upon conviction by a $1 000 fine or six months' imprisonment or both (s.4(2)).

The Waste Material (Disposal) Act, S.N. 1973, No. 82, as amended.

This Act, administered by the Department of Consumer Affairs and Environment, authorizes the Minister to declare areas as waste disposal sites and to contract for their operation (ss.8, 9). It is an offence to dispose of waste without authority on any land; contravention of the Act or regulations incurs liability to a $2 000 fine per day on conviction (ss.19, 23, 25).

The Waters Protection Act, R.S.N. 1970, c. 394, as amended.

This Act, administered by the Department of Consumer Affairs and Environment, makes it an offence to establish a sewerage disposal system on any land, the watershed of which is likely to affect a public supply of water (s.6). Penalties vary according to the duration of the offence (s.8).

Northwest Territories

Environmental Protection Ordinance, R.O.N.W.T. 1974, c. E-3.

This Ordinance empowers an appointed Chief Environmental Protection Officer to administer its provisions. He may issue protection orders requiring that safeguards, equipment or procedures be installed to prevent or alleviate contamination, stop orders, or remedial orders (ss.5, 7, 8). Where he is required to have remedial action performed, the party responsible for the contamination is liable for the costs arising therefrom. The Chief Environmental Protection Officer may designate inspectors who have investigative powers (s.17). The Territorial Commissioner is authorized to make regulations setting standards and procedures on which protection orders may be based (s.18). Contamination of the environment or failure to comply with an order are offences, the penalty varying according to the nature of the offence (ss.12, 13), but no prosecution may be instituted without the consent of the Director of Public Services (s.15).

Photo 7. Lands burned by forest fires in NWT.
NFB–PHOTOTHEQUE–ONF Mike Van Duffelin

Pesticide Ordinance, R.O.N.W.T. 1974, c. P-4.

This Ordinance, together with regulations made by the Commissioner, controls the use and disposal of pesticides. Contravention of the provisions of the Ordinance or regulations is punishable on conviction by a $1 000 fine or ninety days' imprisonment or both (s.11).

Nova Scotia

Beaches Preservation and Protection Act, S.N.S. 1975, c. 6.

This Act, administered by the Department of Lands and Forests, prohibits unauthorized removal of sand, gravel, stone, or other material from coastal and lakeshore beaches (s.6). Offences are penalized by $1 000 fines, but there must be no prosecution until the Minister gives his consent (ss.8, 13).

Environmental Protection Act, S.N.S. 1973, c. 6 as amended.

This Act, administered by the Department of the Environment, makes the Minister responsible for the establishment of standards, the investigation, regulation, and control of pollution, of sources of contamination, and of waste disposal. Additionally, he is to promote restoration and reclamation of degraded areas (s.8(1)). Appointed inspectors are given the right of entry and examination to check for compliance (ss.42, 43). Before a project may proceed the Minister must approve plans and specifications of any operation which is likely to contaminate the environment and he may require modification prior to giving his approval (ss.28, 29).No operation that does contaminate may do so without a permit, which may be subject to terms and conditions (s.23). The Minister is empowered to order an operation to stop contravening environmental standards, to limit or stop its contamination, to use effective control equipment, or to shut down totally (s.26). He may order remedial action regarding pollution, which, if undertaken by someone other than the party responsible, is a debt recoverable from that party (ss.34, 54).Conviction of an offence incurs a $5 000 fine for a first offence (s.48).

Marshlands Reclamation Act, R.S.N.S. 1967, c. 177.

This Act, administered by the Department of Agriculture and Marketing, authorizes the Minister to enter into arrangements whereby marshlands may be preserved or protected (s.2). A $50 fine imposed for committing an offence (s.60).

Salvage Yards Licensing Act, R.S.N.S. 1967, c. 276, as amended.

This Act, administered by the Board of Commissioners, requires that all salvage yards be licensed (ss.2, 3). Conviction for an offence is subject to a $500 fine and issuance of a removal order (s.13).

Smelting and Refining Encouragement Act, R.S.N.S. 1967, c. 283.

This Act prohibits an action for an injunction against milling, mining, smelting, or refining operations, which are subject to the Act, despite the continuance of pollution damage to the earth. An action for monetary recovery is, however, still possible. (ss.4, 5).

Ontario

The Beach Protection Act, R.S.O. 1980, c. 39.

This Act, administered by the Ministry of Natural Resources, forbids the unauthorized removal of sand from the bank, shore, or beach of any lake, river, or stream (s.5). Contravention of this provision is an offence punishable by a $1 000 fine, but no prosecution may proceed without the consent of the Attorney General (s.12).

Conservation Authorities Act, R.S.O. 1980, c. 85.

This Act, administered by the Ministry of Natural Resources, allows the Cabinet, on receiving a request from a municipal council, to establish a Conservation Authority in the area (s.3). The Authority then has the power to do any act necessary to further conservation, restoration, and management of natural resources in that area (ss.20, 21), including the regulation of placing and dumping fill. Contravention of the Act or regulations is an offence subject to a $1 000 fine or three months' imprisonment on conviction (s.28).

The Environmental Assessment Act, R.S.O. 1980, c. 140.

This Act, administered by the Ministry of the Environment, requires that any unexempted person proposing to undertake a major commercial or business activity, is not to proceed until an environmental impact study has been made and the Minister has given his approval (s.5). No licence is to be issued until the project has received that approval, which may be given with or without terms and conditions (ss.6, 14). Designated provincial officers are granted the rights of entry, examination, and investigation for the purposes of the Act which emcompass the protection, conservation, and wise management of the environment – defined to include both land and subsoil (ss.1, 2, 24, 25). Knowingly giving false information, when the Act requires that information be supplied, is one of the offences punishable by a $5 000 fine for the first conviction (ss.35, 39).

The Environmental Protection Act, R.S.O. 1980, c. 141, as amended.

This Act administered by the Ministry of the Environment, provides for the protection and conservation of the land including surface land and all subsoil (s.2). There is a general prohibition against contaminating the environment; anyone so doing may become subject to orders to control, stop, or remedy the contamination (ss.5–7, 13, 16, 113–119). The Director may order any person to maintain equipment to alleviate contamination (s.17) and must approve, with or without conditions, the establishment or alteration of any source of contamination's control or preventive methods and devices before the project may commence (s.8). More particularly, the Director must approve of waste disposals sites and sewage systems in advance of their becoming operational (ss.27, 64); waste deposits are prohibited on any land not approved as a disposal site (ss.39, 40). Unauthorized deposits may be ordered removed and the land restored. Non-compliance with the order may result in the work being done and the costs charged to the person responsible (ss.41, 43).

The Minister has a broad general power to require compliance with any environmental duties and may restrain the contravention of any provision (ss.143, 144). Littering and giving of information falsely are forbidden (ss.75, 145), the former being one of the offences given a separate penalty. Where offences fall within the general penalty category, conviction may be accompanied by the $5 000 fine for a first offence (s.146).

Mining Act, R.S.O. 1980, c. 268.

Among its other regulatory provisions, this Act, administered by the Ministry of Natural Resources, requires that unused tailing areas be stabilized by such methods as planting and maintaining vegetation (s.161).

The Pesticides Act, R.S.O. 1980, c.36, as amended.

This Act, administered by the Ministry of the Environment, is the provincial equivalent of the federal Pest Control Products Act to which it refers. Conviction of an offence is punishable by a $5 000 fine per day for a first offence (s.34).

The Pits and Quarries Control Act, R.S.O. 1980, c. 378.

This Act, administered by the Ministry of Natural Resources, prohibits unauthorized operation of a pit or quarry in designated areas. An application for a licence must be supported by a site plan before it will be considered for approval with or without conditions (s.4). Offences may incur fines up to $5 000 per day, but no prosecution may be instituted without the consent of the Minister (s.18).

Wilderness Areas Act, R.S.O. 1980, c. 533.

This Act, administered by the Ministry of Natural Resources, allows the Cabinet to make regulations to provide for the care and preservation of a designated wilderness area and for the prohibition, regulation, and control of the use of the land therein (s.7). Offences are punishable by a $500 fine on conviction (s.8).

Prince Edward Island

Agricultural Chemicals Act, R.S.P.E.I. 1974, c. A-4.

This Act, administered by the Department of Agriculture and Forestry, is the provincial equivalent of the federal Pest Control Products Act to which it makes reference. The penalties for an offence are a $1 000 fine or ninety days' imprisonment or both (s.22).

Environmental Protection Act, S.P.E.I. 1975, c. 9 as amended.

This Act, administered by the Department of the Environment, forbids unauthorized pollution or impairment of the quality of land (s.9). The Minister has the power to investigate any cause of pollution, including the rights of access to and examination of any land (ss.5, 6, 8).He has been given the power to require remedial action regarding any cause of real or potential pollution and to recover the costs incurred from the person responsible (s.7). Offences under the Act or the standards set by Cabinet regulation are punishable by a $5 000 fine on conviction (ss.22, 23).

Photo 8. Open pit mine at Timmins.
NFB–PHOTOTHEQUE–ONF George Hunter

Quebec

Ecological Reserves Act, R.S.Q. 1977, c. R-26.

This Act, administered by the Ministry of Lands and Forests, empowers the Cabinet to designate lands as ecological reserves (s.2) for which it may set standards by means of regulations (s.9). Any activity changing the terrain within the reserves is forbidden, the penalty being a $300 fine for a first offence (ss.6, 12). Prosecutions are instituted by the Attorney-General or by anyone who has his written consent (s.14).

Environmental Quality Act, R.S.Q. 1977, c. Q-2.

This Act, administered by the Ministry of the Environment, makes the Minister responsible for the preservation and depollution (sic) of the environment including soil (s.2). No one may contaminate the environment beyond standards set by regulation or to the degree that damages soil quality (s.20). Before initiating any potentially contaminating activity, the person responsible must make an application including plans, specifications, evaluations, and, in specified instances, a land reclamation plan, for the approval of the Director of Environmental Protection Services who may require that alterations be implemented, or that terms and conditions be followed (ss.22–24). In situations set out in the regulations by the Cabinet, no project may be undertaken until environmental impact assessment and review procedures have been completed prior to Cabinet approval being given, possibly with conditions or after amendments (ss.31a, 31e). Particular operations are subject to the supervision of the Director, *e.g.* waste management systems, (s.54), or the Minister, *e.g.* sources of radiation (s.90). Furthermore, a special regime is created for control and prevention of contamination in the James Bay and Northern Quebec Region (ss.166–248). Under this regime, evaluation and review committees and commissions, are established to study and make recommendations to the Director concerning proposed projects. Certain projects such as mines, pits, quarries, and waste disposal systems (Schedule A) are automatically subject to the mandatory requirement of environmental impact assessment (ss.188, 223), but others, not exempted (Schedule B), may still be required to make submissions (ss.192–194, 227, 228).

Generally, under the Act, the Minister may require disclosure of information and exercise powers of investigation, seizure, and examination (ss.119, 120, 123). The Director may order the installation of control or prevention apparatus, the cessation of contamination, and, in the case of a quarry or sand pit, implementation of a landscaping programme (ss.25–27). The Minister is empowered to order that remedial actions be effected and to recover the cost from the person responsible, if he fails to comply or is convicted of an offence under the Act (ss.113–115).Should anyone contravene the Act, regulations, or order, not only is he liable to the various fines applicable but also, because the Act recognizes the right of every person to the protection of the environment, to an injunctive action brought by an individual resident or municipality in the area of the contamination (ss.19, 106–109).

Saskatchewan

The Department of the Environment Act, R.S.S. 1978, c. D-14.

This Act, administered by the Department it created, authorizes the Cabinet to make regulations prescribing and controlling waste disposal and the duties, with respect to soil conservation and reclamation, of persons conducting operations that result in the destruction or disturbance of the surface of land (s.13). The Ministry is given the right to enter upon any land in the exercise of its investigation and inspection powers (s.15). The Minister may issue a stop order against contaminating activites and may have the order enforced by the Courts if there is no compliance with it (s.12). Contravention of the regulations is an offence, the penalty on conviction varying with the type of pollution and the duration of the offending activity (s.14).

The Litter Control Act, R.S.S. 1978, c. L-22.

This Act, administered by the Department of the Environment, prohibits abandonment of waste on Crown or private, *i.e.* another person's, land which is not authorized as a disposal site (s.3). Whether or not a prosecution is instituted for contravention of the prohibition, the Attorney-General may apply for a court injunction against the person responsible (s.17). On conviction, the offender may be ordered to remove the waste in addition to or in lieu of a fine (s.4).

The Mining, Smelting and Refining District Act, R.S.S. 1978, c. M-19.

This Act is the equivalent of Manitoba's The Mining and Metallurgy Compensation Act.

The Pest Control Products (Saskatchewan) Act, R.S.S. 1978, c. P-18.

This Act is the provincial equivalent of the federal Pest Control Products Act and provides for a $1 000 fine or ninety days' imprisonment or both upon conviction of a violation (s.25).

Yukon Territory

Area Development Ordinance, R.O.Y.T. 1971, c. A-4.

This Ordinance authorizes the Territorial Commissioner to designate an area as a development area and to make regulations for zoning, allocation of land, and disposal of garbage and sewage (ss.3, 4). Failure to comply may result in remedial action being ordered and the costs thereof recovered from the person responsible, who is also liable to be fined $200 on conviction (s.6).

Lands Ordinance, R.O.Y.T. 1971, c. L-3.

This Ordinance applies to Crown land subject to the control of the Territorial Commmissioner, who may require any unauthorized user to cease that use, *e.g.* quarrying, and restore the land to a satisfactory condition (ss.3, 26). The Commissioner has the power to seize the machinery, equipment, materials, goods, and chattels that the unauthorized user has on the land (s.28). Failure to comply with an order of cessation is an offence punishable by a $250 fine or three months' imprisonment or both (s.29).

Summary

There are other pieces of legislation, on matters common to most of the provinces and territories, that deal with land in a perhaps less direct manner, usually as part of a regulatory scheme. For example, Public Health Acts empower health officers to supervise and control waste disposal sites and sewage systems. Mining and Petroleum Resource Acts regulate prospecting, developing and abandoning sites, and licensing requirements. Municipal Acts give municipalities power to regulate matters within their boundaries by means of by-laws, *e.g.* zoning related to garbage and refuse dumps. Planning Acts, although often urban-oriented, require that development proceeds in accordance with official plans. Park Acts limit the uses that may be made of land within a park's borders, *e.g.* camp-site placement, waste disposal. The foregoing list is, of course, not all-inclusive of statutory provisions. When the subordinate regulations, orders, and departmental policies and guide-lines are also considered, the influence of legislation is even further defined.

CRIMINAL LAW

The Criminal Code[32] may be useful for environmental purposes when the accused is a persistent violator of other statutes that provide for a fine alone. Whereas someone might be willing to deduct nominal fines from profits, as a necessary expense of doing business (often less expensive than installing pollution control equipment), the psychological and social impact of being charged and possibly convicted of a criminal offence may have a greater influence. In the right circumstances, the Code might be an effective means of ensuring adherence to sound environmental policy and standards.

It should be noted, however, that because the intent of the Criminal Code is not specifically environmental and that there is other legislation, both federal and provincial, of that nature, the Courts may be disinclined to have the Code used to punish for environmental damage. That view may be different when the violator's actions are sufficiently anti-social to be characterized as criminal, *e.g.* because of the persistence of the harmful actions or the reckless disregard for the consequences. Granted that the Criminal Courts are more accessible and speedy than their civil counterpart, they should not, however, be used gratuitously, *i.e.* for a private prosecution of little or no merit. They are properly the venue of matters concerning social values.For issues of a more personal kind, a civil action may often be appropriate, remembering that the Code was not meant originally to be compensatory, although a Criminal Court may require restitution as a condition of probation or discharge from penalty.

Subject to the foregoing qualifications, the following Code provisions may be applicable to some incidents causing environmental harm.

Recognizance — If a Justice of the Peace, before whom both parties appear, finds that an applicant has reasonable grounds to fear that another person will damage his property, he may require the defendant to enter into a recognizance, *i.e.* a written promise, to keep the peace and refrain from bothering the applicant for up to twelve months. On the other hand, the Justice of the Peace could imprison the defendant for that same period, an alternative that can still be exercised should the defendant fail to enter into or comply with a recognizance (s.745).

Volatile Substances — Every one, other than a peace officer exercising his duty, who deposits, throws or injects or causes to be deposited, thrown or injected in, into or near any place, an offensive volatile substance that is likely to cause damage to property is guilty of an offence punishable on conviction by a $500 fine or six months' imprisonment or both (ss.174, 722).

Common Nuisance — Every one who, by doing an unlawful act or failing to discharge a legal duty, endangers property or obstructs the exercise or enjoyment of a public right, thereby endangering the public generally, or harming someone in particular, is guilty of an offence incurring liability to two years' imprisonment (s.176).

Mischief — Every one commits mischief to property who wilfully acts or omits to discharge a duty and thereby either destroys or damages property, renders it dangerous, useless, inoperative or ineffective, or obstructs, interrupts or interferes with its lawful use, enjoyment or operation. The penalties involved vary according to the ownership (public or private) of the property, but if actual danger to life occurs the sentence can be as high as life imprisonment (s.387).

Criminal Negligence — Every one is criminally negligent who acts in such a way, or omits to do anything that is his duty to do, that shows wanton or reckless disregard for the lives and safety of others. Should injury or death result, the punishment is ten years' or life imprisonment (ss.202–204).

Although a duty imposed by law can be by either statute or Common Law, whichever is at issue must first be proved, before the Court will consider the question of whether or not the accused's actions amount to the degree requisite for a conviction, *e.g.* wanton or reckless in the case of criminal negligence. If some of the Code's penalties appear harsh, one must realize that in order for most offences to be proved, it must be shown that the wrongdoer acted with the intention to commit a crime or at least acted regardless of the knowledge that harm would probably result from his acts or omissions. Consequently, if the offence itself cannot be proven, nor can charges of attempting (s.24), conspiring (s.423), or counselling (s.422) the commission of the offence because they too require a "guilty" intention as a prerequisite to conviction.

The degree of proof is more strict in criminal cases than civil ones, *i.e.* beyond reasonable doubt, but a conviction is no guarantee of recovery for damage suffered. On the other hand, because the Code's prescriptions are aimed at maintaining social values, any member of the general public, and not just the injured party, may seek to enforce it. Certain objections may, however, be raised equally against a case based on a statute as against one based on the Common Law. In essence, these objections concern the good or bad faith of the person commencing the proceedings. If the Court finds the action to be an abuse of process, or frivilous and vexatious, the case may be thrown out of Court without the issue of fault or liability for environmental damage ever being adjudicated.

PRIVATE PROSECUTIONS

A person need not wait for the government to prosecute an environmental offender; in some situations, he may do it himself.[33] The right of private prosecution is limited only where the enactment establishing the offence prevents it: when an administrative discretion must first be exercised, when only a particular agency may prosecute; when the permission of the Attorney-General is required; or when private prosecution is strictly prohibited. Private prosecution can be useful, particularly when government officials are unwilling or unable to act, for whatever reason, to enforce the law for which they are responsible.

The method of ascertaining if a statutory standard has been contravened is usually by summary conviction proceedings. All provinces have their own Summary Convictions or Provincial Offences Acts, largely based on the Criminal Code, to enforce their laws that create offences. Anyone who has "reasonable and probable grounds"[34] for believing that an offence has been committed, even though he himself has neither seen nor been aggrieved by it, may lay an information, *i.e.* charge. To do this the informant goes before a Justice of the Peace (or Magistrate or Clerk of the Court, depending on the jurisdiction), preferably in the judicial district closest to the commission of the offence, swearing under oath and in writing to the truth of the charge. In precise terms, he alleges that a named corporation or individual (the accused) on a certain date or dates, at a specified place, did certain acts contrary to a section or sections of a particular statute. It is often desirable to use the exact wording of the sections involved. The Justice of the Peace may then in his discretion issue a summons to the accused, commanding him to appear in Court at a given time to answer the charge. Henceforth, the summons is served on the accused, normally by a police or sheriff's officer.

At trial, the informant may proceed with the prosecution on his own or have a representative (usually a lawyer hired by him) act in his stead. At any point in the proceedings, however, the Attorney-General may intervene to stay, *i.e.* stop, the prosecution or take it over. In an indictable offence case (the only one environmentally relevant being Common Nuisance under the Criminal Code), it is habitually the policy of the Attorney-General to step in.

There are two possible drawbacks to private prosecution, not the least of which is the prospect of having to pay the costs involved. Although some costs may be recovered[35] in summary conviction cases, they are minimal. Conversely, no additional costs may be assessed against a private prosecutor unless the case is dismissed, and certainly not if he is successful.[36]

The other drawback should not pose a major concern to a person prosecuting in good faith. But anyone who initiates a private prosecution maliciously, without reasonable and probable grounds for believing that an offence has been committed, may find himself the defendant in a civil suit for "malicious prosecution".

CIVIL REMEDIES

The objective of statutory law is, in general, to state and enforce standards of behaviour in society. When a statute is contravened, the sanction is usually incarceration or fine, all of the latter, with few exceptions,[37] going to the Crown. But legislative provisions do little to remedy the harm done to a person's rights or interests as an individual rather than as a member of society. Such private, civil rights against a wrongdoer are protected by the Common Law (or the Civil Code in Quebec). It is, of course, possible for any single act to have both statutory and civil consequences.

At Common Law, there are certain remedies available, the particular circumstances of the case determining which one or more is appropriate:

Damages	—monetary recover,
Declaratory Relief	—a judicial declaration of rights,
Injunction	—either a temporary or permanent judicial order prohibiting specified acts,
Mandamus	—a judicial order commanding that a legal public duty be done; this is rarely available because most statutes make the power to act merely discretionary.

Basically, there are five types of Common Law rights in relation to land, for which the above-mentioned remedies may be sought: nuisance, trespass, riparian rights, negligence, and strict liability.

Nuisance — There are two kinds of Common Law nuisance: public and private. Both are interferences with property rights, namely the right to the use and enjoyment of land[38] or an interest therein (as would be the case of a tenant). Whereas there are some minor interferences with which the law will not bother interference that is unreasonable, *i.e.* sufficiently peculiar, direct and substantial, is actionable.

A nuisance is public if it is widespread, affecting the members of the community as a whole in more or less the same way, although possibly to differing degrees. In such circumstances, it is the community that is harmed and the suit must be brought by or with the permission of the Attorney-General, who acts on behalf of the public generally; normally the relief sought is an injunction. But an individual may wish to seek compensation and institute a separate claim for an injury to him different from that of the others – some special damage peculiar to that person's rights.[39]

In an older case, unusual in that it dealt with damage to land *per se*, arsenic contamination depreciated the value of the plaintiff's residential property. An injunction and compensation were awarded against a refinery despite its argument that all its neighbours were injured in the same way. The Court ruled that each individual landowner has twofold rights: as a member of the public and as an especially injured landowner entitled to compensation.[40] The distinction on which the Court may have made its finding, is that physical injury to land is considered "special" damage.

A nuisance is private if it affects the rights of an individual specifically.[41] The usual case is one of an act that has consequences for the plaintiff's land alone. In order for the Court to find that nuisance has occurred, it is not necessary that physical damage be done to the property; merely the use or enjoyment of it need to interfered with. Therefore, if the complaint is that particulate matter has blown on to the land, the coating effect is actionable if it is unreasonable. It is not even a requirement that the source of the nuisance be on neighbouring land; responsibility falls upon the person causing the nuisance regardless of his proprietary interests. For example, a firm of sprayers using aircraft was held liable for allowing its chemicals to fall on the wrong land.[42]

Certain defences are ineffectual in a nuisance action: that the complainant acquired his property interest only after the nuisance was under way; that the act or operation causing the nuisance was beneficial to the public at large; that all possible care and skill were exercised to avoid the nuisance; that the site of the operation was the only place suitable for it; that the nuisance was the cumulative result of several independent acts, each of which alone was not sufficient to cause the nuisance; or that although the act did produce a nuisance, it was a reasonable use of the land from which it emanated.[43]

There are, however, two defences that are acceptable: that the nuisance has continued with the plaintiff's knowledge for at least twenty years, *i.e.* prescription; or that the defendant operated under statutory authority. But this last argument is only effective when the authorizing provision, be it in a statute, regulation, licence, or anything else having legal force, specifically requires the operation to be carried on in the exact manner complained of, or exempts the consequences of the operation. For the defence of statutory authority to be successful, it must be shown that the nuisance was inevitable, otherwise private rights are still to be protected.[44]

Trespass — The underlying distinction between nuisance and trespass is a matter of directness; whereas the nuisance comes to the property usually by indirect means, trespass involves a direct, physical entry,[45] even though possibly unintentional.[46] Trespass may be committed by depositing something, *e.g.* stones, earth, water,[47] on another's land without permission. Trespass may also be committed in the unauthorized removal of something from someone else's land, including part of the land itself, at or below the surface. One of the rights belonging to a landowner is the right to vertical support. Should anyone undermine a person's land causing subsidence, in addition to the action for trespass *per se*, the landowner may recover from the trespasser the cost of repairs and the depreciation in value remaining thereafter.[48]

Assuming that the owner of the land also holds the rights to the minerals, he may recover for their removal to the extent of their value to him, less the trespasser's expense of mining them, if he did so without an illegal purpose in mind.[49] So too, the landowner may recover if other commodities, *e.g.* sand, gravel, are removed from his property. In that instance, the damage is assessed at the depreciation in the value of the land, not the cost of restoration. But when the trespasser has taken the commodity for his own use, there may be an additional award to the extent of the value to him of whatever was taken.[50]

Riparian Rights — Riparian rights arise from an interest in land bordering on, or over which there is, a body of water. These rights are distinct from sub-surface water rights. If interference with the sub-surface water amounts to negligence or nuisance, there is a right of action. An example of this occurs when deep-drainage wells are pumped out with no regard for the consequences of lowering the water table of surrounding lands, thereby removing support, compressing the strata, and causing subsidence.[51]

Riparian rights are not dependent on ownership of the bed of a watercourse,[52] which usually belongs to the Crown by Common Law or statute in the absence of an express grant to the proprietor of abutting lands. The basic right is to have the water continue in its natural state without unauthorized interference with its quantity or quality,[53] although each riparian proprietor may make reasonable use of that water for his own purposes. In terms of land degradation, the real value of riparian rights is not in the quality of the water, unless pollutants therefrom are deposited on the land, but rather that the actual presence of the water involved, *i.e.* its quantity, may affect the uses to which the land may be put.

The riparian proprietor has the right to protect his land against erosion by the building of barriers or artificial enbankments. He may prevent, *e.g.* by injunction, unauthorized removal of sand or gravel from the bed at the water's edge which forms a natural barrier to encroachment on the land.[54] When navigable waters encroach on private land, the extent to which the land now becomes the bed of those navigable waters, is the extent to which the land ceases to be private; that portion then vests in the Crown.[55] In protecting his own interest, however, a riparian proprietor must act reasonably so as not to shift an injury to other lands. Whereas a landowner may exercise reasonably his rights to drainage into a natural watercourse and not be responsible at law for the downstream effects therefrom,[56] liability may arise from an artificial alteration. When the natural flow of water across land is artifically increased or obstructed (thereby causing water to flood back on an upper riparian's property) to the detriment of another landowner, the person causing that change is liable for the damage done,[57] even if the watercourse affected is only intermittent, as during spring run-off.[58] Liability is also incurred by anyone who, without authorization, by artificial obstruction, diverts a watercourse from its natural channel on to another's land where it had not previously been.[59]

Negligence — Negligence is the generic term for a type of civil suit for harm resulting from what society deems to be substandard behaviour.[60] Fault is an essential part of the plaintiff's case; without evidence of it, he will not succeed, unlike a nuisance case. There are five fundamental elements to a negligence action: duty of care, breach of that duty, injury, causal link between breach of duty and injury, and lack of exculpating conduct on the part of the injured party.

(i) Duty of Care – This is a duty recognized at law and imposed on persons undertaking any activity to conduct themselves in accordance with a reasonable standard of behaviour accepted by the community relative to that activity. Not only must the duty exist, but also it must be owed to the person actually injured.

(ii) Breach of Duty – The party responsible for the injury must have acted with less care than was required in the circumstances; the test being what would a "reasonable man" in that position have done to avoid causing harm while undertaking that activity.

(iii) Injury – Some damage must have been caused, for without some harm being done, no compensation can be assessed and awarded. It is possible that non-injurious conduct will still result in statutory consequences.

(iv) Causal Link – The damage done must be a direct, foreseeable injury resulting from lack of care. It must be direct in that there has been no intervening negligence, by someone else, which acts as the effective cause. There can, however, be more than one negligent party, acting independently of one another, each liable to the extent that his action contributed to the injury. The damage done must have been foreseeable at least as to its type; the degree of damage need not be foreseeable to incur full liability. But if the reasonable possibility of the harm occurring was too remote to be considered, no liability may arise.

(v) Conduct of the Injured Party – If the person injured knew of the risk of harm and yet agreed to it, he cannot complain when the risk is realized because he has voluntarily given his informed consent. Should the harm occasioned be different from the type he thought he was risking, he may recover. If, in addition to the negligence of the injuring party, the person harmed has also acted negligently, thus contributing to his own injuries, the extent to which he will recover from the defendant will be only in proportion to the degree of the defendant's responsibility for the damage.

Negligence may arise in any situation where there is a relationship between the parties, giving rise to the duty of care that is breached. That breach may take various forms: negligent action, *e.g.* when a government agency constructs improperly a river erosion barrier that is broken apart by ice and waves and scattered on a beach-owner's land rendering it unusable for recreation[61]; negligent omission, *e.g.* if a municipality fails, for six or seven years, to inspect a manhole, it may be judged to have increased materially the risk of harm occurring, such as sewage backing up onto the plaintiff's property because of debris lodged in the city's sewer main[62]; and negligent misrepresentation, *e.g.* when a manufacturer's senior agriculturist recommends a weed-killer as being otherwise harmless to plants without indicating that under certain conditions an injurious residue will remain in the soil - here the plaintiff's crop was virtually wiped out[63]. Once all the elements are proven, the defences (other than "voluntary assumption of risk" previously noted) that absolutely excuse a negligent party's liability - inevitable accident, act of God and act of war - are relatively few and rarely available.

Photo 9. Grape harvesting in the Niagara.
NFB–PHOTOTHEQUE–ONF Julien Le Bourdais

Strict Liability — Unlike negligence, which requires proof of fault, the strict liability concept holds that a party who brings on to his property or the property that he occupies for a particular purpose[64], *e.g.* an oil company's pipeline over private land, something that makes it a non-natural use of land, that party is responsible at law if that thing escapes and causes damage. This thing need not be inherently dangerous, *e.g.* acid, but may be a concentration of a normally relatively harmless substance, *e.g.* water, in such a large quantity that it has become a non-natural use of that land. The principle of strict liability was enunciated in an old case where a water reservoir burst and flooded a neighbouring mine.[65] But this principle applies only when the thing doing the damage is brought on to the property from which it escapes, not when it is found there naturally.[66] It would appear that not only the person who brings the thing on the land and allows it to escape is liable, but also the person who is responsible for having it brought on, as in the case of a crop-duster and the farmer employing him.[67]

It is important to sue all those potentially liable; no matter how sympathetic the Court is to an injured party's complaint, compensation will be awarded only against those responsible. In one strict liability case, an Appellate Court overturned a trial award of compensation for the seven years during which, the Court estimated, the plaintiff would not be able to have the pleasure of his garden because of a gasoline station's contamination of his soil. The suit had been brought against the oil company owning the station, but the Court of Appeal indicated that it should have been against the tenant who was in control of the operations there.[68] It was suggested in another strictly liability decision that an injunction and compensation for loss of use of land may not be the only remedies available to a person whose soil is contaminated (in this instance, also by a gasoline leak), but that the party responsible might be required, in addition, to remove the contamination from the soil.[69] Presumably, where the contamination cannot be removed, as in the radon gas pollution at Port Hope, Ontario, the soil itself will have to be replaced.

Civil objections and remedies in Quebec are not subject to the Common Law, but instead are codified. Consequently, the precedential influence of case law is relatively less in that jurisdiction than in the rest of Canada. Codification merely changes the source of the civil law; in essence the rights are quite similar to those in the Common Law jurisdictions. An injured party still has the right to compensation, and, under the Code of Civil Procedure of Quebec, to the judicial orders of injunction (Arts. 751–761), declaratory judgment (Arts. 453–456, 462), and mandamus (Arts. 834–837, 844–845). The basic duty under the Civil Code is that every person capable of discerning right from wrong is responsible for the damage caused by his fault to another (Art. 1053). Therefore, as in a Common Law negligence action, the injured party must prove fault and that it was the reasonably direct cause of the injury. In so far as the damage done may be an interference with the plaintiff's use and enjoyment of his interest in the land, Article 1053 may also be used to support a nuisance suit. Indeed, this Article is broad enough to support most actions for compensation for interference with property rights.

General riparian rights, on the other hand, have been set out in another part of the Civil Code (Arts. 501–503). These rights state that lower riparian proprietors are entitled to the natural flow of water unaggravated by upper riparians, that lower riparians must not obstruct the flow by building a dam (Art. 501), and that the flow is not to be diverted from its usual course (Art. 503). A special suit may be instituted when these obligations have been breached; in an "action négatoire", the plaintiff seeks the cessation of the aggravation of his rights. The advantage of this action is that it is not subject to the defence, available against an injunction, that, on the balance of convenience, a plaintiff can obtain adequate remedy by seeking monetary reparations alone,[70] whereas the polluter will be more adversely affected by an injunction, *e.g.* if he is required to shut down the commercial operation which is the cause of the damage. There is, however, nothing to prevent an injured party, whether in Quebec or a Common Law jurisdiction, from simultaneously seeking more than one remedy for the damage suffered.

Whatever rights and remedies are available at Common Law or under the Quebec Codes, they are subject to variation by statute. Thus, in Ontario for example, since the enactment of the Trespass to Property Act,[71] the trespasser may also be liable to a fine. Conversely, legislation can restrict or even abolish civil rights or remedies in certain situations. Such abolition occurred in the 1926 amendment to the Quebec Cities and Towns Act[72] which prevented injunctions being granted against industries established for more than five years and authorized by municipal by-law to operate in the community.[73] Another restriction on the enforcement of remedies by an injured party is the time within which an action must commenced, usually running from the date that the damage was done. Article 2261 of the Civil Code requires that actions pursuant to Article 1053 be initiated within two years, while the Common Law jurisdictions have Limitation Acts which set both general and specific limitations, *e.g.* six years regarding trespass, by virtue of the Ontario statute[74]. In addition, some pieces of legislation provide special limitation periods for actions thereunder, *e.g.* three years regarding property damage under the Nuclear Liability Act[75].

There are both advantages and disadvantages in pursuing the civil remedies as opposed to ensuring that legislative standards are enforced. The primary advantage, that of compensation, has been modified by judicial recognition of the possibility of civil remedies for the breach of a statute. When there has been a failure to protect a particular class of persons (rather than just the public at large) of whom the injured party is one, if the breach was the effective cause of the damage, irrespective of negligence on the part of the wrongdoer, a civil action for reparations may be brought against him.[76] Even if an action is based on civil rights alone (whether at Common Law or under the Civil Code), proof of a statutory breach which was the effective cause of the injury is "prima facie" evidence of the wrongdoer's negligence,[77] thereby facilitating the injured party's case. However, it is always incumbent on a complainant to prove his allegations, whether in statutory or civil matters. But just the same, the standard of proof in civil actions is less rigorous than "proof beyond a reasonable doubt" required in criminal law. Instead, all that is necessary in civil proceedings is proof "on the balance of probabilities"; in other words, that it is more probable than not that the complaint is justified.

The main disadvantages to civil actions are that they usually take some time before they are adjudicated, and that they are relatively expensive, particularly if the plaintiff loses the case and is ordered to pay part or all of the defendant's costs in fighting it. Furthermore, in certain situations, the Civil Courts may refuse even to hear a case if the plaintiff does not own the land in question, on the grounds that he, *e.g.* a tenant, does not have sufficient interest in the property in order to seek redress for harm to it.

INTERNATIONAL LAW

Pollution knows no borders, but as yet there is no single, globally accepted body of laws relating to environmental protection.[78] Recently, however, four principles of environmental responsibility among nations have gained some recognition. The first three, the duty not to pollute neighbouring states, the duty not to use areas of common concern to the disadvantage of others, and the duty to compensate for damage done to others, were embodied in the 1973 Stockholm Conference Declaration on the Human Environment (later adopted by the United Nations' General Assembly). The fourth, the duty to consult, in some situations, when such damage might occur, was adopted separately.[79] The effectiveness of these principles lies in the goodwill of each country; there is no policing agency.

Traditionally, recourse to the "law of nations", whether customary law (based on internationally accepted practices and arbitral decisions) or written international agreements (usually the result of negotiating bilaterally or signing multi-lateral conventions), has been found weakest in the area of enforcement, particularly by the individual. In order for an individual's grievance to be heard against another country in the International Court of Justice, for example, he must first persuade his own national government to represent his interests, because states only, not their nationals, are recognized as litigants before the Court. Consequently, it would seem that the Canadian Government can press both its own claim for compensation for damage done to its interests, *e.g.* clean-up costs, and a claim of one of its nationals for injury suffered, or both, in the Court. But this is not an absolute right; both states must agree to submit the case before it can be heard.

It is now apparent that a country is responsible in international law for more than the acts of just its governments or agents thereof. A state is also held vicariously liable if it fails to control activities of its nationals, either human or corporate, that cause harm in another jurisdiction. The landmark decision on this point, based on the complaints of American farmers for damage to land caused by a British Columbia smelter, expressed the law as follows:

"...no State has the right to use or permit the use of its territory in such a manner as to cause injury...in or to the territory of another or the property or persons therein, when the case is of serious consequence and the injury is established by clear and convincing evidence."[80]

That particular case has the distinction of being the only occasion on which Canada and the United States of America have agreed to submit an environmental question, other than one on a water-related matter, to the International Joint Commission under its optional jurisdiction conferred on it by Article X of the 1909 Boundary Waters Convention.

Where pollution originates in the United States and can be traced to a private (as opposed to governmental) source, Canadians may not need to wait for their government to espouse their claim to compensation for damage. In one instance, thirty-seven Ontario residents brought a class action in an American Federal Court for damages caused to their persons and property by pollution carried by air currents from three Michigan companies.[81] The Court ruled that they were entitled to bring their Common Law nuisance action (they subsequently settled out of Court[82]). Presumably, where a foreign statute provides for compensation wherever damage results from a "domestic" act, *e.g.* under the American Atomic Energy Act of 1954, a Canadian citizen could make a claim in his own right in that country's Courts, even though his claim may, in whole or in part, be against the foreign government itself or one of its agencies. But in the situation where a foreign country's liability, absolute or otherwise, arises under an international agreement (*e.g.*, The Convention on International Liability for Damage Caused by Space Objects, 1972, Article II) and the Courts of that signatory do not allow the party harmed to sue in his own right, an individual's claim for compensation could be made only by his national government under the ordinary rules of international law.

FUTURE LEGAL TRENDS

In recent years there has been, and continues to be, emphasis placed on ascertaining, and then reducing, the impact large scale projects will have on the environment once they become operational. The requirement of an assessment report, to be submitted with the application for project authorization, is being legislated in the provinces as an integral part of their Environmental Protections Acts or as a separate statute; an example is the Environmental Assessment Act passed by the Newfoundland Legislature in 1980.

Another current legislative development which is likely to continue and expand is "the polluter pays" principle, no longer applying just to fines but also to cleanup activities, and not only in relation to contamination from normal operations but also to accidents. In Ontario's Environmental Protection Act new sections have been added permitting the Minister wider authority to offer remedial action in the case of "spills" (ss.72–112). Instead of being stymied by the delays occasioned when a polluter appeals against a clean-up order while the pollution spreads (as was the situation in one PCB spill[83]), the Minister may order one or more of the following to take remedial action: the pollutant's owner, the person in control of it, the person whose property is affected or threatened by it, the municipality in which or next to which it was spilled or which is or may be affected by it, any public authority, any person who is or may be adversely affected by it, or any person whose assistance is necessary to combat it (s.85). These spill sections, however, are as yet unproclaimed, although enacted in 1979.

Within the past decade, there has been a greater public awareness and acceptance of the duty not to pollute the environment. This duty has been complemented by a growing public interest in seeing that this duty is enforced, not merely for the benefit of the individual who has been injured but also for the benefit of all who have been injured by a particular incident. Thus far, the concept of the right to a class action has been judicially interpreted as quite finite, limited to a precise class having a common interest and represented by a member of that class injured in the same way as the rest and seeking a complete remedy common to all. Pressure for class actions as an appropriate, expeditious, and less expensive legal recourse is gradually mounting in Canada. This tendency, coupled with an increasingly more sophisticated technology and an increasingly overtaxed Court system, is making the class action a more attractive and practical alternative to dealing with pollution problems of wide scope on an individual basis.

It is apparent that public awareness and pressure have been the motivating forces behind the development of environmental law, whether in the legislatures or in the Courts. As the public learns more and becomes more active, the political response becomes greater; tougher legislation is enacted and proclaimed, stricter regulatory controls are made and enforced, fewer exemptions are proposed or allowed, and more prosecutions are promised and undertaken. A strong, knowledgeable, and persistent citizens' lobby group can be at least as effective in gaining a politician's support as a commercial lobby and, considering his elected status, perhaps even more so. Judges, too, are influenced by what they perceive to be the public good and societal values; the seriousness of the offence is usually reflected in the imposition of a higher penalty.

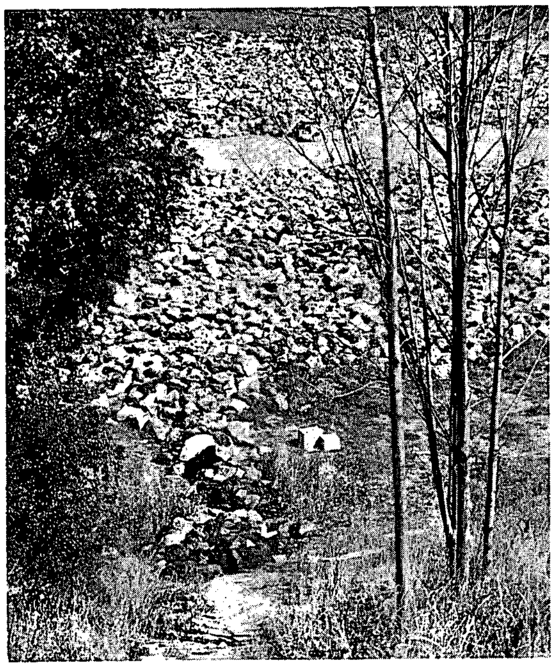

Photo 10. Garbage strewn in open field.
NFB–PHOTOTHEQUE–ONF Tom Bochsler

The law does not develop or function in a vacuum; public values spawn legal standards. So long as the public continues to express a desire to promote environmental responsibility, the law-makers and enforcers will respond by giving the environment legal recognition and protection.

This text was reviewed by Peter S. Haskins, A/Senior Counsel, Legal Services, Environment Canada, Ottawa, Ontario.

FOOTNOTES

[1] This study does not purport to be definitive. For further information, reference may also be made to the following works, but for a particular case of land pollution it is recommended that legal advice be sought.

Emond, P. Stop It!: A guide for citizen action to protect the environment of Nova Scotia (Ottawa: Community Planning Association of Canada, 1976).

Estrin, D. and Swaigen, J. Environment On Trial: A Handbook of Ontario Environmental Law (Toronto: Canadian Environmental Law Research Foundation, 1978).

Franson, R.T. and Lucas, A.R. Canadian Environmental Law, 7 volumes (Toronto: Butterworth & Co. (Canada) Ltd., 1976).

Ince, J.G. Environmental Law: A Study of Legislation Affecting the Environment of British Columbia (Vancouver: Centre for Continuing Education, University of British Columbia, 1976).

Society to Overcome Pollution: The Environment and the Law: The Citizen's Role (Montreal: Society to Overcome Pollution, 1971).

[2] 30 & 31 Victoria, c. 3.

[3] *Ibid.*, ss.91, 94, 95.

[4] The British North American Act, 1871, 34 & 35 Victoria, c. 63, s.2.

[5] B.N.A. Act, 1867, 30 & 31 Victoria, c. 3, ss.92, 92A, 95, as amended.

[6] *Ibid.*, s.129.

[7] 28 & 29 Victoria, c. 63, s.2.

[8] 22 & 23 George V, c. 4, ss.2–4.

[9] *Ibid.*, s.7.

[10] B.N.A. Act, 1867, *supra*, a. 95.

[11] *Ibid.*, ss.91, 92.

[12] Reference Re: Validity of s. 5(a) of Dairy Industry Act, (1950) 4 D.L.R. 689 (P.C.).

[13] Attorney-General of Nova Scotia v. Attorney-General of Canada, [1951] S.C.R. 31.

[14] R. v. C.S.L. LTD, [1961] O.W.N. 89 (Co. Ct.).

[15] See Cardinal v. A.-G. of Alberta, [1974] S.C.R. 695.

[16] A.-G. of Ontario v. A.-G. of Alberta, [1896] A.C. 348 (P.C.).

[17] Interprovincial Co-operatives Ltd. and Dryden Chemicals Ltd. v. The Queen, [1976] 1 S.C.R. 477, at 515-516 (Pigeon, J., obiter dictum).

[18] Township of Uxbridge v. Timber Brothers Sand & Gravel Ltd., (1975) 7 O.R. (2d) 484 (C.A.).

[19] A.-G. of Nova Scotia v. A.-G. of Canada, *supra*.

[20] Coughlin v. Ontario Highway Transport Board, [1968] S.C.R. 569.

[21] Interprovincial Co-operatives Ltd. et al. v. The Queen, *supra*.

[22] B.N.A. Act, 1867, *supra*, s.91.

[23] Income Tax Regulations, Consolidated Regulations of Canada 1978, c. 945, s. 1100(1) (t) under the Income Tax Act, S.C. 1970-71-72, c. 63, s.20(1)(a).

[24] Environmental Assessment Act, R.S.O. 1980, c. 140.

[25] Atomic Energy Control Act, R.S.C. 1970, c. 19, s.9.

[26] R.S.C. 1970, c. P-11.

[27] See La Forest, G.V.: Natural Resources and Public Property under the Canadian Constitution (Toronto: University of Toronto Press, 1969).

[28] The foundation of both systems' approach is the Latin legal maxim, "*Cujus est solum ejus est usque ad coelum et ad inferos.*"

[29] Re Rockcliffe Park Realty Ltd. and Director of the Ministry of the Environment *et al.*, (1975) 62 D.L.R. (3d) 17 (Ont. C.A.). The contaminating activity at issue was the dumping of clean fill on natural marshland preparatory to building housing.

[30] National Parks Act, R.S.C. 1970, c. N-13, s.4.

Indian Act, R.S.C. 1970, c. I-6, s.18. There are other factors involved in the question of the reserves, such as Indian treaties and federal-provincial agreements.

[31] Green v. The Queen in Right of the Province of Ontario *et al.*, (1973) 34 D.L.R. (3d) 20 (H.C.).

[32] R.S.C. 1970, c. C-34, as amended.

[33] See Berner, S.H.: Private Prosecution & Environmental Control Legislation: A Study (Ottawa: Environment Canada, 1972).

[34] Criminal Code, R.S.C. 1970, c. C-34, s.455.

[35] *Ibid.*, s.744

[36] R. v. Adventure Charcoal Enterprises Ltd., (1972) 9 C.C.C. (2d) 81 (Ont. Prov. Ct.).

[37] One half of the fine may be awarded to the informant under the Migratory Birds Convention Act, R.S.C. 1970, c. M-12, s.12, and under the Forfeitures Proceeds Regulations, C.R.C. 1978, c. 827, s.5 pursuant to the Fisheries Act, R.S.C. 1970, c. F-14, s.67.

[38] Walker v. McKinnon Industries Ltd., [1951] 3 D.L.R. 577 (P.C.). For a recent statement of the law see Schenck *et al.* v. The Queen in Right of Ontario, (1982) 34 O.R. (2d) 595, at 602-605.

[39] Hickey v. Electric Reduction Co., (1970) 21 D.L.R. (3d) 368 (Nfld.).

[40] Cairns v. Canada Refining and Smelting Co., (1914) 6 O.W.N. 562 (C.A.)

[41] Hutson v. United Motor Service Ltd., [1937] S.C.R. 294.

[42] Bridges Brothers Ltd. v. Forest Protection Ltd., (1977) 72 D.L.R. 3 (d) 335 (N.B.).

[43] Russell Transport Ltd. v. Ontario Malleable Iron Co., [1952] 4 D.L.R. 719 (Ont. H.C.).

[44] Dufferin Paving & Crushed Stone Ltd. v. Anger, [1940] S.C.R. 174.

[45] Philips v. California Standard Co., (1960) 31 W.W.R. 331 (Alta.).

[46] F.W. Jeffrey & Sons v. Copeland Flour Mills Ltd., [1923] 4 D.L.R. 1140.

[47] Campbell v. Reid, (1857) 14 U.C.Q.B. 305; Pinder v. Sanderson *et al.*, (1911) 2 O.W.N. 726.

[48] Carr-Harris v. Schacter and Seaton, (1956) 6 D.L.R. (2d) 225 (Ont. H.C.).

[49] Wellington Colliery Co. and E & N Railway v. Pacific Coast Coal Mines Ltd., (1918) 26 B.C.R. 315 (C.A.).

[50] Lloyd v. Dartmouth, (1897) 30 N.S.R. 208 (C.A.); McIsaac v. Inverness Railway, (1906) 40 N.S.R. 579 (C.A.); Paffard v. Cavotti, [1929] 1 D.L.R. 111 (Ont. C.A.).

[51] Pugliese *et al.* v. National Capital Commission *et al.*; Beaver Underground Structures Ltd. *et al.*, Third Parties, (1977) 79 D.L.R. (3d) 592 (Ont. C.A.).

[52] Re Snow and Toronto, [1924] 4 D.L.R. 1023 (Ont. C.A.).

[53] John Young & Co., v. Bankier Distillery Co., [1893] A.C. 691 (H.L.).

[54] Kennedy v. Husband, [1923] 1 D.L.R. 1069 (B.C. Co. Ct.).

[55] McCormick *et. al.* v. Township of Pelée, (1890) 20 O.R. 288 (Ch. Div.).

[56] In Re Townships of Orford and Howard *et al.*, (1891) 18 O.A.R. 496.

[57] McCord v. Alberta & Great Waterways Railway, (1918) 59 S.C.R. 667; Watson v. Perine, (1863) 13 U.C.C.P. 229 (C.A.).

[58] Kapicki, Ostashek, Tkachuk and Zabrick v. Andriuk and Andriuk (No. 2), [1975] 2 W.W.R. 264 (Alta. D.C.).

[59] Parr v. Troop, (1922) 65 D.L.R. 785 (N.S.C.A.).

[60] For an easy-to-read expansion on the complexities of negligence and strict liability, see:

Fleming, J.G. An Introduction to the Law of Torts (Oxford: Clarendon Press, 1977).

[61] Rivard v. The Queen, 79 D.R.S., 90-443 (F.C.T.D.)

[62] Dalpe v. The City of Edmundston, (1979) 22 N.B.R. (2d) 621 (C.A.).

[63] Fillmore's Valley Nurseries Ltd. v. North American Cyanamid Ltd., (1958) 14 D.L.R. (2d) 297 (N.S.).

[64] Northwestern Utilities Ltd., v. London Guarantee & Accident Co., [1935] 4 D.L.R. 737 (P.C.).

[65] Rylands v. Fletcher, (1868) L.R. 3 H.L. 330.

[66] Bottoni *et al.* v. Henderson *et al.*, (1978) 21 O.R. (2d) 369 (H.C.J.).

[67] Bartel v. Ector, (1979) 90 D.L.R. (3d) 89 (Sask.).

[68] Boudreau v. Irving Oil Co., (1974) 9 N.B.R. (2d) 377 (C.A.).

[69] Allain v. Texaco Canada Ltd., (1979) 21 N.B.R. (2d) 681 (C.A.).

[70] Society to Overcome Pollution: The Environment and the Law: The Citizen's Role (Montreal: S.T.O.P., 1971), p. 42.

[71] R.S.O. 1980, c. 511.

[72] R.S.Q. 1977, c. C.19, Art. 413(17).

[73] Franson, R.T., Lucas, A.R. Giroux, L., and Kenniff, P.: Canadian Law and the Control of Exposure to Hazards (Ottawa: Science Council of Canada, 1977), p. 143.

[74] Limitations Act, R.S.O. 1980, c. 240, s.45 (1) (g).

[75] *Supra*, s. 13.

[76] Sterling Trusts Corp. v. Postma *et al.*, [1965] S.C.R. 324.

[77] Chapman v. Wilson, (1930) 1 M.P.R.1 (N.B.C.A.).

[78] For more detailed analyses, see:

Ianni, R.W. "International and Private Actions in Transboundary Pollution," (1973) 11 Canadian Yearbook of International Law, pp. 258–270, and

McCaffrey, S.C. Private Remedies for Transfrontier Environmental Disturbances (Morges: International Union for Conservation of Nature and Natural Resources, 1975).

[79] Beesley, J.A. "The Canadian Approach to International Environmental Law," (1973) 11 Canadian Yearbook of International Law, pp. 3–12 at p.8.

[80] Trail Smelter Arbitral Tribunal, (1941) 35 American Journal of International Law, pp. 684–736 at p. 716.

[81] Michie *et al.* v. Great Lakes Steel Division *et al.*, Civil Action #35079 (U.S.D.C.).

[82] "First Canadian Suit Against Air Pollution in U.S. Courts Ends," (1975) 4 C.E.L.N. 40.

[83] Re Canadian Pacific Ltd. and Director of Ministry of the Environment, (1978) 19 O.R. (2d) 498 (D.C.).

APPENDIX OF ABBREVIATIONS USED IN CITATIONS

Acts, Ordinances and Regulations:

S.C.	Statutes of Canada
R.S.C.	Revised Statutes of Canada
S.N.B.	Statutes of New Brunswick
R.S.N.B.	Revised Statutes of New Brunswick
R.O.N.W.T.	Revised Ordinances of the Northwest Territories
R.S.Q.	Revised Statutes of Quebec
R.O.Y.T.	Revised Ordinances of the Yukon Territory

30 & 31	Victoria – This and similar citations indicate the regnal year indexing of British statutes.

C.R.C.	Consolidated Regulations of Canada

c.	chapter
s.	section
Art.	Article

Law Report:

A.C.	Appeal Cases (British series)
B.C.R.	British Columbia Reports
C.C.C.	Canadian Criminal Cases
C.E.L.N.	Canadian Environmental Law News
D.L.R.	Dominion Law Reports
D.R.S.	Dominion Report Service
L.R.	Law Reports (British series)
M.P.R.	Maritime Provinces Reports
N.B.R.	New Brunswick Reports
N.S.R.	Nova Scotia Reports
O.A.R.	Ontario Appeal Reports
O.R.	Ontario Reports
O.W.N.	Ontario Weekly Notes
S.C.R.	Canada Supreme Court Reports
U.C.C.P.	Upper Canada Common Pleas Reports
U.C.Q.B.	Upper Canada Queen's Bench Reports
W.W.R.	Western Weekly Reports

Court:

C.A.	Court of Appeal
Ch. Div.	Chancery Division
Co. Ct.	County Court
D.C.	District Court
F.C.T.D.	Federal Court Trial Division
H.C.	High Court
H.C.J.	High Court of Justice
H.L.	House of Lords (British)
P.C.	Judicial Committee of the Privy Council (British)
Prov. Ct.	Provincial Court

Unless otherwise noted, the case has usually been decided at the provincial Supreme Court level.