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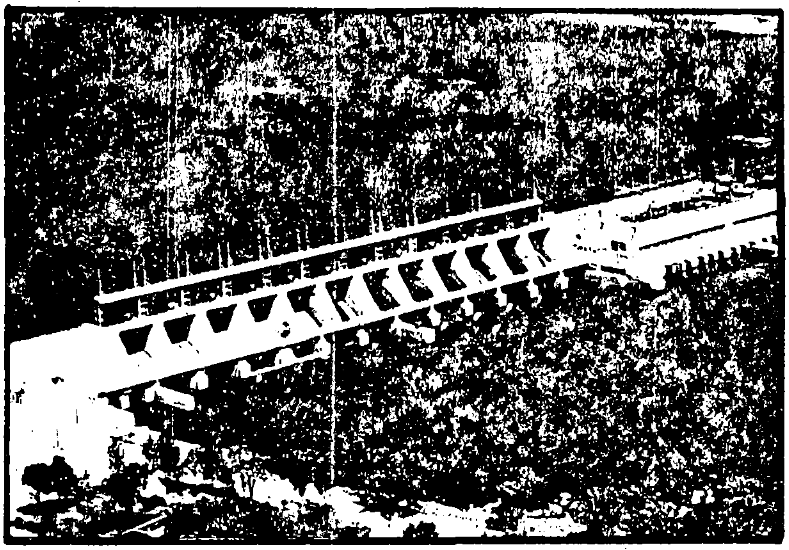

ENERGY FROM WATER

An Information Paper
for a Departmental View
and position

First Draft

February 1982

Water Planning and Management Branch
Inland Waters Directorate
Department of the Environment

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Department of the Environment

February 1982

ABSTRACT

Canada's energy system should be directed away from hydrocarbons (oil, gas and coal) in the long term, and environmental impact should be one of the prime considerations in setting priorities of energy options. Electricity would become a significant source of energy eventually in such an "off-hydrocarbon" energy system. Electric energy generation from sustainable sources such as nuclear, hydro, and non-conventional alternative sources (tidal, geothermal, wave and wind) will play an increasingly important role in the future energy system in Canada. A natural renewable energy source, "energy from water" (hydro, tidal, wave, thermal gradient, and hydrogen) will especially contribute significantly to the overall energy system. By the year 2000, hydro capacity should be double what it is today or over 100,000 Mw. Environmental and social constraints cannot be allowed to stop or delay water-related energy development projects, but rather the best development strategy should be sought that would support such energy resource developments while maintaining an acceptable level of environmental quality.

This report assembles the currently available information on technical, resource potential, environmental, socio-economic and institutional aspects of energy produced from water and also identifies some requirements for water-related energy programs as an information base in establishing the integrative departmental views and position on hydraulic energy developments. Included in this report are: a) general recommendations on departmental policies and programs with respect to water-resource utilization for energy production; b) current technology overviews; c) current resource potential of energy from water; d) electricity forecast; e) discussions on environmental impacts and mitigating measures; f) socio-economic overviews on energy sources

from water; g) discussions on the federal and provincial responsibilities on both water and energy resource areas; and finally h) discussion on the current and future role of water-related energy to the overall energy system of Canada.

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I. INTRODUCTION

The main objective of this report is to assemble the currently available information on technical, resource potential, environmental, socio-economic and institutional aspects of all forms of energy produced from water. The report is also to identify requirements for water/energy related programs as an information base in establishing the integrative departmental views and position on hydraulic energy developments and associated environmental concerns.

Although water is an essential component of all forms of energy production, only that energy production of which water is specifically the prime source or carrier of energy is discussed in this report; i.e. hydroelectric, tidal, wave, temperature gradient and hydrogen energy. Water-use and environmental aspects of other forms of energy production from coal, nuclear and biomass can be found in a separate series of parallel reports. (1), (2), (3)*

As indicated by the recently released report of the Parliamentary Special Committee on Alternative Energy and Oil Substitution (Lefebvre Commission), (4), Canada's energy system should be directed away from hydrocarbons (oil, gas and coal) in the long term, and the environmental impact should be one of the prime considerations in setting priorities of energy options. Electricity would become a significant source of energy in such an "off-hydrocarbon" energy system. Electric energy generation from sources other than hydrocarbon fuels are nuclear, hydro, and non-conventional alternative sources, such as tidal, geothermal, wave and wind.

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*Numbers in brackets indicate reference numbers listed in the List of References.

In Canada, hydroelectric power* contributes about 59 percent of the total electric power capacity and 68 percent of total annual electric energy* production based on the 1980 statistics. Hydroelectric power capacity has grown dramatically as the 20th century has progressed, increasing about 26-fold between 1920 and 1980, although its proportion of the total generating capacity has decreased from 90 percent to 59 percent during the same period. While this trend of a decreasing proportion of hydroelectric power generating capacity to the nation's total generating capacity is expected to continue in the future, installation of new hydro generating capacity will steadily increase and continue to contribute significantly to the total electric power system. By the year 2000, hydro capacity should be double what it is today or over 100,000 MW. In the long term, as hydrocarbon energy sources become scarce and expensive, other sources of energy from water such as tidal, wave and hydrogen should play an increasingly significant role in meeting the nation's energy demands. All forms of energy from water are renewable by the natural input of solar or tidal energy.

Hydroelectric power development is the most significant water resource utilization in Canada and had been for a long time a subject of public concern and criticism. The environmental and socio-economic aspects have been major constraints to water resource developments for hydroelectric power, irrigation, flood control, and municipal, industrial or recreational uses, etc. No water development project, however, is possible without resulting in some changes in the environment and socio-economic structure. All forms of energy from water, however, are relatively clean and non-polluting energy sources compared to hydrocarbon-based energy production and utilization.

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*See the Glossary of Terms for definition.

The Department of the Environment has mandates to maintain an acceptable degree of environmental quality as well as to plan and manage natural resource development and utilization, including water resources, for the best benefit to all Canadians. These two seemingly conflicting departmental mandates, environmental quality and resource utilization, should be managed such that they complement or at least balance each other. As previously mentioned, energy generated from water will play a significant role in the future Canadian energy system which should be directed more to the natural renewable energy sources. In light of the current and foreseeable seriousness of the energy situation, environmental and social constraints cannot be allowed to delay or stop water/energy development projects, but rather the best development strategy should be sought that would support such energy resource developments while maintaining an acceptable level of environmental quality. In order to achieve this imperative and difficult environmental/resource management goal, departmental policies and programs for energy production should place emphasis on the following recommendations:

1. Support a national incentive program on Environmentally Compatible Hydro developments including: (a) small-scale and low-head hydro-site developments; (b) rehabilitation of abandoned or decommissioned hydro power sites; (c) installation of generating facilities at existing non-hydro dams (irrigation, flood control, municipal or industrial, etc.); and (d) retrofit of existing old less-efficient plants. This program would include inventory, feasibility, demonstration, and financial and institutional support.

2. Support a program for detailed review of the anticipated environmental and social impacts of each energy source from water; also a program for

documenting post-development environmental conditions of hydro sites, where information is available, to evaluate the effectiveness of measures taken to minimize adverse effects.

3. Establish a national strategy and guideline to support water-related energy developments while meeting environmental and social requirements.

4. Support a program to determine the national hydroelectric power potential and environmental/social impact indicators for each potential site. The current inactive DOE/EMR joint hydro inventory program should be revitalized.

5. Establish a central co-ordinating body (interdepartmental) for hydraulic energy developments.

Specific recommendations on departmental support with respect to technology, resource potential, socio-economic, environmental, and institutional aspects of hydraulic energy developments are included in the respective chapters.

REPORT FORMAT

Chapter I, the Introduction, provides the objective, a general discussion on water/energy/environmental aspects, general recommendations on the departmental policy and programs with respect to water resource utilization for energy production and the format of the report.

Chapter II presents overviews of the current status of the energy conversion technology of hydro, tidal, wave, thermal gradient and hydrogen energy, and recommendations for departmental support of further technology development.

Chapter III presents the current potential in Canada of energy sources from water and recommendations on government-supported programs with respect to that resource potential.

Chapter IV presents electricity demand projections by regions and brief explanations of the basis of the projections and provincial scenarios.

Chapter V, Environmental Impacts and Mitigating Measures, includes general discussions on the environmental impacts of water-related energy developments with specific emphasis on hydroelectric development impacts and mitigating measures. Included also are the recommendations on departmental programs with respect to the environmental aspects.

Chapter VI presents social and economic overviews on energy sources from water and the socio-economic related programs that the Department is recommended to support.

Chapter VII, Federal-Provincial Relations, describes the federal and provincial responsibilities and linkages in both the water and energy resource areas, and recommendations with respect to institutional aspects for better management of water resources for energy production.

Chapter VIII discusses the current contribution of water-related energy to the overall energy system of Canada and the expected future role of those energy resources.

II. TECHNOLOGY

Energy sources for which water is the prime component are hydroelectric, tidal, wave, thermal gradient and hydrogen energy. This chapter presents brief overviews of the current status of the energy conversion technologies of these energy sources and recommendations for Departmental support in improving technical and economic feasibilities for exploitation.

Hydroelectric power plants, by use of a turbine and generator, convert the potential energy of falling water into electric energy. In Canada, hydro plants have been developed for industrial use since near the turn of the century; the generating capacity has steadily increased and given a significant contribution to the nation's electric energy systems.

Tidal power plants could harness the potential energy of tidal cycles in a similar fashion to hydroelectric power plants. Initial development of a tidal power plant will be realized in Canada upon completion of the current demonstration project at Annapolis Royal in the Bay of Fundy.

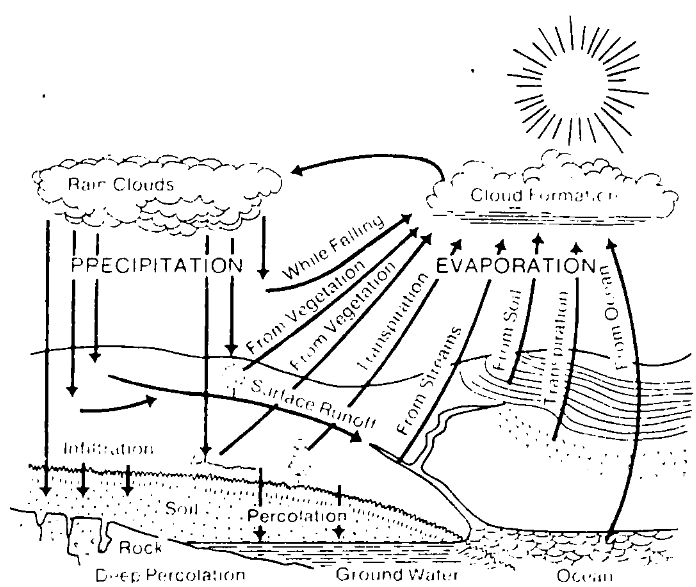
Conversion technology for energy from ocean waves and thermoclines in large water bodies is still in the early research and development stages. Hydrogen production from water is currently limited to small commercial quantities for certain industrial uses; however, it could significantly contribute to the nation's future energy system.

A. BASIC TECHNOLOGY

1. Hydroelectric Power

Hydroelectric power is a renewable energy resource developed by intercepting flowing water and capturing the potential energy of falling water. The power capacity is dependent upon both the water flow rate through the turbine and the height (head) through which it has dropped. The flow, the prime driving force of hydroelectric power, is continuously replenished by the natural process known as the "hydrologic cycle" (Figure 1/II), whose prime source of energy is the sun. The development of hydroelectric energy can, in essence, be regarded as an indirect utilization of solar energy.

FIGURE 1/II
The Hydrologic Cycle.



Hydraulic heads (distance of vertical drop) representing part of the hydraulic potential energy are obtainable by: a) damming a natural river valley, b) diverting flow from upstream of a natural waterfall or rapids,

c) by-passing a sharp bend of a river, or d) diverting flow from one river to another where a natural difference in river elevations exists. Hydroelectric power developments could be classified into three basic types: storage, run-of-river and pumped-storage plants.

Hydro plants having reservoir storage sufficient to regulate flows and power output for monthly, seasonal or annual fluctuations are referred to as storage plants. Storage reservoirs, normally created by damming a river valley or using a natural lake, store water at times of high flows to be released when the flows are low, and provide power generating capability for both base and peak electricity loads. Storage reservoirs often serve for purposes other than electric power generation; for example, flood control, navigation, log transportation, recreation, water supply for domestic, industrial or irrigation purposes, etc.

Plants operating on natural flows or regulated flows from upstream storage reservoirs are referred to as run-of-river plants. This type of plant does not normally have the capability to regulate flows or power outputs for a period longer than a week due to the relatively small reservoir associated with it.

A power plant which pumps water to an elevated reservoir for storage until a higher power demand occurs, is known as a pumped-storage plant. Pumped-storage plants essentially consist of a tailwater pond from which water is pumped by using the reversible pump turbines during off-peak hours, and an elevated headwater pond from which the stored water is released for power generation during times of high load demands.

The technology of hydroelectric power developments is well established and ripe for immediate use with a long-time successful and reliable operating experience. Some noticeable new technology developments in hydroelectric power are: a) development and application of low-head horizontal tube turbines and reversible-type bulb or straight-flow turbines; b) standardized design of "off-the-shelf" generating units suitable for small- or mini-scale hydro sites; c) modernization of old power generating units to improve their energy conversion efficiencies; d) application of new system operation and control techniques including remote and micro-processor controls, integration of pumped-storage into the system, transmission interties and computer-aided system optimization; and e) hydrologic simulation techniques used for the sites where minimum or no flow data are available.

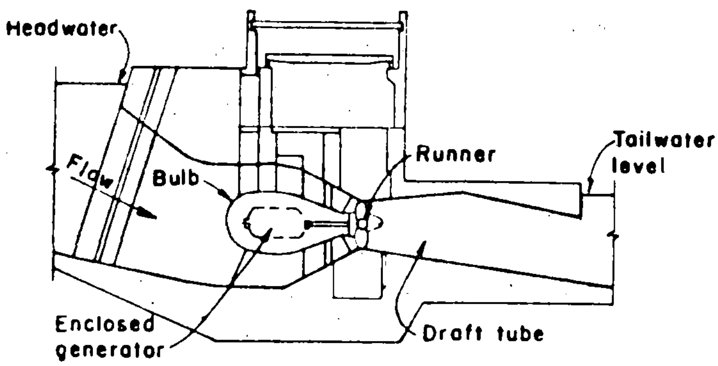
Hydroelectric power production (benefits) and costs both normally vary with the hydraulic head. However when the head is lower than a certain limit, governed by the minimum height of vertical turbines and generating units which control the power plant height and foundation and limited by the energy conversion efficiency constraint of turbines, costs tend to become independent of head while benefits continue to decrease. Hydro developments with the head within this lower limit (about 20 metres with conventional vertical turbines) tend to become uneconomical. Low-head hydro developments with a head within such a lower limit could benefit from the new technical development of bulb-type, straight-flow rim-type or horizontal tube-type turbines which substantially reduce the civil construction costs and improve the turbine efficiencies and hence the overall economy of low-head hydro sites.

The bulb-type generating unit (Figure 2/II(a)) comprises an adjustable blade turbine with a generator contained in a torpedo-shaped casing located in the water passage in a straight horizontal position. The mechanism of the bulb-type unit is essentially the same as the conventional vertical adjustable blade Kaplan turbine except for its horizontal alignment and lack of a scrollcase. By rotating the runner blades, this type of turbine could be made reversible for both flow directions, an ideal arrangement for application to a double-effect tidal power development scheme.

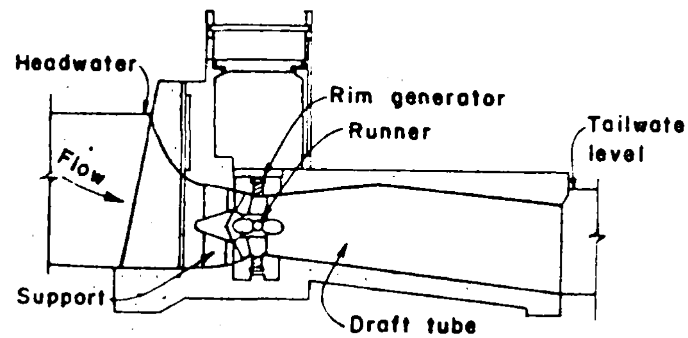
The straight-flow generating unit (Figure 2/II(b)) is a horizontally installed unit with the generator rotor mounted on the periphery of the runner blade tips. The rotor turns in a sealed annular recess of the water passage. The stator is located surrounding the rotor recess as a rim. This type of unit has several advantages over the bulb-type unit by providing a sufficient diameter generator for the large number of poles mounted around the outside of the turbine runner and the resulting higher inertia necessary to achieve stable electrical characteristics. A straight-flow turbine with a rim-mounted generator ("STRAFLO") will be installed at the Annapolis Royal demonstration tidal plant with the largest runner and generating capacity of this type in the world. If this large demonstration unit (runner diameter: 6.7 m, generating capacity: 20 Mw) performs satisfactorily, especially its sealing and bearing arrangements and adjustable blade propeller mechanism, this innovative technology is applicable to both low-head river hydro and tidal plants (5).

The tube-type unit (Figure 2/II(c)), is characterized by a water passage with a gently-angled vertical S-shaped bend, and by a generator located outside the water passage connected to the turbine with an inclined

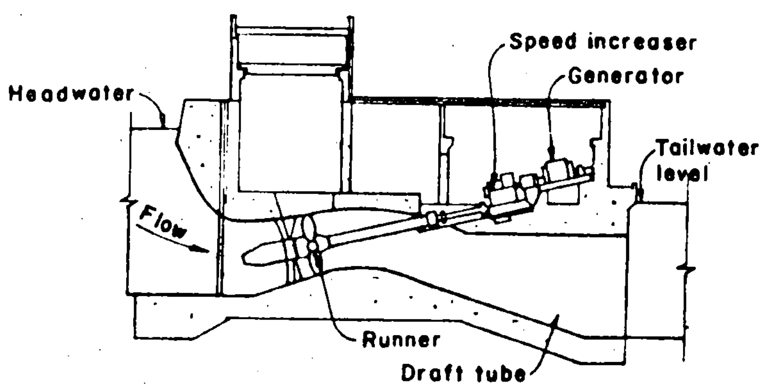
FIGURE 2/II TYPES OF LOW-HEAD TURBINES



(a) BULB TURBINE



(b) RIM TURBINE
STRAIGHT-FLOW



(c) TUBE TURBINE

common shaft. The tube turbines may not have quite as high a hydraulic efficiency as the bulb and straight-flow types; however, substantial savings can be achieved in civil works and they have the advantage of simplicity of design applicable for relatively small scale units.

One of the constraints in small or mini-scale hydroelectric developments is the higher installation cost per kilowatt than that for conventional large scale hydro sites. The higher per unit cost is partly attributable to the costs of site-specific feasibility studies and custom designs for these small projects. This cost disadvantage of small scale hydro projects could be improved by standardizing the design, construction method and costing and screening process through documenting actual project developments and demonstration projects. Recent attempts at standardizing generating units (6), (7) should help in reducing the unit cost and development period of small scale projects. With the developed "off-the-shelf" units, engineering design costs can be considerably reduced. Site specific conditions could make standardization difficult; however, a standard design package for a range of hypothetical site conditions, developed through research, development and demonstration works, would still be of great value in reducing the overall costs and time for such small scale projects.

By raising the efficiency of older less efficient hydro units through rehabilitation or replacement of those turbines by ones of modern design, an added contribution can be made to the energy system without affecting any environmental quality. By modernizing old turbines, a ten percent increase in energy from an individual plant is often feasible. Actual examples (8) indicate generating capacity can be increased in excess of 30 percent by simply retrofitting old turbine runners with ones of new design. The actual potential of increased hydroelectric power generating capacity in Canada attributable to the redevelopment of existing inefficient plants is currently unknown. There are about 800 operating units in Canada which are older than 30 years, and the potential for increased capacity by retrofitting inefficient units could be significant.

Modern technology of remote control and electronic micro-processor control equipment could reduce operating costs through automated unmanned plant operations. Integration of pumped storage plants into a system and system-to-system interties could significantly improve system reliability and flexibility. Modern computerized system engineering technology could optimize plant operations as well as system planning to realize maximum benefit to the system.

Substantial knowledge of variations in river flows is essential in designing and implementing an optimum hydro site development. An accurate analysis of the extreme events of high and low flows is particularly crucial to the success of a project. The extreme event of low flow establishes the criteria for firm power generating capacity and intermittency of output and even the provision for back-up power sources especially for an isolated remote plant, while the extreme high flow sets the criteria for spillway capacity and accommodation for floods. For project sites where minimum or no flow records are available, hydrological simulation techniques could be used to generate flow data and establish criteria for an optimum size of the project.

2. Tidal Power

Given the present stage of technology development on harnessing tidal power and the present global energy shortage, the potential utilization of the energy from tidal amplitudes (difference between high- and low-tide levels) appears to be promising. The basic principle of tidal power is to convert the potential energy of tidal amplitudes into electrical energy by technology similar to that used in river hydro plants. The gravitational attractions of both the moon and the sun on the earth are the forces that influence the tidal amplitudes and cycles. Since this influence varies directly as the mass of the attracting body and inversely as the cube of the distance between the bodies, the moon exerts a greater influence on the tides than the sun with a ratio of about 7 to 3. Thus the tidal cycles which follow the lunar diurnal cycles occur out of phase with solar days; i.e., the high tide water level occurs at progressively later times (by about 50 minutes) on succeeding days. The tidal cycle is, therefore, out of phase with man's activities which follow the solar cycle.

Tidal range also varies according to the lunar monthly cycle and the relative locations of the moon and the sun with respect to the earth. The highest tides occurring twice a lunar-month (29.5 solar days) are called spring tides. They occur at or near the new or full moon when the sun, moon and earth are in line, and the tide-generating forces are additive. The lowest tides (neap tides) of the month occur at the time of the first- and third-quarter moon when the lines connecting the earth with the moon and the sun form a right angle and the influence of the moon and the sun are subtractive. At both equinoxes the tidal ranges are larger than usual. Large differences in tidal ranges occur, however, at different locations along the ocean coasts and estuaries because of secondary tidal waves amplified by the local configuration and physiographic features. For instance, the tidal range of the Bay of Fundy amplifies approximately five times as it progresses from the Gulf of Maine towards the head of the bay as a result of the secondary wave, resonance and the effects of the shelving and narrowing of the bay. The tidal range of the Bay of Fundy, reaching as high as 18 metres (53 feet), is among the highest in the world.

An important feature of the tidal power potential is that the continuously varying magnitudes of local tidal ranges can be accurately predicted, thus it is possible to forecast with assurance the amount of energy available at any future time scale: hourly, daily, weekly, monthly, or annually. Prediction of the future energy production from a river hydro plant is not possible as precisely as a tidal power site.

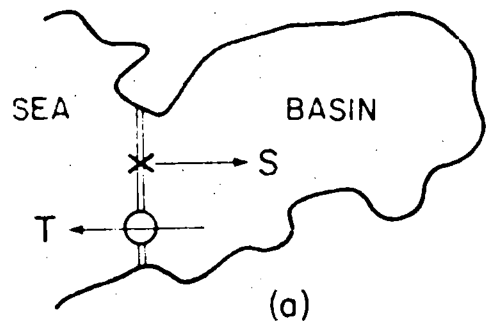
Tidal power can be exploited by the following basic concepts:

a) Single-basin with single-effect: Single-effect generating units are used in this concept with a single basin (Figure 3/II(a)) to generate in one direction only, usually discharging seaward from the basin during ebb tide. A pumping capability could be incorporated in the units to overfill the basin on the flood tide thus increasing the head. This concept is the least complex and least costly, but cannot produce continuous power or dependable peak power because the generation is totally dictated by the timing of the tides.

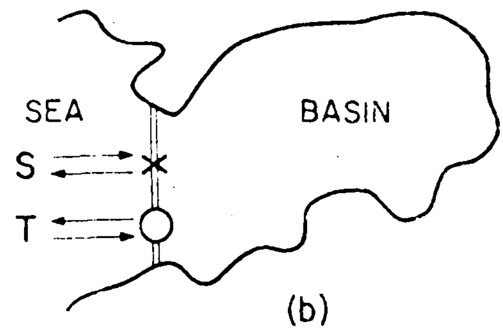
b) Single-basin with double-effect system: The generating units are designed, in this concept (Figure 3/II(b)), to generate power on both the

FIGURE 3/II - SOME CONCEPTS OF DEVELOPMENT

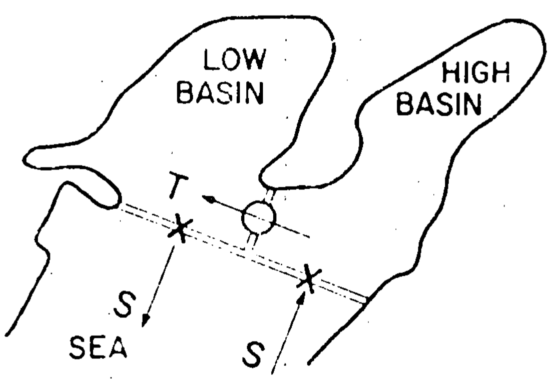
S : SLUICES
T : TURBINES



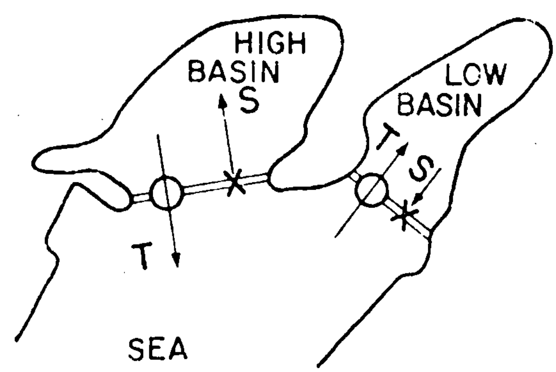
(a)
SINGLE BASIN
Single-effect on Emptying



(b)
SINGLE BASIN
Double Effect



(c)
LINKED BASINS



(d)
PAIRED BASINS

flood and ebb tides using a single basin. Double-effect pumping may also be included to achieve a greater range between high and low water levels. This concept could partly overcome the generation timing problem of the single-effect system but involves more complex and expensive generating units and civil works. Reversible horizontal shaft turbines, such as the bulb-type, are ideal for this concept.

c) Linked double basin with single-effect system: In this concept (Figure 3/II(c)), one of the two basins is operated as a high basin and the other as a low basin with single-effect turbines which produce power by the discharge and head from the high basin to the low basin. This concept could further prolong the generation times but involves more expensive costs, especially in civil works.

d) Paired basins with single- or double-effect system: In this kind of concept (Figure 3/II(d)), two or more single basins may be electrically interconnected and operated to take advantage of the time differences in occurrences of high water at different sites.

Through a combined operation with an external pumped storage plant, the shortcoming of tidal plants in matching the energy demand cycle, could be effectively alleviated. The low-value off-peak portion of the energy output from the tidal plant could be used to pump water up to a storage reservoir where it would be retained pending return of the daily high demand energy cycle.

Generating units with horizontal installations suitable for low-head river hydro plants are directly applicable for tidal power plants. The typical types of those horizontal-shaft turbines are bulb, straight-flow and tube turbines which could considerably reduce foundation civil costs in comparison to the conventional vertical shaft turbines as discussed in the preceding section on hydroelectric power plants.

The first large tidal plant was commissioned in 1967 at the LaRance estuary near the Gulf of Saint-Malo, France. This 240 Mw (24-10 Mw units) plant uses bulb-type reversible generating units and operates in both tidal directions at tidal ranges up to 13 metres. A small scale 400-kw prototype experimental tidal plant was installed in 1968 at Kislaya Gulf on the White Sea, Russia. China operates a 500-kw experimental tidal power plant at Yuequing Bay on the Eastern China Sea.

In Canada, since the early forties when the first major study was carried out on the feasibility of harnessing the tidal power of the wholly Canadian portion of the Bay of Fundy, a great deal of effort and investigation has been undertaken (9), (10). A demonstration tidal plant is currently under construction at the existing Annapolis Royal causeway near the mouth of the Bay of Fundy and scheduled to be commissioned in the spring of 1983. This joint project, funded by the federal government and the provincial government of Nova Scotia, would provide valuable data on both the technical and environmental aspects applicable to future full scale tidal developments in the bay as well as to low-head river hydro sites.

Major obstacles of tidal power developments are the very high initial capital investment and the lack of practical experience. Government support in financing both demonstration and full scale developments is, therefore, essential to realize tidal power developments.

3. Ocean Wave Energy

In many countries there is an increasing interest in the possibility of harnessing the power from the oscillating ocean wave motions. The International Energy Agency (IEA) has put a wave energy R&D program into action by designating Britain as a lead agency. In the R&D program, various wave energy collector systems are to be investigated and technical problems are to be examined. In Canada, under the auspices of the Interdepartmental Task Force on Energy R&D, the National Research Council (NRC) is currently investigating the future of wave energy in a Canadian context including the technology and magnitude of the Canadian wave power resources. These investigations have indicated that the amount of exploitable wave energy in Canada is small and spread over a wide area compared with that of other countries such as Britain, Norway or South Africa.

Wave energy can be thought of as a concentrated form of wind energy. The ocean acts as a giant wind power collector absorbing wind energy over vast areas of the ocean and concentrating it in the form of waves. Devices for the extraction of the wave energy fall into two categories: mechanical and hydraulic. Mechanical devices convert wave energy into electric energy mechanically by use of a string of rafts known as "Cockerell Rafts" and "Salter Ducks" which use the rolling and rocking motion of waves. Hydraulic devices generate electric energy through air-driven turbines by the use of compressed air built up by oscillations of waves trapped in an inverted sealed cylinder or massive rectangular structure floating in the sea with the bottom side open to the waves. This system has aready been used for a power source in navigation buoys and in an experimental wave power generation ship called "Kaimei" (1 Mw generating capacity) in Japan. A recently developed design concept at Britain's Lancaster University called "flexible bag" generates electricity through two-way air turbine generators by use of the compressed air in and out of the huge rubber membrane breakwater against which wave trains exert pressure.

An innovative wave energy generating device could be developed by combining a massive rectangular structure and a "flexible bag" installed at its periphery. This combined device could use two-way air turbines to generate electric energy by use of compressed air built by both the oscillations of waves inside the massive structure and the pressures exerted by the wave trains against the membrane surrounding the structure. This device could also combine with other purposes such as an off-shore drilling platform, air strip or deep-water mooring facilities. These off-shore structures could especially benefit from the "flexible bag" wave energy generator which absorbs the often destructive wave forces.

Exploiting wave energy potential in Canada would require decades of concentrated effort in solving a number of technical and economic problems such as: the development of wave machines of sufficient efficiency, acceptable cost and reliability in the rigorous and corrosive marine environment; the methods of mooring such machines at a considerable distance from shore and in deep water, perhaps off the continental shelves; and a method of transmission of electric energy over the long distance and through deep water, etc. Despite these technical and economic problems, wave energy will eventually become a practical proposition and will contribute, even as a minor source, to Canada's intermediate or long-term energy demands as a naturally renewable energy source.

4. Thermal Gradient Energy

An active research and development program is now underway concerning the possibility of extracting ocean thermal energy, known as OTEC, in the United States. OTEC facilities could generate electricity by use of the difference in temperature between the ocean surface and deep waters. The earth's oceans act as giant solar energy receptors and store the collected solar radiation in the form of heat in the ocean's surface waters. Because of the density difference between warm and cold waters, oceans become thermally stratified with the lighter warm water remaining on top. OTEC installations using this temperature difference could generate electricity through turbines by evaporating water or another working fluid such as ammonia, propane or flourocarbons. Converting the ocean thermal energy into electricity normally requires a temperature difference of at least 18°C. Near the earth's equator in the tropical zone, an exploitable temperature difference always exists between the surface and deep waters within 500 to 1,000-metre depths. Because of the low efficiency of OTEC plants (typically only 4% or less), very large amounts of warm water and cold water must be circulated to extract the energy, thus it requires a very large facility and investment.

The same technology and concept of OTEC could be used for deep freshwater lakes where substantial temperature differences exist between surface and bottom water layers. During summer stratification periods, temperature differences of 15°C or more are not unusual in deep freshwater lakes or artificial reservoirs behind dams. In Lake Ontario, the surface water temperature is normally 20°C with bottom water temperature at 4°C during summer stratification. The vertical distances between those two extreme temperature water layers in freshwater lakes or reservoirs are much shorter than in the ocean, and the corrosive salt water problem does not exist in the freshwater environment. These facts offer some advantages for extending the OTEC concept to the freshwater conditions.

In Canada, ocean temperature differences cannot be feasibly used for energy conversion; however, the freshwater thermoclines during summer stratification periods with combined use of industrial waste heat discharges could feasibly be exploited by extending the OTEC concept. No such initiative has yet been taken in Canada. In the United States, however, the OTEC program has developed to the stage of a prototype plant installation.

5. Hydrogen Energy

Hydrogen (H_2), a colourless, odourless, tasteless and highly combustible gas in air, has a very high energy density per unit weight and is one of the most abundant elements in the universe being bound with oxygen, carbon or other elements (water, hydrocarbon gas, etc.). Its reaction with oxygen can produce electricity directly in a fuel cell or generate heat in a flame with water being the only residue by-product. Hydrogen can be produced from its natural compounds by use of separation processes involving the use of external energy (electricity, heat or sunlight). The production of hydrogen does not have to be dependent on depleting fossil fuel reserves, but requires only water, the most abundant renewable resource on earth, and primary energy available from hydro, tidal, wind, nuclear, or solar power sources. Hydrogen is, therefore, ideal in many ways, especially in Canada, to replace the limited hydrocarbon fuels in the future.

Hydrogen can be produced by a number of conversion techniques including: a) electrolysis from water; b) water-gas reaction; c) thermal decomposition; d) thermochemical process; and e) photochemical process. Of these hydrogen production techniques, the electrolysis process is the most promising and practical method involving only water and electricity. However, the electrolysis process currently generates less than 1% of Canada's total hydrogen supply with the water-gas reaction process supplying the majority of the demand.

Hydrogen separation by electrolysis involves direct current electricity passing through a solution of water and a catalyst which causes the water to decompose into its elemental components, hydrogen (H_2) and oxygen (O_2). One of the largest commercial electrolysis plants in the world is in operation at a Cominco plant in British Columbia generating hydrogen used in the production of ammonia-based fertilizers. This plant has a process efficiency in the order of 65%. The efficiency is the ratio of the equivalent heat values of H_2 output and electric energy input.

The primary use of hydrogen in Canada is in petroleum refining to upgrade hydrogen ratios through hydro-treating and hydro-cracking operations. The water-gas reaction technique is primarily used in the petroleum refinery operations. This hydrogen splitting process involves heating a mixture of water and natural gas or crude oil to release H_2.

Other hydrogen conversion techniques, such as thermal decomposition, thermochemical and photochemical processes are still in the research and development stage and their technical and economic viability is yet to be determined. Canada's main effort in hydrogen production, therefore, should remain with the electrolytic process given our abundant supply of water and electricity. Use of electricity generated from remotely located hydro sites (large or small scale), tidal power plants and large scale nuclear power plants to generate hydrogen by the electrolysis process seems particularly attractive in Canada for technical and economic reasons. In order to resolve some remaining technical problems, especially in storage and transportation of hydrogen, further government-supported concentrated technology research and development programs are required as recommended by the Parliamentary Special Committee report on alternative energy and oil substitution (4).

B. RECOMMENDATIONS

The technical and economic feasibilities of potential water-related energy developments can be improved by conducting further technology development programs in specific areas and it is recommended that the Department support the following technology development programs:

1. National potential inventory and feasibility and demonstration programs for small scale, low-head, existing less efficient, and non-power sites. Such a program could stimulate development of this Environmentally Compatible Hydro potential. As a part of this program, a design/development guide, manual or standardized design package could be developed for use by proponents to reduce cost and time.

2. Development of regional hydrologic models which could generate flow data for those sites where limited or no gauged flow data are available.

3. Comprehensive monitoring of technical data from the government-supported tidal demonstration project at Annapolis Royal.

4. Investigation into the combined use of tidal power with hydrogen production to determine if any economic advantages of the Fundy tidal power sites exist.

5. Continued active participation in international R&D ventures and keeping up-to-date with new developments in the wave energy field.

6. R&D proposals to international joint ventures or interdepartmental energy R&D programs for an innovative wave energy generating device, a combined scheme with a massive rectangular structure and a "flexible bag" installed at its periphery as previously discussed. Such a structure could also serve other uses such as an off-shore drilling platform, airstrip or deep-water mooring facility.

7. Detailed investigation into the viability of extending the OTEC concept to deep freshwater lakes or reservoirs and also a combined use of thermal plant waste heat discharges.

8. Extended investigation into hydrogen production from water, storage, transportation and end-use and its viability for practical application in a Canadian context.

9. Examination into the combined use of hydrogen and remote hydroelectric power sites (large or small scale) and tidal power plants.

III. RESOURCE POTENTIAL

By a natural phenomenon known as the hydrologic cycle (Figure 1/II), a continuing process involving evapotranspiration, precipitation, surface and subsurface runoff; water, the most abundant natural resource, is continuously replenished. About a quarter of the total energy influx from the sun is used for evaporation and precipitation as the prime driving energy of the hydrologic cycle. Energy from water, hydroelectric, tidal, wave, thermal gradient and hydrogen energy, is the largest renewable energy source on the earth. This chapter presents overviews of the currently known resource potential in Canada of the energy sources from water and recommendations on government-supported programs with respect to the information on resource potential.

A. ENERGY POTENTIAL

1. Hydroelectric Power

Every year about 8,000 billion tons of water fall on Canada as rain, snow or hail. It has been estimated that only about 60 percent of this annual precipitation reaches Canada's rivers as runoff after infiltration, evapotranspiration or other losses. The precipitation and runoff are not evenly distributed geographically and temporally. Mean annual precipitation varies from 300 mm on the prairies to 2,500 mm on the Pacific coastal area, and high flows occur in the spring or early summer and low flows during autumn and winter. About 36 percent of the mean annual precipitation in Canada occurs as snow, most of which accumulates over several winter months before melting. At times and locations, therefore, the rate of runoff is many times or only a fraction of the average. The regional variation and seasonal distribution of precipitation and runoff for the six main regions of Canada are shown in Figures 1/III and 2/III.

Both in totality and on a per capita basis, Canada has a very abundant water supply, 400,000 litres per person per day on the average. Regional variations in water availability are, however, more important particularly when considering the locations of high water demand for energy production or agricultural uses. The largest per capita supplies are in the north and the sparsely settled areas on the eastern and western extremities of Canada. Rated on the basis of a reliable minimum monthly flow, five drainage basins (North Saskatchewan, South Saskatchewan, Red-Assiniboine, Milk and South Ontario) have available less than 500 litres of water per capita per day. In these drainage basins and the Okanagan River basin, current and future water demands exceeds supply.

Hydroelectric power potential is determined by the flow rate and available head. A flow of one cubic metre per second when it has dropped over a 12-metre head produces about 100 kilowatts (Kw)* of power and 100 kilowatt-hours (Kwh)* of energy every hour with this constant flow rate and head. Canada's total hydroelectric power potential has never been comprehensively investigated; however, an estimated potential based on the currently available information is listed on the Table 1/III. This information suggests that a further 104,193 megawatts (Mw)* of technically developable hydraulic power potential is available in Canada. As of the end of 1980, the hydroelectric power generating capacity in Canada was 47,919 Mw, about 59 percent of the total installed generating capacity of

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*See the Glossary of Terms for definition.

Figure 1/III
Average Annual Precipitation and Runoff in Canada (in millimetres)

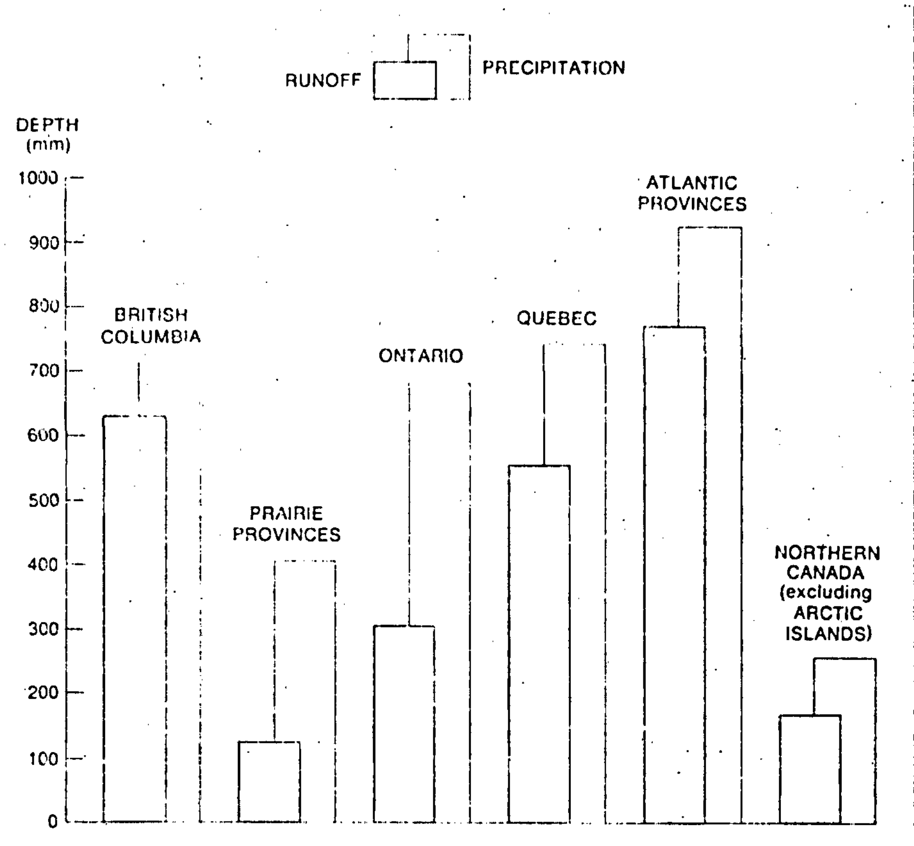

Figure 2/III
Seasonal Distribution of Runoff in Canada (in percent)

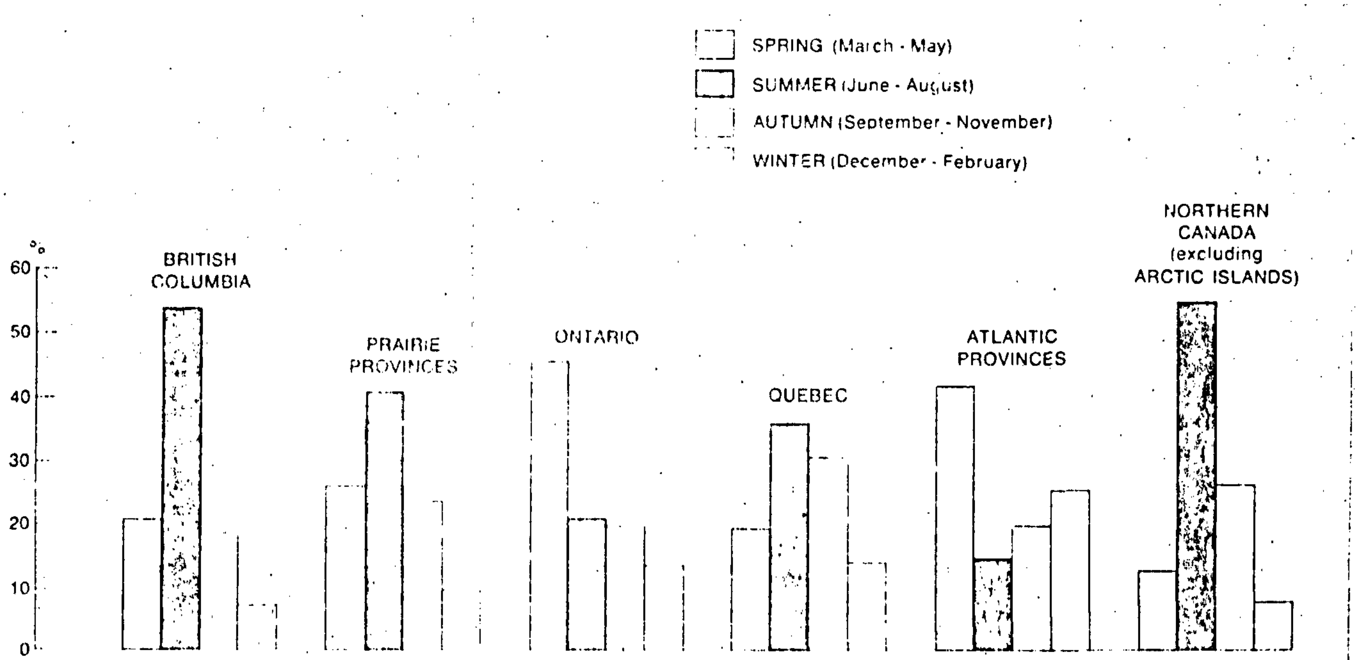

Table 1/III

Current Hydro Capacity (1980) and Undeveloped Hydroelectric Power Potential in Canada

Provinces	Capacity (Mw)	Potential (Mw)
Newfoundland	6,444	6,272
Prince Edward Island	-	-
Nova Scotia	363	100
New Brunswick	893	556
Quebec	19,095	30,750
Ontario	7,086	6,152
Manitoba	3,641	4,945
Saskatchewan	577	1,711
Alberta	718	11,440
British Columbia	8,995	25,827
Yukon Territory	58	10,440
Northwest Territories	47	6,000
Canada Total	47,919	104,193

81,638 Mw. The hydro plants generated 251,000 Gwh of energy in 1980, about 68 percent of the nation's total electric energy generation of 366,700 Gwh. The technically developable hydroelectric power potential is about double the capacity exploited and under development today. The great majority of the undeveloped hydro sites are remotely located or subject to environmental and social constraints. There remains an undetermined amount of hydro potential which would impose minimum environmental impacts. This hydro potential includes: a) small scale and low-head sites; b) abandoned or decommissioned power sites; c) existing storage or head developed for other purposes (irrigation, recreation, flood control or municipal use, etc.); and d) retrofitting existing older less efficient plants. The potential of those Environmentally Compatible Hydro sites in Canada is presently unknown and not included in the remaining undeveloped potential listed in Table 1/III. There is no official definition for subdividing hydro-power plants as small, large, low-head or high-head. There is not even a consensus internationally on the terminology because many countries use their own understanding of the classification. The United States, however, defines small scale hydro as a power station less than 15 Mw. In Canada a plant with less than 20 Mw generating capacity is used as a limit for qualification for federal fast tax write-off for small scale hydro equipment under the federal energy program. According to a recent policy announcement made by the Ontario Ministry of Energy (12), small hydraulic sites with less than 2 Mw generating capacity can be developed by private developers. Traditionally, Ontario Hydro has had first rights of development for any hydraulic project on crown land. Those sites with 2 Mw (2,000 kw) or less capacity could be termed as mini-hydro sites. For the purposes of this report, the following definitions of sub-divisions of hydro-power sites will be used:

Mini-hydro:	less than 2 Mw capacity
Small hydro:	2 Mw - 20 Mw capacity
Large hydro:	larger than 20 Mw capacity
Low-head hydro:	head less than 20 metres (no limit in capacity)

The small scale and low-head hydro development concept has found widespread acceptance in many parts of the world. Installation of electricity generating facilities at those existing dams and reservoirs which were originally constructed for purposes other than power generation and also retrofitting decommissioned hydro sites have also received favourable attention in many western countries including the United States. Development of this hydro potential has previously been uneconomic because of the competitive cost of electricity generated from fossil-fueled generating plants. However, this situation has now changed, and many such previously uneconomic sites are now becoming economically viable because of present fuel costs and the prospect of continued price escalation as well as environmental constraints. They are economically attractive especially for providing electricity to remote areas not served by a transmission system from other generation centres but generally served by costly diesel generators. The economic, environmental and social constraints usually limit development of large scale hydro sites. Small scale, low-head and existing non-hydro dams or decommissioned hydro sites have unique environmental attributes in that their environmental effects are relatively insignificant due primarily to their less impoundment inundation, less reservoir fluctuation, and smaller scale construction activities. Most of the environmental impacts of existing reservoirs have already been incurred and stabilized. Therefore, this environmentally compatible small hydro and existing dam retrofit development potential is generally considered to be extremely attractive both economically and environmentally.

In the United States, a government-supported study indicates that some 50,000 dams have been built for flood control, irrigation and other non-power purposes of which 19,500 sites could be equipped with small hydro units up to 15 Mw. The total capacity of this hydro potential would be 26,600 Mw. The potential of such hydro sites in Canada is unknown and should be determined by a federally-supported program. This hydro potential might be in the order of 20,000 to 30,000 Mw.

2. Tidal Power

Generally, a mean tidal range of at least 7 metres is required for technically developable tidal power sites. Besides the tidal range, tidal power sites require physiographic conditions suitable for damming and reasonable assurance that physical changes, due to tidal site development, would not substantially reduce the local tidal range.

In Canada, besides the Bay of Fundy which is known to have one of the highest tidal ranges and the most promising tidal sites in the world, there are a number of other potential tidal sites such as: Jervis-Sechelt Inlet and Observatory Inlet on the coast of British Columbia, Ungava Bay in Northern Quebec, Hudson Bay and Frobisher Bay on Baffin Island. At these tidal sites, except for the Bay of Fundy and Jervis-Sechelt Inlet, there is neither the chance of transmission system interconnection nor substantial local power demands presently or in the foreseeable future.

According to a recent study on the Fundy Tidal Power Development (10), the following three sites, selected for detailed consideration out of an initial 37 sites, could generate an annual average energy of 20,619 gigawatt-hours (Gwh)* from their total combined capacity of 6,440 Mw. These annual energy generation and installed capacity figures are about 30 percent larger than the current ones for both provinces - Nova Scotia and New Brunswick - in 1980. Capacity and energy output and capital costs of the three tidal sites are shown in Table 2/III.

Unlike a hydro-power development, a tidal power development generally precludes further development of other sites located in series in the same tidal zone, since the sluice of a site would limit the flow capacity to filling its own basin only. For final selection of a tidal power site, therefore, a comprehensive analysis should be carried out to maximize the long term benefit of the overall tidal power potential of that tidal zone.

3. Ocean Wave Energy

The exploitable wave power potential is difficult to determine since it is dependent on the technology of wave energy conversion to be adopted and the local wave and climate conditions. Some quasi-quantitative assessment of wave power potential could be made from wave and climate statistics. The development of power sites exploiting wave energy requires ice free waters with waves of sufficient height and constancy. In Canada, waters off the west coast have the greatest potential while development in east coastal waters is limited by winter ice. The annual average wave power potential expressed in kilowatts per metre (KW/m) width of wave crest has been estimated for the following three locations:

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*See the Glossary of Terms for definition

Table 2/III

Capacity, Energy Output, and Capital Costs of Three Tidal Power Sites in the Bay of Fundy

Tidal Sites	Installed Capacity (Mw)	Annual Output (Gwh)	Capital Cost (1977) (Million Dollars)
Shepody Bay (Site A6)	1,550	4,533	2,197
Cumberland Basin (Site A8)	1,085	3,423	1,234
Cobequid Bay (Site B9)	3,800	12,653	3,988

- Tofino, British Columbia - 35.1 KW/m
- Western Head, Nova Scotia - 12.1 KW/m
- Logy Bay, Newfoundland - 27.6 KW/m

The Tofino site could operate throughout the year with 70% of the wave power potential occurring during the winter months November to March inclusive. At Logy Bay a similar percentage of the wave power can be expected to occur during the same five months but sea ice may preclude operation during February to May. The exploitable wave energy in Canada is relatively small compared with that of other countries and is spread over a wide area.

4. Thermal Gradient Energy

The total energy potential due to thermal stratification in Canadian freshwater lakes or reservoirs is currently unknown. However, it appears that deep freshwater lakes with a substantial temperature difference between surface and bottom layers during summer stratification periods could provide favourable thermal gradient energy development opportunities through extension of the U.S. Ocean Thermal Energy Conversion (OTEC) concept. Lake Ontario is an example of such a thermal energy conversion potential source, which exhibits a temperature stratification during summer periods with temperatures of 20°C and 4°C in the epilimnion* and hypolimnion* respectively.

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*See the Glossary of Terms for definition.

The OTEC technology requires typically a temperature difference of 18°C for a feasible exploitation of thermal energy. Even though the temperature difference of Lake Ontario appears to be a somewhat sub-optimal condition to extend the OTEC concept, the vertical distances between these two extreme temperatures in the lake are much shorter than in the ocean, and the corrosion problems of the energy conversion facilities are much less severe in the freshwater environment. These facts could favour the exploitation of the thermal gradient energy from deep freshwater bodies by extending the OTEC concept.

According to theoretical calculation (13), an enclosure with a surface area about 1,000 m^2 is required to extract 1 kilowatt of power. Extracting 1,000 Mw of power from Lake Ontario, for instance, with the extreme temperatures of 20°C and 5°C requires a net volume of pumped water from the hypolimnion of about 4,000 m^3/s and about 1,000 km^2 of surface area. The total average flow and surface area of Lake Ontario are about 7,000 m^3/s and 20,000 km^2 respectively meaning that about 60 percent of the total flow and 5 percent of the total lake surface area are necessary to provide a 1,000 Mw thermal energy potential from Lake Ontario.

As a considerable amount of heat is discharged to the Great Lakes from thermal electric power plants (coal or nuclear), thermal gradient energy conversion could profit from the waste heat which is normally discharged to the surface layer of the lakes forming a year-round thermal plume surface layer. A comprehensive assessment of the freshwater thermal energy potential of the combination of natural thermal stratification by solar energy and heated discharge from thermal electric power plants should be carried out to determine the feasibility of extending the OTEC concept to Canadian deep freshwater lakes and reservoirs.

5. Hydrogen Energy

The potential of hydrogen production from water can be considered to be unlimited because hydrogen could be produced from both the abundant resource of fresh water as well as from the unlimited resource of sea water. Economic, environmental and social factors, and availability of electricity would rather limit the potential of hydrogen energy from water.

B. RECOMMENDATIONS

The following are the programs with respect to the resource potential of energy from water that the Department is recommended to support:

1. Comprehensive national program to complete the Environmentally Compatible Hydro potential estimates including:

   - conventional large scale sites,
   - small scale and low-head sites,
   - decommissioned old hydro sites,
   - existing non-power dams and reservoirs, and
   - generating capacity increase by upgrading the efficiency or retrofitting with larger capacity units in old hydro plants.

2. Updated tidal potential of the Bay of Fundy sites considering new technology, economic and environmental factors, combined use of hydrogen, etc.

3. Preliminary assessment of the tidal power potential of those sites other than the Bay of Fundy.

5. Study the prospect of extending the OTEC concept to Canadian freshwater thermal energy development and its potential in deep lakes and reservoirs.

6. Study to identify technical, environmental and social limiting factors to the hydrogen energy potential in Canada.

IV. FORECASTS OF ELECTRICITY DEMAND

A. GENERAL

For the electricity load forecast, 1980 is taken as the base year and two separate sets of demand projections by region to the years 1990 and 2000 are presented: one is based on statistical energy modelling by the Department of Energy, Mines and Resources (EMR); and the second, synthesized by the Department of the Environment (DOE), is based on the provincial load growth forecasts of each provincial utility and other available relevant information. The former appears to be lower than the utilities' forecasts while the latter conforms to the average growth projections of the provincial utilities. Table 1/IV compares the two sets of forecast annual growth rates over the period 1980 to 2000.

Forecasting the future demand growth is the most difficult and critical task of the electrical utility, an industry which is solely responsible for meeting the electricity demand of its own region. Since demand forecasts almost always deviate from the actual demand, especially for a long term projection which is required for most major developments (10 to 20 years), utilities have a policy of updating their forecasts annually and maintaining flexibility of actual development schedules. Generally, they have a tendency of maintaining excess capacity rather than under-installed capacity for several reasons: it avoids system service interruptions and maintains the system reliability; it is easier and less costly to delay a construction schedule than to accelerate it; it allows electricity exports to neighbouring systems which could reduce the costs of over-investment.

Table 1/IV

Annual Growth Rates of Electric Energy

Consumption: 1980-2000

Regions	EMR Forecast	DOE Forecast (Based on Utility Forecasts)
British Columbia	3.5%	5.5%
Alberta	4.1%	6.3%
Saskatchewan	3.1%	5.1%
Manitoba	2.6%	3.9%
Ontario	2.8%	3.5%
Quebec	3.8%	6.3%
Atlantic Region	2.3%	
- Nova Scotia		3.7%
- New Brunswick		4.3%
- Prince Edward Island		4.1%
- Newfoundland		4.1%
Canada	3.3%	4.5%

Table 2/IV presents the electric generation capacity requirements for 1990 and 2000 by region based on the two cases, the EMR forecast, and the DOE forecast based on utility projections.

B. BASIS OF FORECASTS

1. EMR Forecast

The EMR forecast of electricity demand growth (2) is based on that department's Inter-Fuel Substitution Demand (IFSD) model. The model is basically one of statistical prediction based on correlations with historical data. Given the historical relationships between the demand and a number of independent variables, such as economic growth, the price of electricity, the price of other fuels, and a variety of variables describing population and housing stock characteristics, future demands can be calculated.

The growth rates predicted by the model are included in Table 1/IV for each region. The growth rate for Canada as a whole between 1980 and 2000 is 3.3 percent per annum. There is considerable regional variation around this average, ranging from a low of 2.3 percent in the Atlantic Region to a high of 4.1 percent in Alberta. Although preliminary indications are that the EMR model performs relatively well in forecasting the 1978 demand with 0.3 percent deviation from the actual demand of Canada, the forecast appears to be too low in comparison with the provincial utilities' projections. This low growth rate, despite the expected future trend towards a larger share for electricity in the total energy system, could be attributable to: reduced output growth in the economy; rising real costs of electricity production; and the question of the validity of the statistical correlation model, which was

Table 2/IV

Electric Generating Capacity Requirement*

Forecasts for years 1990 and 2000

Regions	EMR Forecast		DOE Forecast (Based on Utility Forecasts)	
	1990	2000	1990	2000
British Columbia	12,437	17,216	16,717	26,347
Alberta	8,191	12,015	11,497	18,717
Saskatchewan	2,732	3,854	3,395	4,891
Manitoba	3,818	4,851	5,294	8,376
Ontario	26,869	35,104	32,552	42,002
Quebec	34,553	47,185	38,991	68,842
Atlantic	6,453	8,002		
- Nova Scotia - New Brunswick - Prince Edward Island			6,354	8,344
- Newfoundland			7,966	8,874
Canada Total	95,053	128,227	122,766	186,393

* Generating Capacity Requirement defined as peak demand plus system reserve.

derived solely from the historical data and could not incorporate future politically or socially induced factors. The uncounted factors, such as the impacts of the government off-oil policy or the consumers' tendency to switching to the use of electricity from other energy sources, etc. could significantly affect demand. It seems reasonable, therefore, that the electricity capacity requirement forecast based on the EMR model as presented in Table 2/IV could be used as the lower limit of the forecast.

2. DOE Forecast Based on Provincial Utility Projections

The latest, most likely average growth forecast by the provincial utility or energy agency which makes forecasts, adjusted for non-utility production, was taken as the forecast provincial rate of growth. In the forecasts, total load requirements are based on the provincial peak load and energy expectations, plus exports. Exports embody a rather rough estimate.

The utility approach, from which the DOE forecast is derived varies among utilities; however, it is generally based on end-use forecasting, prepared with a combination of sophisticated economic forecast models in certain utilities. Utilities generally analyse electricity demand separately for residential, commercial, and industrial consumer sectors. They normally forecast gross energy and peak load demands for a 10-year budget period and a 20-year planning period. The former requires a higher degree of accuracy than the latter and some highly detailed analyses are concentrated on the former budget period forecast.

Table 3/IV presents forecasted capacity and energy requirements by region to years 1990 and 2000, and the estimated share of hydro and thermal

Table 3/IV

Capacity and Energy Requirements by Region

for Years 1990 and 2000

Regions	Capacity (Mw) 1990	Capacity (Mw) 2000	Energy (Gwh) 1990	Energy (Gwh) 2000
British Columbia				
Hydro	12,000	19,400	62,500	102,000
Thermal*	4,600	6,900	18,300	34,100
Total	16,600	26,300	80,800	136,100
Alberta				
Hydro	1,300	1,700	2,700	5,600
Thermal	10,100	17,000	54,000	89,600
Total	11,400	18,700	56,700	95,200
Saskatchewan				
Hydro	800	1,400	4,100	8,400
Thermal	2,400	3,500	13,500	18,400
Total	3,200	4,900	17,600	26,800
Manitoba				
Hydro	4,800	7,800	26,900	38,500
Thermal	500	600	1,300	1,700
Total	5,300	8,400	28,200	40,200
Ontario				
Hydro	7,600	9,700	45,700	51,800
Thermal	24,500	32,300	123,000	167,000
Total	32,100	42,000	168,700	219,400
Quebec				
Hydro	36,700	53,700	209,000	279,200
Thermal	2,300	15,100	3,900	70,100
Total	39,000	68,800	212,900	349,300
Newfoundland				
Hydro	6,700	7,300	44,300	48,100
Thermal	1,300	1,600	3,000	1,100
Total	8,000	8,900	47,300	49,200
Maritimes (N.S., N.B., P.E.I.)				
Hydro	1,300	1,400	5,000	5,000
Thermal	5,050	6,650	20,400	30,900
Total	6,350	8,050	25,400	35,900
Yukon & N.W. Territories				
Hydro	320	470	970	1,520
Thermal	45	35	150	110
Total	365	505	1,120	1,630
Canada				
Hydro	71,520	102,870	401,170	540,120
Thermal	50,795	83,685	237,550	413,610
Total	122,315	186,555	638,720	953,730

* Thermal sources include coal, oil and nuclear-fueled plants

generation which includes conventional steam and nuclear capacity plus gas turbine peaking plants and remote, small internal combustion facilities.

C. REGIONAL SCENARIOS

The following presents a brief background summary by province of scenarios to supply electricity to meet the demands up to year 2000.

1. British Columbia

The Revelstoke hydro site (1,800 Mw), now under development on the Columbia River, is scheduled in service by 1985. B.C. will continue developing hydro sites as a least-cost source of electrical energy. Site C (900 Mw) on the Peace River and Murphy Creek (400 Mw) on the Columbia River are scheduled to be developed for generation before 1990. The next lowest-cost viable source of electrical energy is from a coal-fired thermal power plant, such as the Hat Creek mine-head site that is scheduled to be developed to bridge a probable supply deficit in the late 1980's. The major new hydroelectric sites on the northern rivers such as the Stikine, Iskut and Liard Rivers (total over 7,300 Mw) which rank among the lowest-cost sources in B.C., could be developed after 1990.

B.C. has developed only about a quarter of its technically developable hydro potential and would continue to rely on the hydro source, a low-cost renewable energy source, to meet the near or medium-term energy demand probably up to or beyond the onset of the next century. The major northern hydro sites might impose formidable environmental, social and institutional constraints and a longer than normal lead-time might be required for an extensive and thorough study, pre-planning for project release.

2. Alberta

According to an Electric Utility Planning Council study, ten new 735 Mw coal-fired thermal-electric generation units will be needed in the 1980's. Coal would be the basic fuel for generation of electricity to meet the four-fold increase in Alberta's electricity demands during the next three decades.

Major coal-fired generating plants planned for Alberta are Keephills (4-400 Mw), Sheerness (2-375 Mw), Geneese (2-375 Mw), and Battle River (1-375 Mw addition), all of which will be on-line before 1990. Alberta has plenty of mine-head coal-based potential, but the availability of adequate cooling water sometimes poses a problem. For a site such as Keephills, massive amounts of cooling water are to be supplied from the Red Deer River via a pipeline, a distance of 40 km.

Two major hydroelectric sites at Dunvegan (1,000 Mw) and Mountain Rapids (1,500 Mw) are under consideration for development in the 1990's. The Dunvegan site, located in northwestern Alberta on the Peace River, could take 10 years to build. The Mountain Rapids site, located near the boundary between Alberta and the Northwest Territories, has an estimated potential of 1,000 to 3,000 Mw. The most likely optimum capacity is 1,500 Mw. The interprovincial jurisdictional difficulties, the inundation of a part of a national park (Wood Buffalo), and the long transmission distance (830 km to Edmonton) would require extensive and thorough feasibility studies and pre-planning before the project is approved for development.

3. Saskatchewan

Electricity demand prediction in Saskatchewan is somewhat uncertain. Reasons for the uncertainty are spotty bulk demand increases due to the demands by some large industries such as pipeline pumping power and expansion of the potash industry, as well as indecision about the future development of such large demands in the province. In 1980 industrial demand unexpectedly increased by 16 percent. Among the large industrial bulk demands, pipeline pumping power was the largest single demand, one which increased 49 percent during the year.

Saskatchewan Power Corporation (SPC) is continuing to lean toward utilization of coal power generation. A problem in Saskatchewan is that its best coal resources are in the southern part of the province where cooling water souces are scarce. This water scarcity problem may force SPC to switch to the more costly dry cooling tower systems or to transport coal to areas where water is more abundant or conversely bring water from other river systems.

The recent Poplar River plant (2nd unit, 300 Mw) which has been licensed under the International River Improvements Act (IRIA) will be on-line within two years and additional capacity could be considered provided the cooling water problem can be solved and air quality standards and international obligations are met. Other coal-fired thermal generating plants currently under consideration are: Regina (600 Mw), Courval (300 Mw) and Diefenbaker Lake (300 Mw). All these sites pose problems either of availability of cooling water or coal transportation.

A hydroelectric site currently under development at Nipawin (252 Mw) on the Saskatchewan River is expected to be on-line in the late 1980's. Other hydro sites under study are Choiceland (150 Mw) and the Forks (400 Mw). A privately owned operating hydro plant, Island Falls (100 Mw), will be bought by the SPC. Interprovincial electricity imports from Manitoba could provide a significant contribution to meet the provincial system demand.

4. Manitoba

Electricity load growth in Manitoba has dropped to between zero and 2 percent in the last five years after a healthy growth of at least 6 to 7 percent annually up to 1975. The decreased growth resulted in the suspension of the development of the Limestone hydro site on the Nelson River in 1979. There seems to be a number of potential factors which could bring the 1200 Mw Limestone hydro project back to construction. Manitoba Hydro has upgraded the provincial load growth rate to 3.8 percent per annum for the next 10 years. The currently studied and planned western power grid which would connect the three prairie provinces, could increase the demand considerably. It would mean the export to Saskatchewan and Alberta of 500 Mw and 1,000 Mw respectively of electricity to be generated by the hydro-based Manitoba system. Power exports to the United States will also play a significant role for Manitoba Hydro. Exports to Minnesota will continue with increasing quantities and exports to Nebraska in the range of 1,000 to 1,500 Mw could begin in the late 1980's according to a letter of intent signed by utility officials from Manitoba and Nebraska. Several potential hydro sites, new or even rehabilitation of existing hydro stations are currently under study; for example, the Burntwood site (700 Mw) on the Burntwood River and the feasibility of rehabilitating two older stations at Great Falls and Seven

Sisters on the Winnipeg River. All new capacity in Manitoba is expected to be coming from hydroelectric sources in the next couple of decades.

5. Ontario

According to the latest forecast (3.1 percent annual growth), Ontario Hydro must almost double its installed generating capacity by the turn of the century. Ontario is considered to be too dynamic a province to remain in such a low-growth state (about one-half the annual forecast load growth in Quebec). Thus, a higher rate of load growth is expected in Ontario after 1985.

Ontario continues to rely on its nuclear expansion policy to meet the future demand. Currently under construction or committed nuclear or lignite plants will bring an additional capacity of 9,000 Mw to the system by 1991. Those major developments are: Thunder Bay extension (lignite 300 Mw), Atikokan Phase I (lignite 400 Mw), Pickering B (nuclear 2,160 Mw), Bruce B (nuclear 3,200 Mw) and Darlington (nuclear 3,600 Mw).

There are still some economically developable hydroelectric sites that could provide about 2,000 Mw of capacity from 17 sites. A major hydro potential exists on northern Ontario rivers, such as the Albany River (about 3,000 Mw) which would, however, pose some socio-economic and environmental problems due to its remote location in a cold region, native people's lands and environmentally sensitive areas.

6. Quebec

Quebec is seen as matching Alberta in electrical load growth, but for different reasons. This relatively high growth appears to be attributed to development of industrial loads such as aluminium, pulp and paper, and the textile industry. In addition to the industral demand, increasing energy exports, and Quebec's off-oil trend has promoted a change to higher consumption of electricity rather than hydrocarbon-based fuel sources for residential, commercial and industrial heating as well as for processing. These factors are the most significant ones contributing to the high growth forecast.

In Hydro-Quebec's massive expansion plans, thermal plants (including nuclear generation), pumped-storage peaking plants and hydroelectric plants all play a role; however, its major thrust is directed at development of the province's vast and relatively low-cost hydroelectric resources. By the mid-1980's, the La Grande Complex Phase I (10,283 Mw) of the James Bay hydro developments should be on-line. By the mid-1990's, the remaining James Bay hydro potential: La Grande Complex, Phase II (3,258 Mw); La Grande Baleine (2,273 Mw); and the Nottaway-Broadback-Rupert (NBR) Complex (7,255 Mw), should be completely developed. The utility will also investigate the 3,000 Mw hydro potential in the rivers flowing to Ungava Bay; Archipel (1,000 Mw) and the Chamouchouane (1,000 Mw) on the St. Lawrence River; some 5,000 Mw from small or mini-hydro sites on about 100 rivers; and the upgrading of existing hydro stations.

7. Atlantic Provinces

In the Maritimes the "off-oil" policy is seen as attaining most of its objectives through electrical energy generation.

Nova Scotia has a healthy generation mix in its current electric system and development plan. Their emphasis is on an effective "off-oil" policy which started with developing a 200 Mw hydro station at Wreck Cove and a 300 Mw coal-fired thermal station at Lingan. Two additional 150 Mw coal-fired units at the Lingan station are scheduled for service in the mid-1980's. This addition of coal-fired generating capacity will reduce the utility's (Nova Scotia Power Corporation) dependence on imported oil to 24 percent from the current 40 percent. The utility is also testing a 200 kw wind turbine at Wreck Cove; installing two small scale hydro stations at Gisborne (3.5 Mw) in the Wreck Cove area and at Fourth Lake (3 Mw) on the Sissiboo River, and building North America's first tidal power project at Annapolis Royal (20 Mw Straflo turbine) on the Bay of Fundy. Future system expansion in the province would be based mostly on coal-fired thermal generation.

New Brunswick is also determined to reduce dependence on imported oil. The development of the first nuclear power plant in the Maritime provinces at Pointe Lepreau (630 Mw), a study on converting the Coleson Cove generating station from oil to coal, a 200 Mw addition to the Dalhousie dual-fuel (oil or coal) thermal generating station all contribute to implementing the province's "off-oil" policy. An additional interprovincial transmission connection with Hydro-Quebec's system should increase the import capacity by 560 Mw to take advantage of available surplus energy from Quebec in the period 1985-1990. The current program adequately covers the provincial power needs up to the early 1990's. Beyond that, a number of options could be considered including: an additional nuclear unit at Pointe Lepreau; development of new hydro sites and tidal power from the Bay of Fundy; redevelopment of existing plants; expansion of thermal capacity by utilization of native coal and peat; or addition of interprovincial transmission capability.

Prince Edward Island currently meets about 75 percent of its electricity demands by importing energy by submarine transmission cables from New Brunswick, and imported electricity will continue to play a significant role in the island's electric power system. Maritime Electric Company, the only electric utility of PEI is negotiating for an increased capacity of future energy purchases from New Brunswick. Due mainly to economics, the province will rely more on imported energy via the submarine cable while maintaining a relatively low capital cost capacity on the island itself.

Newfoundland will meet the province's electricity demand only until 1984 with the generating capacity now in place and under construction. The new electrical generation sources under construction or under consideration for development are all hydroelectric sites, which include Upper Salmon (84 Mw), Cat Arm (140 Mw) and some mini-hydro sites such as Roddickton (425 Kw), Dry Pond Brook (7.8 Mw) and Lake Michel (12 Mw).

The province's main thrust will be on developing untapped large scale hydroelectric resources in Labrador for the medium to long term future electricity supply. The best sites are Gull Island (1,700 Mw) and Muskrat Falls (620 Mw), downstream from the existing Churchill Falls power plants

(5,225 Mw). The Lower Churchill Falls hydroelectric development needs a long-range transmission line to the island of Newfoundland involving approximately 1,000 km of high voltage direct current (HVDC) transmission lines and an 18-km submarine crossing of the Strait of Belle Isle. An intensive research and experimental program is well underway on the submarine transmission cable project.

V. ENVIRONMENTAL IMPACTS AND MITIGATING MEASURES

A. GENERAL

The most noticeable and common concerns of a hydroelectric development are the loss of land and the land-based resources such as timber, agriculture, and wildlife and fish habitat due to reservoir impoundments; the conversion of wild rivers into regulated rivers or lakes thus modifying the opportunity for fishing, boating, hunting and camping; the barriers dams impose on the migration of fish such as salmon; and the change in downstream river flow regimes.

Additional, but less noticeable, are the changes in erosion, sedimentation, thermal stratification and water quality, directly or indirectly associated with the developments. There is also a progressive change in the plant and animal composition wherein forms which have adapted over a lengthy time period to a river-type environment are replaced by forms which frequent calmer waters. Any diversion from one watershed to another can allow the introduction of foreign biota from one system to the other with effects that can be far reaching. Construction practices and the flooding of land associated with hydroelectric projects do represent impositions of varying degrees on local populations; in some remote areas, these effects can present a drastic disruption of a traditional way of life for native people; in more developed areas, the effects can be more of an economic rather than a social nature. Hazards to human life, through dam failures or even increased earthquake activity, have been recorded throughout the world in recent years. Fortunately, there have been no known dam failures associated with hydroelectric projects in Canada and induced earthquakes have not been large and thus have not caused serious damage.

The major environmental concerns of a tidal power development are the impacts which the barrage and the plant operation can impose on fish migration; changes in the tidal cycle and magnitude; modifications to the coastal and bottom erosion and sedimentation patterns; changes in salinity stratification; and possible effects on upstream flooding if the barrage is located in an estuary of a river. Social impacts of a tidal power development especially during the construction period are similar to that of a hydroelectric development. All of these impacts cannot be predicted in detail at the present time.

The environmental impacts of wave energy development are not of as great a concern as hydro or tidal power developments since most of the currently developed wave energy conversion technologies involve floating structures which cause few changes in the environment.

Thermal gradient energy development could impose some water quality problems due to the large amounts of water circulating between the hypolimnion and epilimnion. The water circulation could result in an imbalance in the lake ecosystem during summer stratification periods by lowering the thermocline.

The environmental impacts of hydrogen energy production, storage and utilization are not yet fully determined; however, they are not expected to be as extensive as other energy sources from water such as hydro or tidal power developments. Quantitative assessment of the environmental impacts of hydrogen energy should be carried out to assist in establishing an energy policy based on energy systems involving the extensive use of hydrogen. In such an assessment, indirect impacts due to the use of electricity generated by other sources should also be considered.

All energy sources from water are clean and relatively non-polluting and their impacts are due primarily to physcial changes in the associated land and water.

Since the environmental concerns of tidal, wave, thermal (OTEC) or hydrogen energy developments are either unsubstantiated or not as extensive as that of hydroelectric developments, the discussions on the impacts and possible mitigating measures contained in the following sections are concentrated only on hydroelectric power developments.

B. IMPACTS OF HYDRO DEVELOPMENTS

The environmental effects of a hydroelectric project can be divided into three primary areas of concerns: the impacts upstream of the dam (reservoir), downstream of the dam, and other associated impacts.

1. Reservoir Effects

a) Land Based Impacts: A reservoir impoundment formed by damming a river involves a loss of productive lands and the resources it supports. The losses could be quantitatively evaluated in certain cases where the resources are of commercial importance, such as merchantable timber, productive agricultural lands or mineral deposits, etc.

The decision on pre-clearing and harvesting timber in a reservoir area has to be based not only on the value of the timber but also on the anticipated use of the reservoir for purposes other than water storage. In remote areas where recreational demands are not high or the economics of removing the timber is prohibitive, reservoir pre-clearing may be judged unnecessary. However, in areas accessible to the general public and with the potential for recreational development, especially boating or municipal usage, partial or clear-cutting of the forest may be a necessary cost of the project. Some changes on the shoreline due to a reservoir impoundment reduce value and usefulness of shoreline resources. Such changes include raising the groundwater table resulting in the water-logging of the vegetation, the subdivision of tracts of land by lateral flooding of formerly dry depressions and flooding of existing shoreline housing, etc. Some of the negative changes and effects are the destruction of fish spawning beds and wildlife feeding habitat and migration routes. Many sites occupied by prehistoric and early historic man are near streams and archaeological or historical interests may be threatened by the reservoir flooding.

b) Shoreline: The creation and regulation of a reservoir poses certain ecological problems. The impacts are particularly severe when a hydro station is dedicated to a peaking operation which involves considerable fluctuation of reservoir levels weekly, daily, and sometimes hourly. The normal procedure for storage reservoir operation in Canada is to fill during the period of high flows (spring to early summer), then maintain the high water during the summer and drawdown starts in the late fall and continues until the next spring when the reservoir water level reaches its lowest. This reservoir operation practice poses some problems. Under natural conditions in rivers and lakes, the peak flood lasts only for a short period, and the water levels generally fall before the growing season is far advanced, therefore the banks are protected by a cover of vegetation that extends down to the low water mark. In reservoirs, however, the extended high water period inhibits growth of vegetation in the drawdown zone so that extensive barren areas are exposed during a large part of the year. The shoreline is also exposed to the erosive action by waves and ice scouring. These erosive actions create a broad unsightly sterile zone between the high and low water marks. In the north of Canada, the development of reservoir shorelines in a permafrost zone is of particular concern. When the permafrost zone is flooded it melts and the surface soils slump into the reservoir. This slumping process repeats itself until the shoreline reaches bedrock or a relatively stable gravel formation. Shoreline development in permafrost areas is therefore erratic and unpredictable.

c) Sediment: Once a reservoir is formed, the water flow velocity is reduced significantly, and suspended sediment loads transported by the inflow are deposited. This deposition plus the results of shoreline erosion and river bed loads can eventually fill in a reservoir to such an extent that the live storage can no longer be useful for power generation. On the other hand, if the transport of the eroded material takes place from the shoreline between the maximum and minimum operating water levels into the deeper dead storage zone, the usable storage capacity will increase as experienced in Lake Diefenbaker (14).

d) Fish: When a watercourse is blocked by a dam, the normal passage of fish migration is blocked. The migrating fish could be either anadromous or catadromous fish. The former are those that are hatched in freshwater and spend their lives in the sea, for example, salmon, and the latter are those that are hatched in the sea and spend their adult lives in freshwater, for example, the American eel. Adult fish are migrating upstream in the salmon-run rivers (Pacific and Atlantic coastal rivers) while in the catadromous fish migrating rivers (St. Lawrence River), young fish are migrating upstream. Compensating structures such as fishways, fish-ladders, artificial spawning grounds or hatcheries could partially ameliorate the impacts of dams on these migrating fish. Even if such facilities are constructed to allow the migration of fish upstream, some deterioration of stocks still takes place as a significant proportion of fish may be destroyed on their downstream migration when they pass through obstructions such as turbines, spillways or sluices.

e) Temperature and Water Quality: Reservoir impoundments may improve water quality through a reduction in turbidity by allowing suspended sediments to settle out, dilution of dissolved pollutants and a reduction in bacteria concentration, etc. On the other hand, it may have a deleterious effect on the water quality in several ways.

Unlike rivers which tend to have well-mixed flow cross-sections with a relatively uniform temperature throughout because of the faster movement of water, lakes and reservoirs experience a density stratification due to water temperature variations. Over the summer, as the upper layer of water is getting warmer by surface heating from solar radiation and warm inflow, a stable stratification is formed in lakes and reservoirs with distinct layers of relatively colder and warmer waters occupying certain depths of the reservoir. The upper layer of warmer or lighter water is called "epilimnion" and the lower layer of colder or heavier water is called "hypolimnion". The water temperature transition zone between the epilimnion and hypolimnion is known as the "thermocline".

The prime effects of reservoir thermal stratification on water quality are: a reduction in dissolved oxygen (DO) level and an increase in carbon dioxide (CO_2) and alkalinity in the deeper part of the reservoir (hypolimnion). During stratification periods, the dissolved oxygen level often becomes depleted in the deeper part of a reservoir because the biochemical oxygen demand (BOD) is increased due to the sludge deposits which are settled from the suspended solids in the low-velocity reservoir flow, and the depleted oxygen cannot be replenished through the natural process of stream self-purification in the hypolimnion. The thermal stratification process changes according to the seasons. The stable stratification, formed during the summer, breaks up and an "overturn" takes place in the late summer or fall due to colder inflow and cooled surface water. Over the winter an almost isothermal condition is formed. This process of changing temperature could drastically affect any fish species with a narrow temperature tolerance by forcing them away from their natural feeding and spawning grounds.

Other water quality problems could be caused by leaching from the flooded lands. During reservoir filling, plant nutrients and other inorganic substances may be leached from the flooded soil or released through the decay of flooded vegetation. This release of nutrients to the reservoir frequently results in a significant rise in productivity that is reflected up through the food chain to its most obvious manifestation, a rapid rise in fish production. This bloom usually lasts only a few years and, following a gradual decline, the reservoir's productivity stabilizes at a somewhat lower level. It is also possible, at the same time, that toxic materials may be leached from the flooded soils and their effects reflected through the food chain. Mercury, for example, has been found in fish in newly created reservoirs in areas where it has not been produced or used in manufacturing. Likewise in farming areas, where croplands have been flooded, the increase in pesticides is often measurable in the fish. Reservoirs created on rivers flowing through industrial or residential areas become sinks for the waste materials that are discharged into the water.

f) Species: As the reservoir fills there is mass mortality and migration of terrestrial organisms. Some, with a good capacity to adapt to the new conditions, may persist for some time before being replaced or eliminated. The most noticeable changes are the migration of the animals and the destruction of terrestrial plant life along with the introduction of shoreline or marsh type plant life. At the same time, the fish species are changing. The reservoir drawdowns inhibit or destroy the spawning success of certain species of fish depending on the timing and extent of the drawdown. Species that require vegetative growth on which to deposit their spawn are most affected if the drawdown zone develops into an extensive barren mud or rocky flat. Likewise, many species of fish during their early life stages use vegetated areas as a source of food and cover, hence their numbers are usually reduced due to a lack of vegetation. Those species adaptive to a lake environment will now flourish and will become predominant where they were once secondary.

If the hydroelectric project involves the diversion of water from another watershed, the possibility of the introduction of foreign species exists. These new species may carry organisms, such as fish parasites, which could prove to be harmful to the existing species.

2. Downstream Effects

An unnatural pattern of variation in flows and water levels due to reservoir operation or its initial impoundment can have effects downstream of the dam that are at least as significant as those above it; although, to an observer, the effects may appear more evident in the reservoir. Many of the changes that occur below the dam are opposite to those that take place upstream. In a reservoir, silt, organic and inorganic material accumulate; whereas, below the dam, they are reduced. Likewise, the natural range of water fluctuation in the reservoir is usually increased through storage operation, while the downstream water level range is reduced. All of these have some effects on the downstream ecosystems, often many miles further downstream of the dam. Generally, the severity of the downstream effects are proportional to the amount of storage behind the dam and the storage operation pattern.

The changes in downstream flow regime due to a reservoir and hydro plant operation are characterized by an increased short term flow fluctuation and a decreased longer term flow fluctuation. The short term (hourly, daily, or weekly) flow fluctuation results from variations in the amount of water passing through in response to the plant load variations. The changes in longer term (monthly, seasonal, or annual) flow fluctuations especially the reduced flood peak and the increased low flow period streamflows are the result of retention of water in the reservoir at times of high natural flows and its gradual releases throughout the low flow period.

Due to the alteration of natural flow patterns, degradation and aggradation at the mouths of tributaries are often observed. Reduced high flood flows in the main stream which lower flow velocity are not sufficiently strong to wash away the deposited material transported by the increased flow velocity at the tributaries, leading to the formation of bars and deltas, which eventually become stablizied by the growth of vegetation on them. Many natural river deltas are productive deltas consisting of a series of wetlands and marshes, interspersed with lakes and ponds of various sizes. This state is maintained in the natural condition because it is flooded almost every year so that the vegetation characteristic of drier grounds is unable to establish itself. This is a typical pulse-stabilized ecosystem as it was in the Peace-Athabasca Delta before the construction of the Bennett Dam on the Peace River. As an impoundment effect, old wetland deltas could become dried due to the reduced flood flows, and dry-ground vegetation could begin to establish itself. Such an impact on the Peace-Athabasca Delta is a classic example of an unexpected consequence or downstream effect of a dam (15) (16). The dried delta in the Peace-Athabasca was the chief cause of concern because the residents of the area depended largely on trapping and fishing in the delta for their livelihoods.

If the water intake to the penstock of a hydro station is situated well below the reservoir surface, the water subsequently discharged downstream will be degraded in quality especially low dissolved oxygen during stratification periods and colder than normal in the summer period, or warmer than normal during the winter period. These changes in temperature could result in changes in the downstream distribution of some organisms and fish as many species of each are tolerant over only a certain range of temperatures. These thermal changes could also have an effect on the timing of downstream freeze-up and break-up which in itself could influence plant and animal communities.

When water passes over a spillway and plunges into a stilling basin or passes through turbines, the entrained air is forced into solution and the water may become supersaturated with gases, especially nitrogen. If these gases at high concentration enter the bloodstream and tissues of fish, the resulting bubbles within the bodies may cause tissue destruction and even death, a phenomenon known as "gas bubble disease" as observed in salmon in the Columbia River (17).

Flow reduction or interruption of downstream flow due to a diversion or the initial filling of a large storage reservoir could cause numerous problems downstream of the dam depending on site situations; such as, destruction of existing biota; deteriorated water quality due to lower dilution capability; shortage of irrigation, industrial or municipal water; loss of downstream power production; possible navigation and fishery impacts; and salt-water intrusion in an estuary situation.

3. Social Effects

a) Lifestyle Impacts: When hydroelectric projects were considered to be of small size, the social impacts did not appear to be of great significance. During the past three decades some projects have increased to the stage that thousands of square miles are being affected and the disruption in the traditional way of life of native people and other populations of remote areas is massive. Existences which are dependent upon hunting and fishing can be severely disrupted through the flooding of vast tracts of lands. Even the increased access to remote territory and the experience of the construction period can modify traditional existence to a large extent.

b) Hazards: There have been a number of instances throughout the world of earthquakes occurring during or after the filling of large impoundments. It is generally agreed that most of these shocks have been a result of the impoundment. The only known such earthquake which occurred in Canada during reservoir filling was the instance associated with the Manicouagan 3 project in Quebec. This well established instance of impoundment-induced seismic activity occurred in October 1975 and registered 4.3 on the Richter scale (18) (19). The induced quakes have not been large and have not usually caused serious damage, except in the case of the Vaiont Dam in Italy. This catastrophic dam failure was caused by an enormous wave generated by a huge landslide into the reservoir which might have been caused by induced seismic activity.

The risk due to dam failures should be of concern to the public due to the potential for direct impact on their lives and property. Although no dam failures associated with hydroelectric projects have been recorded in Canada, about 70 major dam failures have occurred in Western Europe and the United States during the current century. In the U.S. alone, 13 dams associated with hydroelectric generation have failed involving a large loss of lives. The reasons for the dam failures were: insufficient spillway capacity (35%); foundation problems (25%) and other reasons including seismic activity, faulty operation and wave action, etc. (40%). One can only speculate as to why no dam failures have occurred in Canada where 60 percent of electric power comes from hydroelectric sources associated with dams, and more than 500 major large dams are registered, but perhaps conservative designs have contributed to this fortunate situation so far. The U.S. and international estimates of failure rates range between 1 and 2 per 10,000 dam-years for all types of dams (20). Although there are definitely hydroelectric projects in Canada whose siting is such that a failure of the dam would cause a significant loss of life, the largest projects are situated in the more remote areas where loss of life due to failure would be small and the destructive forces would be dissipated somewhat by the time they reach densely populated downstream areas.

4. Associated Effects

a) Climatic Changes: The impact of hydroelectric developments on the climate is generally considered insignificant even in a large scale development such as the James Bay Power Project which impounds an extremely large volume of water. The changes are of a local nature, limited to the vicinity of the reservoirs. The ensuing climatic changes may include: increased frequency of fog formation and convective cloudiness, particularly in spring and autumn, along the leeward shoreline of the reservoirs; increased precipitation in the fall and winter; possible reduction in the annual range of temperature; that is, a slight cooling of air temperature in spring, and a slight warming in autumn, causing a slightly extended local frost-free period of about 5 to 15 days as a result of the temperature modification; and an increased local wind speed and slight modification of predominant wind direction depending on the reservoir orientation.

In the north, the break-up of ice at the mouths of the rivers is induced by the spring floods. With regulated flows, the magnitude of the flood would be lessened, break-up would be delayed, and locally the onset of the growing season could be later than normal but the season might last longer.

b) Transmission Lines: With more remote sites now being developed and to be developed in the future, vast areas of unexploited territory are to be opened by the cutting of transmission corridors. The clearing of a corridor for power transmission lines will leave a permanent scar on the landscape causing an immediate aesthetic impact, especially in areas with high potential for recreation activities.

The amount of land used for transmission corridors can be significant if associated with a remote project, however the land usage is not totally destroyed. Investigations into the electromagnetic radiation effects of transmission lines on humans and animals have so far proven no health hazard. As a result, farming or ranching can exist along with transmission lines over cleared lands.

Migration routes for wildlife may be interrupted and feeding habitat may be affected by the transmission line right-of-way. The terrestrial disturbance may adversely affect water quality, flooding and fisheries resources. The noise generated by high voltage transmission lines is believed to be disturbing to wildlife. The herbicides often used as a defoliating agent to prevent new growth after clearing could adversely affect wildlife and water quality.

C. MITIGATING MEASURES

Most of the changes and environmental damages imposed by the development of a hydroelectric power site are now predictable, at least qualitatively. Carefully planned remedial works and precautionary measures could prevent, overcome or minimize those anticipated adverse impacts. The mitigating measures cannot be generalized but should be custom-tailored to each site-specific situation. Possible mitigating measures on some of the impacts of hydroelectric power developments are briefly discussed in the following sections.

1. Reservoir Effects

a) Pre-clearing of Reservoirs: Removal of trees and shrubs from the entire area to be flooded by a reservoir would be a desirable solution to minimize the environmental impacts due to the submergance of pre-impoundment vegetation. However, the high clearing cost and the low commercial value of the timber render entire clear-cutting unrealistic in most cases. It is therefore an acceptable practice in many cases to adopt a selective clearing scheme which could balance the cost and environmental benefits. Selective clearing is usually planned based on the following criteria. Pre-clearing will be undertaken where: a) sport and commercial fishing activities are expected to be high; b) boat transportation as related to native and tourist activities are high; c) accelerated establishment of new shoreline ecosystems are necessary; d) municipal water use, recreational or aesthetic considerations require local clear-cutting. Most major projects now require timber clearing to the high water mark of the reservoir.

b) Fish: There are no cure-all measures to the damages to fisheries due to lost spawning grounds, habitat and the blocked fish passage by reservoirs and dams. However, compensatory measures, such as an artificial hatchery, a fish-ladder or fishway could partially ameliorate the consequences on fisheries due to site development. Special attention should be given to young salmon returning to the sea which are likely to suffer considerable mortality if they pass through the turbines. Louvered deflectors have been tried with some success to guide the returning young salmon away from the turbines (21).

c) Shoreline Erosion: Shoreline erosion will continue regardless of man's efforts to prevent it but with varying rates. Controlled water level fluctuation in a reservoir could reduce shoreline erosion in certain areas, on the other hand when water levels are maintained constant, wave action would be more concentrated at one level and will hasten bank undercutting. Submerged vegetation left uncleared may be useful in stabilizing the shoreline in some areas. Artificial bank protection measures by rip-rap or other structures could be used but only in selected areas where such protection is economically justified.

d) Species: During the filling of certain large reservoirs, mass mortality of animals could be reduced by rescue or relocation operations. There is no possible control on the changing fish species due to the new ecosystem following impoundment. The population of fish species adaptive to a lake environment will increase and become predominant. Special care should be taken with projects involving a considerable water diversion. The transfer of new fish species from one system to another may carry organisms such as harmful fish parasites.

2. Downstream Effects

a) Flow Reduction: Adverse environmental changes due to the reduced flow downstream of a dam could be partially ameliorated by constructing a weir, if the impact is a localized problem such as in the Peace-Athabasca Delta; however, such a measure cannot be the solution to the ecological problems caused by a reduced flow over a large area.

During the initial filling of a reservoir or following a diversion, downstream ecosystems could be protected by maintaining a minimum flow, usually the lowest recorded flow. This measure seems to be a sound solution to the situation where extensive damage to existing downstream ecosystems is expected if the flow is totally interrupted or considerably reduced. It is possible, with careful pre-planning, to fill a reservoir without delay in the in-service schedule of the project by advancing the start of filling and lengthening the filling period. The filling of the large storage reservoirs often requires several years' flows.

b) Water Quality: Several methods for controlling the water quality of a stratified deep reservoir have been developed and are in practical use in many reservoirs. These controlling measures can be categorized as: a) selective withdrawal by multi-level intakes; b) epilimnion water discharge over a submerged weir; c) blending the low quality water with the high quality water by spilling; and d) destratification or aeration (22). The controlling measures have been successfully applied as a remedial measure, however in most cases, only after the water quality problems due to impoundment were recognized through the post-construction performance of the reservoirs. This situation has severely restricted the choice of controlling methods since any structural modification would be too costly to be employed once the initial construction has been completed. Economical control of the water quality of a deep impoundment can be achieved only if advance planning is incorporated in the initial development designs using reliable quantitative predictions from computer simulation models.

The problem of gas supersaturation of the water discharges over a spillway or through the turbines could be decreased or eliminated by a modified design of the air valve system to the turbines or a judicious design of the spillway (23).

3. Social Effects

Retraining in new skills or trades or even compensation arrangements could help native people and local residents in establishing new lifestyles when their traditional way of life has been affected by the inundation due to large reservoirs.

Careful pre-project geological studies should be undertaken into the possibility of earthquakes being induced by a reservoir if the impoundment depth exceeds approximately 100 metres. Impoundment depth appears to be an important factor contributing to such induced seismic activity (24). The risk of dam failure is inescapable since dams do exist; however, risks can be reduced by conscious pre-construction designs and vigilant post-construction surveillance and maintenance of dams.

4. Associated Effects

In order to avoid, as much as possible, the disturbance of areas of high ecological significance and aesthetic value, transmission corridors should be located such that impacts on these areas are minimized. The effects on wildlife migration routes could be reduced by using transmission corridors which are as narrow as possible. The ground vegetation cover, except tall trees, should not be removed in order to minimize land disturbance through erosion. The use of herbicides should be avoided as much as possible to reduce the adverse effects on terrestrial and aquatic fauna.

D. RECOMMENDATIONS

The following are the recommended programs with respect to the environmental concerns of water/energy developments that the Department should support:

1. Environmental overview evaluation of each potential large scale hydroelectric site to identify environmental and social concerns and to rate their severity. Reasons, if any, for federal government involvement in any specific potential site should also be identified. This site information would help developers by reducing the lead time requirements, and hence the overall project development period. Such information could be incorporated into the national hydro potential inventory program that is being developed as a DOE/EMR joint project to compile all relevant information for a computerized data system.

2. Detailed review of the anticipated environmental and social effects of tidal, thermal gradient and hydrogen energy developments. A quantitative evaluation of such impacts should be attempted where possible.

3. Documentation of the post-development performance of hydro sites and the associated environmental changes, where such post-construction information is available to evaluate the effectiveness of measures taken to keep adverse changes to a minimum. The post-construction environmental information, which is currently very limited, could be of great value in the future hydro development planning and designs.

4. Establishment of a national strategy and guideline that would support developments involving "Energy from Water" while meeting environmental and social requirements.

VI. SOCIO-ECONOMIC ASPECTS AND RESOURCE USAGE CONFLICTS

The socio-economic effects of the large and unpredictable escalation of international crude oil prices are so broad that they are difficult to specifically identify. The net effect, however, is to keep increasing the relative benefits of fixed-cost renewable energy sources, provided that initial interest rates are reasonable and the outlook for future inflation is high. Renewable energy has always been important in the overall energy system in Canada, but the only major form exploited so far has been hydroelectric energy. This chapter presents the social and economic overviews of energy sources from water and the socio-economic programs that the Department is recommended to support.

A. SOCIO-ECONOMIC ASPECTS

The greatest social and economic effect of stepped-up renewable energy development from water would be financial, due to the capital intensive nature of hydroelectric power and energy research. The demand for capital is expected to continue to exceed the domestic supply necessitating increased imports of foreign capital at high interest rates which results in adverse effects on the international value of the Canadian dollar. In the short run, however, large capital investment stimulates domestic employment and income, demand for imports, and revives prices. If a capital-intensive investment boom develops, domestic inflation usually results. Foreign capital inflow initially balances merchandise imports and keeps the Canadian dollar value high. When interest on foreign loans is paid, the capital outflow depresses the value of the Canadian dollar, raising prices for imported commodities to Canadians.

Canadian utilities, which are mainly publicly owned, finance projects through the sale of provincial bonds in Canada and abroad. The heavy investment requirements for an electric power system weigh heavily on the provincial ability to borrow. Small scale hydro projects may be financed by municipalities or private industries who have more limited borrowing strength requiring some form of government support. Investment in electric power is growing faster than total energy investment which in turn has been outstanding in total investment in the economy. The same trend is expected to remain or accelerate for a long time. Electric power investment as a percentage of Gross National Product is now running at 2.6 percent and by 1990 may by 3.6 to 4.0. Capital funds must either be imported, or diverted from other investment opportunity areas, consumption, or from public works programs, such as housing and highways.

1. Hydroelectric Power

a) Economic Aspects: Hydro site development has an important effect economically because it is more capital intensive than thermal generation, in general, and becomes even more so as less favourable sites are developed. Large hydro projects involve long planning and construction lead times, high fixed costs but very low operation costs. Since costs are fixed, they are inflation-proof. The interest rate at the time of construction is the crucial financial factor.

The economics of hydroelectric power development are evaluated based on both the investment cost of a hydro project per unit of generating capacity (cost per Kw) and unit cost of energy output (cost per Kwh). Both these indices are dictated by the capital cost, interest rate, pay-back period, flow variation and power demand or market. The application of only one of these indices cannot give a full idea of the overall economy of the project and both these indices are needed for economic comparison. The cost per Kw is determined by dividing the total capital outlay at the end of construction by the installed capacity. The capital cost includes: cost of turbines, generators and auxiliary equipment; transmission lines; civil construction works, the largest most variable item because of its site specific nature and sensitivity to local labour costs and markets; and interest charges during the construction period, a substantial factor due to the long construction period. The cost per Kwh is determined by dividing the total annual cost by the annual energy output which is dependent on the installed capacity, local flow variation and power demand. The annual cost includes the annual capital charge at a predetermined interest rate annualized for a pay-back period (normally 50 years) and the annual operating cost. A hydroelectric power project with a unit power cost as high as $2,000/kw and a unit energy cost up to 30 mills/kwh is currently marginally acceptable.

Some small scale hydro sites, located in remote areas where no transmission service is available from major generating centres and electricity is supplied by diesel generating units, could be economically justified at an even higher cost, perhaps up to $3,000/kw and 50 mills/Kwh since oil prices are expected to continue escalating. Retrofitting generating facilities at existing non-power dams or retired sites provides economic opportunities for hydro power supply since, in most of such cases, no civil costs on dams are required and modification or rehabilitation works could be minor compared with new site developments.

The future development of hydroelectric resources will be conditioned by the following evident advantages and by certain negative factors:

Advantages

- Continuously renewable natural resources;
- Non-polluting, in that no foreign by-products of SO_2, CO_2 or thermal effluent are produced;
- Can be integrated into multi-use developments;
- High efficiencies of over 90% are commonly achieved, making hydroelectric energy one of the most efficient energy conversion technologies;
- Long life, low operating costs and zero fuel costs which make hydro a significantly favourable alternative over oil- or diesel-burning generating stations; and
- Mature technology, offering reliable, flexible operation.

Negative Factors

- The location of many of the remaining promising sites are far from load centres;
- Environmental and social impacts;
- Land use impacts of the right-of-way for transmission lines and the reservoir inundation; and
- High capital cost.

In an economic analysis of a hydro site, other alternative sources of electricity should always be considered such as; thermal plants fuelled by coal, nuclear or oil, diesel plants for remote areas and other hydro sites, etc.

b) Social Aspects and Water Use Conflicts: All resource development projects have social and environmental consequences and resource usage conflicts, and hydroelectric power development is no exception. The social effect of a hydro development may be advantageous to some users and disadvantageous to others, thereby creating certain conflicts in water resource usage.

In hydroelectric projects where the reservoir flooding area is relatively small due to the scale or nature of the project such as small scale, low-head or run-of-river sites, the social impact does not appear to be of great concern. However, in those hydro projects involving reservoir flooding over a large area, the social impacts on the affected population are relatively intense, since human habitation has traditionally occurred at or close to rivers. The social impacts are generally caused by the disruption, through the flooding of vast tracts of land, in the traditional way of life of native people, for example, their hunting, trapping and fishing; the loss of cultivated lands, timber lands, residential or cottage lots. These social impacts which are generally local, can be mitigated through retraining, relocation, income transfer or negotiated compensation, etc. The mitigation measures are justified if the public benefits from the hydro development are sufficient to cover the local losses.

Water use for hydroelectric energy generation often conflicts with water use for other purposes such as flood control, irrigation, municipal or recreational uses, etc. The conflicts are generally resolved through established water management practices by water resource agencies. Comprehensive river basin studies and system operation studies are currently used as a means of establishing the optimum resource use strategy especially where conflicting or complementary multi-purpose water uses are to be properly managed.

2. Tidal Power

a) Economic Aspects: The economic aspects of hydroelectric energy developments, as discussed in the previous section, apply equally to tidal power developments except that tidal site developments generally involve even heavier capital requirements and less flexible operation than hydro developments. Tidal power characteristics generally involve low head and large flow requiring large capital costs on the construction of barrage, sluice and foundations. Due to the fact that tidal ranges follow the lunar cycle, a tidal power plant offers very limited flexibility in generator operation except to allow the regular tidal cycles which may be out of phase with electric energy demands.

b) Social Aspects: Unlike hydro-power developments with large reservoirs the social impacts of tidal power developments do not appear to be of great significance. This is because no reservoir inundation is involved in this case except some alteration of tidal water levels which could adversely affect somewhat the groundwater tables and salinity of the coastal farm lands. Temporary manpower movements and a shift of social structures in the vicinity of the development site during construction could be significant.

3. Wave, Thermal Gradient and Hydrogen Energy

The energy conversion technologies of wave, thermal gradient and hydrogen are still in the research and development stage except for some limited commercial production of hydrogen for industrial applications. The economic and social aspects of those energy alternatives are, therefore, yet to be investigated under certain scenarios depending on their future contribution to the total energy system. Only a limited contribution from wave and temperature gradient energy is expected in the medium or long term energy picture. Hydrogen energy, however, could contribute a considerable share to the nation's future energy system depending upon political and environmental concerns. The overall economy of the energy system, especially the electric energy system, could be considerably upgraded once the hydrogen technology is technically and economically proven to be feasible. The economy of untapped remotely-located large scale hydro sites, currently unfeasible due to high transmission costs, could be enhanced by producing hydrogen at site.

Hydrogen production by use of low-value off-peak electricity generated from hydro, nuclear or future tidal power sources could also considerably improve the overall economy of an electric energy system. Replacement of hydrocarbon fuels by hydrogen could positively contribute to an energy-short society by saving depleting oil reserves for future use by the petrochemical industry, such as plastic or synthetic fibre glass products. Costs of hydrogen production depend on the cost of electricity and the type of process used; however, they currently range from $40 to $80 per barrel of oil equivalent.

B. RECOMMENDATIONS

Recommendations on programs with respect to the socio-economic aspects of energy developments from water are as follows:

1. Through feasibility and demonstration programs of small scale, low-head, existing less efficient, and non-power sites, economic prescreening and evaluation criteria could be developed for use by non-professional developers of such small scale projects.

2. Economic updating of the Bay of Fundy tidal potential sites including optimum sequence of development and combined use of tidal power generation and hydrogen production.

3. Investigation of the economic advantages of combined use of hydrogen produced by electricity from remote hydroelectric power sites and off-peak electricity from other large scale thermal plants.

4. Monitoring the socio-economic aspects of the Annapolis tidal demonstration project.

VII. FEDERAL-PROVINCIAL RELATIONS

This chapter describes the federal and provincial responsibilities and linkages in both the water and energy resource areas, and recommendations with respect to institutional aspects for better management of water resources for energy generation.

A. WATER RESOURCE ADMINISTRATION

1. Statutory Authority

The legislative powers are divided between the federal parliament and provincial legislatures. Administrative control of the nation's water resources is vested in either the provincial government or the federal government or sometimes both, depending upon where the resources are situated. The federal responsibility and statutory authority on water resources are currently based on the following acts and treaties:

- British North America (BNA) Act, 1867;
- Dominion Water Power Act, 1917;
- The Alberta, Manitoba and Saskatchewan Natural Resources Acts, 1930;
- The Natural Resources Transfer Act 1941;
- Lake of the Woods Regulation Act, 1920;
- Boundary Waters Treaty, 1909;
- International River Improvements Act, 1955;
- Canada Water Act, 1970;
- Northern Inland Waters Act, 1970;
- Environmental Contaminants Act, 1977;

- Fisheries Act, 1952 (amended 1970, 1979);
- Arctic Waters Pollution Prevention Act, 1970;
- National Energy Board Act, 1959.

The provinces are the owners of water resources within their boundaries, except those on federal lands, and have the authority of proprietors, as well as the power to legislate under various articles of the constitution (BNA Act, 1867), in matters affecting water. The federal level has important specific and general powers which affect water in a major way. Riparian owners are entitled to access and reasonable use subject to public rights of navigation, fishing and log driving. Provinces have basic powers to manage and control their water resources, authorize development, license uses, regulate flows, and levy fees. They have authority over domestic and industrial water supply, electric power (subject to compliance with federal navigation, fisheries and contaminant regulations, and international obligations), irrigation, reclamation, recreation and pollution abatement.

The federal government has exclusive statutory powers for laws affecting navigation, fisheries and native Indian affairs; has general powers respecting all waters outside provincial boundaries, that is, in the northern territories, or on federal lands; and for the waters crossing or on the international boundary. It has shared responsibility for agriculture with the provinces, and also has authority in the case of works or undertakings extending beyond a single province or which have been declared to be of general advantage to Canada. A major piece of federal legislation, the Canada Water Act (1970), provides for water resource management jointly with the provinces where a federal responsibility is involved. The basic principles followed nationally are to address problems through a co-operative approach;

to preserve aquatic quality and ecosystems, as well as related social and cultural features; to move towards a "polluter pays" philosophy in control aspects; to reduce damage caused by drought and floods; and to resolve conflicts between differing regional views and different users by utilizing a co-operative approach such as basin studies under intergovernmental arrangements.

With respect to power developments, it has already been pointed out that legislative jurisdiction in respect of power projects in a province resides in that province, subject to compliance with federal regulations with respect to navigation, fisheries and international concerns as applicable. Federal authority herein may rest on a purely proprietary basis where Canada owns the land (be it the riverbed, lake or other land) on which a power project is contemplated. Parliament may, if it so wishes, exercise its declaratory power under the BNA Act (Section 92(10.C)).

2. Federal Responsibilities on Water Power Resources

The Parliament of Canada is the legislative authority with respect to water power resources situated in the Yukon and Northwest Territories and on federal lands within provincial boundaries. It also has exclusive legislative authority over navigation and fisheries on Canadian rivers. On "international rivers" and "boundary waters" which flow across or along the international boundary, water power developments which affect the flow conditions of the stream in the neighbouring country are controlled by the federal government under the International River Improvements Act (IRIA, 1955) and the Boundary Waters Treaty (BWT, 1909) in addition to the provincial laws and regulations.

A number of engineering boards and boards of control, consisting of federal and provincial representatives, carry out special studies on water resource matters including power development on Canadian rivers. In matters involving international rivers and boundary waters, similar boards representing both Canada and the United States are established either by the federal governments or by the International Joint Commission (IJC) which was set up under the provisions of the Boundary Waters Treaty of 1909. To encourage the development of the resources of northern Canada, the federal government established in 1948 an agency known as the Northern Canada Power Commission for the planning, construction and management of electric power utilities.

a) Historical Background: A basic requirement for the effective planning of water power projects is the availability of adequate surface runoff and water level information. The measurement, compilation and analysis of these data on a systematic basis began in Canada in 1894 when stream measurement was taken in connection with irrigation surveys made by the Department of the Interior. In 1909 the Hydrographic Survey was first established with headquarters at Calgary, Alberta, to undertake water surveys in southern Alberta and Saskatchewan. The Dominion Water Power Branch of the Department of the Interior was established in 1911 consolidating the hydrometric survey programs, the water power investigations on the Winnipeg and Bow Rivers,and the administration of water power on the federal lands. In 1913 arrangements were made with the Government of British Columbia for this branch to continue the hydrometric survey program in that province. Subsequently, similar arrangements were made with the Governments of Nova Scotia, New Brunswick, Ontario, Quebec and Prince Edward Island. The natural resources of the prairie provinces were administered by the federal government until 1930. They were transferred during that year to the respective provincial governments of Alberta, Saskatchewan and Manitoba, except the operation of hydrometric surveys under similar arrangements with other provinces. A similar arrangement was also made with the Province of Newfoundland on its entry into Confederation in 1949.

The Dominion Water Power Branch of the Department of the Interior became the Dominion Water Power Bureau at one time and underwent numerous name changes prior to its emergence in 1956 as the Water Resources Branch of the Department of Northern Affairs and National Resources. The water resource sector, Inland Waters Branch, emerged in the Department of Mines and Technical Surveys in 1966, subsequently the name was changed to the Department of Energy, Mines and Resources in 1967. In 1971 under the new Government Organization Act, the Inland Waters Branch became the water resource sector of the Department of the Environment.

Under co-operative agreements with the provinces, the water resource sector of the federal government collects and publishes systematic and continuous streamflow records for the whole country. These data, together with information from reconnaissance surveys and other data from federal, provincial or private sources, form the basis for analysis of the water power resources of Canada. Both the water resource sector of the Department of the Environment and the electrical sector of the Department of Energy, Mines and Resources maintain an inventory of these water power resources.

Among a number of water power studies undertaken by the water resource sector under joint federal-provincial efforts, the studies which have made a significant contribution to Canadian hydroelectric power developments involve the following rivers: the Columbia River; Fraser River; Nelson River; Northern Ontario; Atlantic Provinces; and Yukon Territory.

b) Current Federal Involvement on Water Power: The water resource sector of the Department of the Environment (DOE) has been involved extensively with energy related water quantity and quality aspects, and social and environmental issues including: hydrological data; federal-provincial joint programs under the Canada Water Act (CWA); international water development implications under the Boundary Waters Treaty and International River Improvements Act; energy/water related research and development programs; federal Environmental Assessment and Review Processes (EARP) for projects receiving federal funding; national hydro-power potential and environmental data, etc. Most federal or federally-supported water power projects have been exclusively administered by EMR through the electrical sector. Federal support has been given to such projects as the $25 million (federal share) Annapolis Low-head Tidal Power Demonstration Project; Small Scale Hydro Demonstration Project at Roddickton, Newfoundland; mini-hydro potential study in British Columbia and has been based on responses to utility or provincial initiatives and funded through EMR. There are a number of hydroelectric power related activities among various federal departments as listed in a compendium, "Federal Involvement in Hydro-Electric Development" (29). There appears to be a need for closer co-ordination between various departments involved in hydroelectric power related activities.

B. RECOMMENDATIONS

In order to improve management of the water resources, especially with respect to water use for energy development, it is recommended that the

Department support the following institutional initiatives:

1. Major institutional problems in administration of energy/water programs are the lack of a national policy on energy-related water use, and insufficient co-ordination between federal departments: those through which the programs are funded and the others where related major expertise is available. Closer co-ordination between relevant federal departments is, therefore, a must in order to achieve the most effective implementation of energy/water programs under a jointly established energy-related water use policy for the maximum benefit to all Canadians.

2. Establishment of a joint interdepartmental body to administer matters on Energy and Water either as an independent agency or as a sub-committee of the current Interdepartmental Committee on Water (ICW) which is currently an information exchange body.

VIII. ENERGY FROM WATER: Current and Future Role

This chapter briefly discusses the current contribution of energy from water to the overall energy system of Canada and the expected role of energy from water in meeting future energy needs under regional demand scenarios and anticipated constraint factors.

A. CURRENT CONTRIBUTION

Of the energy sources from water (hydro, tidal, wave, thermal gradient and hydrogen), only hydroelectric power currently contributes significantly to the overall electric energy system of Canada. At the end of 1980, about 68 percent of total electric energy was supplied from hydroelectric energy sources. Electric energy generation and installed generating capacity for each province at the end of 1980 are listed in Table 1/VIII. Hydroelectric energy currently accounts for more than 10 percent of Canada's total primary energy needs.

As indicated in Table 1/VIII, four provinces (British Columbia, Manitoba, Quebec and Newfoundland) supply almost all their electricity from hydraulic generating plants. The present generating capacity in Alberta, Saskatchewan, New Brunswick, Nova Scotia and Prince Edward Island is primarily by fossil-fuelled generation (coal, oil and gas). The province of Ontario currently is obtaining about an equal amount of energy from each of the sources, hydroelectric power, fossil-fuelled (mainly coal), and nuclear. The installed capacity of hydro-power generation in the province is about 27 percent of the total capacity, but the energy supplied from these hydro stations is about 37 percent of the total provincial electric energy generation in 1980.

Table 1/VIII

Electric Generation Installed Capacity

and Output - 1980

(c): Capacity in Mw

(o): Output in Gwh

Provinces		Hydro	Thermal	Nuclear	Total
British Columbia	(c)	8,995	1,772	-	10,767
	(o)	40,860	2,474	-	43,334
Alberta	(c)	718	5,082	-	5,800
	(o)	1,699	21,692	-	23,391
Saskatchewan	(c)	577	1,755		2,332
	(o)	2,549	6,639	-	9,188
Manitoba	(c)	3,641	500	-	4,141
	(o)	19,096	366	-	19,462
Ontario	(c)	7,086	13,033	5,600	25,719
	(o)	40,192	34,054	35,880	110,126
Quebec	(c)	19,095	1,114	266	20,475
	(o)	97,560	247	-	97,807
Newfoundland	(c)	6,444	744	-	7,188
	(o)	44,860	1,398	-	46,258
New Brunswick	(c)	893	1,892	-	2,785
	(o)	2,666	6,617	-	9,283
Nova Scotia	(c)	363	1,675	-	2,038
	(o)	903	5,960	-	6,963
Prince Edward Island	(c)	-	127	-	118
	(o)	-	127	-	127
Yukon Territory	(c)	58	36	-	94
	(o)	322	63	-	384
Northwest Territories	(c)	47	132	-	179
	(o)	292	163	-	455
Canada Total	(c)	47,919	27,853	5,866	81,638
	(o)	250,999	79,800	35,880	366,679

All the electrical energy generated in a province is not consumed in that province. A considerable amount of electricity was transferred between provinces and exported to the United States in 1980 as shown in Figure I/VIII. The increased trend of electricity transfers and exports is expected to continue in the future. The major interprovincial transfers are from Newfoundland (Churchill Falls, Labrador) to Quebec, Quebec and Manitoba to Ontario, and Quebec to New Brunswick. The main exports to the United States are from British Columbia, Ontario, Quebec and New Brunsick. About 8 percent of Canada's total electric energy was exported to the United States in 1980.

There are a number of provinces where increased power exports are possible, and may be advantageous; for example:

- Manitoba has underdeveloped northern hydro resources plus present surplus capacity, and could export more to the north-central states, as well as gain through diversity exchanges;
- the Atlantic provinces could export to New England - possibly for a period up to ten years - from the large nuclear unit at Point Lepreau, and also from new hydro or tidal developments in nearby areas;
- a Quebec and Labrador interconnection could export surpluses to New York and the eastern central Atlantic region, as well as engage in profitable diversity exchanges;
- Ontario to New York and the eastern central Atlantic area could be an enhanced five- to ten-year firm power market, providing capacity installation is not discouraged and transmission capacity is enlarged; and
- Alberta lacks intertie facilities with the United States. However, British Columbia has them and there may be a possible advantage in mixing northwest U.S. hydro with Alberta thermal in a larger market area. In regard to

ALL VALUES IN GWH (1 GWH = 1,000,000 KWH)

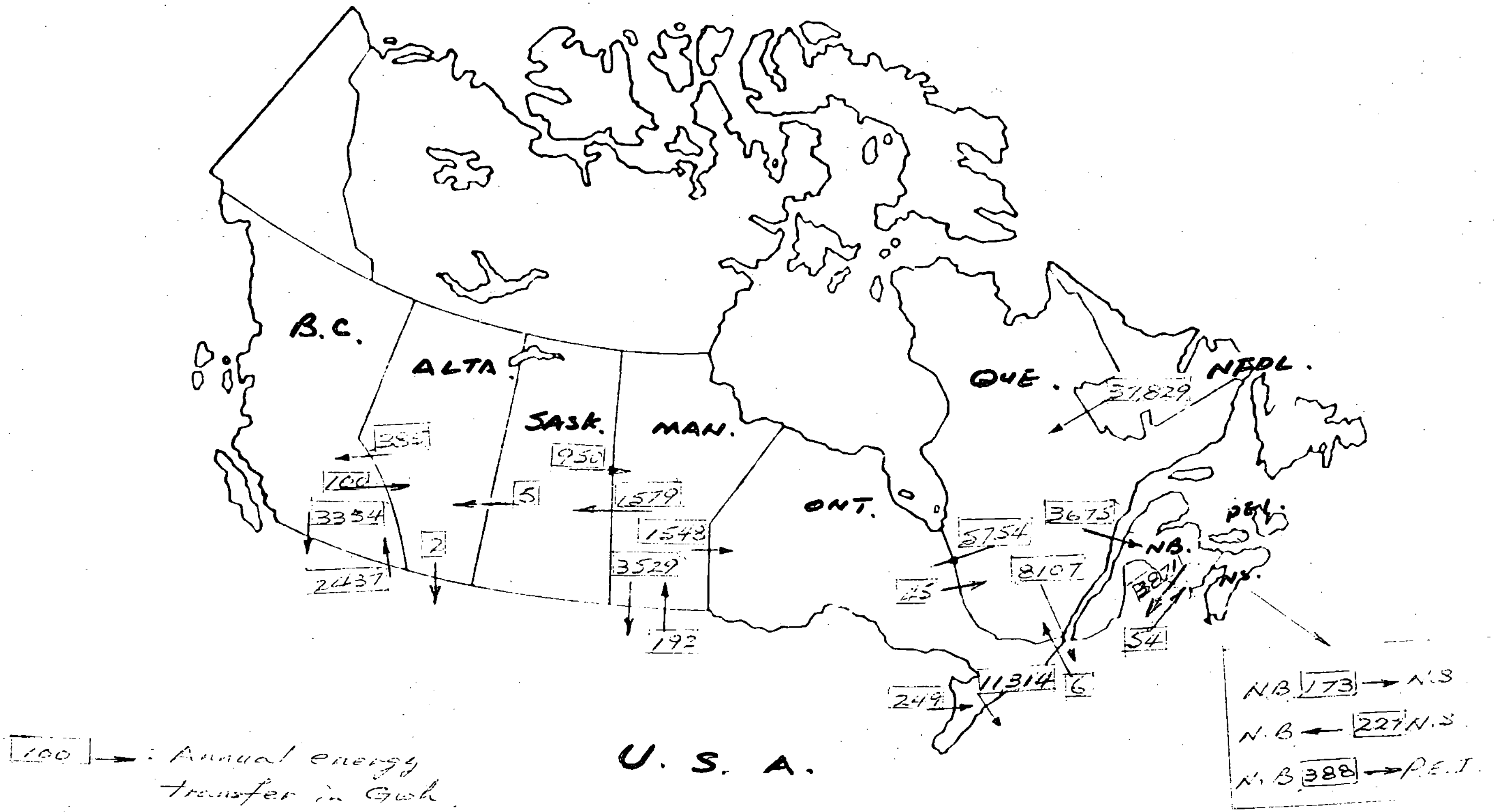

Figure 1/VIII
Electrical Energy Net Transfers + Exports – 1980

exports from British Columbia, the problem is a lack of transmission capacity and a public opposition to energy exports. The objection appears to be against B.C. Hydro using public funds to "overbuild" generating capability in order to profit through exports to the United States, and hence to planning for a wider market area.

B. FUTURE ROLE

As depicted by the Parliamentary Committee report (4), our energy system must ultimately be shifted from one dominated by fossil fuels to one which runs on sustainable sources of energy. The reasons for the necessity of this shift of energy system away from hydrocarbons are: a) to counter the otherwise formidable environmental problems we see arising in the future, especially "acid rain" if coal becomes a principal element in our energy supply: and b) to preserve the depleting resources of crude oil, natural gas and coal for such non-energy uses as the production of petrochemicals. Possible alternatives for such sustainable energy sources are the renewable energy sources such as solar, wind, biomass and "energy from water". Nuclear power would also significantly contribute to such future sustainable energy sources.

Among the prospective future renewable energies, energy from water (hydro, tidal, wave, thermal gradient and hydrogen) is the most promising and has the largest potential.

In the following sections, prospects and expected future roles of each energy source from water and constraints to the resource developments are discussed:

1. Hydroelectric Power

In spite of the expected steady increase of hydroelectric power generating capacity in the next ten years, mainly by developing very large developments such as James Bay in Quebec; the Nelson River in Manitoba; and Revelstoke, Mica Creek and the Peace River in British Columbia, hydroelectric energy, as a share of total electric energy generation, is expected to continue to diminish to about 60 percent in ten years, and to about 50 percent in 20 years. Most of the favourable large scale hydro sites have already been developed or are being constructed for completion in the next 10 to 15 years. However, there are substantial remaining hydraulic resources, most of which are large scale, a long distance from the load centres and are in difficult locations for construction, or have particularly difficult environmental or social implications. These remaining large scale hydro resources are mainly in British Columbia, Yukon and Northwest Territories, Quebec, Labrador and Northern Ontario.

The constraints to these large scale hydro resource developments are: a) financial and economic factors, b) environmental and social implications, and c) institutional aspects. Since most of the economically attractive large scale hydro sites have been developed or are under development, and with the expected continuing high interest rates, high inflation and increasingly tighter money markets, the financial and economic factors would further limit developments of remotely-located large scale hydro sites. No hydro development is possible without some environmental and socio-economic consequences but they can have varying degrees of impacts. Most of the remaining undeveloped large scale hydro sites in Canada would be environmentally and socially sensitive mainly due to the extent of the affected areas. Major environmental and social impacts of hydro development, as discussed in detail in Chapter V, are caused by the construction of large dams which inundate large areas to create reservoirs, block fish migration, and change upstream and downstream river flow regimes, etc. As discussed in the preceding chapter, control of water resources in Canada is administered by either or both the provincial governments and the federal government, depending upon where the resources are situated. Hence certain hydro developments need to be cleared or licensed through a number of acts, regulations and/or treaties administered by both federal and provincial governments or agencies, requiring long periods for project releases. Since the government regulatory "red tape" is applied equally to both large and small scale developments, the impact of the institutional constraint is especially intense to small scale hydro site developments.

In the next 20 years, most of the large scale sites having an economic potential and many small scale hydro sites which would cause relatively less environmental and social impacts due mainly to their size, are expected to be developed, bringing the total hydroelectric power generating capacity in Canada in the year 2000 to about twice what it is today or more than 100,000 Mw. Details of expected increases in generating capacity and energy generation in each province by the year 2000 are included in Chapter IV, Forecasts of Electricity Demand.

2. Tidal Power

The main constraint of tidal power development is the economic factor due to its immense capital requirement. A 1,085 Mw station at Cumberland Basin in the Bay of Fundy, for instance, would cost in excess of $16 billion

(1981 dollars). As other energy costs (oil, gas or coal) continue to escalate, tidal power could become a more economical proposition toward the end of the century. Its contribution to the future energy system, however, would be regional.

The combined use of tidal power generation with pumped-storage power plants and hydrogen generation by off-peak energy could enhance the economy of tidal power plants. Tidal power in Canada would not be developed in the next ten years except for the current demonstration plant at Annapolis Royal. The future of the Bay of Fundy tidal power development will be reassessed based on the current undertaking's cost updating and the technical, economic and environmental data to be obtained upon the completion of the Annapolis Tidal Power Demonstration Project.

3. Wave, Thermal Gradient and Hydrogen Energy

The potentials of wave energy, thermal gradient energy, and energy from hydrogen are not foreseen to be developed for full scale commercial production by the year 2000. Hydrogen, however, could become an economically, technically and environmentally attractive proposition and an alternative to the hydrocarbon based energy system in the next 20 years, depending on the technology research and development applied to its production, transmission and storage and the government policies approved in the near future.

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GLOSSARY OF TERMS

Electric power	:	A measure of the strength of electric capacity to deliver energy and typically is expressed in kilowatts (kw) or variation of this unit such as megawatts (Mw = 1,000 kw).
Electric energy	:	A measure of the amount of total electricity output or consumption during a period of time. Its value depends on the time period over which electricity is generated or consumed and the capacity, and is typically expressed in kilowatt-hours (kwh) or similar units such as: megawatt-hours (Mwh = 1,000 kwh), gigawatt-hours (Gwh = 1,000 Mwh).
Kw (kilowatt)	:	A unit of power equal to 1,000 watts.
Mw (Megawatt)	:	A unit of power equal to 1,000 kw.
Kwh (kilowatt-hour)	:	A unit of energy equal to 1,000 watt-hours
Mwh (megawatt-hour)	:	A unit of energy equal to 1,000 Kwh
Gwh (gigawatt-hour)	:	A unit of energy equal to 1,000 Mwh.
Epilimnion	:	Upper layer of reservoir water containing warmer or lighter water in a stratified impoundment.

Hypolimnion : Lower layer of reservoir water containing colder or heavier water in a stratified impoundment.

Thermocline : Layer of temperature transition, with a sharp temperature gradient, between the epilimnion and hypolimnion in a stratified impoundment.

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