MANAGEMENT OF WASTE FROM ARCTIC AND SUB-ARCTIC WORK CAMPS

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for the

Environmental-Social Program
Northern Pipelines

September 1973

Environmental-Social Committee
Northern Pipelines,
Task Force on Northern Oil Development
Report No. 73-19

Information Canada
Cat. No. R72-10173

QS-1520-000-EE-A1

The data for this report were obtained as a result of investigations carried out under the Environmental-Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is equally useful in planning and assessing highways and other development projects.

The research was carried out and the report was prepared under contract for the Arctic Land Use Research Program, Northern Natural Resources and Environment Branch, Department of Indian Affairs and Northern Development. The views, conclusions and recommendations expressed herein are those of the author and not necessarily those of the Department.

The assistance of A. Gunter, J. Greenwood and S. Hart is acknowledge in preparing an interim report on which much of this report is based.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. SUMMARY

The discovery of oil and gas in Northern Canada and Alaska has resulted in increased exploration and construction activity in Arctic and sub-Arctic regions.

The Mackenzie delta region of the Northwest Territories has been a focal point for oil and gas exploration and it is possible that a large diameter gas pipeline will be built to transport gas from the delta to southern markets. The probable route for this pipeline in the Northwest Territories is down the Mackenzie Valley.

The construction of the pipeline would be a major engineering undertaking which could be capable of causing serious and long-lasting environmental damage unless some constraints are placed on the project. The construction itself would generate large quantities of waste material, including construction debris and waste from camp kitchens and residences. It is the purpose of this report to assess various methods of waste disposal which may be deemed suitable for construction camps and to propose guidelines, to be published separately, for the disposal of waste from construction.

The development of construction camps must be accompanied by sound waste management policies if we are to protect and preserve the natural environment of these areas. The harsh climatic conditions, variable terrain and abundance of permafrost with high ice content make the problems of waste disposal much more difficult to solve than those of southern areas.

It is difficult to make an accurate estimation of waste production in camps which would be associated with pipeline construction. These construction camps would probably be situated approximately every 60 miles along the pipeline route and are expected to consist of from 500 to 700 men. As a rough estimate, it is believed that from 2-3 tons of solid waste would be produced per camp per day. The wastewater to be treated could be as high as 80 to 100 gallons/cap/day but is more likely to be in the range of 40 to 50 gallons/cap/day.

The primary objectives of waste management should be the protection of the public health and the natural environment.

In the past, solid and liquid wastes were looked upon as being a product of human activity which could only be disposed of at a cost to both the waste producer and the natural environment. We believe that much of the waste which would be generated by construction camps when processed, could be a valuable resource and since this is a time of new growth and new policy formulation for the Arctic and sub-Arctic, the practice of utilization of waste should be adopted. It is our philosophy that a large proportion of waste material could be disposed of in a manner that is beneficial to the natural environment and that these disposal methods should be practiced whenever possible. For example, pilot studies are underway to determine the feasibility and advantages of spreading shredded refuse on cleared and scarred land where it can act as an insulating cover and as a possible nutrient source for new plant growth. We have suggested innovative techniques of waste disposal which are to a large extent untried and unproven, but we believe that the development of the best practicable technology will result from the demonstration projects which are currently being conducted and evaluated.

These innovation methods of waste disposal, which are herein given as tentative, must be thoroughly evaluated in pilot projects before they can be definitely recommended. It is also true that each situation would require different management techniques due to variation in both the environmental conditions and the waste characteristics, but the utilization of waste should become standard practice in the North.

1.1 SOLID WASTE MANAGEMENT

At present, there appear to be two main alternatives for solid waste treatment and disposal which are feasible for northern construction camps. They are:

1. Disposal in a sanitary landfill
2. Incineration

Disposal in a landfill and incineration are commonly used methods of solid waste management. The most difficult problem associated with a landfill operation could be the selection of a suitable location for a disposal site in a region where permafrost is extensive. Solid waste should not be disposed of in an area where the ground is permanently frozen. It must also be kept in mind that biodegradation is slow in these northern areas under any circumstances. It should be possible to select landfill sites where thawing of the refuse would take place each year, so that the complete stabilization of the refuse material would eventually occur. However, research is necessary to ensure that runoff and ponding of leachate does not occur.

Incineration is also a proven method for waste disposal but difficulties could arise when using such sophisticated equipment under severe weather conditions as those common to the North. A heated building therefore appears necessary. Studies are underway to determine the extent of ice-fog buildup from incinerating operations during temperature inversions. Pyrolysis-combustion appears to be a suitable method of incineration for northern work camps. Incombustible material must still be disposed of in a landfill in most cases.

An alternative method of solid waste treatment is to process the waste by shredding and to discharge the homogenous shredded material either to a cleared and scarred land surface or to a landfill site. There are several refuse shredding machines available which are capable of shredding frozen material and yielding a final product suitable for spreading on land.

The feasibility of shredding solid waste and discharging the milled refuse to cleared or scarred land has yet to be proven in pilot projects but we believe it has a number of beneficial effects to recommend it. Shredded solid waste placed in a landfill would also be an advantage over unmilled refuse disposed of in this manner since the reduced volume and compaction of the refuse would result in a saving of landfill space. The unattractiveness of the material to birds, rodents and other animals is an additional advantage. For esthetic reasons and also for leachate control, a final cover is required over the shredded material.

It must be emphasized that at time of camp abandonments all forms of landfills must be covered and seeded with an approved plant species so that the area is returned to as natural a condition as possible. In addition, every measure must be taken to prevent all forms of erosion and to prevent contamination of ground or surface water. Return visits to the site may be necessary to ensure that slumping or leaching does not become a problem.

Materials such as solvents, oils, greases and toxic substances should be incinerated or transported to a suitable alternative area for disposal. This type of material cannot be discharged to the land or water. Metal parts, machinery, abandoned vehicles and other inert construction debris may be temporarily stockpiled, transported to southern processing areas or buried, possibly in old borrow pits.

A proportion of the trees and shrubs cleared from the pipeline route should be chipped and stockpiled for use in the event of oil or fuel spills or for use as an insulating material to prevent thermal degradation of the permafrost. Alternatively, the cleared vegetation should be burned under controlled conditions.

1.2 WASTEWATER MANAGEMENT

The treatment and disposal of liquid effluents from northern work camps can be effected by several methods. These are:

1. Lagoon
2. Treatment Plant
3. Discharge to a natural lake
4. Discharge to swampland
5. Land irrigation

A properly designed and operated lagoon is a proven method of sewage treatment for northern settlements and would be relatively cheap to operate, but there are a number of considerations which must be kept in mind. It is anticipated that there would be a rerequirement that all sewage treatment methods used for camps with a population of more than 300 man-days, achieve the equivalent of secondary treatment. This level of treatment would require a lagoon to have a one-year retention capacity with total containment during the winter and release during the summer. There would also be areas where lagoon construction would be too costly because of terrain and soil characteristics.

Alternatives to a lagoon are biological package treatment plants which have a wide range of capacities. These units are capable of high treatment efficiencies. Biological treatment plants such as activated sludge and its modifications may require a long start-up time in order to reach maximum efficiency. They are also susceptible to shock loading, and efficiency is considerably lowered if operated under widely varying flows, but these problems may be overcome by proper operational procedure. Trained operators are consequently necessary to ensure an efficient operation. It appears therefore that these types of package plants may not be entirely suitable for short term camp operations where the camp population shows considerable fluctuation.

Physical-chemical treatment plants have the potential for most efficient operation, but again, they require trained personnel for efficient performance. In addition, the costs of chemicals in northern areas could be considerable, which makes the overall operation expensive. One further problem with package treatment plants is that of finding suitable methods of disposal for the quantities of sludge produced. This sludge may be disposed of on land or incinerated. Sludge from physical-chemical plants is compact and therefore the sludge handling process may be relatively simple.

The discharge of sewage effluent to a natural lake is an inexpensive alternative, but one which may be unacceptable from the standpoint of preservation of the environment. This method should not be considered as an acceptable means of disposal.

The discharge of sewage effluent to an isolated swampland area appears to be an acceptable disposal method. The lagoon effluent at Hay River drains into such an area and continuing investigations indicate that a high level of treatment is achieved within a relatively small area of swampland. Primary treatment of the effluent is necessary before discharge to the swampland. Provided that the effluent does not contaminate any water bodies or water courses which could be used for drinking or domestic purposes, there can be few genuine objections to this method of disposal.

Using sewage effluent as a fertilizer to encourage existing or new plant growth on cleared or scarred land is a waste disposal method which must be studied in pilot projects before it can definitely be recommended. Because of the shallow active layer in permafrost regions, there is a deficiency of nutrients.

available for plant growth. If the vegetation in a permafrost area is stripped off and removed, then return of nutrients to the active soil layer through decay and decomposition of the vegetation is prevented. It therefore seems logical to replace the nutrients removed in the vegetation by the nutrients in the sewage effluent so that revegetation and consequent stabilization can be encouraged to proceed at a maximum rate. The idea of adding nutrients to the soil and at the same time utilizing waste products, appears therefore to be sound, but it must be emphasized that these are only proposed methods and must be proven in pilot projects.

Before any particular waste management system can be approved, it would be the responsibility of the regulatory personnel to make a thorough investigation of all possibilities for each campsite. As mentioned earlier, each situation is different and therefore no single method will be adequate for all situations. The proposed guidelines in this report have not been written to recommend any particular treatment method but rather to assure that the disposal method and final product would result in minimum detriment to the natural environment. The recommended guidelines could require revision and additions but we believe that at the present state of knowledge, they should adequately protect the public health and ensure that serious deterioration of the natural environment does not occur.

In general, waste management at work camps must be based on a sound program and would have to be managed by a responsible person who was familiar with the equipment and the difficulties associated with the extremes of both climate and terrain in northern areas. Equipment poorly maintained and operated is inefficient of manpower and capital. It must be kept in mind that waste can be a valuable commodity if properly managed, and may be disposed of in a manner that is beneficial to the natural environment.

2. INTRODUCTION

2.1 SCOPE AND NATURE OF REPORT

This report was prepared under the Environmental-Social-Program, Northern Pipelines, of the Task Force on Northern Oil Development in conjunction with the Arctic Land Use Research (ALUR) Program of the Water, Forests and Lands Division, Department of Indian and Northern Affairs, Government of Canada.

The objectives of this study were to evaluate collection, processing and disposal methods for sewage and solid waste generated by oil and gas development and pipeline construction in Northern Canada, and to recommend guidelines for the management of these wastes so that the detrimental effects on the natural environment would be minimal.

The discovery of considerable quantities of oil and gas near Prudhoe Bay, on Alaska's north slope, and the prospects of further large finds in the Canadian Arctic, have led to considerable interest in developing these fields and in building pipelines to export the fuels to southern markets. The coincidence of this activity with a relatively new-found concern for the integrity of northern wilderness areas has created a requirement for strict controls over construction and development activity to ensure a minimum impact on the environment. In the area of waste disposal from camps in the Arctic, this concern is particularly evident. For example, notwithstanding very low populations which are spread over large areas of land and water, liquid wastes from camps in arctic Alaska are frequently undergoing secondary treatment in sophisticated treatment plants, prior to discharge into the surface waters of the state. This level of treatment is equivalent to or considerably better than that afforded most communities in the continental states and in Canada and reflects the concern felt by many for careful development of wilderness areas.

The construction of a Mackenzie Valley Pipeline would entail traversing some 1,000 miles of continuous and non-continuous permafrost land in the Yukon Territory and Mackenzie District of the Northwest Territories.

The construction activity would probably be conducted from short term "base camps" located approximately every 60 miles along the pipeline route. It is expected that in the permafrost regions the camps would be operated four months during the winter and in the non-continuous permafrost regions for eight months. The population of the camps would vary, reaching a maximum of approximately 700 men. Upon completion of each stretch of construction the camp would be moved and the area returned to as close to its natural condition as possible.

During its existence, each camp would generate a significant quantity of "construction wastes" and a quantity of "life support wastes". The construction debris would probably consist of camp-site and pipeline route timber clearings, broken machinery and equipment, concrete rubble, waste oil, solvents and packaging debris (metal strapping). The life support waste would be typical residential and office waste, (paper and other debris) and food (kitchen) waste from the institutional feeding of the camp crew. There would be additional sewage from the toilets, showers and kitchen.

It is important that all the waste be collected, processed and disposed of (discharged to the environment) in a manner that is designed to conform with public health requirements and at the same time to avoid degradation of the natural environment. It is the intention of the proposed guidelines to set standards for the waste management practices so that this objective is achieved.

Guidelines can be based on procedure or performance or both. A procedure-based guideline for waste disposal typically spells out the kind of treatment system that is acceptable, features of design, etc. It is practically impossible to prepare guidelines of this type which would ensure that the discharge to the environment would in fact be non-polluting and acceptable in all cases. Performance-based guidlines specify that effluent quality meet some measurable standards for pollutant concentrations. In general, performance-based guidelines seem more logical to meet the Arctic conditions. Recommended guidelines for the management of these wastes for the operation of each type of common treatment system which have merit are included in supplementary reports.

The effects of camp waste disposal on the environment should be seen as one part of the total environmental stresses exerted by a pipeline construction project.

Pipeline construction would bring with it a large amount of localized ecological change, through extensive brush clearing, soil movement, the construction of roads and gravel pads for campsites, barge loading facilities and airfields, etc. It is worth bearing in mind, during any discussion of waste disposal procedures in the camps, that the physical extent of the environmental changes (brush clearing, landfill area, etc.) made necessary for waste disposal facilities would be very much smaller than those incurred for other land uses, and the seriousness of the waste disposal problem could be minimized by careful planning.

Careless practices by some exploration parties in the past several years have given industry a bad name in the North. Responsible officials in these companies are generally aware of this, are sensitive to it, and are making great improvements in their practices through self-policing. The offences for which they have been held culpable have been associated usually with poor ground transportation procedures which lead to long term scarring of tundra, careless solid waste disposal or littering. The human appeal of the wilderness has been reduced by these and other construction practices; however the actual ecological change may be less severe and is under investigation.

2.2. OBJECTIVES

1. To review current practices in waste management at camps and settlements in Alaska and Northern Canada in order to understand the constraints of weather, permafrost and the availability of necessary skills and services which have led to the adoption of these practices; to review the state of the art in waste treatment technology for the small flows such as would be produced by northern work camps and assess the applicability

of the various available systems to these arctic and sub-arctic areas.

2. To assess the scale and the seriousness of the waste disposal problem at outlying northern campsites and arrive at reasonable conclusions about the treatment efficiencies which should be required for liquid waste, and to assess the effects of its disposal and the disposal of solid waste on the environment in terms of public health hazard and aesthetic and ecological changes.

3. To recommend practices for waste management for northern work camps.

4. To recommend guidelines covering aspects of the construction, operation and maintenance of waste treatment plants, and sewerage systems, and for the management of solid waste.

5. To recommend guidelines for good waste management practices in the North. These guidelines should assist both the regulatory authority and industry in determining reliable systems which would be compatible with the regulations, protecting both the public health and the environment.

2.3 ACCOMPLISHMENTS

1. A number of visits have been made to northern communities, native villages and industrial camps in Northern Canada and Alaska, where facilities for waste treatment and disposal have been observed at first hand, usually under the guidance of the responsible personnel in each settlement. A variety of northern residents have been interviewed, whose knowledge of northern conditions and problems made their viewpoints invaluable.

2. A number of people in various government offices and departments have made valuable contributions which have been incorporated in this final report.

3. Herein presented are proposals for practices and guidelines for the collection, treatment and disposal of waste. Regulations and guidelines of Alaska and Alberta were considered in the preparation of these proposals.

4. Sections which contain the operating requirements and limitations of those common alternatives for sewage treatment at small flows; lagoons, extended-aeration, and physical-chemical treatment; and for those common alternatives for solid waste disposal; trench or area method of sanitary landfill and incineration have been prepared.

3. INTRODUCTION TO SOLID WASTE MANAGEMENT

The objective of all the requirements is to ensure that the waste discharged to the environment is neither hazardous to the public health nor degrading to the environment. It is not to encourage or discourage any specific avenues of waste processing and discharge to the environment. However, some systems have greater potential for performing well at minimal cost than other systems. It is thus appropriate to discuss some system possibilities and to relate them to the expected wastes of pipeline construction camps.

Arctic experience with mechanical equipment has indicated that exotic and intricate controls usually fail during severe winter weather. For this reason, and since the local government has asked for an option to purchase all equipment used in conjunction with pipeline construction in the North which subsequently becomes surplus, we should examine the equipment that may be used to ensure that it meets the requirements of simple mechanical maintenance.

In order that waste management be effective, it is essential that the whole operation of collection, processing and disposal at each work camp be under the direction of a designated responsible person who has received training in the field of sanitary engineering and who is familiar with the operation and maintenance of the equipment used. The importance of engaging qualified operators and paying them at a level which is commensurate with their training can not be over emphasized, since it would allow the formidable constraints imposed by northern conditions to be overcome.

4. CHARACTERISTICS AND CLASSIFICATION OF SOLID WASTE

4.1 CHARACTERISTICS OF SOLID WASTE

We shall assume for the purposes of discussion that construction of a pipeline in the Mackenzie Valley would require 500 to 700 men camps at approximately 60 mile intervals which, in permafrost areas, would be operated for four months of the year. Regrettably, no one has a really accurate idea of the quantity of waste which would be generated at a campsite. Interpolating from somewhat similar arctic industrial activities suggests that there might be 1200-1500 lb/day of municipal type wastes (office paper, packaging cardboard, soda cans, kitchen cans and bottles, and the like), 200-500 lb/day of food scraps and cooking wastes, and 1-2 tons/day of "garage and repair shop" wastes, consisting of equipment repair metals, oils, solvents, washdown water with oil, pallets, strapping, more packaging, and concrete and form lumber. This is a total of 2-3 tons/day of extremely diverse waste and does not include any route and campsite timber clearing wastes.

The results of daily refuse sampling at the Murphy Dome Air Force Station in Alaska[1] has indicated that the quantities may be slightly higher than the average American generates (5-6 lb/day/capita). Alaskan Department of Environmental Conservation officials have been advised by camp operators that they have been hauling in the equivalent of 10 lb. of packaged supplies per employee per day. On this basis, they believe 8 lb/day per capita is a better figure than 6 lb. in the Murphy report. If we use 8 lb. per day/capita and the ultimate size is 700 men, the weight of refuse is 5,600 lb/day. The Murphy Dome Air Force Station sampling indicated the wastes were distributed as follows:

Combustible Rubbish	86%
Non-Combustible Rubbish	14%

Based on, say, 6,000 lb. per camp per day:

Combustible Rubbish	86% of 6,000 = 5,160 lb.
Non-Combustible Rubbish	14% of 6,000 = 840 lb.

In addition, there would be broken equipment parts and other metals to be disposed of because of breakage due to metal fatigue and lack of salvage markets within economic haul distance.

4.2 CLASSIFICATION OF SOLID WASTE *

1. Type 0 - Trash, a highly combustible waste material, such as paper, cardboard cartons, wood boxes and combustible floor sweepings, from commercial and industrial activities.

   (a) 10% moisture
   (b) 5% incombustible solids
   (c) Heating value of 8,500 BTU per pound as fired

2. Type 1 - Rubbish, a mixture of combustible waste, such as paper, cardboard cartons, wood scraps, foliage and combustible floor sweepings, from domestic, commercial and industrial activities.

   (a) 25% moisture
   (b) 10% incombustible solids
   (c) Heating value of 6,500 BTU per pound as fired

3. Type 2 - Refuse, consisting of an approximately even mixture of garbage and rubbish by weight, commonly from apartments and residential occupancy.

   (a) 50% moisture
   (b) 7% incombustible solids
   (c) Heating value of 4,300 BTU per pound as fired

4. Type 3 - Garbage, consisting of animal and vegetable waste from restaurant cafeterias, hotels, hospitals, markets and the like.

   (a) 70% moisture
   (b) 5% incombustible solids
   (c) Heating value of 2,500 BTU per pound as fired

* Adapted from Incinerator Institute of America, Incinerator Standards, 1968.

5. <u>Type 4</u> - Human and animal remains, consisting of carcasses, organs, and solid organic waste from hospitals, laboratories, abattoirs, animal pounds and similar sources.

   (a) 85% moisture
   (b) 5% incombustible solids
   (c) Heating value of 1,000 BTU per pound as fired

6. <u>Type 5</u> - By-product waste, consisting of gaseous, liquid or semi-liquid, such as tar, paint, solvents, sludge, fumes, etc., from industrial operations.

   (a) Moisture and incombustible contents must be determined by individual waste

   (b) Heating value varies with waste

7. <u>Type 6</u> - Solid by-product waste, such as rubber, plastics, wood waste, etc., from industrial operations.

   (a) Moisture and incombustible contents vary with waste

   (b) Heating value varies with waste

<u>NOTE</u>: Large pieces of scrap metal and discarded equipment are not included in the classifications above. It is proposed that this category of waste material be disposed of separately.

REFERENCE

1. Scientific Research Data and Reports. Solid Waste Management in Cold Regions, State of Alaska, Department of Health and Welfare, Office of Research and Academic Co-ordination, Alaskan Water Laboratory, College, Alaska, 99701. August, 1969.

5. SOLID WASTE MANAGEMENT

5.1 GENERAL CONSIDERATIONS

A construction camp would be a miniature and temporarary "industrial city". The waste from the activity would be a spectrum of materials in terms of kind, weight and volume, degradability and potential amenability to management. Figure 1 suggests the range of wastes, typical items to be expected and the possibilities for managing each.

Although the aforementioned figure suggests approaches to waste management, the actual practice can be appreciated best by reviewing the total sequence of unit operations involved in handling any waste. There are five specific steps which are always applied to the handling of wastes; these are: 1. Storage; 2. Collection; 3. Transport; 4. Processing; 5. Discharge to the Environment.

Often the first three steps are combined and are really only a preface for the last two. The objective of all waste management is to make the last step, the "discharge to the environment", occur without pollution and environmental degradation and this is why waste must be processed.

One of the advocated approaches for solid waste management is to transport all such debris out of the Arctic. This could be feasible if trucks were returning empty to southern centers. However, problems could occur; during storage awaiting transport, the waste could become odorous, attractive to wild animals, or could be rained or snowed upon and the leachate become a pollutant.

In addition, the cost of transportation in terms of total pollution generated must be considered. It is possible that the sum total of pollution generated by trucking refuse out of the Arctic, including such pollution sources as the refinery producing the truck fuel as well as the trucks themselves, may be more damaging to the total environment than well-planned on-site refuse disposal.

SOLID WASTE MANAGEMENT MATRIX

Refactory and Inert			Combustible and Chippable		Putrescible			Hazardous	
Steel Cast Iron Machinery Abandoned vehicles	Bottles Glass Ash	Tin Cans	Pallets Lumber Paper Plastics Packaging Trash & Rubbish	Trees Shrubs Slash	Food Wastes	Body Wastes	Dead Animals	Poisons Solvents Oils Greases Fuel	Radio-active
Stockpile	Incinerate and bury the incombustible residue in a landfill site								Special Regulation
Bury in a landfill site				Burn	Bury in a landfill site			Transport Out	
	Shred or bale and bury in a landfill site			Chip and Stockpile	Treat in Sewage System				
	Shred as refuse and place on land areas.								

FIGURE 1.

Transport out of the Arctic is really a viable waste management alternative only for special radioactive and similarly hazardous, toxic wastes which cannot be satisfactorily discharged back to the environment at or near the construction site, and for major equipment and components which have a salvage or scrap value.

When campsites and a pipeline are to be constructed in timberland the first waste would be the debris from clearing the campsite and the pipeline route. In general, the timber will be non-harvestable, so trunks as well as stumps and the slash would have to be disposed of. Obviously the most economical management technique for this material is to pile and burn it in the open. Such burning should generally occur at a time when forest and tundra fire hazards are negligible and under suitable weather conditions.

Alternatively, the use of a simple "fire wagon" might offer some advantages in that the danger of forest fire is reduced. A more sophisticated portable wood incinerator using forced air may be employed to reduce the levels of smoke emission.

In permafrost areas, the removal of the vegetation cover and its elimination by incineration may result in severe depletion of the plant nutrient resources available for the revegetation of cleared areas since the normal sequence of nutrient cycling through vegetation decomposition and the return of nutrients to the active layer would no longer take place.

In addition, the removal of the vegetation cover may result in thermal erosion of the permafrost or water erosion of the soil.

The biodegradable, solid waste material is a possible source of plant nutrients which may be conserved and used to promote the regrowth of vegetation and to maintain the natural soil temperature regime.

To be specific, if an indigenous ground cover is removed, the construction regulations could specify that erosion of those areas is not to occur and that natural vegetation is to be re-established. The contractor's environmentalists may decide that this can best be accomplished by using a mulch, which may consist of shredded refuse, wood chips or both, and chipping the cleared timber may well be the cheapest and most satisfactory method of healing the scars.

Several methods may be used for chipping the timber on a pipeline route. A machine has been developed which may be used to clear and chip and standing trees and bushes. Using this method, the wood chips are evenly distributed over the soil surface, prior to construction work, where they may offer some protection to the surface.

Alternatively, a pipeline route may be cleared by hand or machine and the trees and slash put through a wood chipper. The chipped material could then be stockpiled until needed.

There is the possibility that large quantities of wood chips would inhibit revegetation. The effect of wood chips on revegetation would therefore have to be determined before this method could be used in a revegation program. Research is presently being conducted to determine the feasibility and effects of using wood chips and shredded garbage for a mulch. The idea of having wood chips available for badly scarred areas which would be subject to a large degree of thermal erosion is sound. Examples of such areas would be where heavy equipment has accidently uprooted the protective vegetation layer. Stock piles of wood chips could also be available for emergency use as an oil spill absorbent.

Biological and chemical reduction of organic material proceeds slowly under low temperatures. Putrification and decomposition occur in cold regions under certain conditions, but the usual processes of decomposition do not appear to occur within the permafrost. For this reason (and possibly because of damage to the surface environment), burying of solid waste is prohibited in permafrost areas by the Alaska State Department of Environmental Conservation.

This does not seem to be necessary in the Northwest Territories and Yukon Territory. It is appreciated that at low temperatures, biostabilization of the buried refuse would be minimal. It seems that if the waste is properly "processed", it can be discharged in the Arctic without environmental degradation of any significant degree.

Areas of high ground with dry stable soil not liable to flooding and suitable for landfill sites may be found throughout the continuous permafrost zone. The preferred locations for landfill sites in permafrost areas are on south-facing slopes on high ground where the maximum thawing and consequent decomposition of the refuse would take place every year. The area method of sanitary landfill may be employed, which takes advantage of natural ground surface depressions and irregularities. Surface depressions may be filled with refuse, compacted and provided with a final cover of soil.

5.2 STORAGE, COLLECTION AND TRANSPORTATION

The storage, collection and transportation of waste prior to processing and disposal represents approximately 75 to 80 percent of the overall cost of the solid waste management program for most communities. Northern work camps would probably incur this high level of expenditure so the pre-processing costs of camp solid waste systems may be substantial. The different methods of solid waste handling should therefore be examined. However, the final method decided upon should not be based upon cost alone. Environmental, aesthetic and health aspects should also be taken into account.

All solid waste handling systems must meet three requirements. These are:

1. prevent nuisance
2. protect the waste from degradation
3. facilitate emptying, storage and handling.

Figure 2 is a schematic diagram of some of the possible variations of a solid waste management system. The five basic procedures of storage, collection, transportation, processing and disposal can be adjusted and interchanged to form the best practicable method for anv situation. This discussion, however, would be limited to the pre-processing operation of a solid waste management system for northern work camps.

5.2.1 In-House Collection

All waste management systems start at the point of waste generation. At a pipeline construction

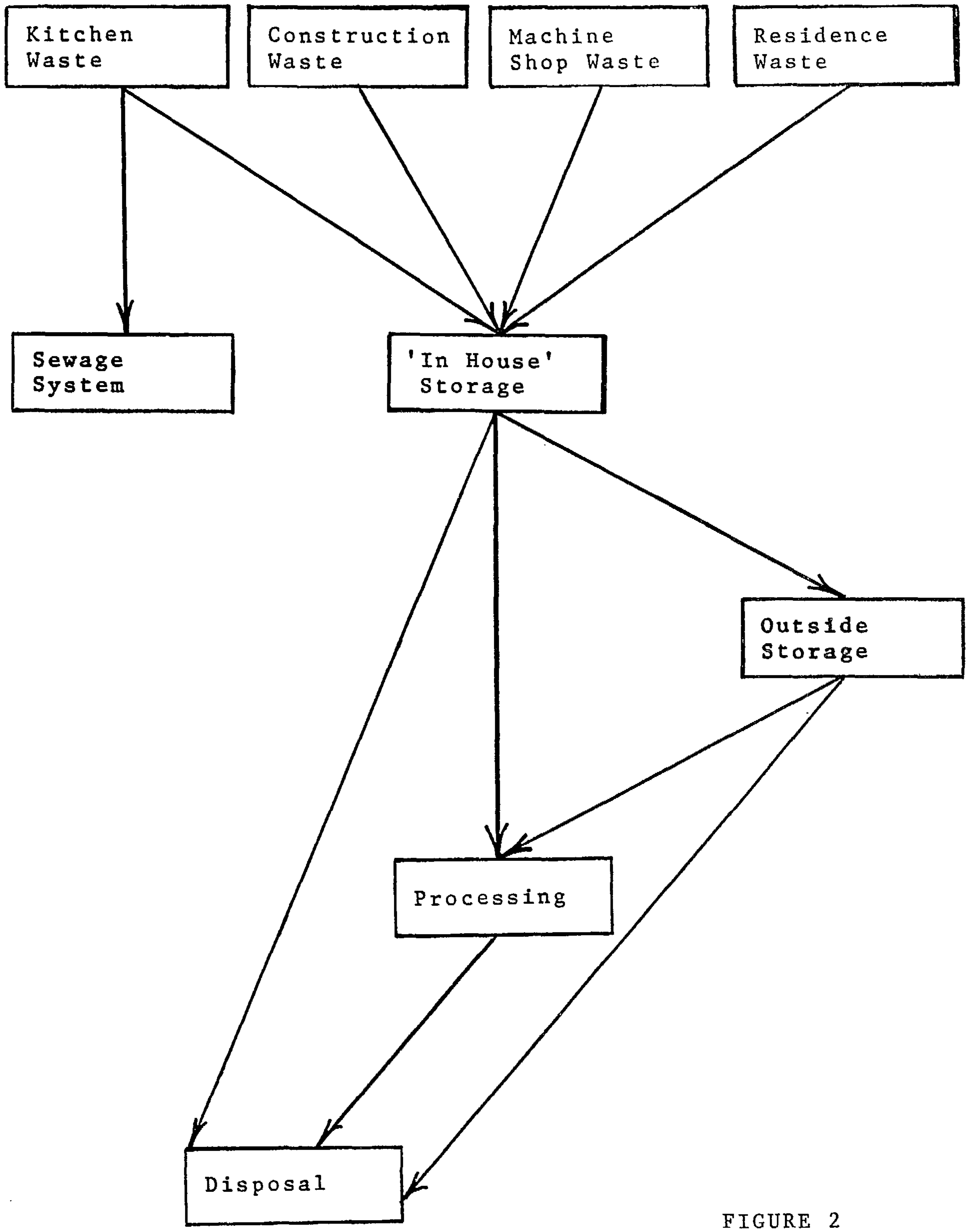
Kitchen Waste
Construction Waste
Machine Shop Waste
Residence Waste
Sewage System
'In House' Storage
Outside Storage
Processing
Disposal

FIGURE 2

camp there would be four of these "waste generation points", each producing waste unique to its function. These points would be 1. Residences; 2. Kitchen; 3. Garage and Repair Shop; 4. Actual pipeline construction site.

Waste generated from the residences and kitchen will be discussed in greater detail because it may pose more diverse problems than that from the garage, repair shop and construction sites.

In the residence area, waste would undoubtedly be placed in small containers within the living quarters. The "in-house" collection and storage could be accomplished in two different ways, either by having one individual collecting the refuse from each of the living quarters or by having the residents empty their refuse containers into strategically placed larger containers outside the living quarters. The larger containers could then be collected on a regular basis for outside storage or processing. The latter method appears to be more desirable in that it would reduce manpower requirements as well as maintain a certain degree of privacy within the living quarters.

Methods of "in-house" storage can also vary which again emphasizes that the many sub-systems within the overall waste disposal system create a very complex management program.

The choice of containers for "in-house" storage, includes metal containers, plastic containers, plastic bags and wet strength paper bags. Metal and plastic containers could create a handling problem in that they would have to be emptied into a larger storage container or into the transporting equipment. Use of metal containers would also result in a noise problem during handling. The advantage to this type of "in-house" storage is that the containers are reuseable. Plastic bags and wet strength paper bags would be advantageous in that they are easier to handle, chances of spillage are lessened, cleaning is unnecessary, they are disposable, collection is quieter and they do not harbour flies or emit odors. Large plasticized paper bags are used in Greenland and some European countries and they have proven to be very satisfactory. These bags are easily mounted on holders attached to a wall and are fitted with a metal lid. The disadvantages of using a bag collection system are that plastic bags become brittle in cold temperatures, containers or holders must be provided, a continuing supply of bags must be maintained, bags may be expensive, plastic bags are non-biodegradable and the bags themselves are a solid waste.

5.2.2 Collection and Transportation

The "in-house" storage can be followed by a number of methods of collection and transportation to the processing and/or disposal area. The common methods are for storage in larger outside containers prior to truck pick-up, direct transport by truck to the processing or disposal area, or truck pick-up from outside or "in-house" storage and transport to a large storage area prior to processing. A process of compaction before outside storage and/or pick-up should also be considered. There are a number of small compacting units available which not only compact but also containerize the material in plastic or paper bags or sheaths. This would not only facilitate handling and reduce the volume, but it would also eliminate the attractiveness of the material to insects and rodents as well as eliminating odors.

It must be emphasized however, that no matter what method is used for storage, "in-house" or outside, the material should not be attractive to insects, rodents or other wildlife, and it should not be odorous.

In general, the methods for collection and storage of waste from the residences would also apply to kitchen waste. It is absolutely necessary that containers for kitchen waste have a tight seal. Kitchen waste should be collected for outside storage or processing daily, whereas collection for outside storage of waste from residences may be on a less frequent basis.

In the past, transport of refuse has been mostly by vehicles of one form or another. The selection of the type of vehicle to use is another problem which must be considered and would depend upon factors such as volume of waste, haul distances and processing methods.

A relatively new transporting system is the vacuum system in which waste is deposited in a chute near the "waste generation point". A vacuum then draws the waste to the processing and/or disposal area. This type of sytem is in operation at several centers in the United States.

Solid waste vacuum transporting systems have not been demonstrated in Northern Canada and we therefore cannot give an appraisal of how well they would function at a pipeline construction camp. However, when considering the difficulties with truck transportation under the extreme climatic conditions of the north, the possibility of a vacuum type of system should be investigated.

It must be remembered that any solid waste system at a pipeline construction camp would be complex. Each of the sub-systems as well as the overall waste management system would depend on a variety of factors such as climate, terrain, camp layout, volume of refuse and topography. In all cases, the system instituted must be:

1. Efficient,
2. Simple to operate,
3. Unattractive to insects, rodents and other animals,
4. Odor free,
5. Sanitary,
6. Environmentally acceptable.

5.3 PROCESSING AND DISPOSAL ALTERNATIVES

5.3.1 Dumping on Land, on Ice or in Water

Severe winter weather and limited access to dump sites because of snowdrifting, pose serious problems in the disposal of solid waste in remote areas of the North.

Dump sites at villages are not covered with fill material under a planned program due to the lack of heavy equipment and the extreme cost of winter operations. The natives and white residents accept waste disposal in this manner in the north because they are used to it and it does not offend their sense of values in living and in earning a living.

As a result, in the spring and early summer, there are unsightly, offensive accumulations of mixed garbage and sewage which are a hazard to the public health. The ravens, gulls and animals feed on these wastes and scatter the material.

At some coastal settlements garbage and sewage bags are piled on the Arctic Ocean ice in the hope that at the time of spring breakup the waste will float away and disappear. In many cases, the tied bags float and are washed up on the shore at the settlement. One solution adopted was to shoot the floating bags so that they sank out of sight. Subsequently, the bags were slashed as they were deposited on the ice.

At drilling sites in the Northwest Territories, holes are blasted or bulldozed in the surface and solid waste, drilling mud, metal scraps and sewage are all discharged to them. At the completion of the activity these holes are covered.

In Alaska, at Prudhoe Bay, there are a number of similar operations. The British Petroleum site superintendent advises that they no longer excavate holes in the surface for drilling mud. Instead, a gravel dyke is built on the existing surface beside their drilling pad to contain the mud, some of which, when dry, is used in road construction whenever the available gravel fill lacks fines. Solid waste from camp operations is burned regularly in open dumps beside the gravel pads and covered with gravel in the spring. This covering of gravel has cost as much as $25,000 per campsite.

Alaskan environmental research engineers have pictures of drilling camps in operation using holes blasted or dug in the permafrost for disposal of solid waste, sewage, drilling mud, etc. The following summer, pictures of the same site show a festering sore in the tundra surface where the garbage and litter had been dumped. When this situation is multiplied 100 times in a relatively small area, it is small wonder that there has been violent public reaction to developments with solid waste disposed of in this manner.

5.3.2 Sanitary Landfill

Sanitary landfill is a method of disposing 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 area, to reduce it to the smallest practical volume and to cover it with a layer of earth at intervals as may be necessary.

In temperate climates, this method of waste disposal is probably the most economical and, if done with good management, is the simplest and most satisfactory. The more frequently the refuse is covered, the more expensive the operation becomes.

In the permafrost regions, the ground temperature remains below 32° F and biodegradation is so slow as to be negligible. Microorganisms may not be active below 26-27° F. For this reason, and because of the problems of permafrost degradation and erosion which may be initiated by the removal of surface cover and excavation, the Alaska Department of Environmental Conservation has issued the objective that "no unprocessed solid waste will be discharged to land or water; soil and water cannot be considered to provide adequate natural processing" in continuous permafrost regions.

There are areas of granular ridges, suitable for landfill sites, in permafrost regions which do not remain frozen in the summer. These ridges may be suitable for landfill sites. The depth of burial would depend on the depth of thaw which may only be up to 10 feet.

Under permafrost conditions, sanitary landfill at a proper site and under a managed program is therefore both feasible and acceptable.

For those locations which are long distances from a campsite, the economics together with better control of "good housekeeping" may favor incineration.

Trench Method

There are significant but not overwhelming problems in constructing and operating a waste burial trench in winter. Firstly, it may be extremely difficult to do the excavation. It may be necessary to crack frozen soil by blasting, but for many locations and small excavation, a ripper on a heavy duty tractor would be able to do the job. Certainly the logical machine for trench construction and care is the crawler with a dozer blade (and ripper for construction).

In certain areas, it may be possible to construct the trench during the summer when the ground has thawed. It would then be possible to stockpile cover material for use during the winter, although attempts to do this at Fairbanks, Alaska have failed.

In terms of efficiency in filling the trench and in keeping the refuse compacted and contained, dumping should be done from the side of the trench. Snow will drift into the excavation and of course would have to be pushed out of the area in which the waste was being deposited, and ultimately out of the whole trench. Before the spring thaw and at the time of camp abandonment, the trench would have to be refilled. The excavated soil should of course be used, and, because of the volume of waste put in the trench, much of the originally excavated earth would be a surfeit. This could be mounded over the trench area. Then, in summer, with thawing and draining off of excess water, consolidation would occur. With proper design and operation of the burial trench, there would be a very minimal scar in the environment. When the whole trench, or a significant length of it, is filled to within about one foot of the natural ground level, waste depositing could stop and the refuse could be compacted and covered with the excavated soil. It should be specifically noted that the burial trench need not be operated as a true sanitary landfill, with daily covering; rather, this covering need be done only as the refuse fills a particular section of the trench.

If a construction camp is scheduled to operate for more than one winter, some of the problems associated with sloughing of the side walls could be overcome by using a separate trench for each winter's operation.

After the landfill has been finally covered and abandoned, periodic visits to the site should be made for several years to determine both the amount of slumping and the need for further work to maintain the site at an acceptable level. It is therefore important that funds be set aside to cover the cost of the necessary cleanup operations which may have to be carried out several years after the site has been abandoned.

Consider the quantities of solid waste which may be developed for disposal.

A 700-man construction camp would generate an average of 4,000 lb/day of compactable material; 500 lb/day metal scraps and machine parts; 1,000 lb/day non-compactable packaging, wood wastes, etc.

Compacted refuse would weigh approximately 770 lb/yd^3 (Table 1). Metal parts would weigh approximately 10,125 lb/yd^3 (S.G. - 6). Wood scraps and packaging material would weigh approximately 1,200 lb/yd^3 (S.G. = 0.7).

Total volume/day

$$= \frac{4000\ lb}{770\ lb/yd^3} + \frac{500\ lb}{10{,}125\ lb/yd^3} + \frac{1000\ lb}{1200\ lb/yd^3}$$

= (approximately) 6 yd^3.

Total volume for 8 months = 6 yd^3 x 7 d/wk x 35 wk
= 1,470 yd^3.

Size of Trench

The trench must be large enough to contain 1,470 yd^3 of refuse plus any intermediate cover material that is required. Since the intermediate cover would likely be applied less frequently than daily, an estimated 10% of the refuse volume must be added to allow for this intermediate cover.

The volume of refuse + intermediate cover

$= 1,470\ yd^3 + 147\ yd^3 = 1,600\ yd^3$ (approx.)

Assuming a total depth of refuse of 6 ft the area required for an 8 month camp

$$= \frac{1600\ yd^3}{2\ \ yd} = 800\ yd^2$$

Assuming a final cover depth of 2 ft., with excess soil being used for other purposes, then:

Volume of cover material $= 800\ yd^2 \times \frac{2}{3}\ yd = 530\ yd^3$

The total yards to be excavated to a depth of 7 ft

$$= 1600\ yd^3 + \frac{530\ yd^3}{2} = 1,860\ yd^3$$

Estimated Cost - Landfill Trench for Eight Months

1. Trenching - 1,860 yd^3 @ \$3.00/yd^3 = \$ 5,580

2. Operating costs per week -

   (a) Collect waste at camp
   1 laborer
   \$4.50/hr x 8 hr/d x 7 d/wk = \$ 252

   (b) Haul to site
   Truck and driver
   \$18.50/hr x 8 h/d x 7 d/wk = \$1,036

   (c) Spreading, compacting and intermediate cover
   Cat @ \$30/hr x 8 hr/wk = \$ 240

   Weekly total = \$1,528

   Total for 8 months
   = \$1,528 x 35 = \$53,480

3. Final covering and grassing

   Covering - 530 yd^3 @ \$2.00/yd = \$ 1,060
   Grassing - (approximately) = \$ 500

   TOTAL COST = \$60,620

For both single-winter and year-round burial trenches, there probably should be significant control on the materials which are deposited in the landfill. In general, the biodegradable kitchen waste materials could be handled by running them through a garburetor, and discharging the macerated solids into the camp's wastewater disposal system, provided that this system had been designed to handle the extra load. However, there are also cans containing food scraps, bottles, wrapping paper and packaging of food, paper napkins and table debris. We therefore think that, if possible, these waste materials should be processed in a manner which renders them unattractive to rodents, birds, disease vectors and other animals.

Area Method

The area method of sanitary landfill involves the utilization of natural depressions or ridges. When using a low area, the wastes are spread to fill up the depression and then covered. The cover material must be imported because the refuse is placed on the natural ground surface without, in most cases, any excavation. This operation could be very expensive if suitable cover material is not in close proximity to the landfill area. Care must be taken to ensure that there is proper drainage around the landfill area. Proper site selection is also very important because in many cases natural depressions represent areas of high moisture content.

There are areas in the North where natural ridges could be used for landfill areas. Waste material could be placed and compacted on a south sloping side of these ridges and material from the top could then be used as cover.

The overall cost of the area method of sanitary landfill is expected to be less than that of the trench method, because of the reduced excavation requirements. Other operational costs should be very similar to those of the trench method. There are many variables involved in using the area method of sanitary landfill, the greatest being site location and access. A reasonably accurate estimation of costs is impossible to make, but as mentioned earlier, this type of operation could reduce costs if a convenient location were available.

5.3.3 Refuse Shredding

This method of solid waste treatment may offer advantages over incineration or unmilled refuse provided a shredder capable of doing the job can be obtained.

Experience at Madison, Wisconsin, and Edmonton, Alberta has indicated that "in terms of land savings, rodent and vector control, leaching, odor production, paper blowing, debris, and dust prevention", landfills containing milled refuse are superior to those containing unmilled refuse.

Shredding and compaction in a landfill reduces volumes required for solid waste by between 10-30% (av. 16%) as compared to compacted raw refuse. (See Table 1).

Shredded material, when placed in a landfill does not require a daily cover, thus further reducing the total space required for a landfill as well as effecting savings in operating costs. However, since unmilled refuse is unlikely to be covered daily in isolated northern areas in winter, it is difficult to determine the savings in cover material which might result from shredding the refuse. For purposes of comparison, a daily or intermediate cover cost is included in the estimate of total costs for either milled or unmilled waste.

Shredding refuse prior to baling has been shown to reduce the volume by up to 50% of that required for unmilled baled refuse.[1] This may be important if it is necessary to haul the waste to a distant site.

It should also be noted that shredded waste, when placed in a landfill, would support the weight of a dump truck so that the trucks could be driven on to the surface of the waste for emptying.

Shredded solid waste may possibly be used as insulation or quick cover in sensitive areas where the original vegetation cover has been disturbed, or to give protection for new growth after the pipeline cover has been reseeded. It is a method of making use of a waste and recycling it back to nature, but it must be evaluated in pilot projects before it can definitely be recommended.

The volume of material which results from a shredding operation together with the volume of unshreddable material is given below:

TABLE 1

Summary of Actual Densities of Milled and Raw Refuse

Grate Size (inches)	Range of Actual Densities (lb/cu yd)	Average Actual Density (lb/cu yd)	Comparative Reduction in Volume after Milling
3 1/2	760 - 950	854	10%
5	1,094	1,094	30%
6 1/4	810 - 1,130	920	16%
3 1/2 - 6 1/4	760 - 1,130	916	16%
Raw	660 - 950	772	---

Figures adapted from "A Report on the Demonstration of the Gondard Grinding Mill for Pulverizing Refuse and Landfilling Milled Refuse Without Daily Cover." by John Reinhardt, Project Director, Department of Public Works, City of Madison, Wisconsin.

4,000 lb of shredded material (920 lb/yd^3 - see Table 1, page 32), would require a volume of 4,000 lb/920 lb/yd^3 = 4.3 yd^3/day. The unshreddable materials would require a volume of approximately 1 yd^3/day (see estimates of sanitary landfill)

Total solid waste/day = 5.3 yd^3

Total solid waste for 8 months = 5.3 yd^3/d x 7 d/wk x 35 wk = 1,298 yd^3

Volume of refuse and intermediate cover (10%) = 1,428 yd^3

Assuming a depth of refuse of 6 ft, the area required for the landfill would be:

$$\frac{1428}{2} = 714 \text{ yd}^2$$

Assuming a final cover depth of 2 ft, with 1 ft above natural ground level, then:

Volume of cover material = 714 x 2/3 = 476 yd^3

Therefore total yards to be excavated to a depth of 7 ft.

$$= 1428 + \frac{476}{2} = 1660 \text{ yd}^3$$

Estimated Cost of Shredding for Eight Months

1. Collection and Shredding Costs

(a)	Collection - 1 laborer $4.50/hr x 8 hr/d x 7 d/wk	= $ 252
(b)	Shredding - 1 operator $5.50/hr x 4 hr/d x 7 d/wk	= $ 154
(c)	Fuel - 200 gal/wk x $0.80/gal	= $ 160
(d)	Truck haul to and from shredder $18.50/hr x 8 hr/d x 7 d/wk	= $ 1,036
(e)	Front end loader $20/hr x 4 hr/d x 7 d/wk	= $ 560
	Total weekly costs	= $ 2,162
	Total for 8 months - $2,162 x 35	= $75,670

2. Capital cost of unit and housing = \$40,000

(a) 3-yr. write off @ 10%. Capital recovery factor = 0.4021

Therefore, cost/8 mo

= 0.4021 x \$40,000 = \$16,084

(b) Repairs (10% of capital cost) = \$ 4,000

3. Landfill costs

(a) Trenching

1428 yd^3 x \$3/yd^3 = \$ 4,284

(b) Spreading, compacting and intermediate cover
Cat @ \$30/hr x 8 hr/wk x 35 wk = \$ 8,400

4. Final covering and grassing
Covering - 476 yd^3 @ \$2/yd = \$ 952

Grassing - (Approx.) = \$ 500

Total cost of shredding plus landfill = \$109,890

A reduction in costs would be achieved if some of the shredded waste is spread on scarred areas as an insulation cover, thus saving on required landfill space. In addition, costs can be reduced by taking advantage of ground surface irregularities such as hollows which would reduce the amount of excavation needed.

5.3.4 Incineration

Open dump burning is practiced at many northern communities. The resulting charred putrescible materials provide food for ravens, grounds for fly-breeding and are a public health hazard. Two bears have been shot in five years at the dump grounds at Inuvik, N.W.T. Open dump burning is, therefore, not acceptable in camp operations.

The use of an incinerator appears to offer the best method of processing solid waste from camps.

Thus comes the question of what kind of burning and what level of performance needs to be specified for this burning. Multi-chambered, forced draft incinerators are on the market which can combust the refuse with minimal smoke and particulate emission, and would meet air pollution control regulations. However, such sophisticated equipment is difficult to keep operational in the Arctic, and manpower is inefficiently utilized when working under extremely cold conditions. This problem can be overcome to some extent by providing heated shelters.

Incinerators are currently in use at the Canadian Arctic Gas Camp at Sans Sault, at Prudhoe Bay, and at seismic and oil drilling camps.

The waste from the camps is collected in plastic bags placed at strategic locations, which are set outside in temperatures as low as -40 to -50^{o}F, prior to burning.

The kitchen waste usually becomes frozen and if the incinerator is not preheated prior to charging, the frozen garbage may not be entirely burned. In addition, there are, of course, some materials which are quite difficult to incinerate without producing smoke, although there are units now available which could overcome this problem.

Because of water problems at the camps, a great quantity of soft drinks is consumed which results in a large number of cans being discharged to the incinerators. These cans act as a block in the combustion process, and must be removed by the operator using rakes or other tools.

Many of the incinerators have no shelter over them. The charging doors on these may become broken, partly because of overheating due to lack of satisfactory damper controls and also because of snow blowing onto the hot castings. Those incinerators which are enclosed or inside buildings do the best job. Sophisticated electronic controls are unreliable under outside arctic conditions, since they are designed for operation at 70^{o} F. The ashes from incinerators are dumped beside the camp pads and covered with gravel. Bulky items may have to be disposed of in a landfill. Because of these problems, an incinerator operation should have many adjuncts which include:

1. A heated shelter for the incinerator with adequate heated storage space for garbage,

2. Primary and secondary combustion burners,

3. Primary and secondary air supply fans with controls,

4. A pyrometer to control burners automatically,

5. A temperature controller in the secondary combustion chamber to control after burner,

6. An induced draft fan in the incinerator stack to ensure draft and disperse fogging,

7. A responsible, factory-trained person to properly operate the incinerator,

8. Improved dumping ability or separation of incombustibles for direct burial,

9. A certificate affixed to each incinerator testifying that the incinerator has been approved and will comply with air quality regulations.

<u>Estimated Cost of Incineration for Eight Months</u>

1. Collection and Trucking Costs

(a) Labor $4.50/hr x 8 hr/d x 7 d/wk	= $	252.00
(b) Trucking 5 hr/d x 7 d/wk x $18.50/hr	= $	648.00
(c) Incinerator Operator $5.50/hr x 8 hr/d x 7 d/wk	= $	308.00
(d) Fuel 100 gal/d x 7 d/wk x $.80/gal	= $	560.00
(e) Power	= $	50.00
Total for eight months		1,818.00
35 weeks x $1818/wk	=	$63,630.00

2. Capital Cost of Incinerator and Housing - \$40,000

(a) Three Year Write-Off at 10%.
capital recovery factor = 0.4021
Therefore cost/year

= 0.4021 x \$40,000	= \$ 16,084
Repairs (10% of capital cost)	= \$ 4,000
	\$ 20,084

3. Landfill ash and incombustible material
Assume 500 lb of ash with S.G. = 2

$$\text{Vol.} = 500\ \text{lb}/(2 \times 62.4\ \text{lb/ft}^3 \times 27\ \text{ft}^3/\text{yd}^3)$$
$$= 0.15\ \text{yd}^3/\text{d}$$

Assuming burial of metal and S.G. = 6 for metal waste

Total volume

$$0.15\ \text{yd}^3/\text{d} + \frac{500\ \text{lb/d}}{10{,}125\ \text{lb/yd}^3} = 0.20\ \text{yd}^3$$

Landfill costs	
$0.20\ \text{yd}^3/\text{d} \times 7\ \text{d/wk} \times 35\ \text{wk} \times \$3/\text{yd}^3$	= \$ 147
Cost of final cover and reseeding (approximately)	= \$ 500
	\$ 647
Total Cost of Incineration	= \$84,361

The operation of an incinerator in the Arctic may contribute to the problem of ice fog buildup. The Atmospheric Environment Service indicates that its records show problems in ice crystal formation during periods of temperature inversion which occur 25% to 30% of the winter time in Inuvik. It may be possible to predict problem areas at specific campsites and to recommend suitable locations for airstrips.

Environmental conservation considerations suggest that incineration may be preferable to landfill in the Arctic. The disposal of ash in the gravel pad at the campsite ensures a cleaner operation than occurs when the waste is required to be hauled away to a distant landfill.

5.3.5 Pyrolysis - Combustion

Pyrolysis-combustion is an improved method of incineration which has recently been developed to overcome some of the limitations of a simple incinerator. It is a demonstrated process utilizing the "best practicable technology".

A pyrolysis-combustion incinerator employs a two-stage burning system. The large primary furnace is designed to hold all the waste material which is normally collected during one day. At the end of the day the primary furnace door is closed and sealed. The incinerator is automatic in operation and is started by a push button. A burner in the primary chamber ignites the waste, but the air flow to this chamber is restricted. Volatile compounds and gases pass to the reactor section where they are mixed with a turbulent air supply and ignited by a second burner.

This type of incinerator has a number of advantages to recommend it. These include:

1. It acts as a storage unit for waste.
2. It is cold during the day for cleaning and charging.
3. It is sealed during operation and no attendant is required.
4. It operates on the principle of "controlled air combustion", and is capable of meeting strict emission control regulations.

Since the waste is fed directly into the pyrolysis-combustion incinerator, the cost of either a laborer or incinerator operator can be eliminated. In addition, the fuel cost could be reduced.

Estimated Costs - Pyrolysis-Combustion

1. Collection and Trucking Costs
   (a) Labor
       $5.50/hr x 8 hr/d x 7 d/wk = $ 308

   (b) Fuel
       5 gal/hr x 8 hr/d x 7 d/wk = $ 224

(c) Power = \$ 50

(d) Trucking
5 hr/d x 7 d/wk x 18.50/hr = \$ 648

Total per week = \$ 1,230

Total for 8 months (1230 x 35) = \$43,050

2. Capital Cost of Pyrolysis-Combustion incinerator and housing = \$50,000

(a) 3-yr. write-off at 10%
Capital Recovery factor = 0.4021
Therefore cost/year = 0.4021 x 50,000 = \$20,105

(b) Repairs (10% of capital cost) = \$ 5,000

3. Landfill costs
0.20 yd^3/d x 7 d/wk x 35 wk x \$3/yd^3 = \$ 147

Cost of final cover and reseeding = \$ 500

Total cost of Pyrolysis-combustion Incineration = \$68,802

5.3.6 Pyrolysis

An advanced concept of solid waste management is pyrolysis; this is "the chemical decomposition of a material by heat in the absence of oxygen". It does convert oxidizable waste into somewhat less noxious materials, but ultimately this too must be discharged to the environment. Additionally, pyrolysis requires sophisticated equipment and is expensive in capital, fuel and labor costs. In total, pyrolysis does not appear to have any significant potential for short-term construction camps, or even for permanent arctic communities.

5.3.7 Fermentation or Composting

Composting is the aerobic, usually thermophilic, bio-stabilization of biodegradable waste. All the food scraps, body solid waste, and to a degree, paper, packaging and other cellulose waste could be composted. However, the waste which can be readily composted would be a relatively small fraction of the total quantity of waste from a construction camp; by far the largest quantity is expected to be metal scrap, non-organic debris and other organic material which is slow to decompose. Composting would not be effective in reducing the bulk or in changing the characteristics of most of this waste. A major objection to composting in the Arctic is its need to be conducted under moderate temperatures to encourage the thermophilic features of bio-stabilization. This would require conducting the operation in a heated building. Composting has not proven to be an entirely satisfactory disposal method in other areas of the world, considering economics and final discharge of the material back to the environment, and is less likely to be satisfactory in the Arctic.

It is reported from Alaska that at one village a form of composting was in operation, but no data is available on which to base an opinion of the value of the process.

5.3.8 Reduction - Recycling

Recycling of waste presupposes recoverable materials in quantities sufficient to meet an economic demand at a nearby market, and is therefore not practical in remote northern areas.

5.3.9 Feeding to Animals

Kitchen waste has been used as livestock feed for hogs, etc. in temperate regions. Since there are no livestock feeding operations along any proposed arctic pipeline route, this is not considered to be a suitable method of solid waste disposal.

5.3.10 Dilution

(a) Grinding and disposal into the sea, lakes or river.

This is not considered to be a suitable method of waste disposal because it is contrary to the Fisheries Act.

(b) Grinding and discharging into a sewer and thus into a sewage treatment facility.

This may be considered as a possible method of disposal of kitchen wastes as it eliminates waste going into a sanitary landfill which might attract bears, foxes, etc.

5.3.11 Miscellaneous Methods

(a) Chemical Disintegration

This is not considered practical because of the amount of waste and the cost of equipment and disposal.

(b) Baling

If there is limited sanitary landfill space, baling might be considered as one way of compacting refuse at the site instead of shredding. In addition, tin cans may be incorporated into bales. Baling may be used also as a pre-storage process.

Up to the present, solid waste disposal in the Northwest Territories has not been under the supervised management that is suggested herein. In addition, the many variables which would be involved with each individual campsite along a pipeline route prevent a truly accurate cost estimate for each disposal method from being made. We do believe, however, that the cost arrived at for landfill, shredding and incineration, which are summarized in Table 2, are comparative costs. The cost which could vary the greatest would be that for sanitary landfill operations because of the larger number of variables which are involved.

There are two alternative methods of waste disposal which appear satisfactory for small camps of short duration. Solid waste from such camps may be disposed of by burial or incineration in a manner which does not contravene any regulations governing the large camps or the solid waste may be collected and transported to the main camps for disposal.

Reference

1. From the report, "Refuse Milling in Europe" by Robert K. Ham and John J. Reinhardt. 1973.

TABLE 2

Comparative Cost Estimates of Waste Management Systems

(8 month basis)

	Landfill	Shredding	Incineration	Pyrolysis-Combustion
Equipment	$ ----	$ 16,084	$16,084	$20,105
Maintenance of equipment	----	4,000	4,000	5,000
Fuel	----	5,600	19,600	7,840
Power			1,750	1,750
Personnel Wages	8,820	14,210	19,600	10,780
Haulage	36,260	55,860	22,680	22,680
Trenching	5,580	4,284	147	147
Spreading	8,400	8,400	----	----
Final Covering	1,560	1,528	500	500
TOTAL COSTS	$60,620	$109,890	$84,361	$68,802

6. SUGGESTED GUIDELINES FOR SOLID WASTE MANAGEMENT

1. All the procedures to be used for collection, storage, treatment and disposal of solid waste must be considered and completely specified in the initial planning stage for each camp. It is important to realize that a partial approach, for example merely specifying the treatment or disposal methods, would not be sufficient.

2. If cans are to be used for the collection and storage of garbage and trash within the camp, they should be lightweight for ease of handling, rugged, non-corrosive, and able to withstand cold. They should be provided with covers to limit the dissemination of odors and the attraction of flies. Furthermore, a washing area with a concrete floor should be provided, so that the cans may be cleaned at intervals.

3. It is not the intention of the proposed guidelines to require any particular approach to solid waste handling and disposal. Instead of this procedure-based approach, we have preferred to write performance-based guidelines which spell out what standards have to be achieved, regardless of method. The only requirement of a performance-based guideline is that the performance must be measurable. Subject to these restrictions, a camp operator has a choice of incinerating the refuse or processing it in an approved sanitary landfill, or shredding it and distributing the shreds to scarred land.*

4. Air pollution from burning operations should not be considered a serious issue at outlying campsites. Nevertheless, it is desirable to achieve some degree of conformity with emission control laws which are applicable in other parts of Canada and Alaska. There should be assurance that the contractors would operate the incinerators in a satisfactory manner, achieving reasonably complete reduction of the waste to ash.

* Tentative recommendation, subject to confirmation by field studies yet to be undertaken.

5. Special waste, such as non-combustible materials (waste metal, equipment, etc.), waste oils or toxic waste, requires special approaches, and is dealt with specifically in the guidelines. In general, inert materials may be buried, even in permafrost regions. The best burial sites for old vehicles and waste metals are likely to be road borrow pits, while the campsite gravel pad itself may be useful for burial of smaller quantities of inert materials. On the other hand, oils and toxic materials should not be disposed of on the ground.

6. Wherever possible, waste material should be utilized. A proportion of the trees cleared from the pipeline route could be chipped and stored for use as an insulating material for disturbed areas or for use in fuel or oil spill emergencies. Construction debris could be placed in a landfill or incinerated where possible. Larger pieces of metal or discarded equipment could be buried or transported to southern regions for recycling.

7. TENTATIVE GUIDELINES FOR SOLID WASTE MANAGEMENT SYSTEMS

7.1 GENERAL

1. All solid waste management systems should comply with Regulations Respecting the Sanitation of Camps in the Northwest Territories.

2. All domestic solid waste from camp operations should be collected on a daily basis or as required, and processed immediately or stored in designated areas.

7.2 STORAGE

1. All waste classified as Type "2, 3, 4 or 5" should be stored in approved sealed containers.

2. Storage in areas other than sealed containers should be a minimum of 150 feet from kitchen and living quarters, unless the waste is stored within a pyrolysis-combustion incinerator.

3. Storage should be in fenced or enclosed areas to prevent access by unauthorized personnel and animals.

4. Waste under the classifications Type "0" or Type "1" should be either baled for storage or placed in an area which would prevent the waste from being blown or scattered by the wind.

7.3 PROCESSING

7.3.1 Type "0" and Type "1" Waste

1. Waste under these classifications may be incinerated; disposed of in a landfill (shredded or unshredded); baled (shredded or unshredded) and disposed of in a landfill or transported to another area for further processing and ultimate discharge to the environment; shredded and placed on scarred land, cutlines, rights-of-way, etc.*, shredded and placed in roadbeds.*

*Tentative methods of disposal, subject to results of pilot projects.

7.3.2 Type "2" Waste

1. Waste under this classification may be incinerated; disposed of in a landfill (shredded or unshredded); baled (shredded or unshredded) and disposed of in a landfill; shredded and spread on scarred land, cutlines, rights-of-way, etc.*

2. Type "2" waste may be separated into Types "1" and "3" and disposed of according to disposal methods governing same.

7.3.3 Type "3" Waste

1. Type "3" waste may be garbureted and treated along with the domestic sewage and be subject to guidelines governing sewage treatment.

2. It may be incinerated.

3. It may be disposed of in an approved area of a landfill and under approved conditions which may be different from those of the overall landfill operation.

4. It may be mixed with Types "0" and/or "1" waste and treated according to disposal methods governing same.

7.3.4 Type "4" Waste

1. Type "4" waste should be incinerated.

7.3.5 Type "5" Waste

1. It should be either incinerated or transported to an acceptable processing area.

2. Type "5" waste should not be deposited in a landfill site.

3. Oil waste may be applied to roadways in compliance with "fog coat" highway requirements and in an area where it would not result in an environmental or health hazard.

*Tentative methods of disposal, subject to results of pilot projects.

7.3.6 Type "6" Waste

1. Wood waste may be disposed of according to the governing disposal methods for types "0" and "1" wastes, or incinerated.

2. Wood waste may be chipped and spread as an insulating cover on scarred land areas.*

3. Rubber and plastics may be placed in a landfill site; transported to another area for final processing and disposal or mixed with Type 0-3 waste and incinerated in a pyrolysis-combustion unit.

7.3.7 Solid Waste Which Cannot be Shredded, Baled or Incinerated

1. This waste may be transported to southern areas for recycling.

2. It may be stockpiled in an approved location, and at time of camp abandonment the materials could be either buried or transported to a suitable disposal area.

3. Approval for a given method of ultimate disposal would be granted by the regulatory personnel.

7.3.8 Cleared Trees, Shrubs and Other Vegetation

1. It may be shredded or chipped and used as an insulating layer over scarred land areas, cutlines or the rights-of-way; or used in road-beds or beneath gravel pads for equipment.*

2. It may be burned under controlled conditions at a time of negligible forest fire hazard, when meteorological conditions are suitable and at a time when inhabited areas would not be affected.

3. Stockpiling of wood chips to meet environmental emergencies (e.g., oil or fuel spills, scarred surface areas) should be a requirement at all camp sites.

* Tentative methods of disposal, subject to approval.

8. WASTEWATER MANAGEMENT CONSIDERATIONS

The primary objectives of wastewater management as applied to work camps in the North should be:

(i) The protection of the natural environment.

(ii) The protection of the public health.

(iii) The development of innovative techniques for the treatment of wastewaters.

(iv) The beneficial utilization of wastes.

Preliminary technology studies indicate that there is much potential for the use of waste for the alleviation of environmental stresses induced by construction activities.

As seen by workmen in the North, the major issues with respect to sewage treatment and disposal are that they should be provided with services approximately as good as those available to southerners and that their sewage disposal techniques should present no risks to public health or be a public nuisance. These relatively basic demands can often be met at small settlements and camps with only minimal sewage treatment, while the degree of treatment necessary to prevent significant environmental damage is less readily evaluated, and is the subject of a considerable diversity of opinion. The current concern for the preservation of a "clean north" combined with a growing awareness of the very real water and air pollution problems in the larger cities of the South, has led many people to assume that equally stringent sewage treatment standards are necessary throughout the country to ward off progressive deterioration of water quality. As a result, authorities in Alaska are requiring secondary or tertiary treatment for the sewage from oil and pipeline camps in northern Alaska.

The level of treatment required for camp sewage should take into consideration the nature and needs of the receiving body, be it river, lake, sea or swamp; the relative isolation of the camp; and the size and mobility of the camp. Very small camps, involving less than perhaps 20 men, and camps which only occupy an area for a short period of time can dispose of sewage to the land. This practice would exert negligible environmental stress, but careful consideration should be given to protecting the public health.

The waste treatment guidelines should take these considerations into account, although each situation would require individual study to determine what level of treatment is needed.

The complaint is frequently heard that any restrictions, which are likely to be applied to industrial operation in the North, would be considerably more stringent than those which are required of the communities. A small community represents in many ways a more significant environmental health problem than a temporary camp of the same scale and certainly would exert at least as great a stress on downstream waterbodies. There is, therefore, good reason to insist that in time all communities, villages and camps of an equivalent size be brought to the same high standards of waste handling and treatment. However, the native communities have special problems, particularly the lack of an economic base and of skilled labor, which impede the progress of these settlements towards better water supply and waste disposal systems. Thus, the existence of an apparent "double standard" in the immediate future should not become an argument for relaxing the requirements placed on industry.

For many camps of less than 300 man-days, "secondary waste treatment", which removed 80-90% of the BOD and suspended solids from a liquid stream is probably unnecessary.

The disposal of effluent from treatment plants without disinfection poses a problem whenever the water downstream is used for drinking by local people. This happens unexpectedly due to the habit of individuals setting up tents and temporary buildings downstream of work camps, and their casual approach to obtaining drinking water. It is therefore necessary to keep strict control over treatment processes to prevent contamination of water supplies.

These points have been combined with several others which were made during discussions with operators in Canada and Alaska, to produce a wastewater management policy for northern industrial campsites (See Section 12).

9. CHARACTERISTICS OF WASTEWATER

Certain unusual characteristics of the waste from northern camps have a bearing on the success or failure of a treatment unit. Although there have been no thorough studies reported on the composition of sewage from these camps, certain writers have observed features of camp life which affect waste flows and organic loading, and their predictions have been qualitatively borne out by the few tests which have been carried out. There is therefore, a need for further studies to determine waste flows and organic loadings from construction camps in northern areas. Typical design parameters used in Canadian and U.S. communities are contained in Table 3.

Quasim, and others[5] give anticipated loadings of 65 USgpd/man, 400 mg/l BOD_5 and 400 mg/l SS for non-polar advanced military bases of 500-1,000 men.

Table 3

Community	USg/ cap/d	ig/ cap/d	lb BOD/ cap/d	lb SS/ cap/d
Construction Camp	50	42	0.15	
Average Subdivision	80	67	0.17	
Hospitals	200	167	0.30	
Major Cities	135	112	0.20	0.23
Values Most* Frequently Quoted	100	83	0.17	0.20
Subdivision[6] (Zanoni and Rutkowski)	45	37	0.10	0.08

*These values yield a BOD_5 concentration in raw sewage near 200 mg/l, and a suspended solids concentration of 230 mg/l.

In the arctic, however, water can be a scarce commodity and water costs have ranged up to $1 per gallon. Where this is so, the pressure to reduce water use may result in unusually high concentrations of various constituents. Murphy, and Wagner[4] point out that the per capita organic load (assumed near 0.17 lb BOD/day) would be roughly constant regardless of the water use, from which they calculate that at a waste flow of 20 USg/cap/d a BOD_5 concentration of 1,030 mg/1 or more could be expected. Kreissl, and others[3] calculated concentrations of constituents in camp waste, using various assumptions, and concluded that by comparison with a typical municipal wastewater, camp sewage might be twice as high in BOD_5 or COD content and in NH_3-N, and perhaps five times as high in oil and grease. Clark and others[1] reported the results of a dozen test samples from north slope camps and the BOD_5, COD and SS values reported are nearly all extraordinarily high, bearing out the comments of the above authors. However, most of these samples were grab samples taken at arbitrary times of the day; and as the same authors point out, the routine of shift work in small camps would lead to severe peak hydraulic loads which are many times the average. A grab sample of raw sewage from the Yellowknife Correctional Camp had a BOD_5 of 516 mg/l and a SS of 523 mg/l. The camp had about 20 inmates at the time.

The figures on camp water use, indicate that the per capita usage varies between 50 and 120 US gal/day, averaging 84 USg/cap/d (70 ig/cap/d). Apparently, the high cost of water does not greatly concern the man on the job.

Waste treatment plants for northern campsites should be designed to handle wide variations in daily and hourly hydraulic loads and organic (BOD_5) loads. Flows may vary ten-fold almost overnight as crews arrive or leave, and may vary two or three-fold over the day, as different activities take place. BOD_5 loads, especially during periods of low flow, of over 1,000 mg/l should be expected. It may be possible to reduce fluctuations in flows by operational scheduling.

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10. WASTEWATER MANAGEMENT

10.1 COLLECTION AND HANDLING

There are many variables which influence the choice of a method for collection and handling of sewage from northern work camps. The most important considerations are population of camp, availability of water and the duration of the camp.

There are basically two types of toilet units that could be used at construction camps, fixed and portable.

Probably the portable types of toilets would be suitable for only very small, short term camps. The fixed types of unit most appropriate for the larger camps are minimum flush toilets, recirculating chemical toilets, vacuum toilets and standard flush toilets. The type of toilet to be used at each campsite would be decided by the contractor and would probably depend to a great extent on the availability and cost of water.

The type of collection system for the wastewater from the camps would in turn depend upon the types of toilet units used, climate and terrain, water consumption and the anticipated treatment method. The system may either utilize pumpout tanks and haulage trucks or it may be a piped system. If standard flush toilets are used, the system could probably be a piped one, either in a utilidor or underground. A vacuum system would require a pipe network to the vacuum tank.

Regardless of what type of system is used, it would be the responsibility of the contractor to ensure that the overall system was capable of operating under the extreme and varied climatic conditions of the North.

A detailed description of the various kinds of toilet units, along with the advantages and disadvantages of each is given in a supplementary report.

10.2 PROCESSING AND DISPOSAL ALTERNATIVES

10.2.1 Spray Discharge or Ditch Irrigation of Treated Sewage onto Scarred Land

A concept that has been considered is the irrigation of scarred land with treated sewage. Throughout large areas of the world, farmers have been using human and animal waste for centuries to fertilize soil. Even treated sewage effluents contain high concentrations of dissolved nutrients which would in general be more valuable if returned to the soil than if flushed out to sea. Furthermore, in the South, where population is more dense, the discharge of nutrients into surface waters frequently results in undesirable growths in our most prized lakes and rivers, and thereby upsetting fishing, swimming and drinking uses of these waters. Returning the sewage to the land can be a means of preventing deterioration of the recreational waters.

To a large extent the active soil layer, overlaying permafrost, has a low level of fertility. Revegetation of areas which have been cleared and scarred by construction is limited by the availability of plant nutrients.

While plant nutrients from sewage effluent are potentially dangerous to receiving waters, they may be regarded as a valuable land fertilizer which may be used to encourage revegetation of cleared and scarred areas.

There is, therefore, a need to devise and develop alternative methods of sewage disposal for the North which would not result in deterioration of the natural environment and at the same time would provide a resource of some benefit to these areas.

Problems may arise in operating spray equipment during periods of low temperature, and, in addition, the effluent may pond or become dispersed in the spring runoff.

Pilot projects are underway at present to evaluate the feasibility and impact of methods of wastewater disposal to scarred land to determine its value in promoting revegetation.

This method must be proven before it can be recommended as a disposal method.

Maximum application rates would be specified by the licensing authorities, depending on the permeability of the soil and the susceptibility of the area to erosion.

10.2.2 Discharge of Partially Treated Sewage to Remote and Inaccessible Swampland

This practice would seem to be satisfactory as long as settling ponds are provided for primary treatment and the drainage is generally away from inhabited areas. The main ecological change which might be expected is increased primary productivity caused by the added nutrients in the sewage. Such increased productivity is sometimes a problem in inhabited areas, where recreational or multi-use lakes and rivers are detrimentally affected by enrichment. Each swampland area must be inspected and approved before receiving effluent and must be inspected regularly.

A study of the swamplands at Hay River and Pine Point, to which settled sewage is being discharged, is now being conducted under the ALUR program.

10.2.3 Lagoon Waste Treatment (Sewage Oxidation Ponds)

The treatment of sewage in lagoons has been an accepted practice for a quarter of a century. With present technology this method of treatment is limited to use where there is sufficient isolated land.

In operation, the suspended and dissolved degradable substances are stabilized in long retention lagoons during the summer by aerobic microbial populations which are supplied with oxygen by algal photosynthesis or surface gas transfer. During periods of ice cover, the oxygen level falls to zero and anaerobic organisms degrade the organic materials in part.

With the present state of knowledge it is necessary to provide 100% storage of the sewage in a lagoon for a complete year. This retention allows the winter accumulation to be stabalized aerobically during the summer when there is sunlight for up to 24 hours per day.

Lagoons are, however, not universally applicable. In most small, northern operations, earth moving would be an expensive operation costing $\$2/yd^3$ or more. Suitable fill material for berm construction may be scarce and the haul distance long, raising the overall cost. Ground disposal of liquid waste by lagooning involves uncertainties associated with the nature of the soil, the presence or absence of massive ice deposits or ice wedges nearby, and possible thermokarst or thermal erosion. These uncertainties may, in unfortunate cases, lead to degradation of the lagoon berms and draining of the lagoon, to unwanted siltation or pollution of streams or to an unsightly and possibly odorous site. Changes in the lagoon cross section due to such degradations may further compromise treatment efficiencies.

While it is unlikely that a carefully sited and sensibly constructed lagoon would suffer from degradation to any serious degree, even in arctic areas, the fact remains that lagooning is essentially an uncontrolled process and that unforeseen difficulties of this nature are particularly hard to solve. Since a major objective of any waste treatment would be to prevent significant long-term despoliation of the campsite and its surroundings, the guidelines must require that the results of soil studies, drainage studies and surface mapping accompany a lagoon application to ensure as far as is possible, that the site chosen is indeed suitable. Furthermore, clauses must be included which require the maintenance of the lagoon in good order during use, and which, by means of draining, revegetation, or other expedients, ensure that the lagoon is left in a stable condition after the camp is vacated.

Unfortunately, because of many local variables, it is difficult to specify a reasonable set of preconditions for lagoon construction which would guarantee the structural integrity of the lagoon for all time. It is therefore possible, in permafrost areas, that there would be unforeseen extra costs in maintaining the lagoon site both during and after the camp operation, and extra funds could be allocated for this.

There are certain prerequisites which determine whether a lagoon could or should be built. The primary ones are geological and topographical; there must be a suitable site for the lagoon, from which the effluent can drain or percolate away from the camp. If permafrost exists at the site, the construction of a lagoon would create a thaw bulb in the permafrost; for this reason, relatively stable, low moisture soils are to be preferred at the lagoon site. The material used for berm construction must be left open to choice, since it would doubtlessly depend on the nature of the indigenous soil and the availability of gravel. Moisture-laden organic soils would be more subject to annual frost heaving and erosion difficulties, which would necessitate annual repair of the berms. Gravel berms have the disadvantage of permeability, but impermeable liners could be used in the lagoon.

Experience with sludge buildup has led authorities to recommend the provision of deep, short detention primary ponds to trap much of this material. An added benefit that these ponds provide is the maintenance of a relatively higher temperature in their lower layers, giving rise to a higher rate of anaerobiosis.

Mechanically aerated sewage lagoons were introduced within a decade of the acceptance of sewage lagooning as a treatment method. They consist of either oblong - or doughnut-shaped ponds in which very small bubbles of air are mixed into the contents of the lagoons. The efficiency of these systems in the North has not yet proven to be completely reliable.

10.2.4 Wastewater Treatment Plants

Biological Treatment Plants

All available biological treatment units operate essentially on the same principle, that of the conversion of degradable organic material in the wastewater into a microbial mass with the accompanying production of CO_2, H_2O and NH_3, thereby reducing the solids to be disposed. In practice, the microbial mass is wasted by settling, dewatering and disposing on land. The activated sludge treatment plant and its modifications, are frequently-used methods of wastewater treatment. A relatively new type of biological treatment plant is the bio-disc process, where the bacterial mass develops on large rotating discs, which are partly immersed in the wastewater.

Biological treatment plants are capable of high levels of efficiency and do not require costly chemicals for operation. However, such plants require considerable power input as well as trained operators to maintain maximum efficiency to be achieved and may require a certain time to achieve maximum efficiency after initial start up.

In general, the plants require a certain time to achieve maximum efficiency after initial start up.

Physical-Chemical Plants

In a physical-chemical treatment plant, a coagulant is added to the sewage which causes a floc to form. The floc entraps the suspended and colloidal material which settles or is filtered out. Carbon adsorption may be used to remove the remaining dissolved organic material.

These treatment plants are resistant to shock hydraulic and organic loads and do not require a start-up time to achieve maximum efficiency. They do require significant quantities of chemicals to operate and produce large quantities of sludge which must be disposed of, possibly by incineration, landfill or spreading on land. In addition, to perform efficiently, they require trained operators.

In general, all systems involving treatment plants must be critically analyzed for their sensitivity to mechanical failure and provisions must be made for spare parts and standby units in case of shutdown. The plants must be housed and heated so that operators may carry out needed repairs and maintenance programs in relative comfort. It must be emphasized that the waste disposal system should be under the direction of a responsible person if efficiency of operation is to be attained.

The principles of operation of both biological and physical-chemical plants are discussed in more detail in a supplementary report.

11. SUGGESTED GUIDELINES FOR WASTEWATER MANAGEMENT

The primary objectives of wastewater management as applied to work camps in the North should be:

(i) The protection of the natural environment.

(ii) The protection of the public health.

(iii) The development of innovative techniques for the treatment of wastewaters.

(iv) The beneficial utilization of wastes.

Preliminary technology -- by construction activities.

High standards should govern the treatment and disposal of waste along the Mackenzie Valley Pipeline Corridor. No single sewage treatment alternative is optimum everywhere in the North when economics, operator requirements, public health and environmental effects are considered. Conversely, none of the major alternatives can be considered to be unsuitable for every situation. The guidelines, therefore, should not be concerned with the choice of system, but rather they should specify the requirements which any particular system should satisfy if it is to be acceptable.

Eventually standards should be prepared which would be applicable throughout both the Yukon Territory and the Northwest Territories; and all sets of standards should be equally high and compatible. It is recognized that it is impracticable to require all the settlements to attain compliance with these high standards immediately, but they should take steps to do so as soon as reasonably possible. The installations in a Mackenzie Valley Pipeline Corridor would be new, and initial compliance should be required.

Standards should take into account the differences of size and duration time of workcamps. For example, small camps which move every two to five days could be permitted, in most cases, to utilize acceptable methods of ground disposal. Varying degrees of treatment should be required of more permanent or larger camps following a study of the situation.

Innovative methods of treatment of waste should be encouraged. In this way there may be technological development which would benefit not only the particular industries and workcamps involved, but also other installations within the Valley and also throughout the Canadian North.

A waste management control agency could be named to receive applications for workcamp permits, granting licenses, inspecting and monitoring, and applying guidelines.

APPENDIX

EXISTING LAWS, REGULATIONS AND GUIDELINES AFFECTING WASTE DISPOSAL IN NORTHERN CANADA

1. Territorial Lands Act, 1950. Amended 1970.

   The 1970 amendment provides the legislative authority for the Territorial Land Use Regulations promulgated for the protection control and use of the surface of territorial lands. These regulations provide general rules for the protection of land wherever excavation, clearing or construction is proceeding, maintenance of campsites, fuel storage and archaeological sites. The amendment also provides for the establishment of land management zones within the territories in which more stringent regulations can be applied and in which the operator must apply for and receive a permit prior to commencing a land use operation. The "Mackenzie Pipeline Corridor" is situated within land management zones 1 and 2 of Northwest Territories and land management zone 3 of Yukon Territory.

2. Northern Inland Waters Act, 1970.

   The Act is a management piece of legislation and its provisions deal with the preservation, protection, multiple use and restoration of the inland waters of the North. Property and the beneficial use of all northern waters is vested in the Crown with the right to use water obtainable by licence. Territorial water boards, set up under the Act, assist the Department of Indian Affairs and Northern Development in the management process and it is the Boards who consider applications and issue water use licences. There is a nine member Board in each Territory, comprised of six officials from federal agencies with certain water interests in the North and three members named by the Commissioner of the Territory.

   The Northern Inland Waters Regulations, promulgated on 14th September, 1972, were directed primarily at the licencing process. In addition to establishing certain geographical regions in each Territory as water management areas, the Regulations classify uses of water, outline procedures for licencing water use, and prescribe application and user fees.

   Although the Act authorizes the prescription of water quality standards by regulation, no such regulations have been promulgated. However, the deposit of domestic waste is controlled under the present Regulations while the deposit of all other waste is controlled through the terms and conditions attached to water use licences.

A set of Regulations defining water quality standards is being prepared. The approach will probably be similar to the Alaskan approach in that the standards adopted will be at least as good as the current water quality and therefore no degradation will in theory be permitted. Effluent standards will also be established for specific water use operations.

3. The Fisheries Act, 1932. As Amended.

The pollution of fish frequented waters, or of streams flowing into these waters by "lime, chemical substances, drugs, poisonous matter, dead or decaying fish, or remnants thereof, mill rubbish or sawdust or any other deleterious substance or thing"... is specifically prohibited in Section 33 of this Act. Regulations interpreting this potentially powerful section have recently been updated and relevant sections will be appended to this study when available. The Canadian Fisheries Service and the Environmental Protection Service are represented on the Land Use Advisory Committee, and also on the Water Board of each territory. Any standards recommended in the regulations under this Act will therefore carry much weight in permit or license processing.

4. The Northwest Territories Public Health Ordinance and the Yukon Territory Public Health Ordinance.

These two ordinances, which are administered by the Northern Region, Medical Services Directorate, Health and Welfare Canada, on behalf of the Commissioner of each Territory, contain regulations to control the disposal of wastes in the two territories.

For example, the General Sanitation Regulations of the Northwest Territories state in Section 21, "No sewerage system, septic tank or cesspool shall be so constructed, operated or maintained that the effluent therefrom discharges:

(a) In a location or in a manner likely to be injurious to health;
(b) Into any stream, river, channel, watercourse, or lake without the written permission of a Medical Health Officer;
(c) Less than 100 ft. downstream from the inlet of any pipe withdrawing water for human consumption."

The pertinent regulations under the N.W.T. ordinance are:

(a) General Sanitation Regulations
(b) Eating and Drinking Regulations
(c) Camp Sanitation Regulations
(d) Public Water Supply Regulations
(e) Public Sewerage System Regulations (pending)

and under the Yukon ordinance are:

(a) Eating and Drinking Regulations
(b) Camp Medical Care Regulations
(c) Regulations Respecting Public Health
(d) Regulations for the Sanitary Control of Lumbering, Mining, Construction and other camps.

SUPPLEMENTARY REPORT A

SEWAGE LAGOON SYSTEMS

Part I - The Design of a Sewage Lagoon System
Part II - Case Histories of Lagoon Sewage Treatment in the Mackenzie District

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This report is published as a supplement to the report "Management of Waste From Arctic and Sub-Arctic Work Camps", by J. W. Grainge, R. Edwards, K. R. Heuchert and J. W. Shaw.

PART I

THE DESIGN OF A SEWAGE LAGOON SYSTEM

Basic Design Considerations

In designing a sewage pond system which will provide acceptable treatment, we must first understand the unusual characteristics of the ponds which are related to the amount of sunlight and the temperatures which occur in the North.

There is ice and snow cover on the ponds for a much longer period of time in winter, which reduces the sunlight, so that the algae cannot photosynthesize. This process is the principle factor in the reoxygenation of the water in the pond. In addition, of course, the ice prevents the physical reaerating of the water by the dissolving of oxygen at the surface. As a result, the aerobic decomposition processes in sewage ponds in winter are not significant. Studies of lagoons in Alberta[6] and the Mackenzie District [2,3] have demonstrated that when the ponds are anaerobic in winter, there is sedimentation, but little organic decomposition activity.

In summer, the sunlight reaches the surface of the water for a much longer period of time each day than in the temperate zone. This results in almost continuous algal photosynthesis and although the metabolic processes may be slower due to the colder temperatures, the longer periods of algal activity more than compensate for this deficiency. As a result, dissolved oxygen levels of over 200% saturation have occurred in the surface layers of the N.W.T. lagoons.

It is necessary to consider these two effects in planning a sewage pond system. Where primary treatment is satisfactory, two "primary" ponds which provide a few days of theoretical retention time will be adequate.

When secondary treatment for the effluent is required, a "secondary" pond is required which will provide 100% storage of the sewage for a full year. Effluent from the pond would not be discharged until the aerobic conditions had existed throughout the pond for a complete summer. Under these conditions, treatment equivalent to secondary treatment would be obtained.

A new set of criteria should be developed to judge the effluent from sewage ponds, because of fundamental differences between ponds and treatment plants. Secondary sewage ponds are in fact very fertile lakes, and the effluent should probably be judged by standards which take this into consideration rather than by those which have been developed for effluent from mechanical treatment plants.

The development of these standards should be based on comparative studies of the protection given to water supplies and the concentration of nutrients maintained in the downstream receiving waters by both treatment plants and ponds. It would be most interesting also to have a study done by biologists on the comparative effects of the discharges from sewage lagoons and naturally eutrophic lakes on receiving waters.

Sewage Lagoon Construction Criteria

Dawson and Grainge[4] proposed design criteria for wastewater lagoons in arctic and sub-arctic regions based on studies by Dawson in 1965 and 1966.[2,3] More recent routine examinations of the operation of lagoons in the Mackenzie District tend to substantiate their conclusions and recommendations which are summarized herein.

The basic objective is that the lagoon should provide effective methods of wastewater disposal without creating objectionable conditions or public health hazards in the vicinity or downstream in the receiving water course.

The lagoon should incorporate the following qualities:

1. The lagoon should be structurally sound and esthetically acceptable.

2. The operation should be free from objectionable odors or nuisance conditions.

3. Breeding of macroinvertebrates, such as insect larvae and adults, worms, etc., should be minimized.

4. Seepage from the lagoon should be prevented if pollution of drinking water aquifers or surface streams might occur.

Effluent quality of the lagoon must maintain certain standards:

1. The lagoon must be designed to provide effective removal of organic material and destruction of

harmful biological organisms.

2. The levels of oils, grease, color and floating and settleable solids in the effluent should meet the currently acceptable effluent standards.

3. Conditions in the receiving water should meet the currently accepted standards.

Classification of Lagoons

Wastewater lagoon systems for the arctic and sub-arctic regions will be classified into four types:

1. Single-Cell Long Retention
2. Primary Short Retention
3. Secondary Long Retention
4. Aerated.

The term "secondary long-retention ponds" is used to distinguish between single-cell and multiple-cell lagooning systems.

Single-Cell, Long-Retention Lagoons

These ponds are most suitable for small installations. The ponds should allow for variable depth operations. A summer operating depth of 4 to 5 ft is optimum. However, in winter, the pond will freeze to depths which vary up to 5 ft. Therefore, the winter operating depth should be such that there is a 3 ft minimum depth below maximum ice cover, i.e., from 6 to 8 ft.

In order to achieve the equivalent of secondary treatment, the retention time should be 12 months, which will allow complete storage throughout the winter and stabilization in the summer months. BOD loading may be up to 20 lb of 5-day BOD/day/acre. The pond site should be located a minimum of 1,000 ft from the nearest residence. If practical, the pond should be situated so that the prevailing low winds blow across the pond towards uninhabited areas. Also ponds should be downhill and downstream from sources of water supplies.

The berms should be constructed of impervious material and compacted to form a relatively stable structure. A minimum top width of 10 ft is desirable to permit maintenance vehicle access. A horizontal to vertical slope of 3:1 is most common with clay soils. However, steeper slopes can be utilized if the structural properties of the soil permit. Where wind erosion or unstable soils are factors, shallower slopes, such as 6:1, are recommended. A minimum 2 ft summer freeboard is advisable which can be reduced to 1 ft during winter to increase the storage volume. The berm should be made impermeable to prevent surface ponding outside of the lagoon. Following construction, the berms should be seeded to grass.

The bottom should be made impermeable if water-aquifer contamination, short-circuiting to a surface stream, or ponding on the surface outside the berms could occur. In addition, if seepage causes exposure of sludge banks, sealing is required.

Normally, the lagoon should be square or rectangular with rounded corners. However, if mixing and circulation is not impaired, a lagoon of another shape may suit the topography and be more pleasing in appearance and less expensive to construct.

The inlet should extend well into the lagoon, so that the sludge will be distributed by wind-induced currents. Usually the inlet will be subsurface, and located along the bottom of the pond.

Forcemains should be extended to the center of the lagoon terminating with an upturn elbow set on a concrete pad. The forcemain must be so designed as to avoid any possibility of the lagoon contents siphoning back into the lift station in the event of a check valve failure or any other mechanical failure. A forcemain discharging above the surface of the lagoon would be a satisfactory anti-siphon measure.

Gravity mains should extend past the toe of the berm, and sludge should be prevented from blocking the end of the pipe by horizontal discharge to a saucer-shaped excavation in front of the pipe.

Both overflow and drain outlets should be provided. The overflow device should be adjustable to permit operation at depths between 3 and 8 ft.

Primary Short-Retention Ponds

These ponds are suitable for use either by themselves where an equivalent of primary treatment is required, or with secondary long-retention ponds. At least two ponds capable of series operation generally are used.

A four-pond arrangement, inter-connected for any combination of series or parallel operation, is preferable to provide efficient treatment and flexibility of operation in case of odors.

An operating depth of from 10 to 25 ft is desirable. Deep ponds conserve heat and help maintain an efficient anaerobic process. A deep water layer is also provided on top of the decomposing sludge to prevent the escape of odorous gases.

A two to four-day retention period in each pond is desirable. A loading from 6 to 9 lb 5-day BOD/day/1,000 cu ft is optimum. Short-retention ponds should be isolated at least one-quarter mile downwind of the nearest residence of any permanent settlement. The construction criteria are the same as for the long-retention ponds with the following exceptions:

1. The berm slope should be steeper if stable soil materials are available (i.e. 2:1 horizontal to vertical maximum).

2. Impermeable berms must be provided.

3. For pond inlet structures the inlet sewers should discharge to a depth of approximately 6 ft. They should terminate well above the accumulating sludge. A concrete pad and riprapped slopes are required to prevent erosion of the berms.

4. Short-retention ponds will overflow all year long. Therefore outlet structures need not be capable of variable depth operations. The outlet should draw from a depth of approximately 4 ft.

The four-pond system allows flexibility in operation. Three ponds can be operated in series for several years until the primary pond is half full of sludge. At this time, raw sewage can be introduced into the unused pond in series with the other ponds, while the initial primary pond is rested. After a long period of digestion, the sludge can be pumped from the pond used as a primary cell and then this pond can be returned for service.

Secondary Long-Retention Lagoons

The secondary pond should be designed according to the criteria established for single-cell lagoons. However, the inlet arrangement is usually a simple valved overflow pipe from the short-retention pond. The combination arrangement of short-retention and long-retention ponds is now the preferred method of lagoon sewage treatment for permanent establishments. The long-retention ponds should have a 12-month retention time.

Aerated Lagoons

Aeration of deep short-retention lagoons allows increased loadings with maintenance of aerobic conditions and equivalent efficiency to secondary treatment.

We recommend a minimum depth of 10 ft, a maximum of 20 ft, a retention time of 30 days and a BOD loading of up to .6 lb 5-day BOD/day/1,000 cu ft.

Compressed-air introduction of oxygen is preferable to mechanical aeration since ice buildup in the latter might be excessive unless care is taken to avoid this. Construction of the lagoon should conform to the criteria established for short-retention ponds. Since aerated lagoons are completely in the aerobic state, isolation of the ponds is not critical as with long or short-retention ponds. A minimum of 300 ft from the nearest residence and 100 ft from the nearest roadway should be satisfactory.

Waste should be discharged by the forcemain or gravity inlet to a minimum depth of 6 ft. Outlets should be designed to draw from a depth of 3 ft below the liquid surface during summer and 6 ft below the surface during the winter. Pond drains should be provided so that the cells may be emptied completely if necessary for maintenance. Multiple pond installations are desirable and should be designed to allow either series or parallel operation.

A settling zone should also be provided prior to the effluent discharge.

Soil Conditions and Berm Construction Methods for Lagoons in Permafrost Areas

We have no experience with lagoon construction in very unstable permafrost conditions. However, some conclusions may be drawn from various other investigations of permafrost.

Mackay[7,8,9] defines the distribution of ground ice in permafrost areas, and how it was formed. He points out that a high percentage of the massive ice deposits found in the western Arctic were formed through a process of "ice segregation" in which water from the unfrozen regions of the soil migrates to the freezing surface, creating a supersaturated condition in the frozen soil which contrasts markedly with the saturated or unsaturated condition of frozen soils.[8] It is these supersaturated soils that cause nearly all of the problems associated with engineering and construction in permafrost regions. Should the surface cover be disturbed, this tends to result in an increase of the mean surface temperature in the summer months, and hence an increase in the depth of the active layer.

Increasing the depth of the active layer is not in itself necessarily a problem. If the upper layer of permafrost consists of undersaturated material, and is of adequate thickness, then little or no settlement will result from thawing this layer. If, however, the upper layer of permafrost is supersaturated then, upon thawing, the excess water will separate from the smaller amount of saturated soil and settlement will occur. This is what is known as "thermokarst", and it is this phenomenon rather than thermal erosion, which is of chief concern to engineers. Supersaturated conditions in the upper 5 or 10 feet of permafrost are "widespread" in the western Arctic, and the ratio of excess water to saturated soil may be as much as 5:1 or 10:1.

The depth of the active layer in undisturbed ground is reasonably clearly related to ground-surface cover and surface soil type. If the surface is removed or disturbed, then from this knowledge we can predict approximately the new equilibrium depth of the active layer. From a knowledge of the ice content of the permafrost at the site, we can then compute simply the amount of permafrost that will melt to establish the increased active layer depth.

To summarize, with respect to lagoons, if an area is chosen which does not intersect any significant surface or subsurface drainage patterns, thermokarst, rather than thermal erosion will be the primary disturbance feature. If the lagoon is then bulldozed clear, removing the surface cover and the upper foot or so of the active layer, the worst result one could reasonably expect would be a settlement of the lagoon bottom some 2 or 3 ft, depending on the supersaturation of the exposed permafrost. The excess water released would largely remain on the surface if the soil is not permeable, forming a typical thermokarst lake.

Gold, and others[5] warn that disruption of drainage patterns is likely to have more far-reaching effects. If the lagoon were sited, for example on a slope, then the impoundment of water caused by the berms will create a lake, and new drainage channels, both of which will upset the previous equilibrium and cause melting of permafrost. In addition, the flowing effluent may exert a thermal erosion effect, in addition to thermokarst, which may cause gullying at some distance from the original construction. In many such areas, ice wedges* are common[7] and running water will move along these wedges as they melt.

For these reasons, it appears logical to site the lagoon in a flat area where erosion by drainage is unlikely to be a problem.

Gold, and others[5] summarize the available methods for estimating heat transfer in soils and the effects of various construction such as pipelines or insulating pads on the permafrost. These methods assume numerous simplifications; among them, homogeneous soils, simple conduction as the sole form of heat transfer, uniform moisture content, and the like. Such conditions are rarely found in practice, and the authors point out several limitations to the theory. This paper contains no indication of detailed methods for estimating undercutting of a linear berm beside a lake or a lagoon although some simplified theory can undoubtedly be established that would assist in recommending lagoon berm designs for permafrost regions. It would be logical to pursue this study.

On the basis of this limited survey, the following preliminary recommendations emerge for lagoon siting and design in permafrost regions.

<u>Lagoon Siting and Design in Permafrost Regions</u>

1. Site the lagoon in a flat or low-lying area, or a natural depression, where no significant surface or subsurface drainage paths will be affected.

2. Determine the ice content of the permafrost, and the existence of any massive ice or ice wedges by taking core samples under the lagoon site. Make estimates of the extent of thermokarst and of any predicted erosion effects.

* Ice wedges are vertical sheets of wedge-shaped ice in the ground which result in the formation of the polygon ground patterns common in tundra areas.

3. The berm designs should contain features which will tend to aggrade, or raise the permafrost underneath the berm. This will reduce the annual maintenance which would otherwise become necessary as the berm foundations slump and erode.

   Methods which could be considered are:

   (a) Construct the lagoon and berms in late fall, to avoid thermokarst problems until the following summer.

   (b) Ventilate the berms in winter through conduits placed during construction.

   (c) Choose insulating soils or artificial insulating layers to preserve the frozen foundation.

4. The effluent from the lagoon should be diverted either to existing drainage channels wherever possible, or to ditches in unsaturated soils which are free of massive ice deposits.

5. The lagoon and effluent channel should be sited so that, in the event of unforeseen thermal damage, no harm can come to nearby constructions and no contamination of water supplies in the vicinity will occur.

Further Research Required

In addition to the further investigation required to refine the design and construction criteria for sewage lagoons, research into the alternatives noted in Part I is also needed.

There are many places in the North where irrigation with water containing nutrients might be desirable from the point of producing a more interesting landscape. For example, large areas of the Arctic are bare ground, gravel or tundra. It would not be wrong to landscape some of this and make it more interesting visually by inducing plant growth of some kind in some barren areas and replacing some of the native vegetation with grass. Many of the small communities may be made more pleasant by an improvement of the landscape around them.

Many settlements in the North border swampland and, usually, the most obvious effluent disposal point is to one of the lakes in the area. Often, too, the swampland is so close to the town that there is no room for pond construction in the area. There is a need to define the effects of sewage effluents on swamps and likewise the effects of swamps on sewage effluents.

Treatment Obtained by Seepage from Ponds

Seepage from sewage ponds may be up to 100%. The treatment of the effluent which is obtained by seepage through the soil will vary according to the particular sizes of the soil and the length of the seepage path. Very little treatment would be obtained when the effluent seeps only a short distance away from the pond. However, in some cases, the effluent seeps through sandy soil for a considerable distance before it surfaces.

A few studies have been made on the extent of the treatment which will be obtained by seepage of sewage through soil, but the information has not been evaluated and compiled so that the design engineer can make dependable predictions about the degree of treatment to be obtained in the seepage.

It would be worthwhile to make a literature survey of the subject of treatment obtained by the seepage of sewage through soil and compile the information in the form of a report. An actual research project is not warranted at this time because it would yield too little information considering the time which would be required for the study.

However, whenever the soils investigation indicates that there will be a substantial amount of seepage from a pond, then there should be an assessment by the design engineer of the probable effect on water aquifers and surface water bodies in the vicinity.

It would be undesirable from public health and esthetic standpoints for the seepage to appear on the surface near to a pond.

To conclude this section suitable designs for the various types of sewage lagoons are illustrated in Figures A-1 to A-7.

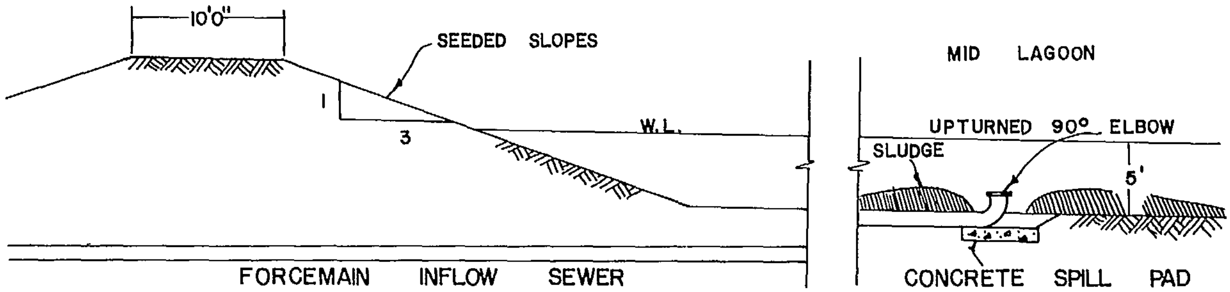

FIGURE A- 1 LONG - RETENTION POND with typical forcemain inflow at summer operating depth

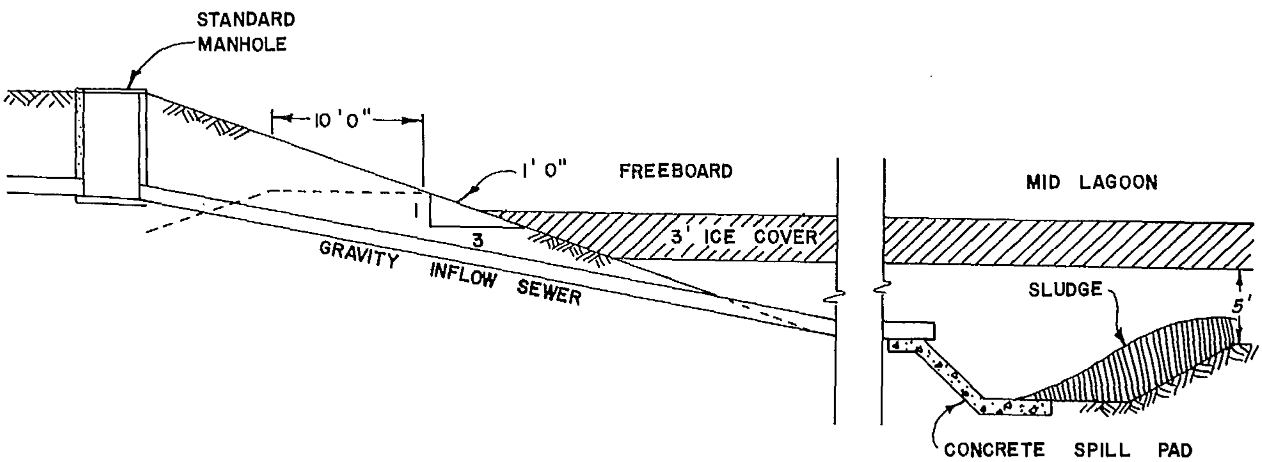

FIGURE A- 2 LONG - RETENTION POND with typical gravity inflow at winter operating depth

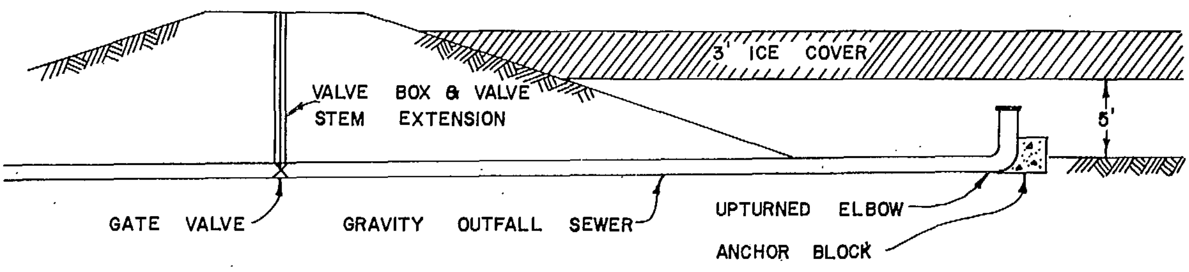

FIGURE A-3 LONG-RETENTION POND with valved overflow pipe at winter operating depth.

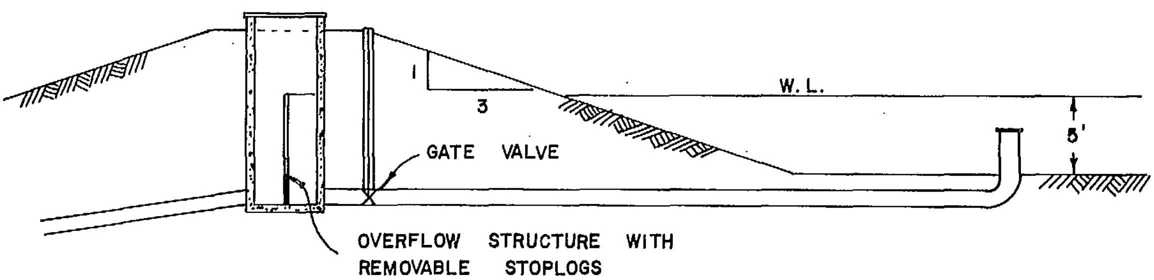

FIGURE A-4 LONG-RETENTION POND with variable depth overflow weir at summer operating depth.

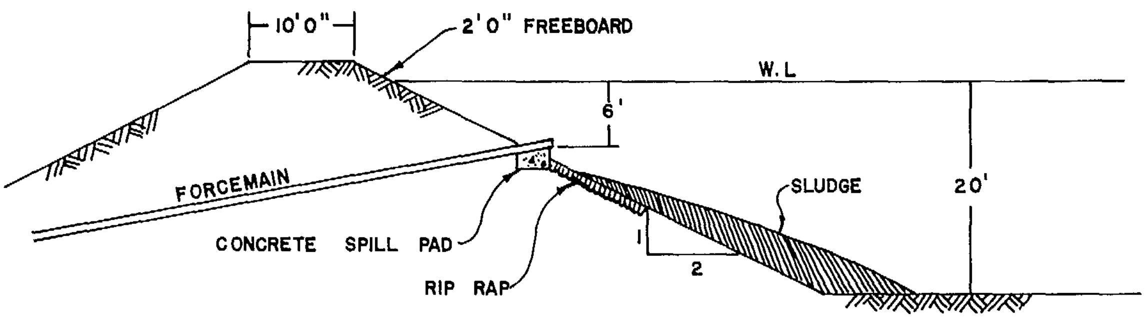

FIGURE A-5 SHORT-RETENTION POND - typical forcemain inlet.

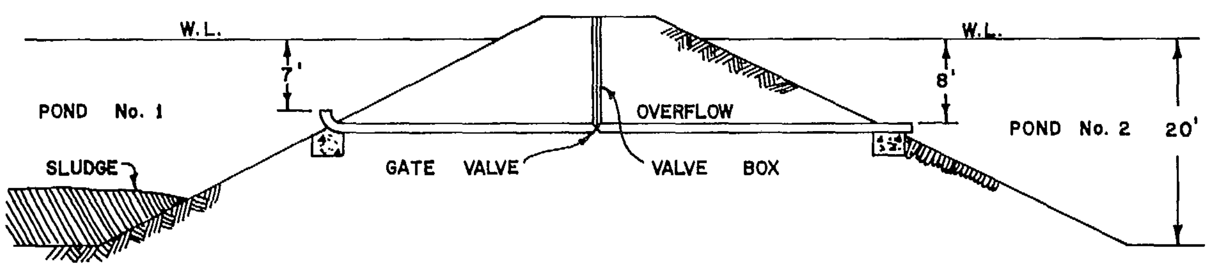

FIGURE A-6 SHORT-RETENTION POND - typical overflow between series ponds.

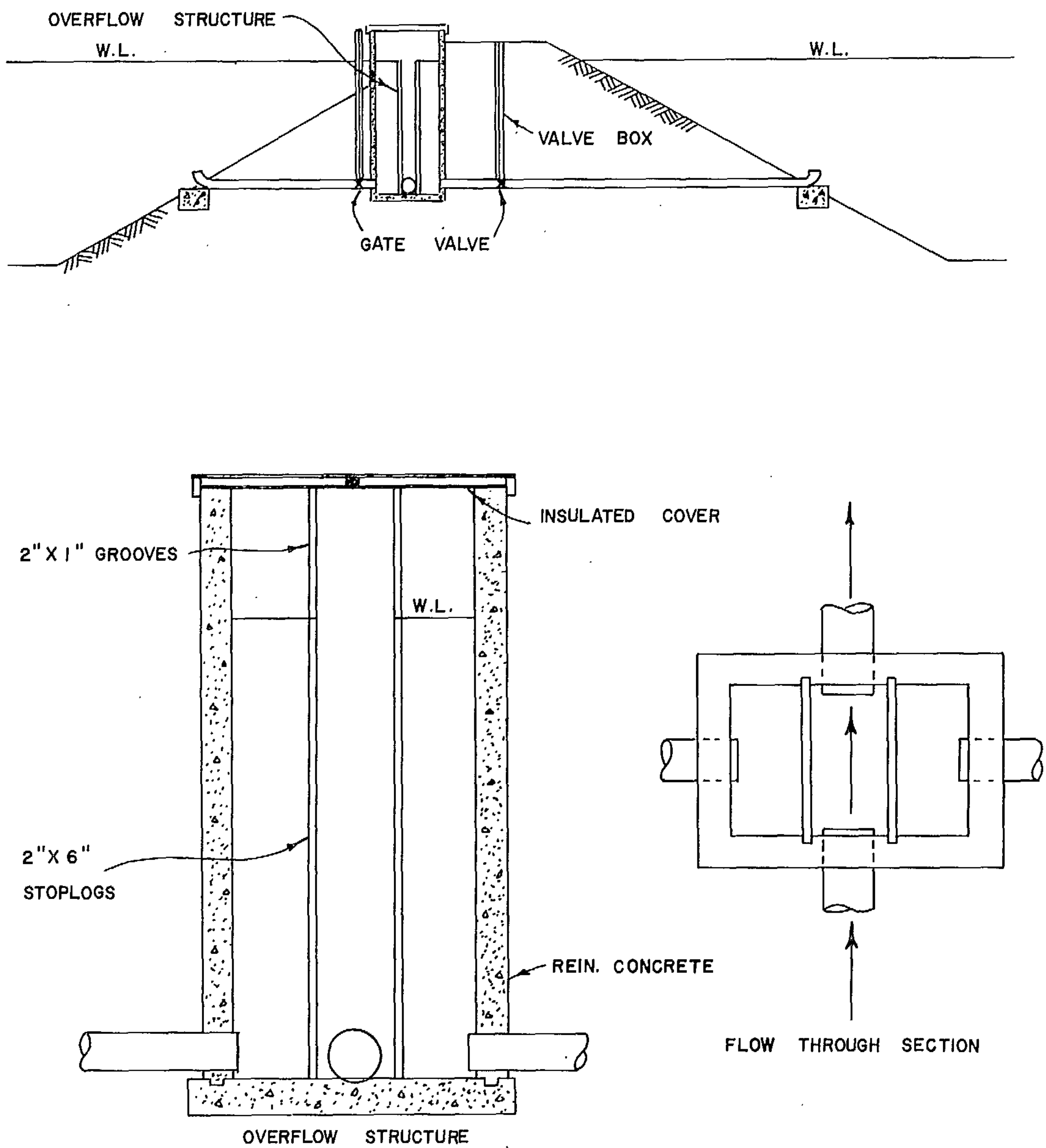

FIGURE A-7 SHORT-RETENTION POND - variable depth overflow from parallel ponds

PART II

CASE HISTORIES OF LAGOON SEWAGE TREATMENT IN THE MACKENZIE DISTRICT

Long-Retention Lagoons

1. The Town of Inuvik Sewage Lagoon

The northwest lagoon, which we have studied, is that serving Inuvik. Inuvik is situated on the east boundary of the Mackenzie River, approximately 60 miles from the Arctic Ocean at 68°21' N Lat. Originally, the ultimate population of Inuvik had been estimated to be 1,000 people. The lagoon was required, therefore, to provide at least a year's retention time for the anticipated sewage flow equivalent to this population.

The lagoon was built in 1959 by the simple expedient of constructing a road along the western boundary of a natural depression. The lagoon does not conform to the usual design criteria for berm construction, bottom preparation, etc. The sideslopes on the three sides boundaried by the road are 3:1 horizontal to vertical, while the natural slope on the eastern side varies from 4:1 to 30:1. Bottom preparation and brush cutting in the lagoon basin were not attempted during construction because of the swampy nature of the overburden. Therefore, approximately 60% of the lagoon is covered with scrub willow and alder and many large trees up to 6 inches in diameter. At the north end an effluent weir consisting of removable stoplogs controls the liquid level.

Effluent from the lagoon follows the original drainage course of the depression to a point of discharge into the Mackenzie River approximately 4,000 ft downstream from Inuvik. The lagoon is approximately 43.5 acres in area and averages about 4 ft in depth. It is 3,200 ft long and from 300 to 700 ft in width.

When Dawson[2] studied the operation of this lagoon in 1965 and 1966, the contributing population had already reached 1,500 people. Runoff into the lagoon reduced the theoretical retention period to about one-half year. Nevertheless, despite the construction deficiencies and the increased population, the lagoon produced an 85%

reduction in BOD from raw sewage to effluent in summer and 45% reduction in winter. The suspended solids were reduced by 91% in summer and 90% in winter and coliform bacteria were reduced by 99.9% in summer and 99.8% in winter. The last data which we have from the latter part of 1968 shows the lagoon still providing over 85% reduction in BOD with the contributing population approaching 2,000. The contributing population is now close to 3,000 but the lagoon is still apparently providing yeoman service. There is a slight odor problem for a short period in spring which affects some houses which have been built very close to the lagoon.

The mean annual temperature at Inuvik is only 16°F. The average temperature at Inuvik rises above 32°F for only 4 months of the year, i.e., June, July, August and September, as compared for example, to the 7-month periods in the prairie provinces where lagoons are common. This is particularly important during the ice-covered season when light is excluded from the lagoon.

Precipitation is very light in Inuvik, being only a little over 9 inches a year. A feature of the climate which favors lagoon treatment is that during the 4 summer months the daily temperatures at Inuvik are not much lower than in the prairie provinces, and for most of the open water period the sun shines for almost 24 hours a day.

2. <u>The Town of Fort Smith Sewage Lagoon</u>

Fort Smith is situated on the west bank of the Slave River just north of the Alberta-N.W.T. boundary, which is the 60th parallel.

The lagoon serving this town is an engineered design and well constructed. The lagoon is square in shape, 10 acres in area and with a common usual depth of 4 ft. The inside berm slopes are 4:1 horizontal to vertical, and the exterior slopes 3:1. It was built in 1960 to serve the population of 1,000 people on the basis of 100 people per acre of lagoon surface. Currently, it serves about 2,000 people, receives 100,000 imp gal per day of sewage, and has a retention time of about 3.7 months.

In summer, the lagoon achieves an 87% reduction in BOD, 95% reduction in suspended solids, and significant reductions in nitrogen, phosphate and methylene blue active substances. In winter, it achieves a 53% reduction of the BOD and 72% reduction of the suspended solids. Unfortunately, there are no bacteriological data.

The sewage is comminuted and pumped to the lagoon. At the end of the forcemain there is a 100 ft x 100 ft x 2 ft deep pit in the bottom of the lagoon. A large sludge bank has accumulated in this pit over the years and its top surface is now only 1 or 2 in below the lagoon surface.

The forcemain ends in one corner of the lagoon at a point about 100 ft equidistant from the two sides. It is possibly due to the location of the forcemain in this position, rather than in the center of the lagoon, that the solids have accumulated and have not been more evenly distributed throughout the lagoon by wind currents. In summer, the lagoon shows signs of overloading in that the dissolved oxygen is absent or very low throughout much of the lagoon. Nevertheless, the lagoon is maintaining a very high level of efficiency. The lagoon is odorous for a short period in spring but it is quite distant from the town so that there is no nuisance.

The effluent from the lagoon flows towards the Slave River, but in summer it percolates into the sandy soil of the river bank before reaching the river.

In winter it is probable that the effluent flows under the snow and finally reaches the river.

3. <u>Fort Smith Airport Sewage Lagoon</u>

This lagoon serves about 95 people who are resident on the airport complex and approximately 8 other employees and 30 to 40 passengers a day.

The lagoon is square in shape with bottom dimensions of 200 ft x 200 ft and a maximum depth of 6 ft with 1 ft freeboard. At the forcemain inlet there is a 30 ft x 30 ft x 2 ft deep pocket at the bottom of the lagoon to hold the accumulating sludge. Berm slopes are 3:1 horizontal to vertical and the berm is 10 ft wide at the top.

The lagoon capacity is 1,780,000 imp gal at the maximum depth which is 6 ft. The lagoon is lined with 6 mil polyethylene which is protected by 6 in of coarse sand. This lagoon operates on the fill and draw principle. The full winter flow is retained in the lagoon long enough during summertime for stabilization of the contents to occur. The effluent is then released.

The effluent seeps away into the sandy soil of the woodland between the lagoon and the Slave River which is about ½ mile west.

The lagoon was built in 1961 for a design flow-rate of 8,000 imp gal per day and a retention time of about 7 months. Currently, the lagoon receives about 5,000 imp gal/day and the retention time is approximately 12 months.

In summertime, the lagoon supports a prolific growth of algae. In the mid-afternoon the lagoon is usually supersaturated with dissolved oxygen. The lagoon contents showed reductions of 80% in BOD from the raw sewage and 46% for suspended solids. However, two-thirds of the remaining BOD and most of the remaining suspended solids are not due to sewage but to the concentration of algae in the lagoon liquor. The coliform reduction is estimated to exceed 99.99%.

Short-Retention Lagoon Systems

1. The Town of Hay River Sewage Lagoon System

The Town of Hay River is situated on the south shore of Great Slave Lake where the Hay River discharges, at a Lat of 60°50' N.

The lagoon system consists of two deep short-retention cells, Each cell is square in shape with bottom dimensions of 35 ft x 35 ft and a working depth of 12 ft. The interior berm slope is 2:1. The cells may be operated singly or in parallel or in series.

The system was built in 1968 and designed for a population of 1,700 and 45 imp gal per capita per day allowing a retention time of 10.7 days for the two-cell operation. Currently, the system serves about 1,600 people, but the water consumption is much higher than anticipated, and the retention time for two-cell operation is only 4.4 days.

In the summer the lagoon achieves a 41% reduction in BOD and 69% reduction in solids. In wintertime, the BOD is reduced by 43% and the solids by 81%. The slightly lower figures for summer operation are probably due to the prolific growth of algae which occurs in the surface layers of these primary lagoons. Sunny weather results in supersaturation with dissolved oxygen in the surface layer. Rough measurement of the sludge accumulation in these primary lagoons indicates that the accumulation rate is about 9.4 cu ft/1000 persons/day. This compares with the accumulation rate found by Dawson[3] at Yellowknife of 12.9 cu ft/1000 persons/day. Higo[6] found an average accumulation of 7.6 cu ft/1000 persons/day in 4 Alberta ponds.

The effluent flows from the lagoon approximately 4 miles through swampland to Great Slave Lake. The effluent is drawn from a depth of 4 ft in the lagoons and is usually devoid of dissolved oxygen. In summer, the drainage into Great Slave Lake from the swamp, including the sewage effluent, has a dissolved oxygen of 5.6 mg/1, a BOD of 2.2 mg/1, suspended solids of 16 mg/1 and very low nitrogen, phosphate and methylene blue active substance levels. These reductions cannot be accounted for by dilution in the drainage from the swamp area. It must be assumed that there is considerable uptake of nutrients in the swampland and further stabilization of the organic content of the sewage effluent.

2. <u>The Hamlet of Pine Point Sewage Lagoon System</u>

Pine Point is situated 4 miles from the south shore of Great Slave Lake about 60 miles east of Hay River at a lat of 60°50'N.

The lagoon system, which was built in 1963, although based on our recommendation for an anaerobic lagoon system, does not meet our currently proposed criteria for anaerobic lagoon systems.

The lagoon consists of two cells in series. The first cell has 384 ft x 148 ft bottom dimensions, a working depth of 6 ft and a 3 ft freeboard. An overflow channel in the berm limits the depth. Interior berm slopes are 3:1 horizontal to vertical and the berm is 10 ft wide at the top. There is a wedge-shaped sludge pocket in the bottom of the lagoon at the raw sewage inlet. The pocket is 50 ft x 50 ft x 2 ft deep at the inlet side. The cell has a capacity of 2.5 million imp gal or 401,000 cu ft and a surface area of 1.77 acres at a liquid depth of 6 ft.

Raw sewage flows into the first cell at the middle of one long side. Effluent is drawn from the bottom of the lagoon in the middle of the other Long side at a point directly opposite and only 125 ft from the inflow.

The second cell is 675 ft x 50 ft at the bottom and has a working depth of 3 ft. The freeboard declines from 6.5 ft at the inlet to 0 ft at the outlet. The sideslopes are 2:1. The cell has a capacity of 700,000 imp gal or 112,200 cu ft and a surface area of .97 acres at a liquid depth of 3 ft. This cell is an excavation. It was designed as an effluent channel to keep the outfall from the first lagoon ice-free.

In 1970, the system served 900 persons and received an average daily flow of 135,000 imp gal allowing a retention time of 18.5 days in the first cell and 5.2 days in the second cell. There is considerable short circuiting between the raw sewage inlet and the outlet to the second cell. During the summertime, the BOD was reduced only 30% in the raw sewage to the effluent and the suspended solids only 15%. However, the second cell contained a heavy growth of algae which contributed in a large part to the high BOD and suspended solids levels of the effluent. Methylene blue active substances were reduced by 91%.

In winter, by contrast, the overall BOD removal was 46% and the overall suspended solids reduction was 82%. These reductions are due entirely to sedimentation and to no interference from algal growth. Because of the short circuiting, the second cell receives substantially less well treated effluent than occurs in the surface layers of the first cell. Therefore, the reductions in the second cell are apparently considerably lower than the reductions in the first cell.

The first cell is generally aerobic over its whole surface during the summer, but the second cell is generally anaerobic, and there is some odor problem which is accentuated by the high sulfate concentration in the Pine Point water supply. In the anaerobic condition the sulfates are reduced to sulfides by a group of organisms which can utilize the sulfates as a source of oxygen. Some of the sulfides are released to the atmosphere as the foul smelling gas hydrogen sulfide.

The effluent drains away to inaccessible swampland and may eventually reach the Little Buffalo River, about 30 miles southeast of Pine Point.

Combination Lagoon Systems

1. The City of Yellowknife Lagoon System

Yellowknife is situated on the north shore of Great Slave Lake at a Lat. of 62°28'N.

The Yellowknife lagoon was originally a shallow slough called Niven Lake. Because of the rocky terrain this was the only available location for a sewage lagoon. A concrete dam was constructed across the natural outlet from the lake at the northeast and thereby increasing the pond area to 21 acres and deepening it to a surprisingly uniform 3.2 ft at overflow level.

This lagoon system is currently the only combination system in the N.W.T. Prior to 1961 the sewage was treated in a mechanical primary treatment plant and the effluent was pumped into Niven Lake (the main sewage oxidation pond). During 1961 the mechanical treatment plant was bypassed and the raw comminuted sewage was pumped directly to Niven Lake. At this time, the population of Yellowknife was 3,245. A 1962-63 study showed that the sewage was being treated effectively in the oxidation pond. However, there were sludge banks emerging from the oxidation pond from which objectionable odors were emanating. During 1964, a deep primary pond was constructed with dimensions 90 ft x 50 ft x 8 ft deep. A study conducted by Dawson[3] in 1965 and 1966 showed that the sludge was being confined to the primary pond and this resulted in the stabilization pond operating much better. The color of the main pond became dark green instead of greyish, the odor was reduced and there were no emergent sludge banks.

The current population of Yellowknife is close to 7,500 people. Sludge accumulates rapidly in the primary settling pond and is removed from time to time by draglines. The 1966 study by Dawson[3] shows theoretical retention times of .6 days in the primary pond and 49 days in the main pond, Niven Lake.

The combination system was producing a BOD reduction of 73% in summer and 60% in winter, and a solids reduction of 91% in summer and 98% in winter. Coliform bacteria were reduced by 99.99% in summer and 97.7% in winter.

More recent studies show that the theoretical retention times have been reduced to .3 days in the primary pond and 26 days for the main pond. The BOD reductions are 59% in summer and 39% in winter. Owing to a very high algal content in the summer there was no apparent suspended solids reduction.

In winter, however, the suspended solids were reduced by 69%. High levels of dissolved oxygen were maintained in the main pond in the summer. In fact, the water was often super-saturated with dissolved oxygen. Even under ice-cover in April there was dissolved oxygen present in the main pond. Although actual figures are not available, there was apparently a very high reduction in coliform bacteria. The effluent from the pond discharges to Back Bay of Yellowknife Bay. Although Back Bay is a relatively stagnant water body, the bacterial levels are consistently below the accepted criteria for receiving waters.

No objectionable odors were noticed around the primary or stabilization ponds. There was a slight septic odor emanating from the discharged effluent.

The natural slopes of the lake are choked with bullrushes and other emergent aquatic vegetation, but most of the pond is free from emergent growth.

It is now anticipated that Niven Lake will be filled in eventually, and then used for building development in the City of Yellowknife which is expanding rapidly. The consulting engineers for the City of Yellowknife have recommended the use of Kam Lake as a new sewage lagoon. This lake is much deeper and larger and should meet the needs of the city for many years to come.

The pertinent data regarding the construction and operation of the various sewage lagoon systems previously discussed is summarized in Table A-1. Design data for these lagoon systems and their geographic location is given in figures A-8 to A-15.

TABLE A-1 SUMMARY OF OXIDATION POND INSTALLATIONS, MACKENZIE DISTRICT, NORTHWEST TERRITORIES

Location	Latitude	Tributary Population	Sewage Flow Daily ig	Sewage Flow Per Capita igpd	Lagoon Type	Average Depth Ft	Area Acres	Loading lb BOD_5/d
Inuvik	68°21' N	1,500('66)	190,000	127	Single Cell, Long-Retention	4	43.5	392
		1,900('68)	209,000	110	" "		"	586
City of Yellowknife	62°28' N	3,500('66)	373,000	110	Combination -			
					1 day Short-Ret.	12	0.1	534
		6,000('70)	699,200	117	& Long-Retention	3.2	21.0	636
Yellowknife Correctional Camp	62°31' N	44	1,440	-	Single Cell, Long-Retention Following Ext. Aer. Plant.	3	0.09	-
Hay River	60°50' N	1,200	180,000	150	Two Short-Retention Cells	12	0.263 each	135
Pine Point	60°50' N	900	135,000	150	Two Short-Retention Cells	6 3	1.67 0.75	113 -
Town of Ft. Smith	60° N	2,000	100,000	50	Single Cell, Long-Retention	4	10	215
Ft. Smith Airport	60° N	120	4,500	-	Single Cell, Long-Retention	6	1.1	11

TABLE A-1 (Cont'd)

Location	Loading: lb BOD 1,000 ft^3/d	Loading: lb BOD/ acre/d	Theoretical Retention Time Days	Efficiency: BOD % Reduction Summer	Efficiency: BOD % Reduction Winter	Efficiency: Solids % Reduction Summer	Efficiency: Solids % Reduction Winter	Efficiency: Coliforms % Reduction Summer	Efficiency: Coliforms % Reduction Winter
Inuvik**	--	9	180 Summer*						
			300 Winter	85	45	91	90	99.9	99.8
		13.5	160 Summer*						
			270 Winter	89.5	85.3	--	--	--	--
City of Yellow-knife**	14.8	--	0.6 & 49	73	60	91	98	99.99	97.7
	14.7	--	0.3 & 26	59	39	--	69	--	--
Yellowknife Correctional Camp**	--	--	52	--	--	--	--	--	--
Hay River**	3.07	513	1.5 each	41	43	69	81	--	--
Pine Point**	--	68	17						
	--	--	5.3	30	42	15	82	--	--
Town of Ft. Smith***	--	21.5	110	87	53	95	72	--	--
Ft. Smith Airport***	--	10	365	80	21	46	56	99.99	--

* Retention time reduced by surface runoff to lagoon.

** Continuous effluent discharge.

*** Periodic effluent discharge.

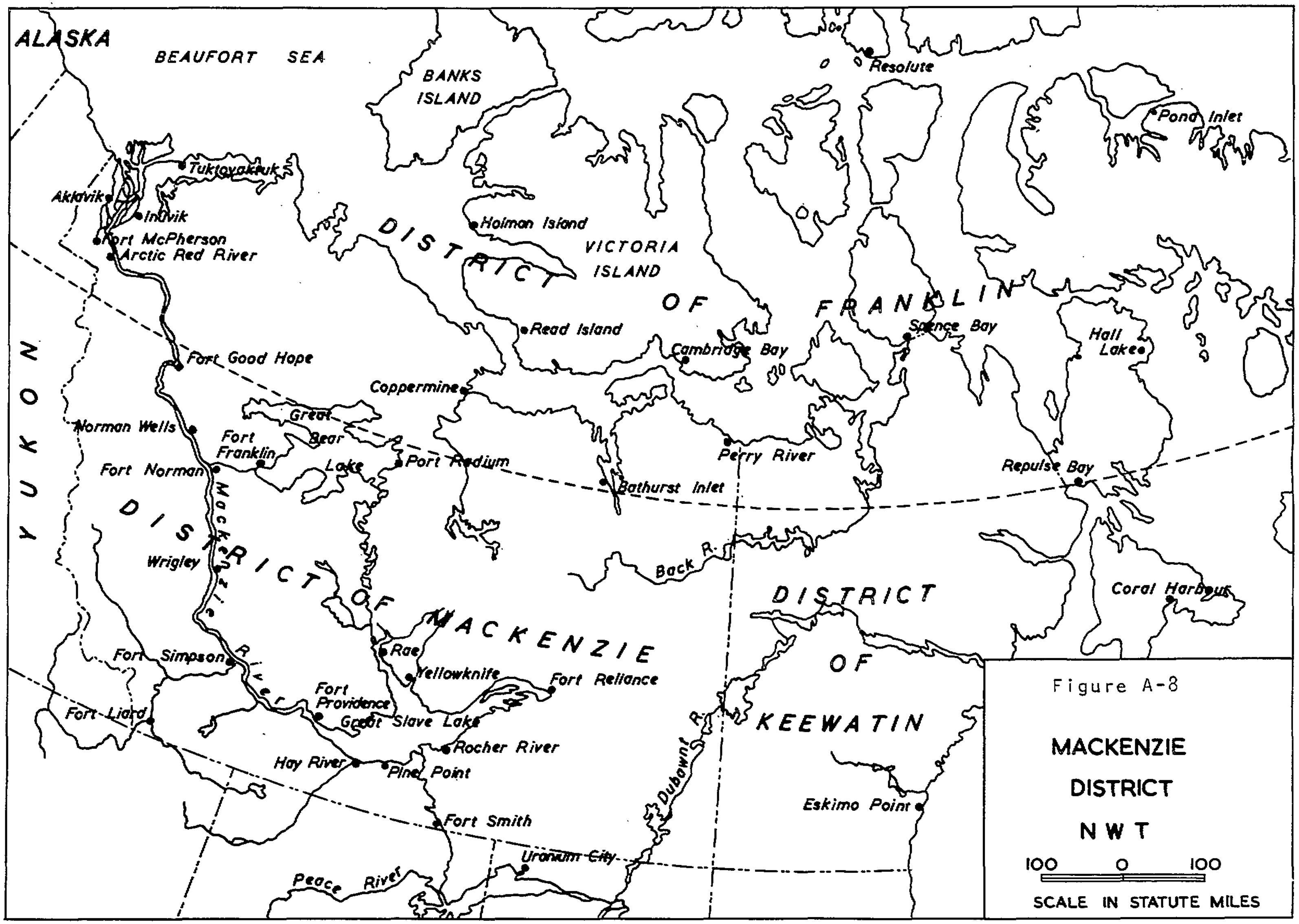

Figure A-8

MACKENZIE DISTRICT N W T

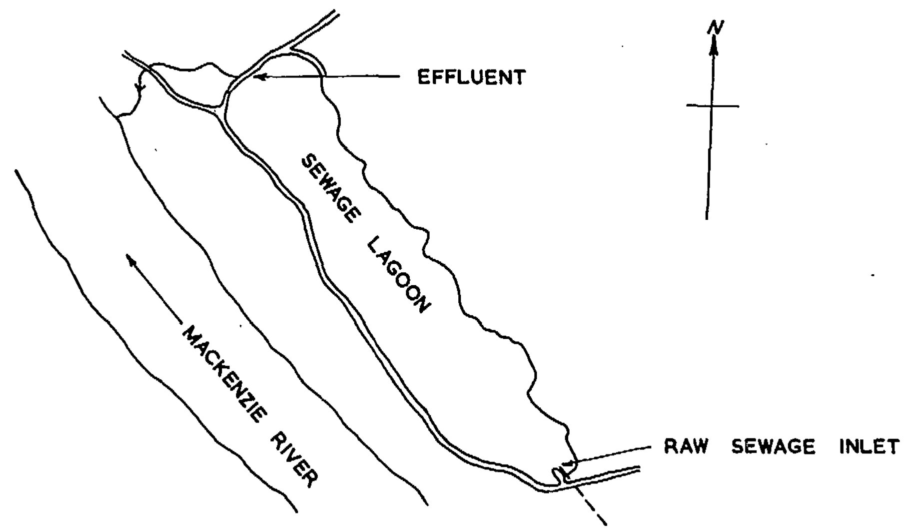

Figure A-9

INUVIK SEWAGE LAGOON

SCALE 1" = 1000'

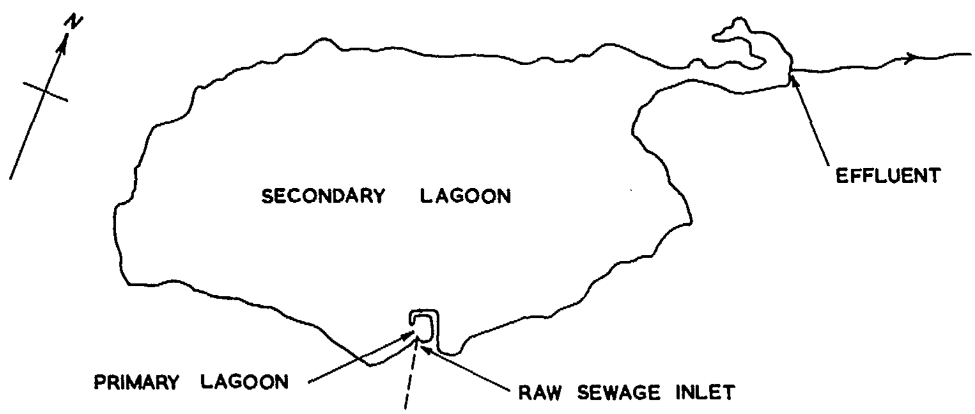

Figure A-10

NIVEN LAKE, YELLOWKNIFE SEWAGE LAGOON

SCALE 1" = 400'

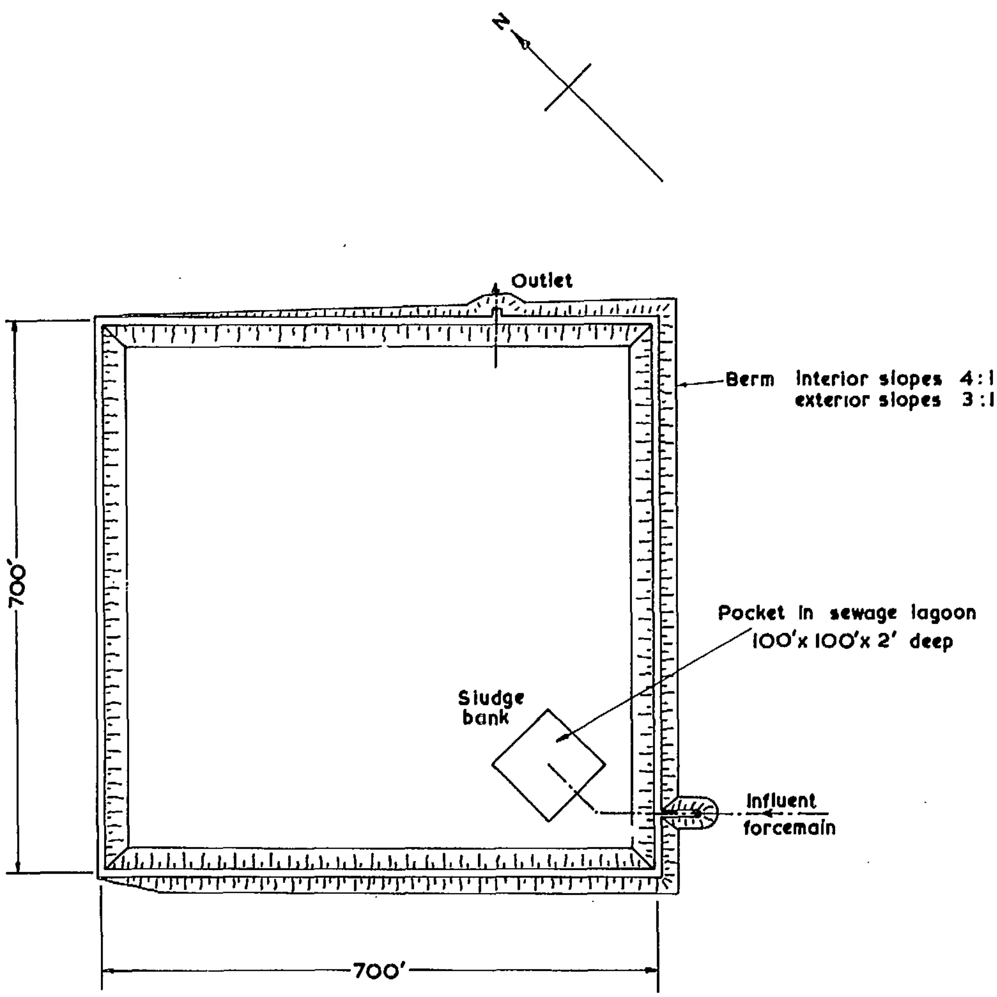

Figure A-11
TOWN OF FORT SMITH
SEWAGE LAGOON
Scale 1" = 200'
Sampling points thus ③

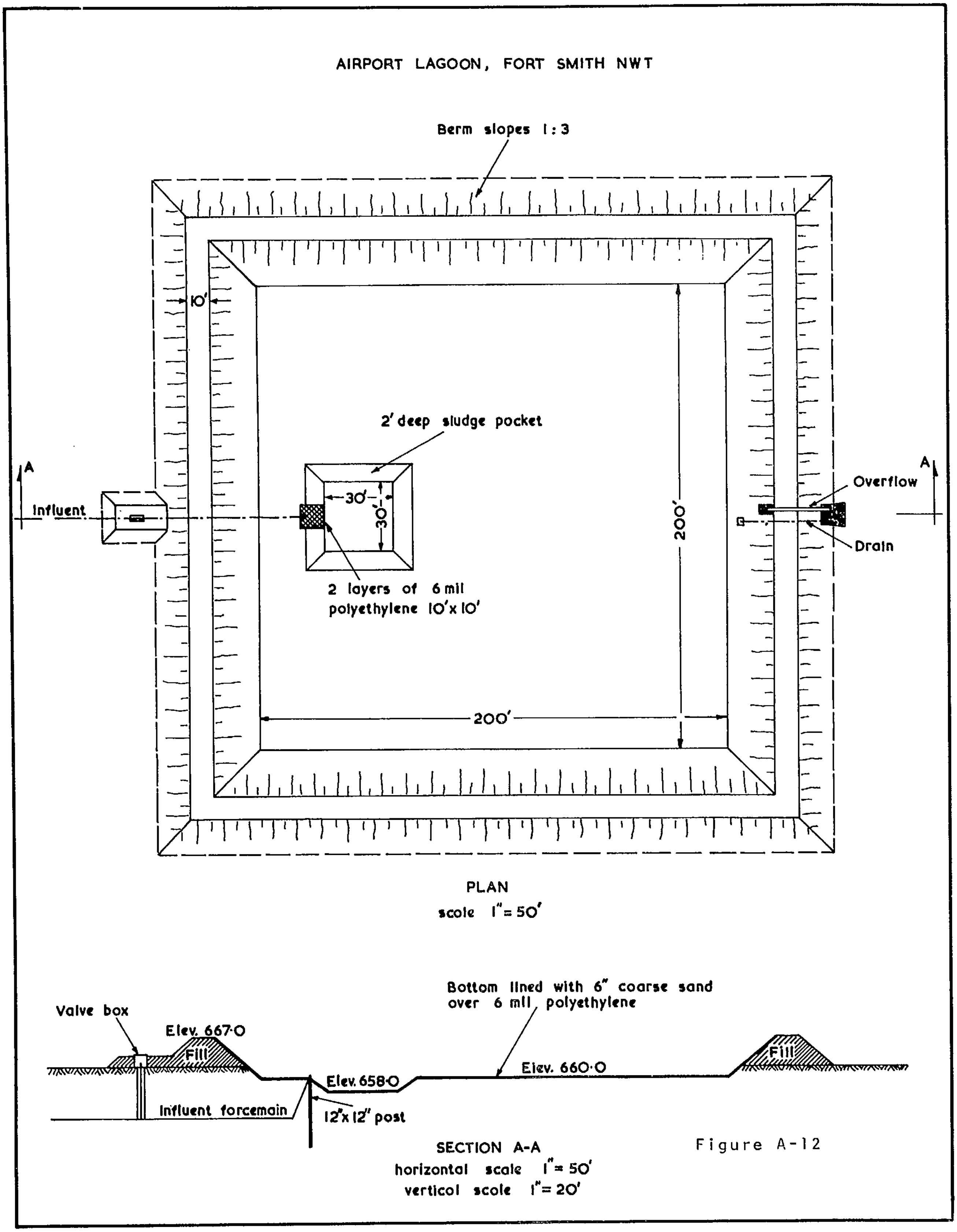
AIRPORT LAGOON, FORT SMITH NWT
Berm slopes 1:3
10'
2' deep sludge pocket
30'
30'
A
Influent
2 layers of 6 mil
polyethylene 10'x10'
200'
200'
A
Overflow
Drain
PLAN
scale 1" = 50'
Bottom lined with 6" coarse sand
over 6 mil polyethylene
Valve box
Elev. 667.0
Fill
Elev. 658.0
Elev. 660.0
Fill
Influent forcemain
12"x12" post
SECTION A-A
horizontal scale 1" = 50'
vertical scale 1" = 20'

Figure A-12

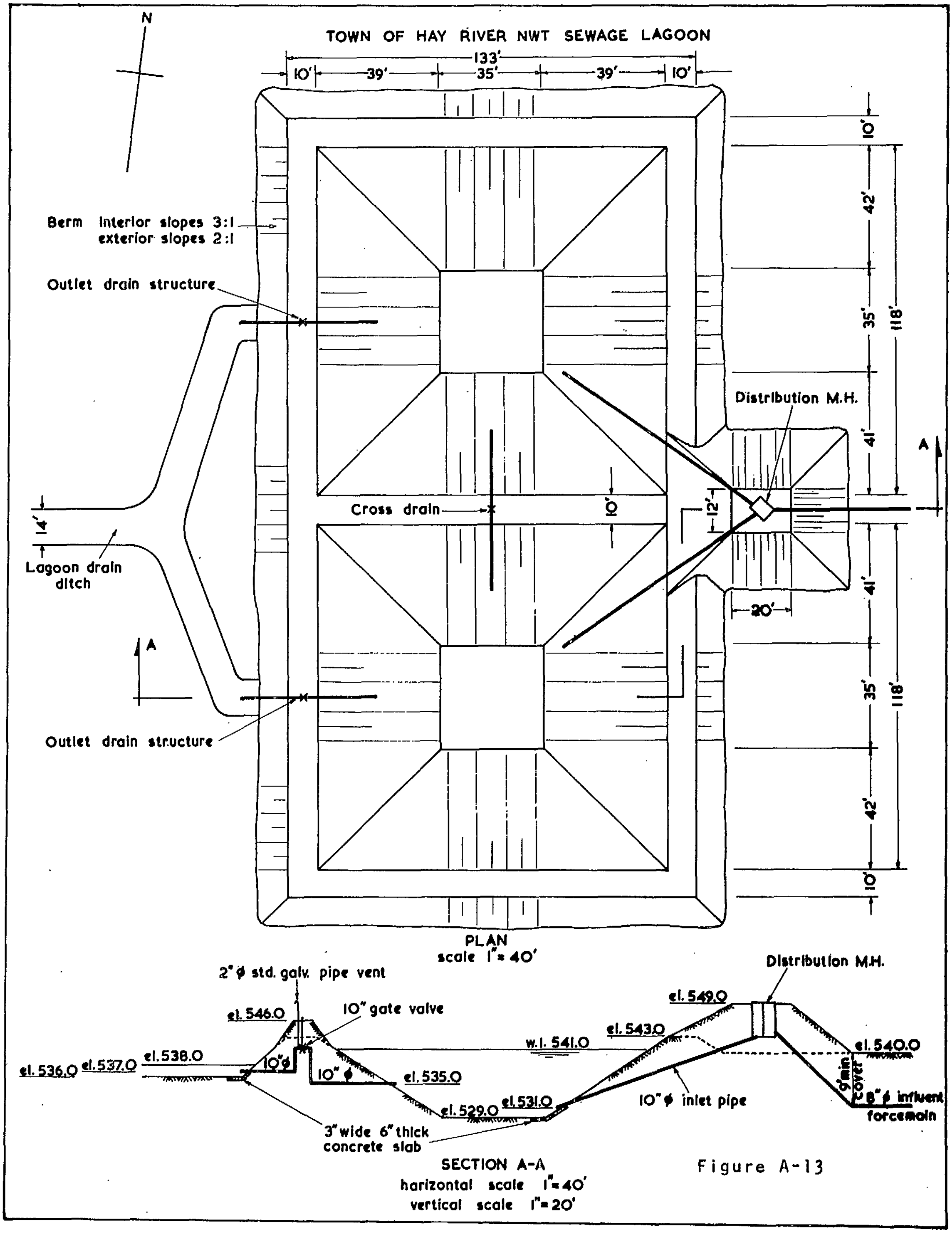
N
TOWN OF HAY RIVER NWT SEWAGE LAGOON
133'
10'
39'
35'
39'
10'
Berm interior slopes 3:1
exterior slopes 2:1
Outlet drain structure
Distribution M.H.
A
Cross drain
10'
12'
14'
Lagoon drain ditch
20'
A
Outlet drain structure
10'
42'
35'
41'
41'
35'
42'
10'
118'
118'
PLAN
scale 1" = 40'
2" ϕ std. galv. pipe vent
Distribution M.H.
el. 549.0
el. 546.0
10" gate valve
el. 543.0
w.l. 541.0
el. 540.0
el. 536.0
el. 537.0
el. 538.0
10" ϕ
10" ϕ
el. 535.0
9' min cover
8" ϕ influent forcemain
el. 529.0
el. 531.0
10" ϕ inlet pipe
3" wide 6" thick concrete slab
SECTION A-A
horizontal scale 1" = 40'
vertical scale 1" = 20'

Figure A-13

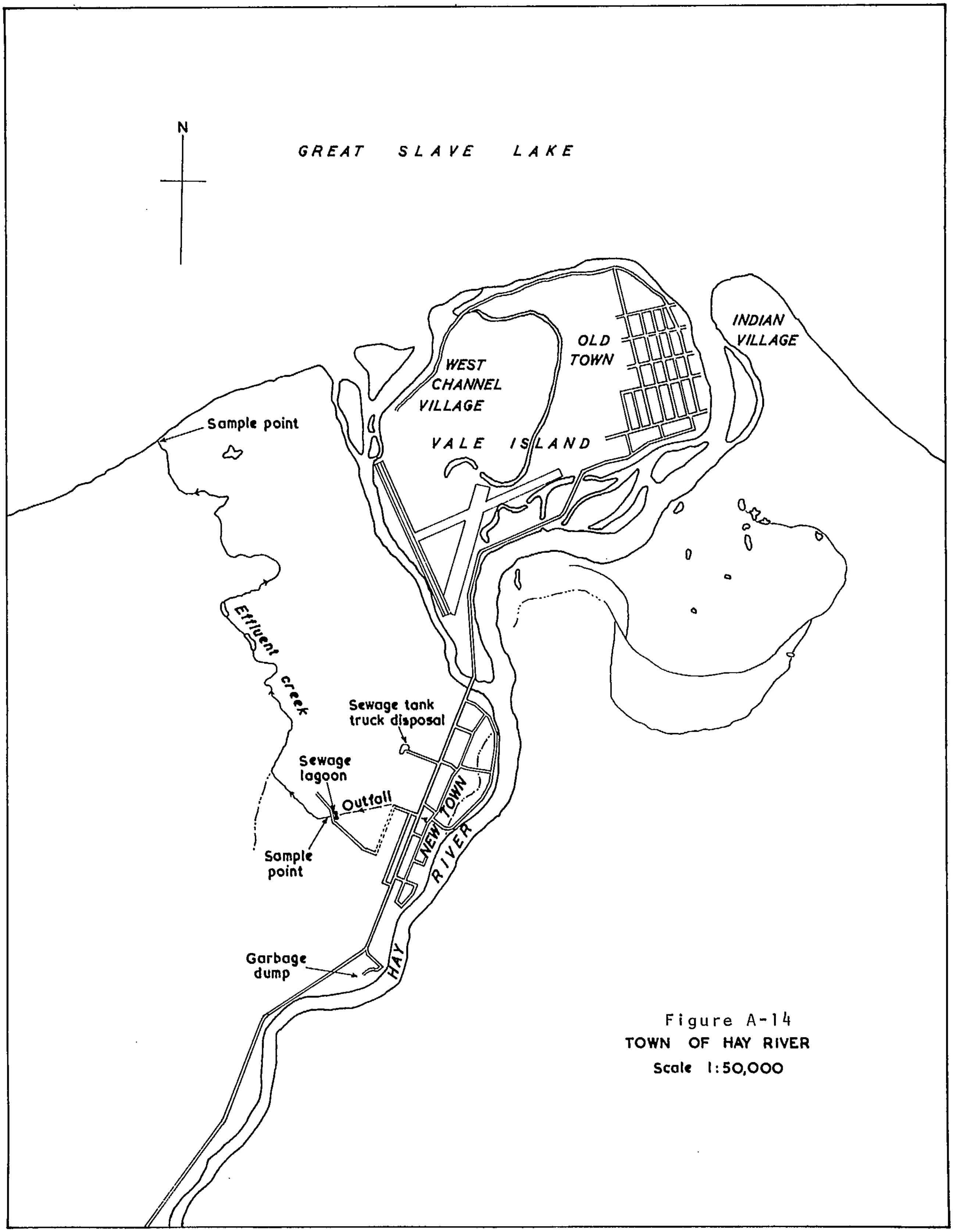

Figure A-14
TOWN OF HAY RIVER
Scale 1:50,000

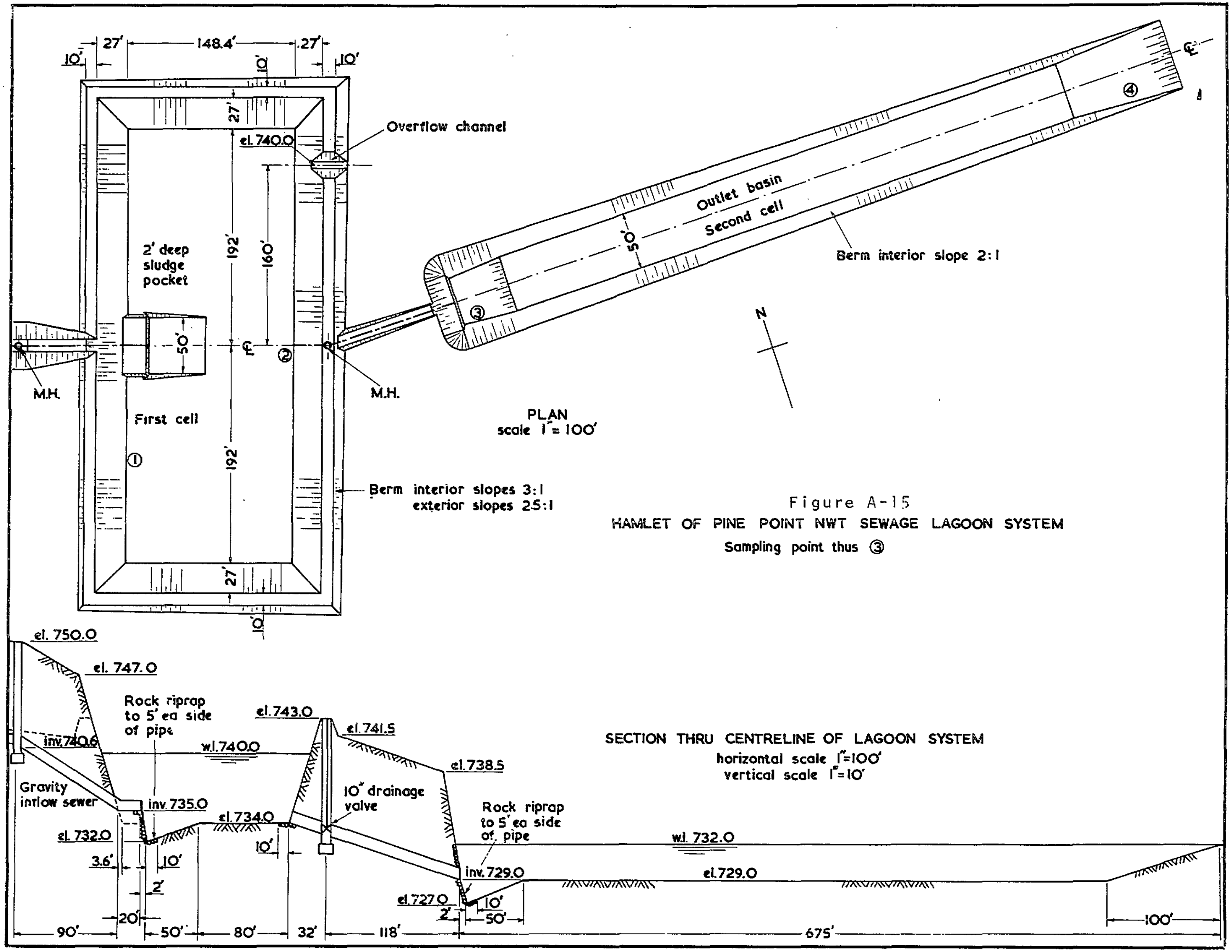

Figure A-15
HAMLET OF PINE POINT NWT SEWAGE LAGOON SYSTEM
Sampling point thus ③

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SUPPLEMENTARY REPORT B

FACTORS AFFECTING THE DESIGN AND OPERATION OF ACTIVATED SLUDGE PLANTS FOR WASTEWATER TREATMENT FROM NORTHERN WORK CAMPS

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This report is published as a supplement to the report "Management of Waste From Arctic and Sub-Arctic Work Camps" by J. W. Grainge, R. Edwards, K. Heuchert and J. Shaw.

FACTORS AFFECTING THE DESIGN AND OPERATION OF ACTIVATED SLUDGE PLANTS FOR WASTEWATER TREATMENT FROM NORTHERN WORK CAMPS

BOD_5 REMOVAL

All biological treatment plants rely on the conversion of degradable organic material in the sewage into a microbial mass, with the accompanying production of CO_2, H_2O and NH_3. In principle, if you then aerate these newly formed bacteria long enough, they will themselves eventually be converted into CO_2, H_2O and NH_3, leaving no solid material to dispose of except for any inorganic matter which has entered the plant in the sewage. Extended aeration plants are designed to work on this "total oxidation" principle.

Actually, "total oxidation" never occurs. It has been shown that for every pound of BOD_5 oxidized biologically, a minimum residue of 0.12 lb. of inert organic matter remains. See Fig. B-1.

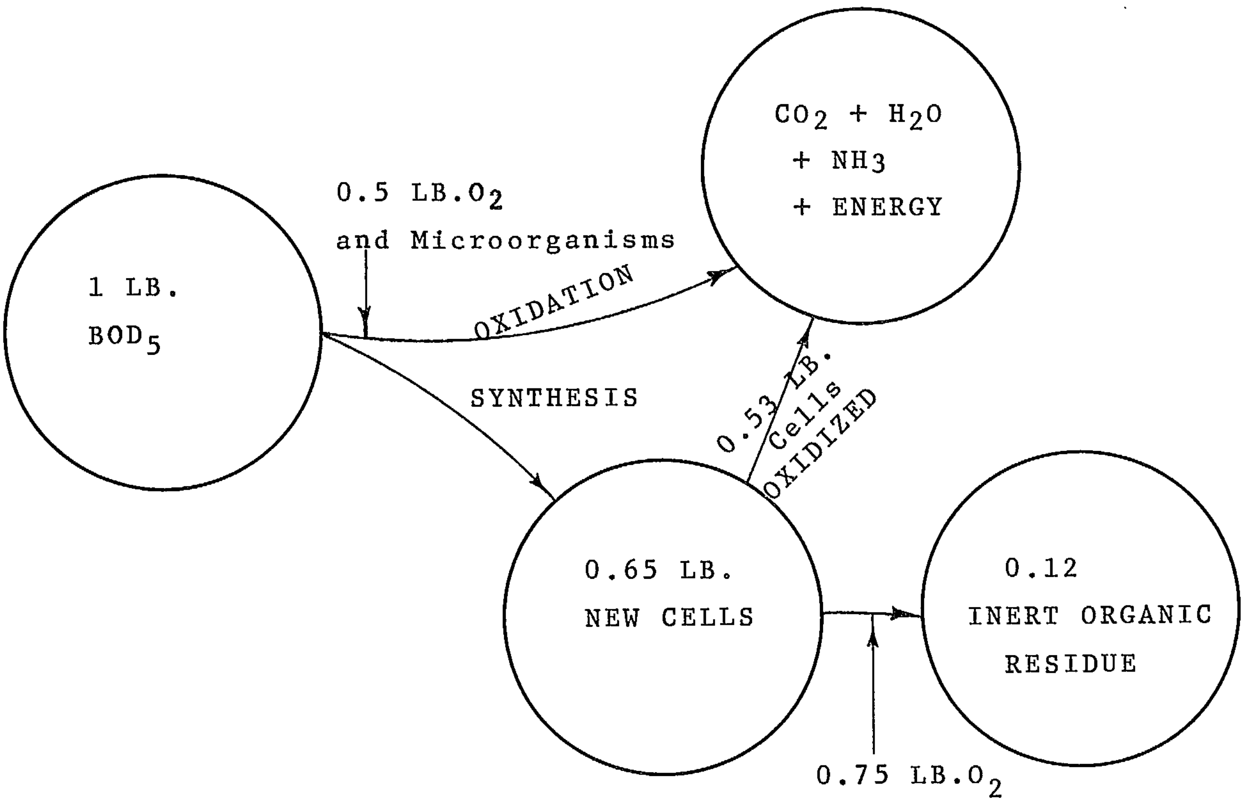

Figure B-1

Furthermore, in a well-mixed aeration tank, undegraded organics mix throughout the tank with bacteria in all stages of growth, and thus there are always some active bacteria swept out with the effluent. Thus, in a real system there is inevitably a solids buildup, which must periodically be checked by "wasting" solids, and there is always some residual BOD_5 in the effluent, chiefly associated with the small quantity of active sludge solids which escape.

Extended aeration plants operate at a high level of accumulated solids, and a long detention time (by comparison with conventional activated sludge systems) because it has been shown practically and theoretically that these conditions give almost complete substrate BOD removal, at a relatively low rate of solids accumulation.

In the following equation:

F_i = influent substrate BOD_5 mg/l

F_o = concentration of substrate BOD_5 mg/l, passing to the settling tank.

S_a = mixed liquor biological mass - usually measured as mg/l volatile SS.

t = theoretical detention time in hours.

K = a constant, known as the average removal rate coefficient.

Theory shows that $F_o = \dfrac{F_i}{1 + K\,(S_a t)}$

Thus, it is apparent that if F_o is to be very small, the product of $S_a t$ should be as large as possible.

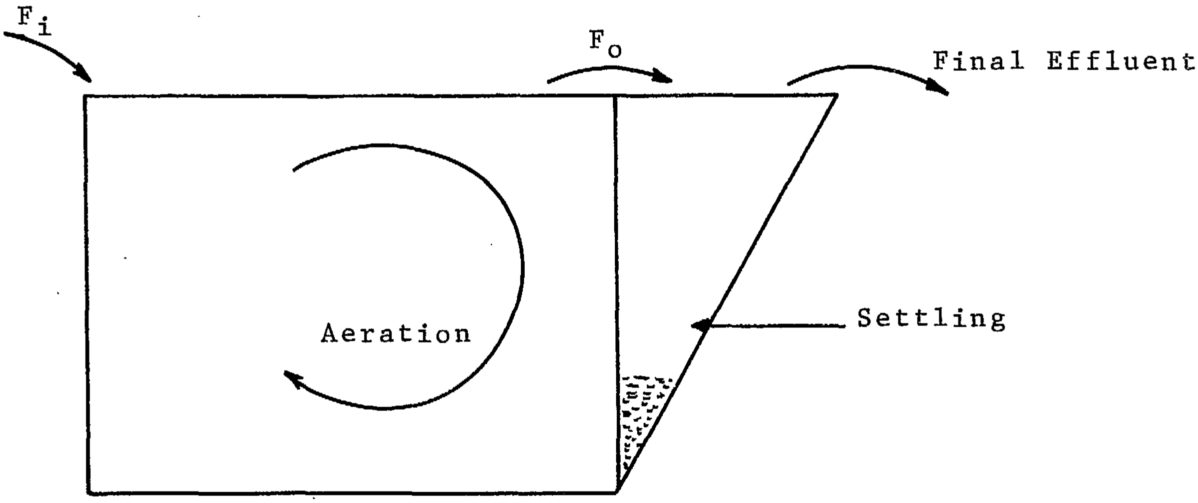

Figure B-2

A simplified extended aeration plant is shown diagramatically in Fig. B-2.

Fig. B-3 shows the relationship of BOD_5 remaining in the tank (F_o) to the product $S_a t$.

Conventional activated sludge plants operate at mixed-liquor suspended solids (MLSS) levels near 2000 or 2500 mg/l, and aeration times of 4 to 8 hours. In these units, $S_a t$ varies from 8 to 20 x 10^3.

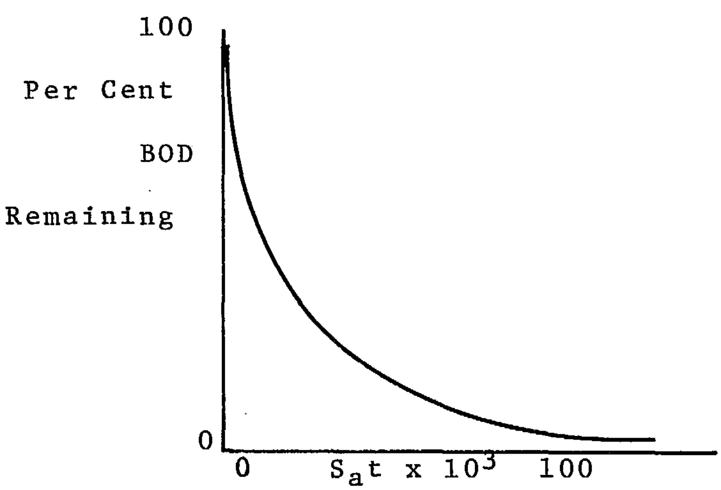

Figure B-3

Extended aeration processes operate at MLSS values from 2000 - 10,000 mg/l, and aeration periods of 18 - 30 hours, which gives $S_a t$ values between 32 and 300 x 10^3. As Fig. B-3 shows, removals of substrate BOD of over 90% can be consistently expected of a well-run extended aeration plant. Very little undigested organic material can pass out of the plant operated under these conditions and it is apparent that any effluent BOD which does appear must be associated with active solids escaping in the effluent, and then undergoing endogenous respiration.

Tests on effluent from a number of extended aeration plants do indeed show that the effluent BOD_5 is directly proportional to the effluent suspended solids or to the volatile suspended solids.

McKinney (1968) held that:

Effluent $BOD_5 = F_o + 0.6$ (effluent active mass), where F_o as previously discussed, should be small. The active mass of solids in the effluent is some fraction of the volatile SS, which is a more manageable concept. In practice, the equation becomes empirically:

Effluent $BOD_5 = 0.43$ (Effluent VSS).

The true efficiency of an extended aeration plant is then critically dependent on how effectively the clarifier actually separates solids from the effluent stream.

Solids Separation

Another advantage of operating at high activated sludge concentrations, and long retention times, is that a flocculent sludge is readily formed which should undergo "zone" settling and leave a very clear supernatant above the floor. When this kind of behavior takes place, the rate of fall of the interface between the floc and the clear supernatant is easily measured in standard tests. The result will be similar to Fig. B-4, with the interface height falling rapidly at first, and then slowing down as the lower sludge layers are actually compressed by the weight of those above.

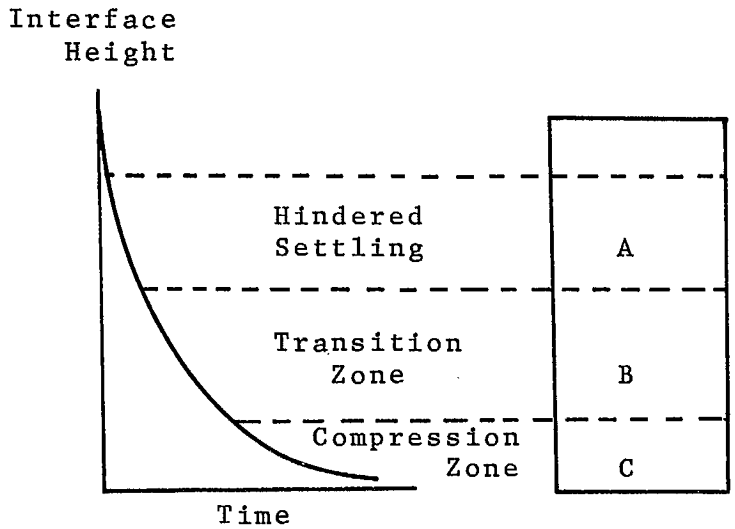

Figure B-4

In the steady state situation, the lowest sludge layers are being continuously removed by a sludge return pump, and the interface should be falling, relative to the fluid, at a steady rate similar to the initial rates of fall in the batch test described above. (Eckenfelder has devised a graphical method of converting batch settling test results to the continuous flow situation, but this is not of great concern here). The interface level will appear steady in the settling tank when the zone settling velocity of the interface (V_S) is just equal to the upflow velocity of the water, usually known as the surface overflow rate (O_r) and measured in gal/sq ft/d.

$$O_r = \frac{\text{Volume Flow Rate (gal/day)}}{\text{Clarifier Surface Area (sq ft)}}$$

Critical situations, from a solids separation viewpoint, can develop at peak flow periods in each day, when the surface overflow rate may exceed the zone settling velocity, thus allowing solids to escape from the plant. Thus, peak hydraulic loads, rather than mean loads, should be used when sizing the clarifier surface area.

The zone settling velocity of a flocculent sludge is far from being a constant, and in fact depends markedly on the concentration of the sludge. This should be obvious, looking back to Fig. B-4.

Typical activated sludge zone settling rates are:

MLSS (mg/l)	Zone Settling Rate (ft/hr)
1,000	20 - 30
4,000	5 - 6

Clearly it becomes a disadvantage to have too high a sludge concentration, since settling rates become so slow that solids separation becomes impossible without oversizing the clarifier and creating other problems.

The efficiency of the clarifier is further complicated by the operation of the sludge return pump, which at high rates will inevitably stir up the solids in the tank to some degree, and by the operation of any foam control sprays which may increase the overflow rate as much as 10 gal/min. This equipment should therefore be operated only intermittently and any foam or floating solids which do accumulate should be prevented from leaving the clarifier by the provision of baffles in front of the effluent weir.

Contact Stabilization Activated Sludge Process

Many package treatment plants are based on contact stabilization as a modification to the activated sludge process. This adjunct to the activated sludge process continues the assimilation of soluble organics, absorbed onto the microbial mass, in a second aeration tank. The sequence in the overall system thus becomes one of aeration - sedimentation - reaeration. The subnatant from the clarifier is reaerated prior to discharge, back to the raw wastewater stream.

The advantage of having a contact stabilization activated sludge process are: it provides for operational flexibility such as a sludge holding process rather than sludge wasting; it reduces the aeration unit requirements; a well-aerated thickened and active sludge is returned to the primary aeration unit; and it improves the sludge-digestion liquor returned to the plant for treatment.

Nitrification and Denitrification

Another factor to be considered when designing and operating extended aeration plants is the optimum level of dissolved oxygen (DO) to be maintained in the aeration tank. Too low an air supply will create inadequate mixing and will fail to keep the active solids suspended throughout the tank. Too high a DO concentration, on the other hand, will cause nitrification, or the oxidation of the organic nitrogen to nitrites and nitrates. The disadvantage here is that in the settling tank, low oxygen levels tend to occur, particularly if the detention time is long, and the nitrates act as oxidizing agents for combined bacterial respiration. Nitrogen gas then forms and the bubbles provide buoyancy to the sludge which seriously inhibits settling. Sludge "mats" may form on the surface and will pass out with the effluent to some degree even if a surface baffle is provided.

In theory, about 1.25 lb. of O_2 are required for every pound of BOD_5 entering the plant to accomplish "complete" oxidation. With the known efficiency of aeration equipment, this leads to the result that about 1,500 cu. ft. of air will be required per pound of BOD_5 entering. From an operating standpoint the guide to adequate aeration should be the ability to maintain 1-2 mg/l of DO in the aeration tank.

The important thing to remember is that equipment sized to handle peak loads will produce high DO concentrations, in the neighborhood of 5 or 6 mg/l, when loading is at a low level. This may well occur at construction camps where loading hits high peaks diurnally and where the number of men in camp can vary greatly. To avoid nitrification/denitrification problems, a flexible aeration system must be provided, in which the hours of aeration per day can be adjusted to suit the loading. The operator, of course, must understand the need to do this, and to relate the amount of aeration to the camp population, and the DO levels in the aeration tank.

Startup and Solids Accumulation

Perhaps the most critical factor affecting the efficiency of extended aeration plants in isolated situations is the time they take to establish a good activated sludge, and achieve full treatment efficiency. The National Sanitation Foundation tests at Ann Arbor, Michigan[1] showed that a solids level of 2,500 mg/l was the minimum concentration at which the plant should be operating effectively. Under highly controlled conditions, at their test site, their plants took between 36 and 49 days to reach these solids levels. The indications are that in the field, under less knowledgeable and carefull attention, this rather sensitive startup phase may be considerably lengthened, and in fact effective operations may in some cases never be achieved.

The rate of solids accumulation, if we assume for simplicity that no inert solids enter the plant, can be expressed as follows:

$$A = aF - bM_d - M_e,$$

Where A = Accumulation of Solids (lb/day)

F = Organics entering system (lb/day)

M_d = Degradable Solids Produced in System (lb/day)

a,b = Constants

M_e = Solids Lost in Effluent (lb/day)

From this equation, it is clear that the rate of accumulation of solids will be decreased, if:

1. F is small. This represents a low loading rate which can easily occur if camp is not full for any period of time. It can also occur if any breakdown occurs in the system, requiring sewage to be diverted for several hours or days. Under such conditions, any previous buildup can be surprisingly quickly destroyed.

2. M_e is large. At low solids levels, settling is often poor, and much of the daily solids accumulation can simply pass out with the effluent. Any other of the previously discussed reasons for poor clarifier operation can increase the solids loss.

3. bM_d is large. This is the rate at which active solids in the system are degraded.

During the startup phase the plant is undesirably sensitive to shock; sharp changes in either hydraulic or organic load will sharply affect the rate of solids accumulation. Clark, and others[2] found that startup periods of at least 60 to 90 days are to be expected from operational experience with several plants installed in field camps around Alaska. The experimental operation of a small extended aeration plant under winter conditions in Fairbanks, Alaska, and the operations of similar plants in the N.W.T. and Banff National Park, Alberta, more than bear out this statement. It has to be concluded that such plants will not perform particularly well in any short term operation, or in any operation where the loading characteristics are unlikely to be steady for several months at a time, unless sound operational procedures are instituted.

Operation and Maintenance

Observation of plant operation, both in Alaska and in Northern Canada, indicates that a standard of operation and maintenance necessary to ensure the efficiency of package treatment plants, will not be achieved even in large camps without a sound operator training program. In addition to this requirement for a trained operator, it is essential that the camp manager appreciates the need for a well-run plant, so that the operator is allowed sufficient time and assistance to attend to his work conscientiously. Any such treatment plant must be well housed so that maintenance work can be carried out with a minimum of difficulty. All lines to and from the treatment building must be similarly protected and heat-traced, since any breakdown due to freezing compromises the usefulness of the complete system.

The operator must also be responsible for a regular testing program if the plant is to avoid upset with every change in the loading parameters. The best and quickest procedures for field determination of suspended solids may well be a turbidity measurement with a spectrophotometer[1]. It is found that BOD_5 values in the effluent can be deduced reasonably accurately from the same test.

The Northwest Region office of the Environmental Protection Service has observed extended aeration plants serving Yellowknife Correctional Camp and Rae in the N.W.T. and also at a motel and a ski resort in Banff National Park, Alberta. In all cases, process control tests had been neglected. In two cases the plants had never functioned effectively at all. The one serving Rae has become merely a storage tank from which the sewage is pumped out and hauled away. The one serving the ski resort, formerly operated only in winter, never accumulated sufficient mixed liquor suspended solids for an efficient operation.

The effectiveness of the other two plants has varied greatly but efficiency has generally been compromised by poor process control. Mixed liquor suspended solids have been too high or too low. Denitrification has produced floating mats of sludge on the surface of the clarifier and excessive solids loss in the effluent. Poor control of a sludge return air lift pump caused too high a hydraulic load on the clarifier and again excessive solids loss.

All but the plant at Rae have had good mechanical maintenance but process control has suffered from basic neglect, ignorance, refusal to invest a few more dollars in laboratory equipment, the erroneous belief that such plants run themselves and simple distaste for handling the contents of the plants.

Not once have any of these plants achieved the effluent standards set under the Federal Water Pollution Control and Abatement Program.

During February, 1972, observations were made of the extended aeration plant being used to treat the wastes from a maximum 40-man camp at the Northwest Project Study Group's test site at San Sault Rapids, near Norman Wells, N.W.T. This plant was being well maintained from a physical viewpoint. It was clean and odor-free. A regular program of simple tests was being conducted and aeration was varied according to camp size. One anomaly was noted. Sludge wasting was practiced periodically and when this happened, the excess solids were wasted through the effluent line to the same area of ground as the rest of the effluent. The point to be made here is not that this practice is going to cause any noticeable degradation of the environment, or increase the nuisance value of the effluent at all; rather it is that the efficiency of the plant is being compromised.

The National Sanitation Foundation study[1] has set out a 15-point check list for routine maintenance which is reproduced here. In Arctic areas, "ground keeping operations" (point 9) would include snow clearing, and checking sewers, vents, and water lines for frosting, leaks, or insulation failure. An anticipated minimum of 1-2 hours conscientious attention per day would be required.

Check List for Routine Maintenance and Operation of Extended Aeration Package Treatment Plants

1. Determine that power is being supplied to the unit and that all pumps and motors are operating or operational as required.

2. Grease and oil equipment, clean air filters, check pressure relief valves, and perform related work as recommended by the manufacturer.

3. Hose down walkways, sideboard and splash-spray zones as needed.

4. Check air lifts and return lines for clogging.

5. Operate skimming device(s) as needed.

6. Perform recommended simple laboratory analytical procedures and adjust operating variables as indicated. The recommended or required analytical procedures for a given plant may include, but are not necessarily limited to, any or all of the following depending on the needs of the installation.

   (a) Influent, effluent, mixed liquor, and return sludge suspended and volatile suspended solids. (Rapid photometric methods for the determination of suspended solids have been found to be reliable).

   (b) Influent and effluent five-day biochemcial oxygen demand. Effluent BOD_5 values can be approximated through correlation with suspended solids values if the oxygen uptake rate of the solids is known. A modified chemical oxygen demand test has also been shown to closely approximate these values.

   (c) Mixed liquor and effluent dissolved oxygen concentration.

   (d) Influent, mixed liquor and effluent pH and temperature values.

   (e) Mixed liquor thirty minute settled volume determination.

   (f) Mixed liquor oxygen uptake rate.

7. If effluent disinfection is required, ensure that an adequate supply of disinfectant is available

and that the feed device is operating properly.

8. Scrape down the insides of clarifier hopper at least daily and/or determine that sludge collection mechanisms are operating properly depending on the design of the plant.

9. Remove litter from the plant area and perform grounds keeping operations as required.

10. Repaint exposed painted surfaces as needed.

11. Inspect aeration equipment thoroughly, including diffusers, impellers and the like which may be submerged. While this need not be done as frequently as some other items of maintenance, it should not be overlooked and the manufacturer's recommendations should be carefully followed.

12. Remove and dispose of in a sanitary manner any material that may accumulate on inlet bar screens and the like. Check and clean the comminutor if one is a part of the plant.

13. Check, clean and maintain any such plant support units such as a sand bed, sludge holding tank, trash trap, and the like.

14. Replace worn parts and/or equipment as needed. Pay particular attention to pulley belts and the like which may require relatively frequent replacement. Maintain a small stock of such items including belts, fuses, heaters and similar items which are essential to plant operation.

15. Waste solids from the system as required to maintain the solids within the desired range.

Comments and Summary

There is no doubt that package extended aeration plants, for use on the wastes of small isolated communities such as pipeline labor camps, can be made to work very well. However, several conditions must be satisfied for this to take place. The plant must be well housed and heated. An operator must be trained to understand the system and must maintain the plant and adjust operating paramenters daily. The camp personnel and manager must be sympathetic to the need for such a plant and interested in its performance.

Practical experience suggests that one or more of these pre-conditions is likely to be absent in only too many cases. Where this is so, the plant will not operate for long at its best level of performance. This in itself might cause few people any concern, because the likelihood is that the mechanical operation of the plant will be attended to sufficiently so that the wastes continue to pass through the plant and out to the field or lake. As long as it does not smell too much, or break down completely, it is only too easy to assume it is working. This is one reason why the waste management systems at all the pipeline construction camps should be under the direction of one person.

Waste disposal from campsites in the North, as anywhere, should be conducted with three goals in mind: the avoidance of any significant public health risk; the avoidance of public nuisance through odors which camp personnel find objectionable and esthetic nuisance; and the prevention of significant environmental degradation.

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SUPPLEMENTARY REPORT C

PHYSICAL-CHEMICAL TREATMENT OF WASTEWATER FROM NORTHERN WORK CAMPS

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This report is published as a supplement to the report "Management of Waste From Arctic and Sub-Arctic Work Camps", by J. W. Grainge, R. Edwards, K. R. Heuchert and J. W. Shaw.

PHYSICAL-CHEMICAL TREATMENT OF WASTEWATER

INTRODUCTION

Physical-chemical treatment of raw sewage is a relatively new application of a technology which has been applied for years in the field of water treatment. It is fast becoming a popular cause among wastewater treatment specialists in the U.S.A. Some of whom see it as the answer to nutrients (particularly phosphate) removal in areas where eutrophication of surface waters has become a major issue.

Recently certain authors have recommended that physical-chemical treatment plants could be used successfully in isolated campsites in the Arctic[1]. The advantages claimed for these units over more traditional biological treatment devices are that they are flexible, more portable and resistant to "shock" hydraulic and organic loads. Furthermore, they can be operated at full efficiency from the day they are put into use, a very significant feature for temporary or mobile operations. However, there are certain drawbacks.

A comparison between the performance claimed for various pilot plants in the continental U.S.A. and that observed in two "package" plants in northern Alaska brings up questions about the time and the skills required of operators if these plants are to perform to capacity. The constraints placed on any operation, particularly waste disposal systems, by the isolation, by the cold, and by the human limitations have to be considered as carefully as possible when designing waste treatment systems for the Arctic.

UNIT PROCESSES IN PHYSICAL-CHEMICAL TREATMENT

Fig. C-1 shows a typical flow diagram for the treatment of raw sewage by Physical-Chemical (P-C) treatment.

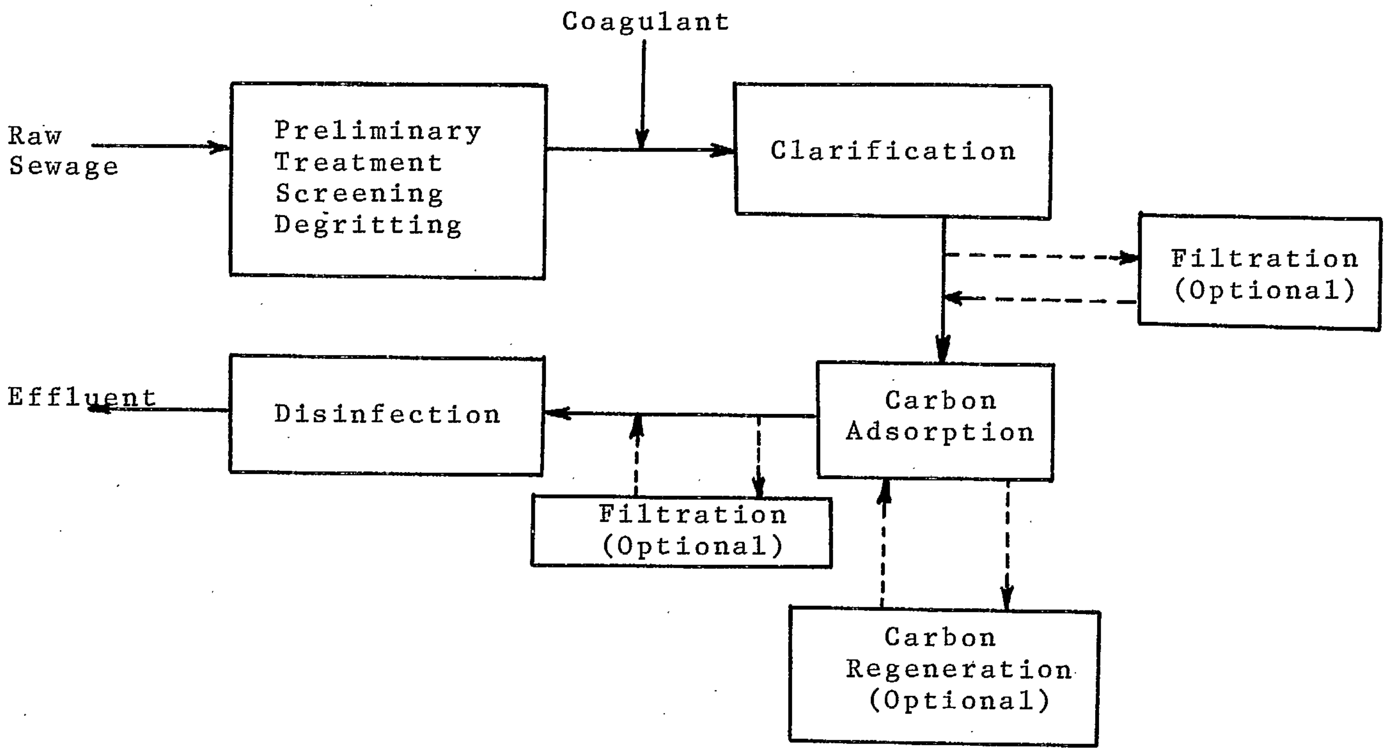

Fig. C-1 - Physical-Chemical Treatment Process Flow Diagram

The clarification step will remove suspended and colloidal solids almost completely, especially if filtration follows clarification. The important extra bonus is that this step also removes phosphorus very efficiently, which a biological plant cannot do. The clarified and filtered wastewater may still contain a quantity of dissolved organic material which can be efficiently removed by adsorption onto the surface of activated carbon, supplied either in powdered or granular form. Inorganic nitrogen in the form of nitrate, nitrite or ammonia may pass through all these processes.

If a high degree of nitrogen removal is required, it will take an extra ammonia stripper, an ion exchange unit and the encouragement at some stage of denitrifying conditions to remove these constituents. Usually, however, phosphorus is seen as the most important nutrient to remove from wastewater and the residual inorganic nitrogen is ignored.

The approximate removal efficiencies claimed by each of these unit processes is shown in Table C-1.

TABLE C-1

	Flocculation-Clarification Filtration	Complete Treatment (with carbon adsorption)	Conventional Treatment (Biological)
Organic Content (TOC, BOD)	65 - 80%	95 - 99%	90%
Suspended Solids	90 - 98%	95 - 99%	90%
Total Phosphorus	90 - 98%	95 - 98%	30 - 50%
Total Nitrogen	30 - 35%	75 - 80% (with ion exchange)	
Total Coliforms		99.99%	99%

These figures indicate a relatively high degree of efficiency. The costs are reportedly competitive with conventional biological treatment so that in many cases it is economical to treat sewage to a quality suitable for re-use. In addition, the high degree of phosphorus removal protects the receiving waters from eutrophication.

Clarification (Chemical Precipitation)

The first stage in P-C treatment improves upon conventional primary settling by the addition of chemicals to form a settleable floc. This floc traps a much higher proportion of the suspended and colloidal materials in the sewage than would settle out unassisted. The chemicals normally used are ferrous or ferric salts, aluminum salts, or lime (CaO).

Ferrous salts, whether $FeSO_4$, $FeCl_2$, or a product of steel processing known as waste pickle liquor, have been used in the past because they are cheap. To be effective, however, conditions have to be created to oxidize the dissolved iron to its trivalent (ferric) state. The pH is raised by adding lime or caustic (NaOH) to pH 8 and the waste is kept well aerated. In some cases, the need for this step may render the process uneconomical so that ferric rather than ferrous salts are now finding greater popularity. In both cases, the floc which forms is largely the insoluble ferric hydroxide.

Either alum (aluminum sulfate) or an aluminate may be used as the source for trivalent Al^{+3}. The floc formation is similar chemically to that formed by iron, though the sludge that results is usually bulkier and more difficult to dewater and handle. With both iron and aluminum, better flocculation and settling is often achieved with the addition of small quantities (0.3 - 0.5 mg/1) of certain organic polymers. The actual quantities of chemicals that should be used vary with the wastewater and can only be determined by laboratory "jar" tests in which the most economical and acceptable result is determined by trial and error.

Precipitation with lime is slightly different in that the dosage is strongly dependent on the hardness and alkalinity of the wastewater. Good phosphorus removal depends on the achievement of a high pH (10), when the phosphorus is precipitated as calcium hydroxyapatite (Ca_5 (OH) $(PO_4)_3$). Floc formation is dependent on a reaction between the lime and the alkalinity to form a dense, settling $CaCO_3$ floc. For a highly alkaline water, this may well be achieved at a relatively low pH.

Good clarification with iron or aluminum implies a high phosphorus removal, which is not the case for lime clarification. In a high alkalinity wastewater, a larger amount of "excess" lime must be added to achieve good phosphorus removal. Generally, a compromise is sought, single "low lime" clarification at pH 9.5 achieves moderate phosphorus removal (down to 0.5 mg/l as phosphate) without requiring enormous quantities of lime.

Low alkalinity waters allow easy phosphorus removal but will require recarbonation to form a good settling calcium carbonate floc and to reduce the pH. The pH is initially raised to 11.5 to precipitate the phosphorus, then recarbonation to pH 10 creates a good floc and settling reduces the excess calcium and suspended organics. Finally, further recarbonation reduces the pH to about 8. With this process, residual phosphate levels as low as 0.1 mg/l can be achieved.

ACTIVATED CARBON ADSORPTION

1. Granular Activated Carbon

After the suspended and colloidal materials have been largely removed from the wastewater by clarification, with or without filtration, the fluid is passed through one or more columns where it comes into contact with activated carbon. The rate at which the activated carbon can adsorb organic material is dependent on several parameters, chief among which are total surface area, pore size distribution and particle size. In general, the smaller the particles, the more surface area is presented to the fluid in that the average distance to "internal" pore surfaces is reduced. Experience indicates that smaller particles have a greater adsorptive capacity and an increased rate of adsorption. Unfortunately, a lower size limit is set for granular carbon systems by the tendency for very fine granules to wash out of the columns at any reasonable flow rate. Particle sizes actually used range from 50 x 100 mesh (0.2 mm dia.) to 8 x 30 mesh (2 mm dia.).

Some thought has been given to the relative merits of "packed bed" columns, where the water flow cannot greatly disturb the carbon particles, and to "expanded" or "fluidized bed" columns.

These latter devices are upflow columns in which the fluid flow lifts the lighter carbon particles, increasing the column "length" perhaps 30%. The packed bed columns tend to suffer from an undesirable level of biological activity. Microorganisms grow on the carbon surfaces, reducing the oxygen level to zero as well as resulting in partial blockage of the pores, increased head losses, more frequent backwashings and some unwanted byproducts of anaerobiosis such as H_2S and soluble ferrous iron.

Chiefly for these reasons, the expanded bed columns are thought superior. The spaces between the "expanded" particles are large enough so that microbial growth has little effect on the pressure loss across the column. Aerobic conditions can be more easily maintained.

Naturally the adsorptive capacity of activated carbon is finite and from time to time the columns must be removed from service and refilled with fresh or reactivated carbon. Regeneration is not a particularly easy task, requiring heating the carbon over 1700° F in a steam atmosphere. Even then the reactivated carbon is not as good as new and a 5 - 7% attenuation rate is observed. In small, isolated plants it is likely that carbon regeneration will not be practiced as it will prove more economic and more reliable merely to replace old carbon with new at regular intervals. Replacement will probably be required at an average rate of 0.4 lb of carbon/1000 gal. of wastewater treated. These considerations, particularly the possibility that replacement will not take place frequently enough in some camps if the supervision is poor, can seriously detract from the viability of activated carbon adsorption in these outlying sites.

2. Powdered Activated Carbon

In theory, both the adsorptive capacity and the rate of adsorption are increased when the particle size of activated carbon is reduced. Powdered activated carbon, with a particle size of perhaps 10 microns, could be much more efficient and considerably cheaper (about 10¢/lb as against 30¢/lb for granular) than granular carbon. Mitigating against its use is the fact that it cannot be used in columns. New processes, both for adsorption and for regeneration, are still in experimental, pilot-plant stages. However, experimental units are being tested under contract with the U.S. Environmental Protection Agency and are described in the literature.[1,3,8]

Greater efficiencies in the use of carbon can be achieved with contact in simple clarifiers of fairly standard design using 2 or more stages and some recirculation of the carbon slurry.

Sludge Disposal

P-C treatment of sewage produces a quantity of chemical sludge from the clarifiers which like the carbon from the adsorbers, must be either disposed of in a trouble free fashion or regenerated and recycled. Aluminum sludges are probably the most difficult to deal with, as they are particularly hard to dewater, and must be handled in relatively large volumes.

Lime sludges are most readily handled. They can be gravity thickened to between 15 and 25% allowing handling of a smaller volume. Furthermore, the lime can be regenerated by recalcination, a process which incinerates the organics, and at the same time, provides for "ultimate disposal". Once again, however, it seems unlikely that recalcining will prove practicable on very small package plants, where operators may prefer to use new lime and dispose of sludge simply on land, rather than by incineration.

Camps in the North will have to provide disposal areas for quantities of solid waste. It should generally be possible for sludges, and waste carbon, to be disposed of in those areas, as long as the possibility of contamination of surface or ground waters is remote.

PERFORMANCE OF PHYSICAL-CHEMICAL PLANTS IN ARCTIC CAMPS IN ALASKA

On the surface, P-C plants offer several features which could make them especially suitable for the treatment of camp wastes. In the North, camp operations will be seasonal and even large camps in permafrost areas may only be in place for a four-month period. "Package" activated sludge plants may take up to two months to achieve proper operating capacity, so the advantage of an instantly effective P-C plant in these circumstances becomes obvious.

P-C plants are flexible, individual stages in the treatment process can be taken out of service at will if their function is not needed or if repair work needs to be done. Conceivably, at periods of very low load, the activated carbon columns, for example, could be removed from service and sufficient treatment accomplished by chemical clarification alone. Similarly, sudden increases of load, associated, for example, with a new crew arriving in camp, cannot "upset" a P-C plant in the same way as an extended-aeration plant might be upset. Addition of extra units or extra chemicals can accommodate the increase.

The possibility always exists of course, that operators may use this flexibility irresponsibly and disconnect many units of the operation for reasons of economy or simplicity even when the camp is full. Adequate supervision should be maintained to avoid this type of occurrence.

A 500-700 man camp (probably the largest size contemplated for northern pipeline operations), may produce 50,000 gpd of sewage. A P-C plant can be designed to handle this quantity and will be compact enough to be housed in a trailer-sized unit. Protection from the weather and portability are two vital considerations for operational equipment of arctic camps. The compact nature of P-C units, relative to biological plants of the same capacity, makes them tempting alternatives from these angles.

There is, of course, very little experience in the operation of physical-chemical treatment plants in the Arctic. Indeed, the bulk of the literature on P-C plants has been based on carefully controlled experimental and pilot-scale units whose high levels of performance may not be duplicated in the less closely supervised situations which may exist in the northern camps.

There is no doubt that the emphasis in such camps will be placed on rapid completion of the job in hand while facets of camp life, such as the efficiency and desirability of waste disposal arrangements, may be only too easily ignored by the bulk of the camp population, especially when weather conditions make regular maintenance work an unpleasant duty. This factor must be borne in mind whenever plans are made to install a treatment plant which requires some degree of regular attention and adjustment. Specific provisions which guarantee that this attention will be supplied must be part of the preliminary plans submitted to the approving authority.

Some evidence that this precaution will be necessary is available. Two camps in northern Alaska[6] have installed physical-chemical package plants in anticipation of federal and state pressure to provide superior sewage treatment.* For much of the time since these plants were installed they have been operating at less than 10% of design capacity, and in fact for some months may not have been operated at all. Information is therefore sparse, but a 1970-71 study by the Alaska Water Laboratory in Fairbanks[6] showed performance on these plants was significantly inferior to the performance claimed by P-C plants in pilot studies elsewhere (Table C-2). All that could really be said was that they produced a less turbid effluent than package biological plants and also operated at lower loadings under these difficult conditions.

This is not a fair test of the ability of P-C plants to perform well in outlying camps, but it does fairly point out some of the constraints and conditions which mitigate against their effectiveness. These inlcude:

1. The fluctuations in camp populations and the differing abilities and rapid turnover of operators.

2. The tendency for certain essential operation requirements, such as replacement of spent carbon, to be ignored or performed haphazardly. This reflects on operator training as well as on the degree of supervision and interest by the camp manager.

* "MET-PRO - 1100-10", at Wagley Construction Camp, Deadhorse, and at ALPS Toolik Lake Road Camp, Northern Alaska.

3. The hazards associated with installing a relatively untried system, designed in the South, for far north camps. Unforeseen "bugs" develop which the operators will circumvent in the most convenient way possible. Often the only sufferer is the uncomplaining environment.

TABLE C-2

A comparison between Repeated Performance of Pilot P-C Treatment Plants in Continental U.S.A. and in Alaska's North Slope (Compiled from several sources - 1,3,5,6,7,8,11).

	Pilot Plants in Continental U.S.A.	P-C Package Plants on North Slope
Unit Processes	Variable - all include chemical flocculation - clarification & carbon adsorption	Alum flocculation upflow clarification. Belt paper filtration of sludge & Carbon adsorption.
Influent	Raw Sewage. BOD_5 120-200 mg/1	Raw Sewage. BOD_5 variable but often high. 380-750 mg/1
Effluent BOD_5	8 - 13 mg/1	50 - 100 mg/1
(Removal Efficiency)	93 - 95%	80 - 85%
Effluent BOD	13 - 45 mg/1	175-375 mg/1
(Removal Efficiency)	90 - 95%	60 - 90%
Effluent Turbidity	1 - 5 JTU	"Clearer than from the biological plants"
Effluent Total P	0.1-0.4 mg/1	No figures
Effluent Color	15 units	No figures

COSTS

Because of the variability in processes available and the near-complete lack of information on the costs of small P-C units, no serious attempt is made here to arrive at a reliable estimate for the cost of installation and operation of a suitable treatment plant in an Arctic Camp. Some authors[1,2,4,5,9,10] have estimated costs for larger installations (10 - 300 mgd) and it is tempting to employ the dubious procedure of extrapolation to 50,000 gpd to arrive at an approximate figure. These costs were taken from an internal report of the Robert A. Taft Water Research Center by Robert Smith and reported by Kugelman and Cohen[8]. At 50,000 gpd indicated total costs run in a range 85¢ - $1.35 per 1000 gal. treated while the costs for chemical clarification alone may be between 32¢ and 60¢/1000 gal. The difference, taken up largely by carbon adsorption, is somewhere between 45¢ and 60¢ per 1000 gal. These costs do not include transportation, perhaps by air, to the site. It is re-emphasized that very little reliance can be placed on these estimates.

CONCLUSIONS

P-C treatment plants are in many ways well suited to the treatment of camp waste from a small body of men. With careful operation and maintenance, they can treat waste of widely varying volume and organic concentration and achieve high removal efficiencies. Experience in the Arctic, however, suggests that human factors work against the effectiveness of any sophisticated treatment units. If high efficiencies of organic and bacterial removal are not required, then it is probably better to employ a simple method of liquid waste disposal which requires a minimum of attention and can be relied upon. Where high removal efficiencies are desired, P-C treatment plants are probably a better solution than biological plants as they are more flexible, more compact, less sensitive to shock and more readily understood by the operators. However, an essential feature in their successful operation is the provision of trained operators and the provision for active supervision of the operation from time to time by agents from regulatory bodies and by the camp Managers. The operator training and supervision arrangements should be specified in the applications for approval of land and water use which precede camp construction.

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SUPPLEMENTARY REPORT D

TOILET UNITS FOR NORTHERN COMMUNITIES AND WORK CAMPS

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This report is pbulished as a supplement to the report "Management of Waste From Arctic and Sub-Arctic Work Camps", by J. W. Grainge, R. Edwards, K. R. Heuchert and J. W. Shaw.

TOILET UNITS FOR NORTHERN WORK CAMPS

1. SUMMARY

A cost evaluation of the various indoor toilet units shows that the bucket toilet with plastic bag liner is the least expensive. It is also the best system if there is a great shortage of water. A minimum-flush-water unit is esthetically much superior and is available in either portable or fixed models. The incinerating type of toilet is clean but operating costs are very high.

There are two types of units; portable toilets which can be carried away to be emptied and fixed toilets from which the effluent must be pumped or otherwise wasted. Wherever practicable, provision should be made for leaching pits near the building.

The effluent from all units except the bucket toilet may be drained or pumped to a leaching pit, if soil conditions are suitable. Soil conditions for leaching range from good to poor in the settlements along the Slave, Liard, and Mackenzie Rivers as far north as Fort Norman. Some settlements farther north contain areas where leaching occurs in summer but not in winter, for example, Inuvik, Lat. 68° N.

The available types of toilets are classified below under two headings -- portable units and fixed units. Classification is in order of increasing cost of operation. Comparative capital and operating costs for all units are given in Table D-1. All costs are based on prices of materials and labor in Inuvik. Costs are based on hauling away the sewage at 3¢ per gallon. Savings may be obtained by the use of leaching pits but this economy was not considered in preparing this table.

The names used are those in most common use in the Mackenzie District or names which have been invented for clarity. Typical units are illustrated diagrammatically.

1.1 PORTABLE UNITS

1. Bucket Toilet
2. Portable Chemical Toilet
3. Portable Minimum-Flush-Water Toilet

1.2 FIXED UNITS

1. Septic Toilet
2. Chemical Toilet
3. Minimum-Flush-Water Toilet
4. Vacuum Toilet
5. Chemical Toilet with Submersible Splash Pan
6. Recirculating-Chemical Toilet
7. Incinerating Toilet
8. Continuous Aeration, Closed-Cycle Toilet

2. DESCRIPTIONS

2.1 PORTABLE TYPES

2.1.1 Bucket Toilet

These are generally listed in catalogues as chemical closets. The toilet consists of a sheet metal bucket inside a painted sheet metal container which has a removable seat. The outer container is vented to the roof either by its own pipe or via the household chimney.

After each emptying, a quart of water is usually placed in the pail together with a small dose of a trade-named chemical product which consists of a biological inhibitor*, a perfume and in some cases, lye. The inhibitor reduces the rate of biological decomposition. The lye raises the pH (makes less acid) so that the biological activity which does occur produces less odorous decomposition products.

During the last 10 to 15 years plastic bags have been used as liners for the buckets and for containing the removed sewage. The bag must not interfere with the venting of the toilet.

2.1.2 Portable Chemical Toilet

A more sophisticated and expensive unit than the simple bucket toilet is known as the portable chemical toilet.

This is a light-weight, one-compartment unit. After emptying, the unit is charged with a quart of water and a chemical mixture of biological inhibitor, liquefaction agent, which may be lye, and perfume. Below the seat is a concave-shaped splash-pan with a hole in the middle, approximately 6-in diameter.

* Bactericide such as creosol.

The unit has a carrying handle and is emptied by opening a valve at the rear. The toilet can be carried to a disposal point, or may be kept in the residence if there is a drain pipe from the toilet to a leaching pit.

2.1.3 Portable Minimum-Flush-Water Toilet

This is a light-weight unit which consists of toilet seat and cover, a toilet bowl with bottom hand-operated valve, a sewage container which also serves as a support for the other parts, and an exterior hand-operated water pump. For flushing, the valve is opened and water is rinsed around the bowl by the water pump. The valve has a water seal, so there is no odor and no need for a vent on the unit.

2.2 FIXED TYPES

2.2.1 Septic Toilet

Septic toilets consist of a toilet seat and an 8-inch to 11-inch vertical drop pipe which extends into a septic tank. A bucket of water, which displaces the sewage downward and maintains aerobic conditions in the sewage in the drop pipe, is added to the tank each day. The drop pipe extends below the liquid surface to prevent the gases produced by sewage digestion in the tank from coming up the drop pipe. A vent pipe extends from the rear of the seat.

The septic toilet tank is intended to be always full and to overflow to a leaching pit. In some models there is a hand-operated paddle in the tank, which moves the solids in the tank so that they do not accumulate directly under the drop pipe.

2.2.2 Chemical Toilet

The construction of a chemical toilet is similar to that of a septic tank. The drop pipe size, the vent and the tank are similar, but the drop pipe does not extend into the tank and the tank is emptied completely rather than being an overflowing type.

A charge of approximately 25 lb of lye ($NaOH$) in 12 gallons of water is added to a 150-gallon tank after each emptying of the tank. The high causticity kills bacteria, inhibits decomposition and liquifies most of the solids.

2.2.3 Minimum-Flush-Water Toilets

In this unit the toilet should be placed directly over the sewage-holding tank. After each use a foot-operated valve is opened and approximately a quart of flush water is retained above the valve, providing a water seal against odors entering the washrooms from the tank. In one model the flush water is hand ladled into the bowl. The tank is always vented.

If there is no suitable space below the washroom, the toilet can be set on a raised floor so that the tank can be placed beneath it. If the bath and basin are also on the raised floor, a larger tank may be used.

However, if it is impossible to locate the tank directly under the toilet, a marine toilet can be used which has a hand pump instead of a foot-operated valve.

Usually the contents are pumped out of the tank to a leaching pit, or hauled away to a lagoon.

2.2.4 Vacuum Toilet

A vacuum toilet is similar to the minimum-flush-water toilet with respect to type of fixture and amount of flush water. However, a vacuum of 7.5 psi draws the contents through a 3-inch pipe to a sewage holding tank.

This type of unit is suitable for connecting together the toilets in several washrooms, located at distances up to 10,000 ft. from the vacuum tank. The vacuum pipe may run upgrade and over obstacles if necessary.

2.2.5 Chemical Toilet with Submersible Splash-Pan

This unit consists of an 8-gallon container below a seat and cover. After each emptying of the tank, it is recharged with 4 gallons of water, containing biological inhibitor, perfume and dye (dark green or blue) and it may or may not contain lye.

A bowl-shaped splash-pan, hinged to the seat cover, is directly under the seat during use, and dips down into the liquid contents when the cover is closed.

There is no odor when adequate chemical is added to the toilet, however, it is advisable to vent the tank in order to provide some ventilation of the room via this unit.

2.2.6 Recirculating-Chemical Toilet

These are chemical toilets in which the bowl is flushed with the contents of the tank. A water solution of lye; biological inhibitor, perfume and dye (deep blue or green) is added to the tank each time after it is emptied. Most of the solids are liquified by the lye. The liquid is used for flushing, and the dye masks the normal yellow-brown color of the sewage.

The flush water is pumped and comminuted by means of a pump which runs for a pre-set time when a button is pushed. The same pump may also be used for emptying the tank. The tank is emptied either to a leaching pit or by hauling away.

2.2.7 Incinerating Toilet

This unit consists of a toilet bowl and a small incineration tank. The bowl has a plastic liner which drops into the incinerator. It can be operated without the liner, but this adds to the housekeeping problems.

The source of heat may be either propane or electricity. The unit must be vented.

2.2.8 Continuous-Aeration, with Recycle to Flush Toilet

This unit consists of a toilet bowl and one or two tanks in which the contents are continuously aerated. The aerated contents which are yellow-brown and usually non-odorous are pumped to flush the bowl. The unit must be vented.

Some units receive all household waste and, therefore, must discharge some effluent. Other units are closed-cycle and receive only toilet wastes.

Evaporation reduces the water content and this must be regularly replenished. The closed-cycle unit requires emptying only once per year.

3. DISCUSSION

The different units have relative advantages which have varying values depending upon the cost of power, cost of water, cost of sewage disposal and the emphasis that is placed on esthetics.

3.1 PORTABLE UNITS

3.1.1 Bucket Toilets

This type of toilet is the simplest unit. There is no odor from a properly vented and operated unit. The contents of the bucket are open to view at all times, and this is generally considered to be esthetically objectionable. When the bucket is more than half full, there is liable to be splash on the user. One of the serious problems, about which there are many jokes, is the difficulties created when there is a large company or a party and the bucket must be emptied during the party. With the advent of plastic bags, this is a much less embarrassing chore than previously.

One of the difficult problems of bucket toilets with plastic bags is the storage of the full bags until they are picked up. The cleanest method is to store them in the house but this requires space, and some consider that the pickup involves an invasion of privacy.

The alternative of storing the bags outside is very poor. In winter, the bags will freeze to the ground or to ice on the ground unless there is a substantial layer of snow on the ground. Storage in boxes or on elevated platforms has resulted in tears on slivers and nails so that these conveniences had to be burned. Winter storage in metal containers results in them freezing to the shape of the container which are then difficult to empty. Probably the best outdoor storage method would be similar to that used in Greenland where the toilet bags are placed in large disposable plasticized paper garbage bags.

3.1.2 Portable Chemical Toilet

This type of toilet is esthetically much superior to the bucket toilet. The contents would be free of bacteria if the amount of lye and biological inhibitor used is adequate. However, this is not dependable, and the wastes should be considered to be dangerous. The bucket must be carefully handled while being carried, to prevent spilling and splashing. The unit should be emptied before the level of the contents reaches the bottom of the bowl in order to avoid splashing.

The contents can be disposed of to a seepage pit beside the residence if this is possible and this can be accomplished by merely turning a valve. If this is not possible then the contents can be removed and discharged into a pit in the yard. If adequate lye has been used, flies, dogs, etc., will not touch the contents.

In some models, a plastic liner may be used but in others a liner would interfere with the drain valve and/or the movement of the agitator.

3.1.3 Portable Minimum-Flush-Water Toilet

This type of toilet is esthetically superior to the two previous toilets. When carrying, the top is sealed, so that there is no danger of spilling or splashing.

As with the portable chemical toilet, the contents can be disposed of to a seepage pit. However, pits should be covered to reduce the odors, and to protect the contents from flies, dogs, ravens, etc.

A plastic bag could be used to line the container and would be useful if the contents are to be carried away.

3.2 FIXED TOILETS

3.2.1 Septic Toilet

Septic toilets have little to commend them. A number of these were installed in institutions, but removed later because of the strong odor which emitted via the seat. Much effort was devoted to reducing the odor by moving the solids from under the seat, improving vents, etc., but the improvements were inadequate. This type of unit is definitely not recommended.

3.2.2 Chemical Toilet

This type of toilet is relatively easy to maintain. When it is well maintained, it is virtually odorless, and superior esthetically to all types of toilets considered in this report, except the "minimum-flush-water", the "recirculating-chemical" and incinerating types. The contents of the tank are liquified and non-corrosive, and therefore can be pumped out with any inexpensive pump. The discharged contents of a well-maintained unit are not odorous, however they must be hauled away or disposed of in a leaching pit. With satisfactory operation the contents will be bacteria-free.

3.2.3 Minimum-Flush-Water Toilet

This type of toilet is the most esthetically acceptable unit of all those considered in this report. It is suitable for use where water and sewage must be truck-hauled or where there must be economy of water use.

The porcelain toilet can be kept clean with no more effort than is required for a standard flush toilet. There is no odor because there is a water seal at the valve. Occasionally the valve sticks on account of paper catching on it, but this can be wiped away without difficulty.

One distinct advantage of this unit is the fact that it can be flushed when there is no water in the reservoir. This is accomplished by manually pouring approximately a quart of flush water in the bowl after each use. Although there is a direct drop to the receiving tank, the toilet cannot be operated without this water because of the need for a water seal at the valve.

3.2.4 Vacuum Toilet

A vacuum toilet has the advantage that it can serve toilets located in different locations in a building or in several different buildings. There are relatively few moving parts directly in contact with the sewage so that there is less cause for breakdown.

3.2.5 Chemical Toilet with Submersible Splash Pan

In this type of toilet a splash pan prevents all but a rare splash on the user, but the dye is difficult to remove from non-washable clothes.

There is little economy of use because of the quantity of water required for the charge. However, there is value in this system if there is a leaching pit into which the contents can overflow regularly. If this is the case, there is much less use of water, because one merely adds more chemical as the chemical in the container becomes diluted.

3.2.6 Recirculating-Chemical Toilet

This type of toilet has all the esthetic advantages of the chemical toilet plus the fact that there is no splashing on the user. The chief disadvantage is that it is rendered inoperable by a pump breakdown (which is not uncommon) or an electrical failure. Also, the holding tank valve may be stuck in an open position by a solid object which would allow the contents to drain out inconveniently.

The kind of inhibitor which is used depends on the period between emptying. A stronger one should be used when several days will elapse.

A unit of this type is used in passenger airplanes. The inhibitor used with this unit is limited in effectiveness. It is suitable only for daily emptying of the toilet. If the toilet is installed for use by only one or two people and emptying is determined by the number of uses, then several days could elapse between emptyings. The unit will emit strong odors after a few days.

3.2.7 Incinerating Toilet

Incinerating toilets are esthetically superior to all the units considered in this report, except the minimum-flush-water type. The main faults are the high operating cost and the difficulty caused by corrosion of the valves and other moving parts. The hot, high-salt-content liquid, which develops during incineration is very corrosive. These units require much maintenance which is too complicated for general maintenance staff.

Incinerating toilets have been installed in diesel locomotive cabs. The initial installations were propane-burning, and these were converted to the electrical-model because of propane losses when the flame was doused accidentally. This type of unit is preferable to a bucket toilet because the latter splashes with the motion of the train. The Pullman type toilet which discharges below the train is not acceptable because the wastes splash on parts of the undercarriage which require maintenance.

3.2.8 Continuous Aeration with Recycle to Flush Toilet

This is the most expensive unit to operate of all the types considered, and it is not as esthetically acceptable as several of the other units. Usually a unit receives all household waste and clarified effluent is recirculated by a separate pressure system to flush toilets. Excess effluent overflows to waste.

The unit is subject to many operating problems, the most important of which is the fact that it is not tolerant to changes in loading. For example, the flush water will be odorous after the return of the occupants from a few days' absence, due to a major part of the biological population having died-off during the absence of regular users. Odors will also develop upon overloading.

Articles which drop into the toilet bowl may damage the pump. Such an accident might render a unit in an isolated community inoperable for long periods of time.

In the closed-cycle unit, the aerated waste which is used for flushing, develops a yellow to yellow-brown to brown color that is esthetically objectionable to most people. Units installed inside buildings in the Arctic have developed a number of problems including high noise level, leakage, fumes and excessive foam. In some cases the foam froze in vents and then under pressure rose back into toilet bowls, wash basins, sinks and baths.

In conclusion to this report, comparative capital and operating costs of the different toilet units are given in Table D-1 and drawings of the various toilet units are given in Figures D-1 to D-9.

TABLE D-1

COMPARATIVE COSTS OF TOILETS AND TOILET SYSTEMS

(20 Flushes per day)

Classification	Type	Unit Cost F.O.B. Plant	Frt. F.O.B. Inuvik N.W.T.	Instal- lation	Total	Esti- mated Life Years	Operating Costs: Write- off @ 8%	Water 2¢/ Gal.	Power 5¢/ kwh.	Chemi- cals	Bags 5¢/ Bag	Haul- age 3¢/ Gal.	Mainten- ance	Total Annual Cost
PORTABLE TOILETS														
Bucket	Vented bucket toilet or chemical closet.	12.31	4.93	12.00	29.29	6	6.33	2.00	-	33.54	10.75	17.64	0.63	70.89
Chemical	A chemical toilet that uses no flush water. Line bottom of bowl with paper prior to use.	76.15	8.50	30.00	114.65	5	28.72	2.00	-	103.10	-	19.20	2.87	155.89
Minimum Flush Water	This toilet has a hand pump for pumping flush water into the bowl.	118.50	4.12	30.00	152.62	5	38.23	18.25	-	103.10	-	43.57	3.82	206.97
FIXED TOILETS														
Septic	150-gal. holding tank below toilet uses 1 pail of water/day.	119.50	23.67	60.00	203.17	15	23.73	14.60	-	-	-	36.30	2.37	77.00

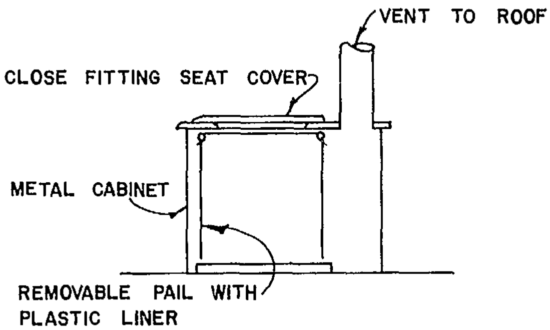
TABLE D-1 (Cont'd)

Classification	Type	Unit Cost F.O.B. Plant	Frt. F.O.B. Inuvik N.W.T.	Instal-lation	Total	Esti-mated Life Years	Operating Costs							
							Write-off @ 8%	Water 2¢/ Gal.	Power 5¢/ Kwh.	Chemi-cals	Bags 5¢/ Bag	Haul-age 3¢/ Gal.	Mainten-ance	Total Annual Cost
FIXED TOILETS (Cont'd)														
Chemical	150-gal. holding tank below toilet uses flake caustic. Caustic solution liquifies solids. A pail a day of water to wash toilet bowl.	119.50	23.67	60.00	203.17	15	23.73	15.87	-	15.90	-	38.21	2.37	96.08
Minimum Flush Water	150-gal. tank below or to one side of toilet. Uses 1 qt. water per flush.	170.60	22.26	60.00	252.86	15	29.53	36.50	-	-	-	69.15	2.95	138.13
Chemical Toilet With Submersible Splash Pan	Splash pan is cleaned by immersion in the holding tank solution.	99.95	4.11	30.00	134.06	5	33.58	8.72	-	103.10	-	29.28	3.36	178.04

TABLE D-1 (Cont'd)

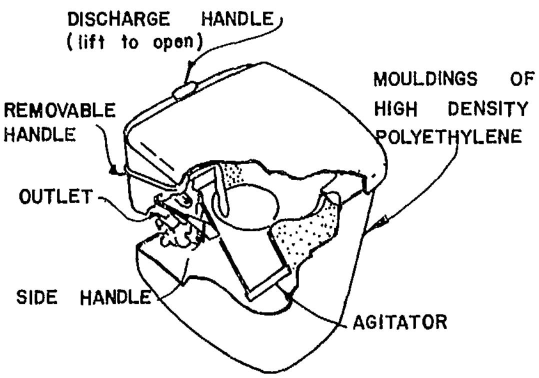
Classification	Type	Unit Cost F.O.B. Plant	Frt. F.O.B. Inuvik N.W.T.	Instal-lation	Total	Esti-mated Life Years	Operating Costs: Write-off @ 8%	Water 2¢/ Gal.	Power 5¢/ kwh.	Chemi-cals	Bags 5¢/ Bag	Haul-age 3¢/ Gal.	Mainten-ance	Total Annual Cost
FIXED TOILETS (Cont'd)														
Recirculating* Chemical	The chemical solution from the holding tank is re-circulated to wash the toilet bowl.	139.95	4.69	30.00	174.64	5	43.75	8.72	-	103.10	-	29.28	4.37	189.22
		274.70	2.18	30.00	306.88	5	76.87	8.72	5.26	155.70	-	27.80	7.69	282.04
Incinerating	Incinerates (burns) all excreta to produce ash.	537.00	15.02	30.00	582.02	7	111.81	-	273.75	-	-	-	11.81	397.37
Continuous Aeration Closed-Cycle	Continuous-ly aerated sewage treatment system with special toilet that uses ½ US ga. water per flush.	435.46	27.54	100.00	563.00	10	83.89	60.80	298.68	-	-	-	8.39	446.76

* The prices quoted are for two different brands of recirculating chemical toilets.



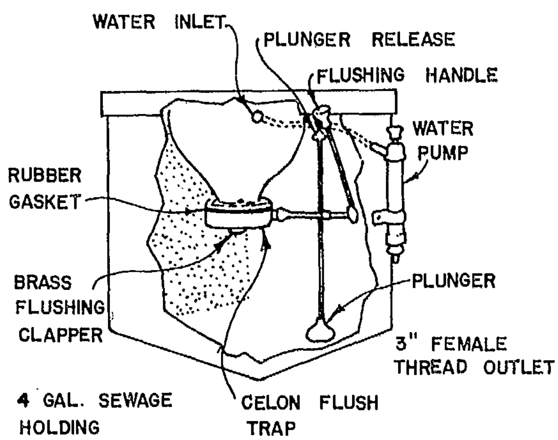
BUCKET TOILET (CHEMICAL CLOSET)

FIGURE D — 1



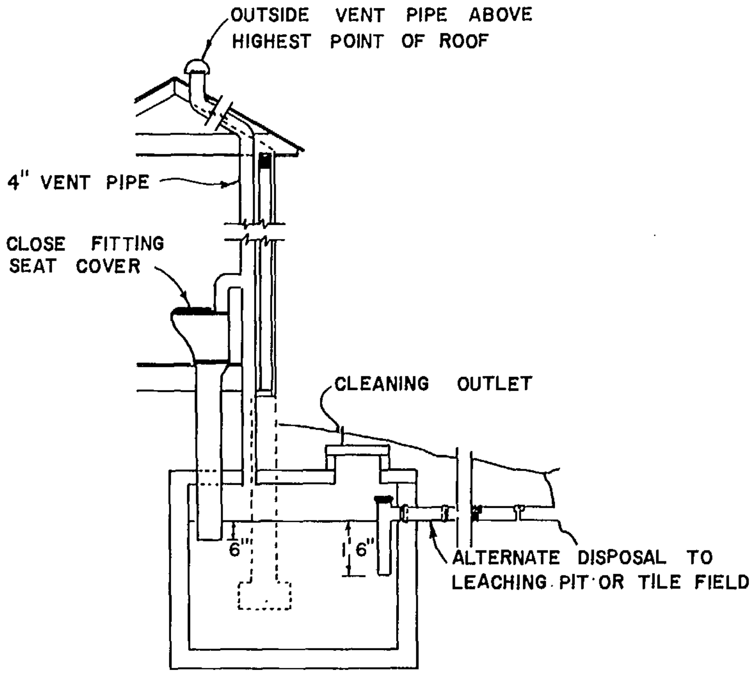
PORTABLE CHEMICAL TOILET

FIGURE D — 2



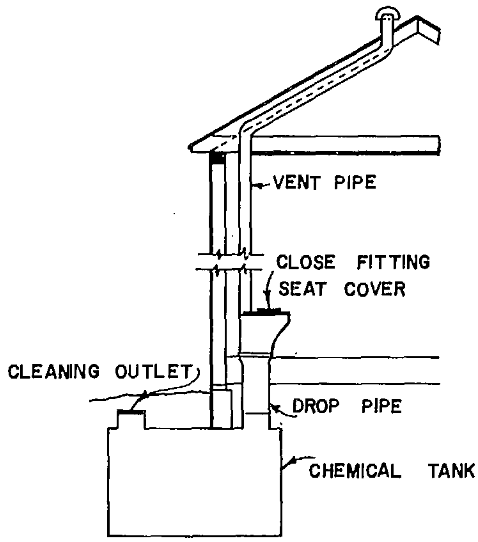
PORTABLE MINIMUM FLUSH WATER TOILET

FIGURE D — 3



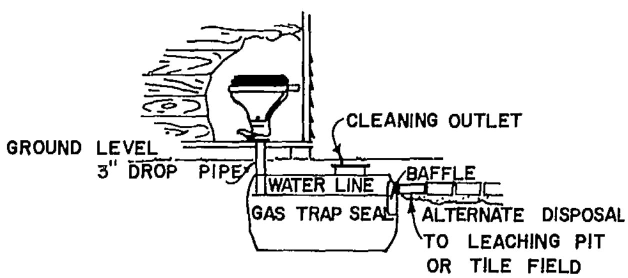
SEPTIC TOILET

FIGURE D-4



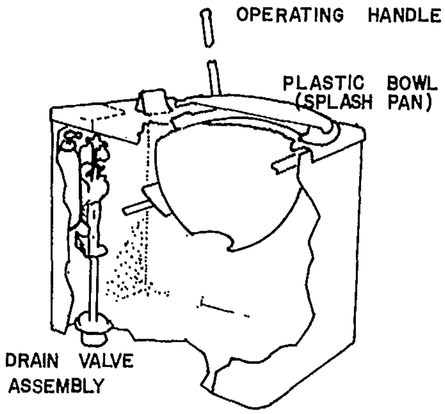
CHEMICAL TOILET

FIGURE D-5



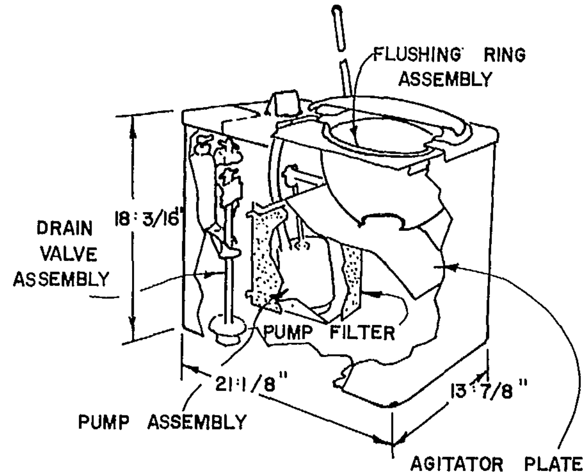
MINIMUM FLUSH WATER TOILET

FIGURE D-6



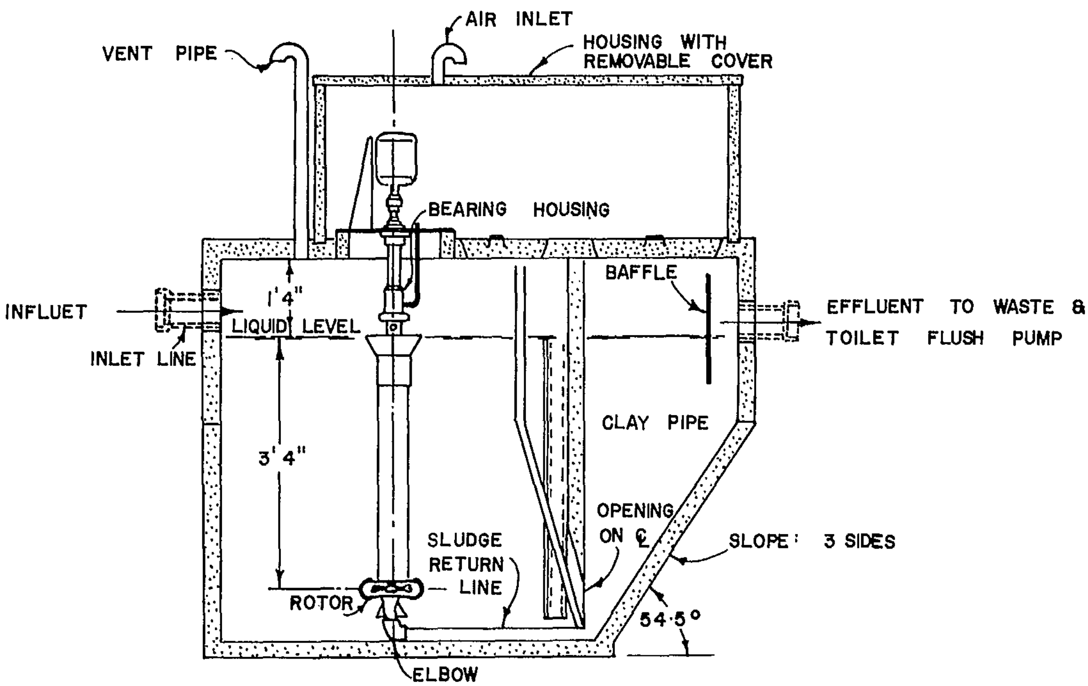
CHEMICAL TOILET WITH IMMERSIBLE SPLASH PAN

FIGURE D — 7



RECIRCULATING CHEMICAL TOILET

FIGURE D — 8



CONTINUOUS AERATION WITH RECYCLE TO FLUSH TOILET

FIGURE D – 9