R. Fairbanks

RESERVOIR CLEARING AND PREPARATION - ENVIRONMENTAL PROTECTION STRATEGIES

ACRES CONSULTING SERVICES LIMITED
5259 Dorchester Road
Niagara Falls, Ontario
L2E 6W1

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SUMMARY

A broad state-of-the-art review was made for reservoir clearing practices. Utilities across Canada and in parts of the United States were contacted for reports on the reservoir clearing strategies employed by them with histories of their effectiveness. Nearly 100 case histories have been assembled from these and literature sources. There is a general lack of information regarding the impacts of different clearing strategies.

The major problem issues related to reservoir creation i.e. erosion/bank stability, floating debris, role of vegetation in controlling erosion and water quality are reviewed.

Currently used clearing practices are described and a comparison made of their relative impacts. The sources of clearing guidelines and the processess of execution are presented as they exist in the Canadian provincial and American State policies.

The criteria used in assessing preimpoundment clearing needs are discussed according to different multiple-reservoir use options, site specific restrictions and jurisdictional limitations. A framework for decision-making is put forward.

The regional considerations which could affect reservoir clearing policies in the Hudson Bay Lowlands and on the Precambrian Shield are appended.

Data gaps are identified and recommendations for further action, made.

1 - INTRODUCTION

There are hundreds of hydro storage reservoirs in operation in North America. Historically, clearing of reservoirs was executed to maximize the storage volume, to salvage merchantable timber, to minimize water quality problems and to minimize debris that could interfere with power generation. To that end, clearing has ranged from none at all to complete removal of all vegetation and topsoil before flooding. Comparative successes have been reported across that range of actions, as have major failures. In the past, the extent of clearing and methods used, were largely determined on economic grounds. Generally, merchantable timber, i.e. that with a monetary value high enough to warrant its extraction and a market for the removed wood, was taken out prior to flooding. Trees that had little or no economic worth or for which extraction costs were too high, were drowned. The costs of clearing were accepted as part of project costs, along with dam construction, as one of the requirements to ensure reliable, uninterrupted and cost-effective operation of the power facility.

Increasingly, hydro reservoirs are being viewed as resources in and of themselves with potential uses over and above their storage capabilities. From this viewpoint and in consideration of the many options available for preimpoundment preparation, the apparently conflicting views regarding the usefulness of reservoir clearing, and the need to plan for ever-broadening user demands, this report attempts to review the state-of-the-art in respect of reservoir clearing and to provide a background on which the selection of appropriate clearing strategies can be based.

A process by which a reservoir clearing strategy can be derived for any given reservoir is depicted graphically in

Figure 1.1. The first step is to describe the physical, biological, social and economic environment in which the reservoir will be placed and to further place priorities on the strengths and sensitivities of the characteristics thus identified.

Then the objectives, i.e. the uses to which the future reservoir is to be put, must be defined. The first priority for a hydroelectric storage reservoir must, of course, be the storage of water for hydropower generation, but within that objective, there are many options relating to operations. In addition to this primary purpose, the proponent of the power project will, in conjunction with others, define at least in principle, any secondary uses for the reservoir, compatible in varying degrees with hydropower generation. In Ontario, this usually involves the Ministry of Natural Resources, from whom water rights are obtained for use of the river and with whom jurisdiction over adjacent lands often rests. Secondary uses such as recreation, fish and wildlife enhancement and flood control are commonly allied with hydro reservoir operation. In some areas of poor water distribution, although not often in Ontario, power generation and irrigation have been coupled. Less common but possible, is the utilization of a headpond as a source of public drinking water (e.g. Arnprior). Once the objective uses of the future water body have been agreed on and prioritized and where possible, defined in terms of limits, the known constraints to meeting those objectives are also defined. Constraints include the physical attributes of the reservoir, its location, the logistics of access and ease of manipulation, the economics of incorporating various alternatives or the financing associated with them, the acts and regulations in place which limit development, compatibility with existing land use in the area and the feasiblity of scheduling activities to meet project demands.

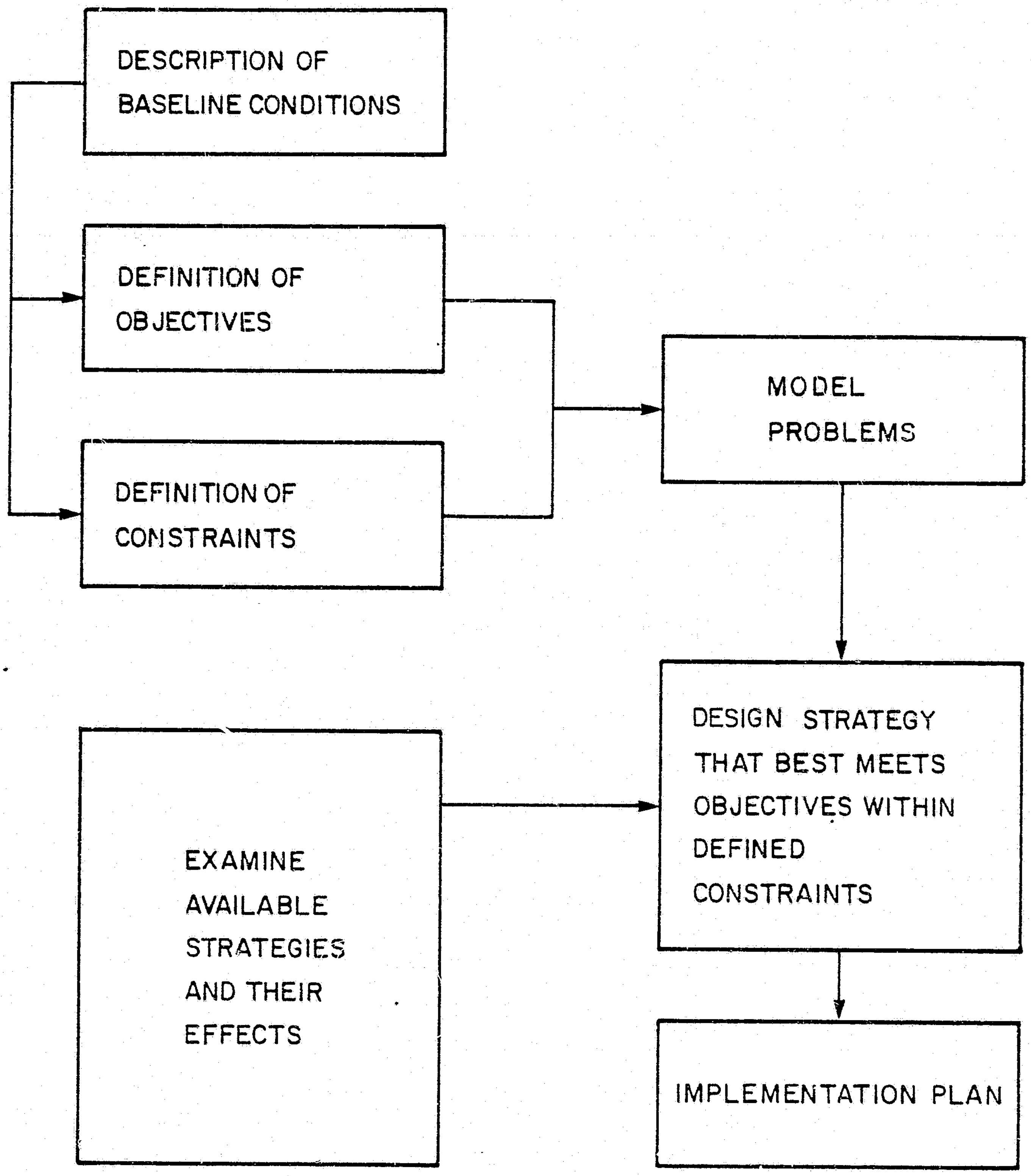

FIG. 1.1

ONTARIO HYDRO
RESERVOIR CLEARING & PREPARATION – ENVIRONMENTAL PROTECTION STRATEGIES
STRATEGY SELECTION PROCESS

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The combination of objectives and constraints leads to a model (description) of the "problem", whereby those objectives most likely to meet with success, can be seen and further work arranged to improve their chances of success. Reservoir clearing is a management tool in this context--one of the many factors that can contribute to the meeting of the originally stated objectives. It is not an objective itself--simply a means to a conceptually defined end product.

There are many ways to prepare a reservoir prior to flooding. As their impacts and costs differ, so will their relative appropriateness in meeting the objectives set out at the beginning of this process. One must examine the strategies and methods of execution available, and determine which ones best meet the requirements of any given reservoir.

This report has been set up to follow the process just described. Sections 2 and 3 describe baseline considerations and the current state-of-the-art of reservoir clearing in Canada, parts of the United States and Europe. Section 4 describes the objectives (reservoir uses) and constraints which must be defined early in the process, followed by a discussion of the methods (as compared to strategies) available (Section 5). Section 6 develops a mechanism for evaluating all the options available and the tradeoffs to be made in selecting the best clearing strategy for a given reservoir.

Appended are case histories of North American reservoirs, examples of clearing guidelines and a description of the regional considerations peculiar to the Precambrian Shield and the Hudson's Bay Lowlands.

2 - BACKGROUND AND KEY ISSUES IN RESERVOIR CLEARING

In this section, the processes that take place during reservoir creation and the generally observed impacts are briefly reviewed. This is followed by a specific discussion of some of the major problem issues.

2.1 - Processes of Reservoir Creation

Very briefly, the following processes occur during reservoir creation.

(a) Inundation

- water rises with dam closure; reservoir filling process generally completed in 1 to 2 years

- previously dry soils are hydrated; physical absorption of water changes cohesion of soil particles and, therefore, angle of repose, leading to slumping

- soluble materials in soils go into solution altering chemistry of overlying water; depending on soil types, the levels of nutrients, metals, color and turbidity rise, pH may go up or down (usually down)

- flooded particulate organic material (soils and vegetation) is biodegraded by bacteria and fungi, gradually being made available to higher trophic forms; if conditions at soil/water interface remain aerobic, BOD and CO_2 production will be high but H_2S and methane will not be produced; if anaerobic conditions develop H_2S and methane will replace

CO_2 as respiratory end products; particulate material is grazed on directly by aquatic invertebrates and vertebrates

- dissolved inorganic nutrients are used by primary producers thus being converted to organic form and made available to higher life forms; primary production can be limited by availability of light in highly turbid reservoirs although this situation is usually temporary

- species composition of fish, bottom fauna, plankton and macrophytes changes rapidly during the first few years; standing stocks are potentially high

- some vegetation uproots and floats during early years of reservoir life; this process can continue for very long periods of time; further debris accumulates due to shoreline erosion in weak areas

- inundation causes raising of water table all around the reservoir, the distance away from the shore being dependent on slope, soil porosity, rainfall (inflow) and soil depth; this affects soil moisture regime and, therefore, vegetation

- opening of a forest can cause mortality of exposed trees through sun scald and windthrow in addition to the obvious impacts of "drowning"

- trees that extend above top water level may eventually break off at the waterline through ice action, wave action or degradation; underwater stems tend to remain intact and sound for decades.

(b) Stabilization

- over time, usually within 5 years (except in arctic situations), water chemistry of reservoir stabilizes to reflect inflowing water and in many cases, except for bottom layer, is not significantly different from adjacent natural lakes

- stabilization of the reservoir shoreline is dependent on the soil types along the margin, the amount and frequency of water level fluctuation (drawdown), the size and orientation of the reservoir (wave climate) and the slopes and cover of the backshore; continuing erosion problems can occur in some areas while stable shorelines can be developed in a few years in others

- the stabilized reservoir does not function exactly as a natural lake because of high volume replacement and water level fluctuations, including the attendant disruption of the littoral zone.

2.2 - Problem Issues

2.2.1 - Erosion

The single most often identified problem in the creation of reservoirs is that of continuing shoreline erosion. This leads not only to a visually unpleasant water body, but also prevents stabilization of the nearshore zone and, therefore, biological productivity. It forecloses many backshore uses, contributes to turbidity of the lake water, causes trees and other vegetation in the erosion areas to be undermined and to fall into the water (thereby contributing to floating debris), and if extensive, can shorten the effective lifespan of the water body as a storage reservoir.

The processes contributing to shoreline erosion are varied and complex. It is not possible within the limits of this study to deal with all of them in detail. The major sources of erosion in reservoirs are

- wave action
- water level fluctuation (amount, frequency and rate)
- surface runoff.

The susceptibility of shoreline materials to these erosive forces is a function of

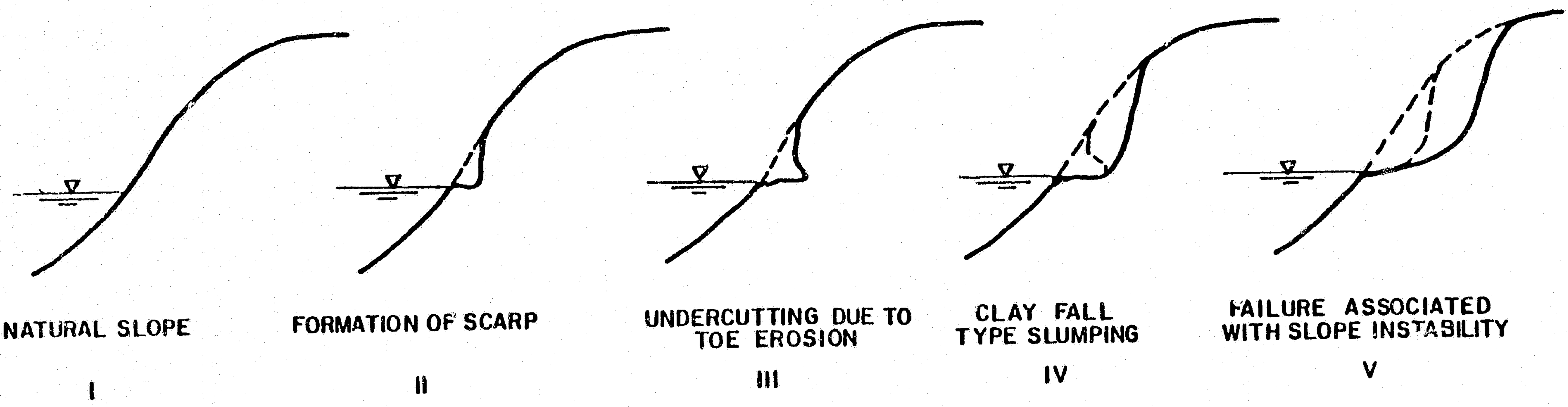
- soil composition and/or bedrock characteristics
- soil depth
- shore slope
- shore exposure
- cover of backshore
- underwater protection
- elevation of water table.

(a) Wave Action - Of the erosive forces acting on reservoir shorelines, wave action is undoubtedly the worst, and is usually magnified by the effects of fluctuating water levels. Waves are generated by the frictional water forces of wind over water and are therefore a function of wind (speed, duration and fetch) and the depth of the water. The maximum wave breaking onshore can be calculated, as can the erosive energy of any particular wave. The actual rate of erosion of a given material is, however, a function of more than just the wave and to predict rates, some observational data are usually required. It is possible, knowing the composition of the exposed material, however, to calculate how far back a shore would have to erode before stability is reached.

The effects of wave action will depend on the physical character of the reservoir shoreline. Materials such as silt and fine sand, which are noncohesive, tend to erode rapidly when exposed to wave action. Cohesive materials, such as clay, tend to stand up longer but when they fail, tend to do so in local falls which can then lead to gross instabilities. Figure 2.1 shows the mechanism of bank failure as cause by wave action on clay. Waterlogged clays subjected to tremors, such as those produced by waves, are highly unstable and show massive slumping. The fine clay particles will usually be carried away or remain in suspension, limiting beach formation to those areas where cross-slope velocities are extremely slow, permitting sedimentation.

In coarser materials such as silt, sand and gravel, beach formation will eventually result. Figure 2.2 shows a typical beach profile. The sandy material is gradually brought down by the waves until a very gradual slope is attained underwater. When this profile becomes shallow enough, waves break offshore, thereby protecting the bank.

Glacial till (a mixture of all particle sizes) tends to be self-armouring, with the finer



REF. ACRES, 1979

FIG. 2.1

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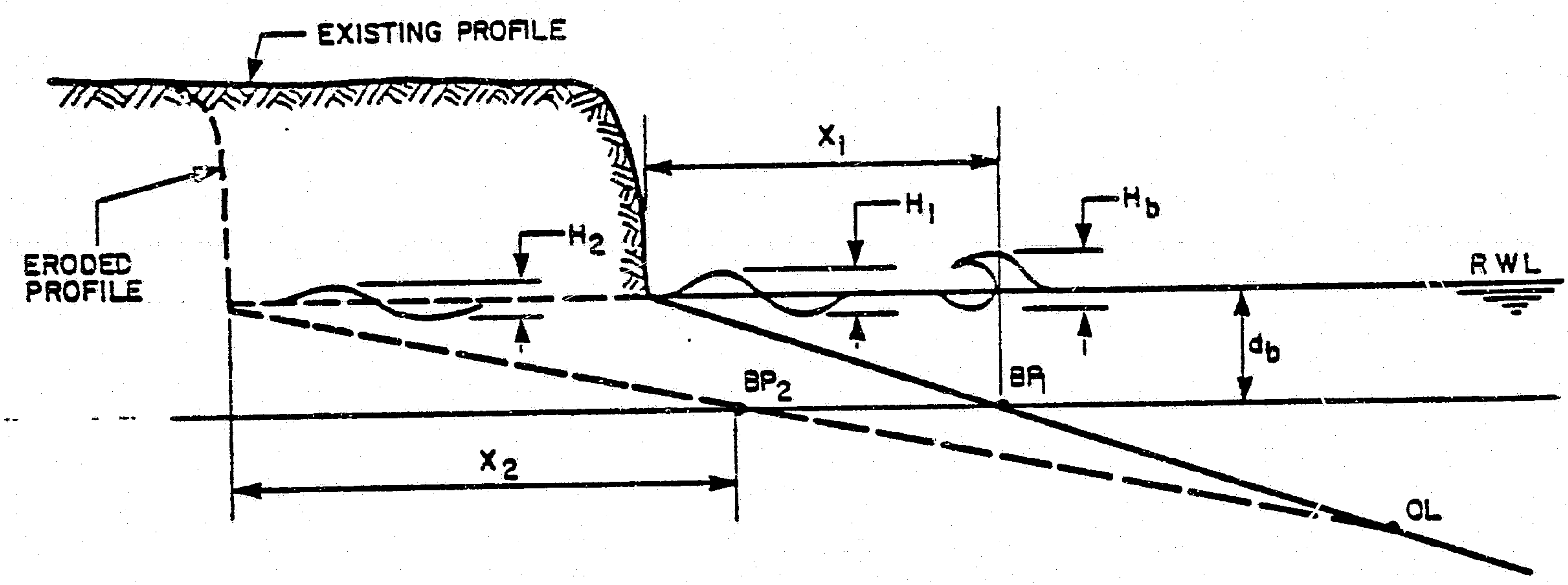
BANK FAILURE IN CLAY



DEFINITION OF TERMS

RWL – RESERVOIR WATER LEVEL

OL – OFFSHORE LIMIT OF SEDIMENT MOVEMENT

d_b – DEPTH AT WHICH BREAKING OCCURS $\approx$ 1.3 H_b

H_b – BREAKING WAVE HEIGHT

BP_1 – POINT AT WHICH WAVE BREAKS

X_1 – DISTANCE BETWEEN BP_1 AND SCARP

REF. ACRES, 1979

FIG. 2.2

ONTARIO HYDRO

RESERVOIR CLEARING & PREPARATION – ENVIRONMENTAL PROTECTION STRATEGIES

BEACH FORMATION

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material being drawn out through the coarse leaving an outer protective coarse particle skin, thereby protecting the bank.

Compounding the formation of stable shoreline against wave erosion is the opening of scarps through the toppling of trees along the shore. If wave action pulls the soil away from tree roots, the plant falls over, disturbing yet more soil. The scar thus generated allows wave penetration and further erosive action.

In natural lakes, stable shorelines vegetated virtually to the water, are the norm. This is because the erosive processes have largely ceased with shore armoring having occurred either through gradual sloping, or an accrual of "hard" material. In reservoirs, fluctuating water levels greatly inhibit these natural stabilization processes, as described in the next section.

Further complications to the initial wave action are added by seiching. This can occur in long reservoirs oriented along the axis of high winds of long duration. The winds cause the water to pile up at one end of the reservoir, sloshing back when the wind drops. Seiching also occurs as a result of major landslides or seismic activity. The erosive action of seiching is equivalent to very rapid water level fluctuations and can be very destructive on that basis.

(b) Water Level Fluctuations - Both directly and by combining with other erosive forces, water level fluctuation is a major contributor to erosion and bank instability in reservoirs.

Most materials have an intrinsic angle of internal friction (angle of repose). In general, coarser grained materials will maintain steeper slopes than fine grained. The exception is a cohesive component that is in part, chemical, which allows vertical natural slopes to occur. The angle is also affected by the degree of saturation and pore water pressure. As a consequence, stable natural slopes, where inundated, can slump to very gradual slopes underwater because of loss of negative pore pressure or destruction of cementation bonds.

With drawdown, shore materials are sequentially exposed to wetting and drying. This subjects them to changes in pore water pressure. Free-draining materials such as sand, are best able to cope with these changes if undisturbed.

But in poorly drained soils, in situations of large and rapid drawdown, pore pressure is often the primary source of bank failure.

In hydro storage, fluctuating water levels are common. This exposes shores to wave action and ice scour at different levels so that the stabilization achieved during a given period of stable water level is negated by erosive action at another. The larger and faster the change, the greater the susceptibility of shorelines to erosion and bank failure.

(c) <u>Surface Runoff</u> - Surface runoff is a secondary erosion source in most reservoirs but when combined with other forces, can be significant.

In areas where surface runoff is high due to high intensity rainfall or poor drainage, water flows over the surface of the soil. The erosion of surface materials is a function of the aggregation of the soil materials, particle size (transportability), volumes and velocities of the runoff water. As this water reaches the edge of a reservoir gullying occurs. If the gullying occurs during reservoir low water periods, the scars thus produced are then subject to wave action and the effects of rehydration when the water level is raised. Stable vegetation in the backshore is a positive feature, reducing surface runoff by allowing water to percolate through the soil rather than running over the top. Seasonal changes in groundwater levels can however, bring about slope instability and failure, which then exposes unprotected soils to the processes described earlier.

(d) The Role of Vegetation in Controlling Erosion - The presence of vegetation cover on stable slopes is effective in reducing erosion from surface runoff. Its effectiveness in controlling erosion and slope failure from drawdown or wave action is less positive. In studies of Great Lakes Shorelines, Dai and Hill (1976), found that a number of favorable factors had to be present before the shoreline could be stabilized - vegetation alone was not sufficient.

Geen (1974) discusses a comparative study on 2 reservoirs in western Canada. He shows that complete removal of all terrestrial vegetation prior to flooding can lead to considerable erosion in the exposed sites and silting in deeper areas of the lake. If clearing is confined to the removal of larger trees, the smaller remaining vegetation provided a measure of soil stability and minimized erosion.

In some cases, shoreline trees may be valuable in preventing erosion even when dead and fallen as they tend to decay slowly, in situ, rather than floating away. However, with steeper slopes, tree falls may produce scars and more erosion thereby increasing the floating debris.

In many Russian and European reservoirs (Gill 1977), trees have been planted to prevent erosion and for silt control. Willow, poplar and alder species are the trees mainly used. (Willow has the ability to quickly produce new roots.) The trees have to be shallow rooted to withstand flooding conditions. This could possibly be disadvantageous in terms of their stabilizing ability.

Where an area is flooded it can be expected that the marginal vegetation may die and new species will replace it which are tolerant to the new environment. Old species may survive but are often unable to regenerate. Many annual plants, with abundant seed supplies, are capable of rapid invasion of reservoir margins. However, annuals do little to aid bank stability; their life cycle being too short and their root system too shallow. Herbaceous perennials use vegetative reproduction to spread into the drawdown zone. Some are capable of withstanding water level fluctuations and can provide some initial stabilization of the margin. Woody plants are extremely vulnerable to displacement during the seedling stage and take considerable time to become established. However, those that do survive offer the greatest protection to waves and flooding.

2.2.2 - Effects on Shoreli.e Vegetation

When an area is flooded, pronounced environmental changes occur in the adjacent land. The water table and regime are completely altered and the vegetation cover must attempt to adjust to these changes. The greatest environmental effects are produced by

- water manipulation practices
- wave action
- soil structure and nutrients
- other management factors.

Water fluctuation and wave action have been described in Section 2.2.1 but their effect on marginal vegetation is discussed below.

(a) Water Manipulation - The most pronounced problem occurs in the drawdown zone. In low water periods, the reservoir can be extremely unattractive with large exposed areas of bare soil. Water manipulation in reservoirs implies more rapid and extreme fluctuations in water level than occur in natural lakes with the result that fewer plants and animals are found along the margins. By their nature, aquatic species cannot stand dryness and terrestrial species are unable to withstand extended periods of flooding. When water logging occurs, the soil atmosphere is replaced by water, gaseous diffusion rates lower and the available oxygen is rapidly used. Nutrients become deficient and phytotoxic compounds may accumulate. The plant response to these changes depends on the species, its age and the time and duration of flooding. No species can survive flooding in the growing season for any length of time (up to 1 month possibly) if it was not previously adapted to a flooding regime. All mature trees in the reservoir, whether totally flooded or subjected to high-low fluctuations adjacent to the margin, will probably die. The shock of flooding, sun scald and wind exposure is sufficient to kill these mature trees. The vegetation which is already growing in low lying, wet areas on sites subjected to naturally fluctuating regimes (caused for instance, by spring flooding) are those species which are most likely to survive on the reservoir margins. Deep rooted trees like pine are those least likely to survive in the drawdown zone; shallow rooted species such as Larch, Black Spruce and Willow being more tolerant of fluctuations in water regimes.

(b) Wave Action - Wave action can be the most important factor in preventing marginal colonization. Waves not only physically damage the plants themselves but also erode the soil in which they are rooted. There is little information pertaining to the adaptation of plants to wave action although indications are (Dai and Hill, 1977) that few if any species can withstand direct wave impact of any magnitude.

Plants used to stabilize banks (e.g. Willow) have the ability to rapidly produce new roots. Some species may be able to increase the number of cells in their stems and so increase stem strength.

(c) Soil Type and Nutrient Status - Soil type and nutrient status of the margins affects colonization rates and susceptibility to damage. As previously discussed, silts and fine clays are easily eroded and in these cases it may be necessary to engineer the banks to stabilize the slopes. They may have to be revegetated with grasses and legumes followed by tree species.

Wave action may first remove the finer particles and, depending on the nature of the parent material, this may leave gravel and stones behind as occurs in some till deposits. These stones may be too large to be removed by wave action. They would not injure adjacent plants and could provide protection to the rooting zone beneath.

The nutrient status of the drawdown zone is not well documented. It would appear that certain margin soils are deficient in both micro and macro nutrients, particularly nitrogen. This is not an important factor in the initial colonization of plants but it is significant in their later growth and survival. An excessive availability of some micro nutrients may exist; both iron and manganese may be present in a highly soluble form which can be taken up by plants in toxic amounts.

(d) Management Techniques - Management techniques used to be such that all vegetation was removed to some standard distance back from the newly created reservoir. The removal of the organic matter was thought to improve the water quality and to reduce the amount of debris entering the reservoir. The quantity of organic matter released by marginal vegetation is often slight in comparison with that being brought into the reservoir by feeder streams and submerged vegetation is beneficial in the development of benthic invertebrates. There would appear to be little reason to remove shrubs, herbaceous plants and young trees from the areas to be flooded if well anchored. They will eventually die and decay but in the interim they can reduce the erosion of the margins and generally improve the ecology of the reservoir. Geen (1974) thought it advantageous to leave vegetation on reservoir slopes based on a comparative study indicating that a completely cleared reservoir was subject to more shoreline erosion than one which was left uncleared.

Other management practices may involve compaction of the soil by heavy machinery during reservoir construction. This makes revegetation much more difficult. Positioning of land-drain outfalls may increase soil moisture and nutrient status. Current management techniques are aimed at alleviating some of the problems discussed here.

Recently there has been a move to encourage plant growth on reservoir margins by design (artificial planting) or by management. Shallow water impoundments initially left uncleared to attract wildfowl have been found to be beneficial to hardwoods growing around them (Gill 1977). A shallow impoundment in which water levels are allowed to stay high either in the winter or spring can improve the soil moisture for the rest of the growing season. Management practices should be such that the vegetation is not flooded during the height of the growing season. In many Russian and European reservoirs trees have been planted to prevent erosion and to provide silt control. Trees are frequently planted before the reservoir is flooded, giving time for stabilization prior to impoundment. In these cases, mulching is often required to encourage shallow root development, an advantage when flooding occurs. Shorelines have also been planted with herbaceous plants to provide fish food and for waterfowl.

2.2.3 - Floating Debris

A commonly reported problem and one to which a significant economic burden can be attached, is that of floating debris.

Standing vegetation that is cut prior to impoundment and not removed at that time will largely float when flooded. The same is true of only partially burned wood. Although it is usual practice to remove felled timber unless float removal is planned, there have been instances where trees were cut and simply left on the reservoir floor, resulting in large quantities of floating debris that was carried to shore or blown against the dam.

In the planning of timber harvesting and removal strategies for reservoir sites, the flotation behavior depends on the specific gravity and moisture content of green wood, and the rate of moisture absorption by the log. Table 2.1 lists average specific gravity and moisture content values for several eastern Canadian tree species which could be part of the forest cover in northern reservoir sites. Specific gravity values (Column "A") range from a low of 0.30 for Eastern White Cedar to 0.60 for Hard Maple.

Freshly cut wood, which is also called "green", contains significant amounts of moisture. The quantity of water depends on: the species of wood, season of harvest, age and size of the stem, or more precisely, the ratio of sapwood to heartwood. The amount of moisture in wood is ordinarily expressed as a percentage of the weight of the wood when oven-dry. The moisture content is stated as

$$\text{MC percent} = \frac{\text{Weight of water in wood}}{\text{OD weight of wood}} \times 100$$

It is apparent from Table 2.1 that in most species green sapwood contains more moisture than heartwood, although some of the denser hardwoods show little moisture variation between sap an. .eartwood. In most species, wood from the lower part of the stem has less moisture than the top of the tree which contains more sapwood. Similarly, young trees with small diameters have a high moisture content. The seasonal variation of moisture in standing trees does not follow a rigid and predictable pattern for all species, although the moisture content of sapwood appears to be the highest during the spring and summer, and lowest in the fall

TABLE 2.1

Average physical properties of logs of Eastern Canadian tree species. Columns (A), (B), (C) and (D) refer to properties of freshly-felled logs.

		Properties Moisture Content (percent)**				
Wood Species	Specific Gravity* (A)	Sapwood (B)	Heartwood (C)	Combined SW-HW (D)	At Flotation Point (E)	Possible Maximum Moisture Content (F)
Softwoods						
White Spruce	0.35	128	34	62	186	220
Black Spruce	0.41	120	35	60	144	179
Balsam Fir	0.34	-	-	117	194	229
Jack Pine	0.42	105	36	53	138	173
Red Pine	0.39	134	34	57	156	191
Eastern Larch	0.48	115	46	64	108	143
Eastern White Cedar	0.30	-	-	55	233	268
Eastern Hemlock	0.40	119	97	104	150	185
Eastern White Pine	0.36	140	60	68	178	213
Red Spruce	0.38	130	34	68	163	198

Table 2.1
Average physical properties of logs of Eastern Canadian tree species. Columns (A), (B), (C) and (D) refer to properties of freshly-felled logs.

Wood Species	Specific Gravity* (A)	Properties Moisture Content (percent)** Sapwood (B)	Heartwood (C)	Combined SW-HW (D)	At Flotation Point (E)	Possible Maximum Moisture Content (F)
Hardwoods						
White Birch	0.51	72	89	81	96	131
Black Ash	0.47	74	46	65	113	147
Trembling Aspen	0.37	113	95	102	170	205
Largetooth Aspen	0.39	110	90	97	156	191
Balsam Poplar	0.37	140	105	115	170	205
White Elm	0.52	92	95	93	92	127
Sugar Maple	0.60	72	62	67	67	102
Silver Maple	0.46	97	58	75	117	152
Red Maple	0.52	97	58	73	92	127
Yellow Birch	0.56	72	74	73	79	114
White Ash	0.57	44	46	45	75	110

* Green-volume basis
**Oven-dry weight basis

and winter. The combined moisture content of sapwood and heartwood is given in Column"D". This may be looked on as a "tree average" moisture content since it takes into account the relative ratios of sapwood and heartwood for a given species.

Column "E" lists the average flotation point moisture contents for the different species. These are calculated values taking into account the average specific gravity of a species, and the moisture content at which the density of wood would be equal to the density of water. It is apparent from the table that the softwood species with relatively low specific gravities can absorb considerable amounts of moisture before they sink. Further, that the average log moisture content of all softwood species is significantly below the flotation point MC. (Compare columns "D" and "E".) Consequently softwoods can be successfully floated after the flooding of a reservoir.

Table 2.1 also illustrates that many hardwood species, especially those with high specific gravities, have average log moisture contents which puts them close to the flotation point MC. For example, White Elm, Sugar Maple and Yellow Birch, have average moisture contents at which some freshly-felled logs would fail to float. Thus, the valuable timber must be removed from reservoir sites prior to flooding.

Another aspect of the log flotation/sinking process is that of time. The question is how long can green logs be expected to float. This is a function of the relative permeability of a species, of log size and of the initial green moisture content. Of the softwood species listed in Table 2.1, all but Eastern Hemlock, Balsam Fir and Eastern Larch can be expected to float for at least 1 to 3 years. The lower density hardwoods (e.g. Aspen, Silver Maple) and the above mentioned softwoods may float for one season. Flotation is also a function of log length, shorter logs sinking sooner than tree length logs.

It would appear that some softwoods will never become genuine "sinkers", however long they are submerged (see Column "F", Table 2.1). Thus, it has been found that sunken logs, even in old reservoirs, continue to float to the surface. This behavior is not understood (G. Balentinecz, pers. comm. 1981). Several explanations can however be postulated.

(a) These persistent floaters are low density flotable softwood logs that were initially anchored by denser, water-saturated logs, to the reservoir bottom. If the anchoring becomes disturbed, the buoyant logs return to the surface.

(b) Some near-neutrally buoyant trees behave as "bobbers", becoming positively buoyant during periods of density destratification when the whole water column becomes 4°C (temperature of maximum water density). When the surface water warms or cools (becomes less dense), these same logs sink, only to rise again when 4°C temperatures are attained.

(c) The floating wood was in fact dead at the time it was inundated.

Dead wood tends to float for a longer time than green wood, attributable to the inefficiency of passive saturation as compared with active uptake of water by living tissues. Some dead wood can never absorb enough water to become negatively buoyant.

Because of its significance to the selection of reservoir clearing strategies, this question warrants further investigation.

Another source of debris is that from tree kills along the shoreline. Raised water tables, sun scorching and windthrow can result in trees dying and eventually falling into the water. Such kills occur within a few years of impoundment and if dead trees are removed before they fall over, floating debris can be reduced. Standing emergent trees will eventually break off at the water line through the forces exerted by ice or by degradation effected by insects, birds, fungi and bacteria. Some of this material will float, some will sink, depending on the species and the length of time it has been exposed. This process is restricted to the shallower portions of the reservoir and is largely confined to shoreline areas where the debris will accumulate.

Shoreline erosion and bank failure, as described in Section 2.2.1, can be a long term and major source of floating debris.

2.2.4 - Water Quality

There are several factors which affect water quality in reservoirs. These are summarized below.

(a) Hydration - Physical disturbances in inundated soils causes increased turbidity.

Chemical processes result in increased conductivity, color, changes in pH and potentially elevated metals (in acidic conditions) and increased inorganic nutrients.

Biotic degradation of organic materials leads to oxygen reduction; increases in phytoplankton with uptake of inorganic nutrients can reduce water clarity.

(b) Erosion - Suspended particles increase turbidity and provide continuing input as described for hydration.

(c) Stratification - Thermal/chemical layering.

(d) Inflow/Outflow - flushing rate and mixing
- inflow water quality
- depth of power intakes and therefore relation to thermocline.

(e) Drawdown - Effects on erosion and biotic components as well as mixing.

In reviewing reservoir case histories, it is apparent that in northern climes, most water quality changes are related to the initial release of nutrients from flooded materials and to the effects of sediment suspension. Factors affecting this are as follows.

(a) Soils - Table 2.2 summarizes the results of experimentation done in the United States

TABLE 2.2

EFFECTS OF HYDRATING DIFFERENT ARCTIC AND SUBARCTIC SOILS ON OVERLYING WATER

Sample Number	Characteristics	Surface	Sample Depth (inches) 3 - 9 in.	6 - 10 in.	8 - 13 in.	12 - 16 in.	13 - 20 in.	[illegible] - 20 in.
1	Soil Type Composition Response	Grass detritus 20 percent volatile solids Rapidly anaerobic dramatic rise in color, alkalinity, tannin/lignin TOC and EC		Organic root matter 31.5 percent volatile solids Same as surface but less severe		Plastic greybrown silt 95 percent fines NO_3 rose for 2 weeks then dropped		Plastic grey brown silt 97 percent fines Similar to lower layer pH dropped to 4.5 and stayed there
2	Soil Type Composition Response	Organic detritus below Spruce-Birch forest 46.4 percent organic Went anaerobic High alk., EC, tannin/lignin TOC, NH_4 and color pH 4.5 - 5		Rusty and grey silt 1.6 percent organic, 24 percent sand, 42 percent fines Small initial rise in NO_3 and tannin/lignin		Sand and gravel 26.1 percent sand, 8.3 percent fines No major changes		
3	Soil Type Composition Response	Tundra plants and roots in an organic matter 78.7 percent organic Rapidly anaerobic High color, EC, tannin/lignin, TOC pH dropped to 4.5		Organic soil 19.2 percent organic, 85.6 percent fines Lowered D.O. Dramatic increases in color and tannin/lignin pH 4.5 and stayed		Organic soil 32.4 percent organic, 38.7 percent fines Similar to layer above but slower response Color, TOC and lignin/tannin Rose to fairly high levels		
4	Soil Type Composition Response	Roots and organic material dark red brown 53.3 percent organic Rapidly anaerobic High to moderate rise in color, EC, tannin/lignin, NH_4 pH to 4.5 for 3 weeks	Red brown silt with grey areas 60 percent organic, 60 percent sand, 40 percent fines DO remained high EC and NO_3 rose some pH went to 4.5 and stayed		Brown organic soil 39.9 percent organics, 26 percent sand, rest fines pH was 4.5 and EC was only constituent to show a rise	Dark brown sand 24.8 percent organic, 10 percent fines, 90 percent sand Very good water quality, only minor changes in constituents		
5	Soil Type Composition Response	Dark brown organic root matter 40.7 percent organic [illegible] to 0 in 1 week EC, NH_4, tannin/lignin and alk. rose to high levels Color rose to 10	Volcanic ash, light red brown sandy material with roots 64 percent fines, 36 percent sand, 1.3 percent organic Good water quality		Ash 51 percent fines, 49 percent sand, 1.3 percent organic Good water quality		Prevolcanic soil dark brown silt/clay 4.7 percent organics, 68 percent fines TOC and NO_3 rose	
6	Soil Type Composition Response	Dark brown organic root matter 63.9 percent organic Rapid deoxygenation but not to 0 till 5 weeks Moderate increases in color, TOC, EC, pH and tannin/lignin High increases in alk. and NH_4	Volcanic ash 23 percent organic, 39 percent fines, 61 percent sand Good water quality		Volcanic ash 30 percent fines, 70 percent sand, 2 percent organic Good water quality		Old organic soil	
7	Soil Type Composition Response	Tundra soil with black root matter 12.4 percent organic Anaerobic in 2 weeks D.O. remained low Color, EC, tannin/lignin showed moderate rise Alk., TOC greatly increased NO_3, NH_4 rose for 5 weeks then dropped to low levels			Brown silt, rocks 2.6 percent organic, 29 percent fines, 57 percent sand, 14 percent gravel Color, TOC and tannin/lignin rose slightly pH rose to 6		Dark tan gravel 3.6 percent organic, 43 percent fines, 49 percent sand, 8 percent gravel More color, EC, Alk., TOC and tannin/lignin than layer above	Permafrost

Reference - D. W. Smith and S. R. Justice, 1975.

concerning the effects of flooding different arctic and subarctic soils on overlying water quality (University of Alaska 1975). The experimental procedures were such that they approximated the effects of a 7-month inundation period. The quantity of organic materials in the soils was reflected in reduced oxygen, increased color, total organic carbon (TOC) ammonia and tannin/lignin levels in test samples. Only the upper soil horizons appeared to be a problem, resulting in reduced water quality. In most cases (except for pH), levels stabilized before the "7-month" test period.

(b) Vegetation - As part of the Wreck Cove Environmental Assessment (Beak Consultants), experimental hydration of peat soils was performed. As in the Alaskan experiments, pH dropped to about 4.5 during decomposition (from CO_2 production), the overlying water became highly colored and displayed a peaty odor. PO_4 and total N rose initially but reduced with aeration. TOC reached a threshold limit (11 ppm) over which it did not increase the time. No toxicities to fish or amphipods were found in accompanying bioassay tests.

There are a few in situ studies of the effects of uncleared vegetation on water quality although in Louisiana reservoirs the presence of standing timber did not affect water quality in uncleared areas as compared to cleared areas, to any measurable degree. In a study of an uncleared forested Russian reservoir, Miterev and Belova reported that water quality, including dissolved oxygen was virtually normal throughout the water column within 3 years following inundation. They reported H_2S production in the first year only.

The reservoir case histories examined do not indicate major water quality variation from natural lakes in proximity.

Exceptions to this relate to use of impounded water for drinking purposes (and to a lesser extent for aesthetic reasons), where taste, odor and color become significant factors. Allen (1960) reports a comparison of cleared versus uncleared reservoirs in which the former developed no taste and odor problems whereas the latter did. Most of the taste problems are attributed to algae which flourish in response to nutrient availability. Other taste problems (medicinal) have occurred as a result of rain and subsequent runoff carrying phenolic substances into a reservoir from slash burning along shore (Allen 1960).

Drinking water quality criteria indicates that color should $\leq$15 TCU. This is an aesthetic requirement and many storage reservoirs built in woody areas with little clearing can exceed this level. (Drinking water criteria are discussed further in Section 4.1.5.)

None of the case histories or the literature surveyed during this study reported any fish kills or other indications of toxicities in newly formed reservoirs. In acidic reservoirs, however, in areas with high natural mercury levels, dissolved mercury is likely to be elevated and could result in resident fish becoming restricted for human consumption.

Erosion - Erosion around a reservoir shoreline or preimpoundment disturbance of reservoir soils will contribute to high turbidity levels and therefore impaired water quality. This is particularly true in very fine-sized material such as clays which are easily suspended and which will be prevented from settling by small current or wave action. The processes contributing to erosion have been described in Section 2.2.1.

3 - SURVEY OF CLEARING PRACTICES

This section provides a review of clearing practices currently in use, presents a review of example clearing strategies and their respective effects, and concludes with a discussion of the jurisdictional variations in the development of clearing guidelines across Canada and in parts of the United States.

3.1 - Current Approaches

Discussion with government agencies and utilities across Canada confirms that there are no comprehensive clearing guidelines for reservoirs. Criteria and guidelines for clearing are usually developed on a site-specific basis and often form part of the environmental assessment process.

The single exception is the approach to reservoir clearing generated by Newfoundland and Labrador Hydro. Their fairly standard set of guidelines is provided in Table 3.1 (Kiell, 1981).

It is only within the last 10 years that environmental as well as recreational and cultural considerations have been influential in the selection of a clearing strategy. Prior to this time, the economics of merchantable timber recovery and reservoir operating requirements for power generation were the key criteria for establishing the clearing strategy.

TABLE 3.1

RESERVOIR CLEARING GUIDELINE - NEWFOUNDLAND AND LABRADOR HYDRO

(a) Examine and evaluate available published and unpublished information pertaining to the reservoir area.

(b) Establish criteria for predicting environmental impacts of flooding on biotic and abiotic components of the flood zone (e.g. forestry, terrain sensitivity, aquatic biota, terrestrial biota, cultural and recreational).

(c) Identify and map the following, based on the above criteria.

- Areas in which clearing is not recommended because of possible negative impacts caused by this action.

- Areas in which clearing is not recommended because of the minimal impact of flooding without clearing.

- Areas in which clearing is not recommended because of possible positive environmental benefit of not doing so.

- Areas in which complete clearing is recommended but could not be done economically (assume disposal of cuttings necessary).

- Areas in which clearing is recommended and in which clearing would be completed economically by salvaging merchantable timber.

(d) Compute area to be flooded, describe the type and compute the quantity of merchantable timber that will be flooded, cut and disposed of, or cut and salvaged, and compute the amount of nonmerchantable timber that will be cut and destroyed for each of the cases listed above.

(e) Specify preparation techniques for each different area and define cost and method of wood disposal, quantify necessary manpower and equipment for the job.

(f) Recommend reservoir preparation strategy based on environmental, engineering and cost data.

3.2 - Example Strategies and Their Effects

The reservoir clearing strategies outlined below have been compiled from literature and knowledge of case histories. The sequence in which these techniques are listed is not intended to indicate a preference for one over another. In practice, a combination of strategies is often utilized and is dependent on specific site conditions and reservoir requirements. The effects of implementing the various clearing strategies are summarized in Table 3.2. It is recognized that the extent of these effects is dependent on site-specific conditions such as surface area and depth of the reservoir, drawdown, flushing rate, nutrient status of the soils, soil type, slope and other parameters.

3.2.1 - Complete Clearing

Where reservoir sites are recommended for complete clearing, all standing trees are cut, leaving low stumps in the ground. Common practice is to cut to a specified contour such as the regulated high water level or 0.5-1 m above it. However, this concept does not take into consideration that fact that some soils and slopes are more subject to erosion than others. Therefore, where a range of landforms are encountered, different guidelines should be established.

A review of 17 reservoirs in Canada where complete clearing was undertaken revealed the following environmental conditions.

- Generally good aesthetics and recreational opportunities (boating, fishing, camping, cottages, etc).

TABLE 3.2

EFFECTS OF IMPLEMENTING VARIOUS RESERVOIR CLEARING STRATEGIES

Strategy	Water Quality	Air Quality	Archaeology Site Effects	Erosion/ Sedimentation*	Fisheries and Wildlife Habitat Potential in Reservoir	Recreation Potential	Aesthetics	Clearing and Maintenance Costs**
Complete clearing	- Nutrient loading dependent primarily on soil leaching - Highly organic soils, stumps and understory likely to change water color, decrease dissolved oxygen (DO) near bottom. Increased turbidity from hydration and shoreline erosion. - Stability attained in approximately 2 years	- Temporary disturbance if debris burned	- Facilitates excavation of sites	- Some shoreline erosion due to exposure to wave action worsened by absence of underwater protection - Floating debris minimized - Bank stabilization within a few years in most soils	- Good potential for fishery if oxygen levels above 5 ppm - Good potential for ducks, if shelters provided - Geese prefer open habitat - Open water drinking supply for deer, moose and other mammals - Lakeshore habitat for fur bearers	- Excellent potential for boating, fishing, swimming and campsites - Possible safety hazard from floating stumps and debris during early years - Cottaging possibilities after shoreline stabilizes	- Excellent; minimum probability of floating stumps in cold deep lakes - Some continuing shoreline erosion in some areas, protection possible in most cases	- High clearing costs may be offset by sale of merchantable timber - Minimum to moderate maintenance required for debris, recreational activities
Complete clearing and grubbing	- Nutrient loading dependent on degree of soil leaching - Biochemical oxygen demand (BOD) expected to be low unless highly organic soils - High turbidity levels - Stability attained in approximately 3 years	- Temporary disturbance if debris burned	- Would destroy potential for excavation unless executed prior to clearing	- Disruption of soil cover likely to create extensive erosion along shoreline - Degree of disruption dependent on soil type and slope - Extreme sedimentation expected in short term	- May be undesirable initially for fisheries due to turbidity - Reduction in aquatic vegetation due to reduced light penetration - Lakeshore habitat for fur bearers limited by unstable shoreline until stability attained	- Excellent potential for boating and campsites - Reduced hazard to boating with no floating stumps - Poor fishing and swimming potential initially until sedimentation problem improves	- Initially excellent except for turbidity - Probable shoreline deterioration if cleared to contour - May require vegetation planting along shoreline to reduce erosion	- Very high clearing costs may be offset by sale of merchantable timber - Maintenance required for recreational activities
Selective clearing	- See comments for "complete clearing" above - Greater increase in BOD expected on temporary basis - Stability in approximately 1 to 5 years	- Temporary disturbed if debris burned	- Opportunity to hand clear archeological sites	- Reduce erosion by leaving water-tolerant species (e.g. willow and cottonwood) - Reduce erosion by not clearing steep slopes - Underwater protection to break waves	- Good habitat for ducks, raptors and shore birds - Good potential for aquatic mammals and fisheries if oxygen levels above 5 ppm - Good shore habitat for fur bearers - Open water drinking supply for mammals	- Good potential for boating, fishing and campsites in selected areas - Possible safety hazard from floating debris	- Good potential but dependent on areas cleared	- High clearing costs may be offset by sale of merchantable timber - Moderate maintenance required to clear debris and for recreational activities
Perimeter Clearing	- See comments for "complete clearing" above - Temporary rise in BOD and poor color if trees in bottom of reservoir remain standing - Stability in approximately 3 to 5 years	- Temporary disturbance if debris burned	- Facilitates excavation of perimeter sites - Hampers excavation potential for other areas	- See comments for "complete clearing" above	- Good habitat for fisheries and geese - Good shore habitat for fur bearers - Open water drinking supply for mammals	- Good potential for boating, fishing and campsites - Possible safety hazard from floating debris - Possible snagging of fishing lines - Some boating hazard unless topped	- See comments for "complete clearing" above if topped	- High clearing costs may be offset by sale of merchantable timber - Moderate to high maintenance required to clear debris and for recreational activities

TABLE 3.2

Effects of Implementing Various
Reservoir Clearing Strategies - 2

Strategy	Water Quality	Air Quality	Archaeology Site Effects	Erosion/ Sedimentation*	Fisheries and Wildlife Habitat Potential in Reservoir	Recreation Potential	Aesthetics	Clearing and Maintenance Costs**
Slash burning, burying or chipping	- See comments for "complete clearing" above	- Temporary disturbance from burning	- Facilitates excavation if debris is burned or in chips - Burying of slash could reduce or destroy potential for site investigation	- Burying of slash should be away from shoreline area to reduce erosion potential - Burying of slash within reservoir site will create sedimentation in reservoir	- Should not adversely affect habitat for fisheries and wildlife if burns well controlled	- May impede boating and fishing if buried slash eventually floats	- Good potential if debris burned - Expect some floating debris from burying or chips	- Low to moderate clearing costs - Minimum maintenance for chips penetrating intake screen or floating debris
Cut, float and burn	- Minimum impact except for turbidity and accrual of organics on bottom to increase color	- Temporary disturbance	- Improved access to sites along rivers	- See comments for "complete clearing" above	- Floating timber a potential hazard to aquatic mammals - Minimum impact on fisheries - Improved shore habitat for fur bearers - Open drinking water habitat for mammals	- Excellent potential for boating, fishing, swimming, campsites - Possible initial safety hazard from floating debris	- Good potential except in bays where log booms are contained prior to removal	- High clearing costs may be offset by sale of merchantable timber - Moderate maintenance for floating debris and recreation
Prescribed burning of forest cover	- Minimum impact (little change in BOD)	- Temporary major disturbance	- Facilitates excavation if allowed following clear-cut and prior to burning - Burning of organic layers likely to disturb site	- See comments for "complete clearing" above	- Good habitat for fisheries and geese - Potential for ducks if shelters provided - Open drinking water supply for mammals - Improved shore habitat for fur bearers - Temporary hazard during burn, control essential	- Excellent potential for boating, fishing, swimming and campsites - Minimum safety hazard	- Excellent, although possibility of some floating debris	- Moderate to high, depending on whether area is clear-cut prior to burning - Minimum maintenance for recreation and debris
Waterline clearing (topping)	- Temporary rise in BOD and poor color from trees standing in bottom of reservoir	- Temporary disturbance if debris burned near site	- No opportunity to investigate potential sites	- Potential erosion at shoreline with dying trees falling into reservoir - Minimum sedimentation	- Excellent potential for fishery if oxygen levels above 5 ppm - Improved shore habitat for fur bearers - Open drinking water supply for mammals	- Potential hazard to boating - Still fishing only, due to snagging of lines - Potential for campsites	- Excellent potential initially - Expect floating debris eventually but may take many years in cold, deep lakes	- Low to moderate - Moderate maintenance required to clear debris periodically

TABLE 3.2
Effects of Implementing Various
Reservoir Clearing Strategies - 3

Strategy	Water Quality	Air Quality	Archaeology Site Effects	Erosion/ Sedimentation*	Fisheries and Wildlife Habitat Potential in Reservoir	Recreation Potential	Aesthetics	Clearing and Maintenance Costs**
Topsoil stripping	- Minimum impact but possibly some nutrient contribution from altered geologic features	- Temporary disturbance if debris burned	- Site investigation must precede stripping	- If backshore stripped, erosion minimized	- Fisheries habitat poor - Littoral production poor - Riparian habitat poor for fur bearers - Beaver pond habitat poor, little prospect for [illegible] to establish - "Bathtub" habitat	- Excellent potential for boating, swimming and campsites - Minimum safety hazard	- Unnatural appearance with exposed rock - Backshore grooming required to provide aesthetically pleasant vista	- High to very high depending on site cover (may be offset by sale of merchantable timber) - Minimum maintenance for recreational activities
Natural clearing	- See comments regarding "complete clearing" above - Greater increase in BOD - Dark coloration of water - Stability in 5 to 10 years	- No impact	- No opportunity to investigate potential sites unless specific program undertaken	- Some shoreline erosion with tree loss - Stable shoreline eventually - Underwater protection to reduce wave impact	- Potential for fishing if oxygen levels above 5 ppm - Shoreline habitat for fur bearers - Excellent for tree nesting waterfowl	- Poor potential due to boating hazards, snagging of fishing lines, undesirable location for campsites - Poor access	- Poor with standing trees above water level and floating debris	- Minimal clearing costs for damsites, forebays and canals - Moderate to very high maintenance required on periodic basis to clear debris
No clearing	- See comments for "complete clearing" above (greater increase in BOD expected on temporary bases) - Water color stained and dark - Reduced DO due to increased BOD and inhibition of photosynthesis by aquatic plants - Stability reached in approximately 5 to 10 years	- No impact	- No opportunity to investigate potential sites unless specific program undertaken	- Dependent on soil type, slope, wave action, size of reservoir - Nearshore trees break waves reducing wave erosion	- Potential for fishery if oxygen levels above 5 ppm - Excellent nesting sites for raptors, herons, waterfowl - Submerged material provides substrate for aufwuchs communities - Still fishing "in stumps"	- Poor potential due to boating hazards, undesirable location for campsites - Access likely to be poor unless specifically provided	- Poor with standing trees above water level and floating debris - "Cluttered" shoreline	- Minimal clearing costs for damsites, forebays and canals - Moderate to high maintenance required on periodic basis to clear debris

* Water level fluctuations assumed to be minimal
**Costs described are relative to other clearing strategies

- Water quality is similar to inflow 10 to 50 years after flooding (exception maybe Wreck Cove, Nova Scotia where revegetation of exposed soils is considered a key factor in changes in water quality after 2-1/2 years of monitoring).

- Waterfowl capability is generally poor due to lack of habitat.

- Floating stump removal is usually required on a continuing basis after flooding.

- Erosion along shoreline also tends to uproot tree stumps.

3.2.2 - Complete Clearing and Grubbing

This clearing strategy involves the cutting of all standing trees at the reservoir site and removal of all stumps (grubbing). The term grubbing is sometimes used to include the removal of all attendant vegetation.

Two reservoirs were identified in Canada where complete clearing and grubbing was carried out prior to flooding (Guelph Reservoir, Ontario; Bighorn Reservoir, Alberta). Indications are that water quality is similar to inflow characteristics at both these reservoirs 5 years and 10 years after flooding, respectively.

3.2.3 - Selective Clearing

Individual trees or groups of trees remain standing while others are cut. Selective clearing may be based on timber merchantability and species requirements, desirability of developing types of wildlife and fisheries habitat, aesthetic requirements, or economics.

There are two possible strategies for selective clearing of a reservoir site.

- Selectively clear trees from the area.

- Designate selected areas for clearing based on requirements for wildlife/fisheries habitat, migration routes, recreation, etc.

As selective clearing of reservoirs is a relatively recent practice, there is little documentation of environmental effects. During the formation of Mica Dam in British Columbia, Kinbasket Lake was selectively cleared in 1972. At low water level tree stumps and other debris are exposed along the shoreline. Extensive debris accumulation is expected to continue for 6 to 10 years and clearing will be carried out until 1985.

Selective clearing is also planned for the Cat Arm Reservoir in Newfoundland. It is believed that this strategy will reduce negative ecological effects and improve shoreline succession, aesthetics and recreational opportunities (Hunter and Associates, 1980).

Minimal selective clearing (approximately 1 percent of total reservoir surface area) has been carried out for the La Grande complex east of James Bay. Clearing involves access ramps at fishing sites and areas suitable for spawning at mouths of tributaries (as well as clearing required for civil structures). Environmental effects for the James Bay reservoirs are outlined in the "no clearing" section since these reservoirs were virtually uncleared.

3.2.4 - Perimeter Clearing

This term refers to an area cleared around the perimeter of a reservoir. It usually applies to a certain distance above regulated high water level and below regulated low water level of a reservoir. The clearing limits are usually based on specific contour levels as stated in Section 2.2.1 but as stated previously, this is unrealistic since it does not take into account variations in soil types and slopes. On occasion, perimeter clearing is considered synonymous with selective clearing (Nelson et al, 1978).

Environmental effects were reported for five Canadian reservoirs where perimeter clearing was selected

- Recovery of floating debris required for first few years following flooding.

- Minimal change in water quality.

- Initial trophic surge followed by stability.

- Temporary disturbance to fish from increased sedimentation.

- Potential recreational hazard from floating debris.

3.2.5 - Slash Burning, Burying or Chipping

The term "slash" includes branches and tops of trees but does not include merchantable timber. In some cases, slash is piled and burned, the debris and ashes buried above top water level.

Alternatively, chippers can reduce brush and small timber to a mulch covering the forest floor or the chips can be used in paper, pressboard or as fuel.

This clearing strategy is most often used in combination with complete clearing, selective clearing or perimeter clearing options.

If burn is above reservoir level, brush should not be dragged as this moves fine grained material and opens future erosion channels.

3.2.6 - Cut, Float and Burn

The cut, float and burn method is utilized where removal of timber from an area with limited accessibility requires alternative action. This involves cutting the trees prior to filling of the reservoir and allowing the rising waters of the reservoir to float wood out of the area. Alternatively, trees are cut along river banks and allowed to float to a burning site. It has been suggested that clearing costs can be substantially reduced using the cut and float method since 10 to 30 percent of the slashed material sinks before reaching the burning sites (Proctor & Redfern, 1980). There is a danger that some of this material will resurface later, however, as described in Section 2.2.3.

While log booms can be used to control the direction and flow of this material, it can be a hazardous and environmentally disruptive operation, depending on the size of the area to be inundated and river characteristics. Only some tree species are amenable to flotation removal. Use in predominantly hardwood areas is not practical.

Boats are used to tow the floating material to preselected burning sites where it is piled by cranes and burned. As cranes are piling the debris, they can also retrieve merchantable logs (Lower Churchill Development Corporation Limited, 1980).

Trees can be cut during ice covered periods if reservoir filling starts during construction phase. Logs are then floated out in the spring for retrieval or burning.

3.2.7 - Prescribed Burning of Forest Cover

This technique involves burning of the entire forest cover including removal of litter and other organic matter. An area is burnt with or without prior cutting of the timber, as determined by economics.

Fire can consume organic matter from the litter, humus and fermentation layers, and its effects may penetrate the mineral layer; this penetration is dependent on fire intensity, amount of organic matter in the soil, and the type of vegetation, as well as the moisture content of the vegetation (Meth et al, 1978). It has been shown that 79 to 81 percent of the organic matter from the litter and humus layers can be consumed by burning (Smith, 1970).

It was estimated that suitable site and operational conditions allowed the burning of 200 to 259 ha/d at the Green River reservoir site in New Brunwick (Meth et al, 1978).

There have been instances where control of the burn has been difficult (due to weather conditions) and fires have consumed forest outside of the prescribed burn limits.

3.2.8 - Modified Clearing (topping)

Prior to flooding, standing trees on the floor of the reservoir site and adjacent slope are cut to a desirable height below the regulated low water level rather than leaving low stumps. Alternatively, only those trees on the reservoir floor which will be evident above the regulated low water level or which may clog control gates are cut. These are then removed or wired down to prevent operational and recreational hazards from floating logs. This latter strategy was common practice by the Tennessee Valley Authority prior to improved mechanization for cutting and removing timber from reservoir sites (Davis, 1946).

A variation of this technique is to mount hydraulic tree shears on a boat or barge after partial filling of the reservoir and to top those trees which are expected to appear above regulated low water level (Koster and Mikuchi, 1978). Topping of trees can also be carried out after freeze-up from the ice surface.

Depending on the size of the reservoir, this clearing strategy may involve considerable maintenance costs following flooding for removal of floating debris.

3.2.9 - Topsoil Stripping

Among the earliest clearing practices employed in North America was stripping, i.e., the removal of all vegetation and topsoil from the bottom and sides of the reservoir site prior to its filling (Stearns, 1890).

To evaluate the effectiveness of soil stripping prior to reservoir clearing, a methodology has been developed by Campbell et al (1975).

- Identify different soil types within the area to be flooded.

- For each soil type sample, analyze topsoil (0 to 10 cm) and subsurface layer (20 to 30 cm) which would be uncovered by stripping operations.

- Immerse different soil types, both topsoil (unstripped) and subsurface (stripped) samples, in river water and monitor overlying water.

The simulation of eventual flooding should be carried out under controlled conditions (temperature, light, oxygenation) and in large plastic tanks installed at the reservoir site where they are subjected to normal summer climatic fluctuations.

Christie reservoir, a small impoundment in Ontario with a surface area of 60 ha, has a recreational surface that was excavated to bedrock. The Hamilton Region Conservation Authority reports good water quality and no problems with algae blooms. The reservoir capacity was increased and there is no continuing maintenance required. Some islands have been created for wood ducks.

3.2.10 - <u>No Clearing</u>

Another early practice was to inundate a reservoir site with no clearing of the land prior to filling of the reservoir. This was a common method used when power chain saws and heavy mechanical equipment were not available and where it was not economically feasible to clear by ax and hand saw. The "no clearing" term implies that the main reservoir area is left untouched except for required clearing of forebays, canals and damsites. Based on a review of 12 case histories in Canada where reservoirs were not cleared, the following environmental effects were identified. *

- Insignificant to extreme variations in physical/ chemical conditions followed by stabilization within 2 to 5 years (La Grande Complex, James Bay).

- Initial trophic surge then stabilization within 2 to 5 years (La Grande Complex, James Bay).

- Higher maintenance costs associated with clearing floating debris (compared with other clearing strategies).

- Recreational activities limited and hazardous in reservoirs not cleared.

- Poor aesthetics expected for decades as a result of drowned forest.

3.2.11 - Natural Clearing

The James Bay Energy Corporation has been experimenting with the clearing of reservoirs by natural agents such as wind and ice. When flooded trees become frozen into ice and the water level is lowered, the force exerted is sufficient to break the trunks of trees of considerable size. The trees are then removed from the water after the ice has thawed (Bollulo, 1978). No information on the success of this approach is presently available.

3.2.12 - Underwater Postflood Clearing

In some cases, particularly where partial clearing or no clearing options are selected or when time constraints so dictate, it may become desirable or necessary after flooding a reservoir to carry out an underwater clearing program. This can be accomplished by mounting hydraulic tree shears on a boat or barge (as mentioned previously) and performing the operation during periods of regulated low water levels. The timber thus removed is sound and when dried, can be used.

3.2.13 - Reservoir Sweeping

It is common practice to "sweep" a reservoir of all floating wood after flooding has taken place. This is usually done for safety and aesthetic reasons, as well as to avoid pile-up of debris at control gates once the reservoir becomes operational. Periodic sweeps and removals are carried out when the District Forester or owner of the reservoir considers floating debris to present a hazard. The debris can be contained by a boom and moved into a bay for subsequent disposal.

3.3 - Survey of Practices According to Reservoir Size

Table 3.3 provides a summary of the clearing strategies identified for a number of reservoirs in Canada where surface area was known. It is readily apparent that the dominant practice for small reservoirs is to completely clear existing trees unless inaccessibility, tree density, timber markets, slope stability or ecological factors are overriding concerns.

TABLE 3.3

CLEARING STRATEGIES IN CANADA ACCORDING TO RESERVOIR SIZE*

Surface Area of Reservoir (ha)	Number of Reservoirs Surveyed	Clearing Strategy					
		No Clearing	Complete Clearing	Perimeter Clearing	Selective Clearing	Clearing and Grubbing	Topsoil Stripping
<1 000	20	2 (10%)	13 (65%)	1 (5%)	2 (10%)	1 (5%)	1 (5%)
1 000 to 10 000	24	3 (13%)	15 (62%)	3 (13%)	2 (8%)	1 (4%)	-
>10 000 to 50 000	11	5 (46%)	3 (27%)	1 (9%)	2 (18%)	-	-
>50 000	13	4 (31%)	1 (8%)	1 (8%)	7 (53%)	-	-
Total	68	14 (21%)	32 (47%)	6 (9%)	13 (19%)	2 (3%)	1 1(%)

*Primarily hydro reservoirs.

For reservoirs with a surface area of 1,000 to 10 000 ha, a large majority are still completely cleared, although there is a tendency toward increasing use of perimeter clearing.

As would be expected, the no clearing strategy becomes more important with increasing size (>10 000 to 50 000 ha) and few reservoirs greater than this size have their entire perimeters cleared.* Reservoirs >50 000 ha are either not cleared in Canada or key areas are identified for selective clearing, e.g. for improved access to enhance spawning areas, for removal of merchantable timber, etc.

3.4 - Jurisdictional Variations

A brief review of current policy and clearing practices in Canadian and US jurisdictions follows. For examples of site-specific clearing practices, see Appendixes A and B.

3.4.1 - Canada

Responsibility for developing clearing guidelines varies between provinces. In Ontario and British Columbia, for example, the provincial forest ministries prepare site-specific reservoir clearing guidelines but in other provinces it is usual practice for utilities to hire consultants for this purpose. In all provinces, except British Columbia, the responsibility for clearing lies with the reservoir operator. For a review of jurisdictional variations in Canada, see Table 3.4.

*Also, more costly techniques such as grubbing and topsoil stripping are presumably no longer economically feasible for reservoirs >10 000 ha in surface area.

TABLE 3.4

SURVEY OF RESERVOIR CLEARING PRACTICES IN CANADA

Province or Territory	Responsibility for Clearing and Costs: Reservoir Operator	Responsibility for Clearing and Costs: Government	Government Approvals Required	Clearing Practice
Alberta	X		Department of Environment, Alberta Forest Service	EA* usually required; common result is that merchantable timber removed prior to complete clearing to high water level. Stumps left are required to be <30 cm high and debris is piled and burned according to specifications (Alberta Forest Service, 1981). Tendency to move away from "no clearing" option due to high cost of cleaning up old reservoirs.
British Columbia	Costs only	Clearing only	B.C. Forest Service	Clearing guidelines established on site-specific basis. Common practice is to clear and burn everything between high water and far enough below low water to permit boating. Exception is inaccessible areas where cut and float practice is used. Merchantable timber salvaged where possible. B.C. Hydro has spent millions of dollars on debris clearing ($30 million to 1981 on one reservoir). Practice is to beach debris during drawdown and pile and burn using crawler tractors. This is the most efficient method. "Boil and burn" method is used where there is little drawdowns or unsuitable beaches are available. This is done using booms and large cranes with specially designed debris grapples.

*EA - Environmental Assessment.

Table 3.4
Survey of Reservoir Clearing
Practices in Canada - 2

Province or Territory	Responsibility for Clearing and Costs: Reservoir Operator	Responsibility for Clearing and Costs: Government	Government Approvals Required	Clearing Practice
Nova Scotia	X		Department of Environment, Department of Lands and Forests	Guidelines developed on site-specific basis by reservoir operator.
Northwest Territories/ Yukon	X		Territory and Federal Government Agencies	North of 60-deg latitude reservoirs generally not cleared prior to flooding. Recent regulations of Northern Inland Waters Act (1972) require perimeter clearing to mitigate unsightly aspects of flooded shorelines in visually sensitive areas (Northern Canada Power Commission, 1981).
Ontario	X		Ministry of Environment/ Natural Resources	General guidelines recommend complete clearing but in practice more comprehensive guidelines are developed on site-specific basis. For MNR reservoirs, Class EA states that timber below flood contour may be cut and removed or left standing for fish and wildlife habitat (also see Section 3.4.1).
Prince Edward Island	X		Department of Community Affairs (responsible for water courses and environment)	Guidelines developed on site-specific basis by reservoir operator.

Table 3.4
Survey of Reservoir Clearing
Practices in Canada - 3

Province or Territory	Responsibility for Clearing and Costs: Reservoir Operator	Responsibility for Clearing and Costs: Government	Government Approvals Required	Clearing Practice
Quebec	X		Departments of Environment/ Lands and Forests	Guidelines developed on site-specific basis by reservoir operator; must be supported by environmental studies.
Saskatchewan	X		Departments of Environment/ Tourism and Renewable Resources	Guidelines developed on site-specific basis by reservoir operator as part of environmental assessment process.

In Ontario, there is no standardized procedure for reservoir clearing, although the Ministry of Natural Resources (MNR) provides brief guidelines on a general basis and some specifically for MNR's reservoirs.

The Design Guidelines for Forest Management, published by MNR, specify that "all reservoir sites should be clearcut to above the floodline and debris removed". In practice, more comprehensive reservoir clearing guidelines are prepared on a site-specific basis by the District Forester in Consultation with the Regional Forester, local MNR fisheries, and wildlife personnel and reservoir operations.

For MNR reservoirs, a Class Environmental Assessment for Ministry of Natural Resources' dams and dikes has been developed and is pending approval by the Ministry of the Environment. It states that areas to be flooded must be cleared of all merchantable timber and remaining vegetation appropriately disposed to avoid hazardous situations. The Environmental Quality Implementation Handbook (MNR, 1979), which was prepared as an appendix to the MNR Class Environmental Assessment for Ministry of Natural Resources' dams and dikes provides the following guidelines for clearing of reservoirs.

(a) The proposed reservoir area should be accurately determined. This can usually be accomplished by mapping flood contours on a topographical map but may, however, require surveying of some areas.

(b) Large timber below the flood contour may be cut and removed or be left standing to provide for fish and waterfowl habitat. The Fish and Wildlife

Supervisor and the Forest Management Supervisor should consult with the Regional Engineer in charge of the project to determine what approach is most suitable.

(c) Timber which is cut should be felled so as to avoid damage to trees which will be left standing. In inaccessible areas such work may best be accomplished in winter when ice conditions permit easier access. If possible, large timber which is cut should be marketed.

(d) In these cut areas, stripping should not be undertaken where the subgrade is composed of inert materials, i.e., gravels, sands and clays. Small shrubs and ground vegetation will reduce the potential for erosion and may enhance fisheries habitat.

(e) The excavation of organic deposits may be necessary in cut areas or in bogs or swamps below the flood contour. This is to prevent nutrient loading of the waterbody or the input of toxic substances which may be contained in these deposits. The District Biologist and Fish and Wildlife Supervisor along with the Regional Engineer in charge of the project should determine in consultation the necessity and feasibility of excavating such deposits. Such activities when undertaken should conform to the MNR Environmental Quality Implementation Handbook for Dredging.

While the above guidelines appear to be somewhat contradictory, the general practice is to remove salvageable timber wherever this is practical unless environmental concerns dictate otherwise.

Sites are generally cleared to a level 1 to 3 m above the regulated high water level, reducing the possibility of trees falling into the impoundment. Stumps are usually required to be no higher than 10 cm except below the regulated low water level where they may be up to about 50 cm, depending on MNR requirements and intended reservoir uses.

Nonsalvageable timber is required to be removed from the area to be flooded and is burned according to MNR specifications. Prior to burning, a permit is required from MNR and may also be required by MOE, depending on the reservoir site. (In some areas of northern Ontario, MOE has an agreement that MNR will make the final decision regarding burning permits.) MNR charges Crown dues to the reservoir operator for all trees of merchantable quality that are affected by clearing of the reservoir site.

MNR usually requires reservoir operators to make reservoir sweeps following flooding when the District Forester determines that floating debris constitutes a safety hazard.

3.4.2 - United States

US Army Corps of Engineers

The Corps has a general policy for the clearing of reservoirs as outlined in Regulation No. 415-2-1 (US Corps, 1978). Two general objectives are

- to clear only to the extent required in order to effect an overall reduction in construction costs

- to clear areas that would otherwise create hazards to the primary project purposes.

During the planning process, consideration must be given to maximum salvage of timber, benefits to fish and wildlife, and aesthetics, as well as minimizing impacts on public health, reservoir operations, navigation, and water quality. In addition, the US Corps outlines clearing limits which stipulate an upper limit of 0 to 1 m above the regulated high water level and a lower limit of 1.5 m below the 10-yr frequency drawdown for multipurpose reservoirs.

Provisions are also made in the regulations for horizontal limits on clearing. Generally complete clearing within the pool is done within 1.6 km of the main dam structure, primary public use areas and major populated areas. Clearing must also be carried out within 0.8 km of each highway crossing of a reservoir.

Additional clearing requirements which concentrate on cleanup are contained in Clearing Guide Specifications for Civil Works Construction (CE 1301).

Recent work by Ploskey (1981) for the US Army presents reservoir clearing guidelines which are designed specifically for the enhancement of fisheries. Briefly, the recommendations are

- clearing below regulated low water level should be limited to that required for efficient reservoir operation

- clearing between low and high water levels should involve selective retention of brush and timber for fisheries habitat

- retention of vegetation above high water level reduces erosion and provides food for fish and invertebrates if flooded.

In the case of the Libbey dam, the US Army Corps of Engineers was responsible for US clearing contracts and for floating debris after initial filling of the reservoir. Subsequent reservoir sweeps were the responsibility and expense of the US Forest Service.

US Department of the Interior

The Fish and Wildlife Service of the US Department of the Interior recommends selective clearing of reservoir flood basins primarily for fish and wildlife habitat. They also point out that by retaining some timber and brush in the upper end of a reservoir, the inflow can be screened to trap debris from the watershed above the reservoir basin (Nelson et al, 1978).

The Western Reservoir and Stream Habitat Improvements Handbook prepared for the Fish and Wildlife Service (Nelson et al, 1978) concentrates primarily on improvements to a reservoir following construction rather than on criteria or guidelines for selective clearing prior to flooding.

Practice in Alaska

Until about 5 years ago, reservoir clearing in the Arctic and sub-Arctic had been based either on practices in warmer states or on economic constraints (Smith and Justice, 1975). The effect of bog soils on water quality has not been clearly defined and an approach was taken by Smith and Justice (1975) to determine the effects of leaching on water quality from soil samples collected at proposed reservoir sites. As a result, recommendations were made for the clearing of 5 reservoirs in Alaska which ranged from no stripping to stripping down to a certain depth to prevent the leaching of organic material. Final recommendations were made following discussion of other criteria, i.e., economics, slope stability and erosion control.

3.4.3 - USSR

In the USSR, the clearing of a reservoir must comply with sanitary regulations. In 1950, paragragh 21 of these regulations stated that future impounded areas should be completely cleared including removal of roots (Miterev and Belova, 19__). However, in 1954, studies were made of the Shirokovsky Reservoir (which was not cleared prior to impoundment) to determine the effects of uncleared vegetation on water quality 7 years after impoundment. The reservoir is being used for energy, navigation and human consumption. It was determined that water quality was not adversely affected after 8 years of usage as a result of the flooded forest. However, it was pointed out that the reservoir was fed from a nonpolluted mountain river and depth of the reservoir ranged from 10 to 20 m.

As a result of these studies, new sanitary regulations were approved in the USSR in 1956 (Miterov and Belova), but the wording of these regulations is not known.

In reservoirs that were not cleared in the Karelion Region of the USSR, Baranov (1961) reported an upsurge immediately following flooding, characterized by increases in plankton, concentrations of dissolved phosphorous and nitrogen. This upsurge was offset somewhat by the inflow of acid humic material from bogs and rarely lasted more than 6 years.

4 - CRITERIA USED IN ASSESSING CLEARING NEEDS

4.1 - Reservoir Uses

As described in the Introduction, the definition of reservoir objectives is one of the first tasks in devising an appropriate clearing strategy. The most common reservoir uses are described below in terms of those desirable characteristics that can be affected by preimpoundment preparation. A summary table is provided at the end.

4.1.1 - Power Generation

In terms of meeting this primary objective, the requirements for the reservoir are simply that it contain water; that the water quality be adequate so as not to cause corrosion or abrasion of the turbine blades or valving systems, and that floating debris be limited to that which can be handled by a trash rack and/or minimal sweeping program. A stable shoreline is desirable as it affects the above 3 parameters as well as storage capacity. Access to the dam and powerhouse or maintenance, operation and fire protection is required.

Reservoir clearing histories are conflicting as to the usefulness of various levels of clearing on hydro production. In some instances, uncleared reservoirs, following an initial stabilization period of only a few years during which regular sweeping was required, have performed well, with no major continuing maintenance costs, hampering of trash racks, etc, occurring. In other cases, e.g., Nova Scotia experience, uncleared reservoirs demonstrated continuing erosion and debris accumulation, while cleared reservoirs were stable and "clean" within 2 years. In Quebec, flooded trees were still rooted to the bottom after 50 years inundation.

The rate of hydration of different tree species becomes an important factor in assessing how much material will float and for how long. The location of the vegetation within the reservoir is also important as trees located in the deepest parts of the reservoir, not exposed to disturbance by waves or wind will likely remain in place whereas those in shallow depths are more likely to become dislodged and rise to the surface. Soil and root depth are an additional feature in underwater anchoring.

As described in Section 2, some trees are more susceptible to flood damage than others. Trees left along shorelines and exposed to rising water levels will therefore respond in different ways. There is a distinction to be made between flood tolerant and flood resistant species; the former recovering from short duration wetting, the latter apparently able to adapt to wet conditions.

In addition to the above factors, the susceptibility of any given soil to the different erosive forces which may act on a specific piece of shoreline, further complicate the picture. It is understandable that no two reservoirs will respond in exactly the same way to inundation.

For the primary objective of power generation, without executing a detailed shoreline assessment for soil depths and types, shoreline slopes, vegetation cover, wind and wave climate, etc, it has become the general practice in Canada to be "safe rather than sorry" and to execute complete reservoir clearing. More appropriate would seem to be a form of selective perimeter cutting. This would involve a moderate assessment of soils, slopes and vegetation that would allow identification of banks susceptible to erosion and/or failure. These areas would be subject to special treatment such as

- hard protection
- selective shore clearing
- underwater protection (standing material)
- vegetation

as indicated by site conditions. In areas with deep soils, valuable timber could be selectively removed, along with deadfall. The remainder of the reservoir could be topped to 3 to 5 m below bottom operating water level (to prevent exposed trees from breaking off or from uprooting). Shoreline treatment in nonerosion areas could include clearing back to anticipated stable slope formation.

This combination of strategies would minimize uncontrolled erosion contributing to debris accumulation and would maximize the probability of those trees left uncut, remaining below the water.

4.1.2 - Recreation and Aesthetics

Water oriented recreational pursuits are varied. Some depend on shoreline as much as on the actual water body. Table 4.1 summarizes some of the differential requirements of assorted recreational uses. Many of these activities are virtually inseparable for

TABLE 4.1

COMPARISON OF RECREATIONAL REQUIREMENTS

	Access	Shoreline Stability	Water Quality	Dead Trees
Cottaging	- Good road access required to bring in building materials, furniture, supplies - Three season access usually necessary - Winter access may be required	- Very stable shoreline required - Gentle slopes preferred for water access - Beach formation preferred	- Good enough for drinking if filtered - High color and turbidity not appreciated for "aesthetic" reasons primarily - Taste and odor unacceptable	- Aesthetically unpleasant - Hindrance of water access - Interference with associated cottage uses
Winter Use Snowmobiling	- Access to within a few miles for day use - To shoreline if associated with cottaging - Abandoned logging roads heavily used	- Gradual slopes for access	- Not important except as affects ice fishing	- Hazardous to snowmobiles
Day Use (Public)	- Access to groomed areas - Parking requirements - Usually requires launching facility	- Stable, gentle slopes for access to water - Beaches popular - Near shoreline aesthetically pleasing	- Nontoxic - Aesthetically pleasing - Piped water can be provided for drinking	- Aesthetically unpleasant - Hindrance to water access
Boating/Skiing	- Good road access to water - Boat launching capability	- Stable for launch areas - Aesthetics of neat shoreline	- Not important outside of aesthetics	- Hazardous for boats and skiers
Canoeing/ Camping	- Access to reservoir at some point for launching or short portage	- Relatively stable shore for aesthetics and shore access from water - Beaches desirable	- Nontoxic	- Interference with sport - Hinders launch and shore access
Swimming	- Access to water by foot - Road access to within walking distance of shore	- Beaches preferred - Stable shoreline aesthetically good	- Nontoxic - Other factors like turbidity and odor aesthetically unpleasant	- Precludes beach formation--incompatable
Sport Fishing	- Access to water for fishing from boat or shore	- Important to fish production--stable shoreline and productive littoral zone preferred	- As required for fish production	- Makes for ideal still fishing - Increases fisheries potential
Hunting	- Good access to within walking distance - Access to shoreline good for further boat travel - Logging roads ideal for access to hunting areas	- Only important as relates to boat launch or wildlife	- Not important except as affects wildlife use	- Not important as interference - Good from viewpoint of encouraging waterfowl

practical purposes as they are carried out collectively by individual user groups, e.g., cottagers usually have boats, like to swim and to go fishing and may wish to snowmobile in the winter. Specific needs and demands will largely be dictated by the proximity of the user to the reservoir (local, regional or tourist). Additionally, the degree of continuing supervision or management varies both with location and recreational type, and because of jurisdictional structure, the attached responsibility rests commonly with someone other than the owner of the power generation facility.

For most of the recreational pursuits mentioned in Table 4.1, generally stable well-vegetated shorelines, reasonable water quality, some natural beach, some road access and safe boating conditions combined with good visual aesthetics would be preferred. A review of reservoir case histories indicates that these criteria are largely met by low-maintenance power storage reservoirs, reflecting their similar basic requirements for stable shore, minimal debris and reasonable water quality. More divergence appears to arise from large water level fluctuations than from reservoir clearing strategies. As recreational usage is a secondary activity in a hydro reservoir, it is apparent that this user group has often accepted less than optimal conditions in recognition of the basic power producing objectives.

The most common complaints from recreational sources in respect of reservoir preimpoundment preparation strategies relate to the following.

(a) Water quality - Color, clarity, taste, odor.

(b) Aesthetics - Dead standing timber, erosion and/or slope failure, algal blooms, shoreline debris.

(c) Navigation hazards - Emergent or submergent trees, high density macrophyte growth, large floating debris.

(d) Access - Not enough or poor grade, too much or too easy, water access from shoreline too steep or unsuited to boat launching, access to shore from water hindered by debris or slopes or underwater hazards.

The first 3 problems have already been discussed in preceding sections. That of access is elaborated here. An all-season road to a dam and power station is usually required by the power operator (even for remote-controlled stations), to allow regular maintenance and fire protection access. It is built for construction purposes in most cases anyway and once opened it is difficult to permanently close any road. If a reservoir is built in an area, hitherto inaccessible by conventional ground transport but under pressure to be "opened up", the road becomes an important and desirable feature. If the opposite pressure prevails as it does in wilderness and environmentally sensitive areas, the existence of a good road becomes a permanent threat.

The process of reservoir clearing requires the admittance of crews and equipment to the whole reservoir area. The heavier the equipment, the better the quality of road required. Haulage of timber away from the reservoir site requires very good quality access. Access simply for cutting purposes, considerably less. The strategy selected will therefore influence the number of miles and grade of road that must be built.

If residual access to the reservoir area is to be limited to only a few designated points, clearing roads can be restricted to elevations below the top operating water level. This will contribute to turbidity in the reservoir after impoundment. Main access roads can be designed, within topographical and economic realities, to conform with postinundation plans for the area. But if roads are retained, they provide access to a much broader area for snowmobiles and ATV's than would be indicated by linear distance. This must be borne in mind for purposes of wildlife management or protection of sensitive areas.

On the other hand, if hunter access is deemed desirable, installation of clearing roads above the flood line is beneficial. The edge habitat and break provided by logging roads is heavily used by wildlife. Use by hunters is common.

4.1.3 - Fisheries

Fisheries development in a water body involves both the stock of fish and the availability of that stock to the fisherman. It is well documented in the literature that in the first few years following impoundment of a reservoir, there is a "trophic surge" incumbent on nutrient availability and the low density of impounded populations. That surge is usually followed by a decline to some stable rate of production determined by the nutrient inflow from contributing streams and rivers and from allochthonous sources.

The biological requirements of individual fish species vary and are available in the literature (Scott and Crossman 1975). Physical conditions in any given reservoir will determine which species assemblages are most likely to become established.

Clearing strategy can be used to benefit fisheries development in reservoirs. In a comparative study of the effects of standing timber on fish populations and fisherman success in Louisiana (Davis and Hughes 1971), 90 percent of the fishermen fished in the areas of dead trees by the third year following impoundment. Fishing success was consistently higher in the tree areas than in the open water and fishermen stayed longer in the sheltered tree zone. The presence of trees did not have a significant effect on total fish catch however. Based on their data, Davis and Hughes recommended that a small percentage of each new lake be left with standing trees as they (trees) increased fishing success by congregating both the native game fish and the fishermen. Burress (61) also found that fishing success was higher in the areas of flooded trees as compared to open water.

The reasons for angler success in flooded tree areas relate to the food, shelter and stability of these zones. The surfaces provided by submerged vegetation are rapidly colonized by periphyton which in turn support high densities of aquatic invertebrates. Cowell and Hudson (1967) report that oligochaetes, chironomids and miscellaneous insect groups were 7 to 30 times more abundant on periphyton substrates of submerged trees and aquatic macrophytes than on bottom substrates. These food sources are utilized by many fish species (juvenile or adult) and these in turn attract predators. In addition, due to the excellent wave breaking capacities of submerged trees, macrophytes are able to establish in the calm habitat provided along the shoreline. With such good food, cover and shade available, very high fish densities can be established and the fisherman is able to benefit from this.

Flooded vegetation necessitates still-fishing techniques, usually from a boat and uncleared reservoirs are not suitable for any efficient net capture methods (commercial fishing). Flooded vegetation is used for spawning substrate by some species (e.g. pike, perch) and many species are known to prefer sunken trees and weed areas for cover (pike, walleye, smallmouth and largemouth bass, yellow perch). The majority of warm water game fish can therefore benefit from selective reservoir clearing. In the Western Reservoir and Stream Habitat Improvements Handbook, (Nelson et al, 1978), selective reservoir clearing involving retention of some standing timber along and above shorelines is used as a fish management tool. In a review of 18 cases, 11 were successful and 6 were marginally successful. Only 1 was unsuccessful.

Encouragement of a fishery also entails the provision of access and safe lake navigation if the resource is to be available to the general public. In some areas, a fly-in fishery may be more appropriate; draft and unobstructed clearance, sufficient for float-plane landing, then become the access criteria.

4.1.4 - Wildlife

Even without deliberate planning and management, the shorelines of many man-made lakes, through natural processes, develop food and cover as good or better than those of the river banks that have been replaced. However, the ideal wildlife lake is almost the opposite of the engineer's: shallow, with gently sloping shore, small low islands and an abundance of vegetation both in the water and along the shores. Dead timber, whether standing or floating is usually and asset rather than a liability in a wildlife impoundment (Trafethen 1973).

Preimpoundment preparation strategies can be used to benefit wildlife capability. The most obvious is the retention of some flooded standing vegetation in nearshore areas. As described in preceeding sections, this provides shoreline protection through dissipation of wave energy and subsequent utilization by invertebrates and fish. Above the water, the natural cavities in dead and dying trees or those opened by woodpeckers and enlarged by decay, provide homes for tree nesting ducks. Osprey prefer dead trees for roosting and nesting whenever these are available in proximity to food sources (fish). Table 4.2 lists the waterfowl and raptors found in the Shield and Lowlands areas of Ontario most likely to benefit from such habitat for nesting purposes. Other shore nesting ducks will use these areas for cover and feeding to some extent but generally prefer emergent vegetation. With food resources abundant and in close proximity, the flooded tree habitat of the nearshore ($\leq$5 m) can support high densities of the aforementioned tree nesting birds. This is a recognized waterfowl management tool and is described in the Western Reservoir and Stream Habitat Improvements Handbook (Nelson et al 1978).

The retention of flood-adaptable vegetation to minimize erosion in gradually sloped areas will encourage

TABLE 4.2

WATERFOWL FEEDING AND NESTING REQUIREMENTS

	Nesting	Feeding	Distribution
Wood Duck	- always nest in trees close to water	- plants and seeds	- lower Shield
American Goldeneye	- preferred tree nester	- animal food - insects, worms, molluscs, etc	- nests on Shield
Bufflehead	- habitual tree nester	- animal food - insects, worms, molluscs, etc	- some shield areas - western part of Hudson Bay lowlands
Hooded Merganser	- always in trees	- fish	- Southern Ontario including lower Shield
American Merganser	- prefers to nest in trees	- fish	- Shield nester
Red Breasted Merganser	- ground nester under trees	- voracious fish eater	- Shield and Lowland nester
Osprey	- dead trees preferred	- fish	- Shield Hudson Bay Lowlands
Black Duck	- sometimes in trees	- vegetation, invertebrates	- Shield
Canada Goose	- sometimes nests in trees in Hudson Bay Lowlands	- vegetation, invertebrates	- Shield Hudson Bay Lowlands

Reference F. N. Kortright, 1967

natural beach formation. These areas will be colonized by submerged macrophytes initially and by emergent vegetation eventually, if water level fluctuations are controlled. This habitat will encourage shore-nesting waterfowl and aquatic mammals such as muskrat. Secondarily mink will colonize abandoned muskrat dens.

Other wildlife considerations in relation to reservoir clearing strategies relate to access to the water for large mammals. Stable shores with minimal debris are required for large game. Access corridors may be required in areas where migration routes (e.g. of caribou) are bisected by reservoirs. These corridors should not be cleared above high water except as necessary to retain slope integrity and underwater obstructions should be removed so as not to interfere with swimming ability.

In addition to the encouragement of wildlife in reservoirs, it may be advantageous to discourage bank-denning species such as muskrat and beaver in cases where slope failure is expected to be a major problem. The bank-denning habits of beaver and muskrat can cause bank failure in reservoirs having easily erodible bank materials. In Arnprior reservoir for example, muskrat denning was particularly destructive in the easily disturbed marine clays of that area, intrusion on the bank allowing wave action to bring about major slope failures. Interestingly, the failure of the banks did not discourage the muskrats, which simply moved to an adjacent bank to repeat their tunneling [R. Peggs (Acres) personal observation].

The tree-felling habit of beaver can also cause erosion problems in sensitive soils. Beaver take the branches from felled trees and drag them down the bank to feed in the water. In some sensitive soils, this can increase runoff erosion by providing new courses for surface drainage.

Wildlife are not compatible with large drawdowns and do not respond well to some human activities. High speed motor-boating and water skiing can create so much disturbance as to render an otherwise valuable wildlife area almost useless. Many mammals and birds, especially those with nests or young, have a low tolerance for extraneous noise and motion (Traethen 1973). If recreational development is a preferred reservoir use, wildlife encouragement may have to be limited to specific areas. These can be effectively "protected" by flooded trees which will limit boat traffic.

4.1.5 - Domestic Consumption

The use of reservoir waters impounded for the primary purpose of power generation for domestic consumption on a large scale is not common in Canada. This is primarily because hydro reservoirs are not often built in proximity to population centers. More commonly, reservoirs are used as drinking water supply sources by recreational users who are individually responsible for any required treatment. Table 4.3 provides the maximum acceptable levels of water for domestic consumption as defined by Environment Canada (McNeely et al 1979). Of the many parameters listed, those most likely to approach maximum acceptable levels are alkalinity, ammonia color, nitrates, pH, turbidity and metals. This could arise during the processes of hydration as described in Section 2.2.4, over the short term, and

TABLE 4.3

MAXIMUM ACCEPTABLE LEVELS IN WATER USED FOR DOMESTIC CONSUMPTION

PARAMETER		LEVEL		REFERENCE
ALKALINITY, TOTAL, as $CaCO_3$	GE	30	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
	LE	500	mg/L	
AMMONIA, as N	LE	0.5	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
ARSENIC, as As	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BACTERIA, FECAL COLIFORM		ND	No./dL	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BACTERIA, TOTAL COLIFORM	LE	10	No./dL	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BARIUM, as Ba	LE	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
BORON, as B	LE	5.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CADMIUM, as Cd	LE	0.005	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CALCIUM, as Ca	LE	200	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CESIUM-137	LE	50	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CHLORIDE, as Cl	LE	250	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CHROMIUM, as Cr	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
COLOUR	LE	15	TCU	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
COPPER, as Cu	LE	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CYANIDE, as CN	LE	0.2	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
FLUORIDE, as F	LE	1.5	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
HARDNESS, TOTAL, as $CaCO_3$	LE	120	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
IODINE-131	LE	10	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
IRON, as Fe	LE	0.3	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
LEAD, as Pb	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
MAGNESIUM, as Mg	LE	150	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
MANGANESE, as Mn	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
MERCURY, as Hg	LE	1.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NITRATE + NITRITE, as N	LE	10.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NITRITE, as N	LE	1.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
NTA, as H_3NTA	LE	50.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
OIL AND GREASE		ND	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA R3.73.033
pH	GE	6.5		DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
	LE	8.5		
PHENOLIC SUBSTANCES, as PHENOL	LE	0.002	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
PHOSPHATE, TOT INORG., as P	LE	0.065	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PHOSPHATE, TOTAL, as P	LT	0.100	mg/L	US ENVIRONMENTAL PROTECTION AGENCY, 440 9-76-023
PHOSPHORUS, as P	LE	0.2	mg/L	HART, 1974, AUSTR. WAT. RES. COUNCIL, TECH. PAPER 7
α– RADIATION, TOTAL	LE	0.02	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA R3.73.033
β– RADIATION, TOTAL	LE	0.19	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA R3.73.033
RADIUM-226	LE	1.0	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SELENIUM, as Se	LE	0.01	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SILVER, as Ag	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SODIUM, as Na	LE	270	mg/L	HART, 1974, AUSTR. WAT. RES. COUNCIL, TECH. PAPER 7
STRONTIUM-90	LE	10	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SULPHATE, as SO_4	LE	500	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SULPHIDE, as H_2S	LE	0.05	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
SURFACTANTS, as MBAS	LE	0.5	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
TEMPERATURE	LE	15	°C	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TOTAL DISSOLVED SOLIDS	LE	500	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TRIHALOMETHANES	LE	0.35	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TRITIUM	LE	40 000	Bq/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
TURBIDITY	LE	5	NTU	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
URANIUM, as U	LE	20	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
ZINC, as Zn	LE	5.0	mg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979

Ref: Environment Canada 1979, Water Quality Sourcebook.

from erosion/bank stability problems and inflow quality in the longer term.

In the United States where reservoir sources of domestic water are more frequent, the most often reported problem relates to the aesthetic parameters of color, taste and odor. These problems are most often reported in geographical areas experiencing much warmer climatological conditions than those prevailing in Ontario and often relate to algal production. Nevertheless these 3 factors (color, tastes, odor) are technically difficult to solve and are best dealt with through avoidance rather than treatment. In this context, water supply reservoirs in the United States are always completely cleared of standing vegetation and even stripped of soils to minimize water quality problems.

In Ontario and particularly in northern areas, the very high algal production, dominated by blue-green algae so often witnessed in the southern United States is restricted to short summer "blooms", usually in August and only in water bodies generally classified as being meso to eutrophic. The majority of northern lakes are oligotrophic and even the nutrients derived from inundated soils and vegetation are rarely sufficient to induce long-term eutrophic status.

Turbidity, if a result of chronic erosion problems, can remain high in impounded water, particularly if regular drawdowns are experienced and the affected soils are fine grained. For the occasional recreational user, this is a difficult problem to overcome as he rarely has filtering equipment at his disposal or the time to allow natural settling. Cottagers often have small filtering and deionizing column water treatment packages that are inexpensive to operate and efficient in removing suspended materials from drinking water supplies.

Aesthetically unappealing water due to turbidity, color, taste or odor are not usually unsafe to drink, however and the water quality parameter that can be of most concern is that of elevated metals levels. The biodegradation processes occurring on the bottom of a newly impounded reservoir produce large quantities of CO_2 and reduce the oxygen content of the overlying water. Although generally confined to the bottom few meters and lasting for a relatively short period of time, this situation reduces the pH and alkalinity of this water layer and increases the solubility of metals. If high concentrations of metals prevail in the hydrated soils, these can be taken up and made available to consumers. Mercury and other heavy metals stand out in this respect because of their toxicities even in fairly low concentrations.

For reservoirs which will be heavily used as a source of drinking water in the first 5 years of impoundment, it is generally therefore advisable to reduce as far as possible the amount of biodegradable material available and to use bank protection whenever necessary to minimize erosion problems.

Ultimately, the long-term water quality will be dictated by the inflowing water and reservoirs will gradually approach water quality conditions similar to adjacent natural lakes. Long-term planning for drinking water supply must bear this in mind. It may not be necessary to go to great clearing and stripping expense if the projected demand is far enough into the future.

An additional consideration is that of agricultural runoff. Reservoirs built in active agricultural areas run the great risk of pesticide and herbicide input. Table 4.4 presents Environment Canada's criteria for these parameters. Generally speaking, the combined effects of power operation and agricultural input would tend to bias against utilization of such a reservoir as a major domestic water supply even in the longer term due to the high treatment costs likely to be incurred.

4.1.6 - Flood Control

Flood control benefits are inherent in any storage impoundment scheme and are usually accepted as an "added plus" from hydro power projects built above flood-prone areas. The extent of preimpoundment preparation does not directly affect this benefit except perhaps as to the displaced water volume incurred by leaving standing forest within the reservoir area.

4.1.7 - Irrigation

The secondary use of hydro storage reservoirs for irrigation purposes is uncommon in Ontario. This is true for several reasons; the first being that water supply is not generally a problem in Ontario; power requirements do not usually correspond seasonally with the needs of irrigated agriculture; concurrent use implies direct competition for live storage.

The reverse situation where irrigation water supply is the primary objective, with power production a secondary benefit does have precedence. In these situations water drawn from the reservoir is passed

TABLE 4.4

MAXIMUM ACCEPTABLE LEVELS OF SPECIFIC PESTICIDES IN WATER USED FOR DOMESTIC CONSUMPTION

PARAMETER	LEVEL			REFERENCE
ALDRIN + HEOD (DIELDRIN)	LE	0.7	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
γ– BHC, (LINDANE)	LE	4.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CAMPHECHLOR (TOXAPHENE)	LE	5.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CHLORDANE, TOTAL	LE	7.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
CARBARYL	LE	70.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
DDT, TOTAL	LE	30.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
DIAZINON	LE	14.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
ENDRIN	LE	0.2	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
HEPTACHLOR + HEPTACHLOR EPOXIDE	LE	3.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
p,p'– METHOXYCHLOR	LE	10.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
PARATHION	LE	35.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
PARATHION - METHYL	LE	7.0	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
PESTICIDES, TOTAL	LE	100	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
2,4-D	LE	100	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979
2,4,5-TP	LE	10	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1979

MAXIMUM ACCEPTABLE LEVELS OF GROUPS* OF PESTICIDES IN WATER USED FOR DOMESTIC CONSUMPTION

PARAMETER	LEVEL			REFERENCE
ALACHLOR	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
ATRAZINE	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
AZINPHOSETHYL	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
AZINPHOSMETHYL (GUTHION)	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
BARBAN	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CARBOFURAN	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CARBOPHENOTHION	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CHLORFENVINPHOS	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CHLORPYROPHOS	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
COUMAPHOS	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
CRUFOMATE	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DALAPON	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DI-ALLATE	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DICAMBA	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DICHLOFENTHION	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DICHLORPROP	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DICHLORVOS	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DIMETHOATE	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DIQUAT	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
DISULFOTON	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
ETHION	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
FENCHLORPHOS (RONNEL)	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
FENOPROP (SILVEX)	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
FENTHION	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
LETHANE 384	LE	100	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
MALATHION	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
MCPA	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
METHIOCARB	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
METHYLCARBOPHENOTHION	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
MEVINPHOS	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PARAQUAT	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PHORATE	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PHOSALONE	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PHOSPHAMIDON	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PICLORAM	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PROMETON	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
PROPOXUR	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
SIMAZINE	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
TCA	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
TEMEPHOS	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
TRIFLURALIN	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
2,4-DB	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969
2,4,5-T	LE	100.	µg/L	DEPT. OF NATIONAL HEALTH & WELFARE, CANADA, 1969

* GROUPS = CARBAMATES, HERBICIDES, ORGANOPHOSPHORUS PESTICIDES

REF: Environment Canada 1979, Water Quality Sourcebook.

through a turbine before entering the irrigation distribution system. The power thus gained is scheduled by irrigation demands and may not have a high economic value.

In any event, the only way in which reservoir clearing practices could reasonably affect utilization of impounded water for irrigation purposes is through its affects on water quality. Table 4.5 presents the Federal Guidelines for irrigation water quality. It is unlikely that failure to clear a reservoir would cause exceedance in any of these parameters with the possible exception of metals, and then only during the first few years of operation.

. Summary of Reservoir Uses - Table 4.6 summarizes the basic needs of the reservoir uses described in this section of the report, and what clearing strategies could apply in meeting those needs.

4.2 - Constraints

4.2.1 - Logistics and Schedule

The logistics involved in a reservoir clearing strategy must be carefully planned and executed to effect economical clearing operations. Logistics can place certain constraints on the selection of a clearing strategy if it is determined that equipment or manpower is not available or cannot cope with site terrain characteristics or local adverse weather conditions.

Based on a preliminary clearing strategy selected, the following logistics should be determined.

TABLE 4.5

GUIDELINES FOR THE IRRIGATION OF FINE-TEXTURED ALKALINE SOILS*

PARAMETER	LEVEL			REFERENCE
ALUMINUM, as Al	LE	20.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
ARSENIC, as As	LE	2.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
BACTERIA, ENTEROCOCCI	LE	20	No./dL	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
BACTERIA, FECAL COLIFORM	LE	100	No./dL	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
BERYLLIUM, as Be	LE	0.50	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
BORON, as B	LE	1.0	mg/L	HART, 1974, AUSTR. WAT. RES. COUNCIL, TECH.PAPER 7
CADMIUM, as Cd	LE	0.050	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
CHLORIDE, as Cl	LE	150	mg/L	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
CHROMIUM, as Cr	LE	1.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
COBALT, as Co	LE	5.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
COPPER, as Cu	LE	5.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
FLUORIDE, as F	LE	15.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
IRON, as Fe	LE	20.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
LEAD, as Pb	LE	10.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
LITHIUM, as Li	LE	2.5	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
MANGANESE, as Mn	LE	10.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
MOLYBDENUM, as Mo	LE	0.010	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
NICKEL, as Ni	LE	2.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
pH	GE	4.5		ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
	LE	9.0		
α– RADIATION, TOTAL	LE	0.02	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
β– RADIATION, TOTAL	LE	0.19	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
SELENIUM, as Se	LE	0.020	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
SODIUM ABSORPTION RATIO	LE	6		ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
TOTAL DISSOLVED SOLIDS	LE	500	mg/L	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
VANADIUM, as V	LE	1.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
ZINC, as Zn	LE	10.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033

* ALKALINE - pH 6.0 TO 8.5 FOR LESS THAN 20 YEARS OF USE

GUIDELINES FOR IRRIGATION OF ACIDIC SOILS / CONTINUOUS USE (ALL SOILS)

PARAMETER	LEVEL			REFERENCE
ALUMINUM, as Al	LE	5.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
ARSENIC, as As	LE	0.10	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
BACTERIA, ENTEROCOCCI	LE	20	No./dL	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
BACTERIA, FECAL COLIFORM	LE	100	No./dL	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
BERYLLIUM, as Be	LE	0.10	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
BORON, as B	LE	0.5	mg/L	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
CADMIUM, as Cd	LE	0.010	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
CHLORIDE, as Cl	LE	150	mg/L	ONTARIO MINISTRY OF THE ENVIRONMENT 1974
CHROMIUM, as Cr	LE	0.1	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
COBALT, as Co	LE	0.050	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
COPPER, as Cu	LE	0.20	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
FLUORIDE, as F	LE	1.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
IRON, as Fe	LE	5.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
LEAD, as Pb	LE	5.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
LITHIUM, as Li	LE	2.5	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
MANGANESE, as Mn	LE	0.20	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
MOLYBDENUM, as Mo	LE	0.010	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
NICKEL, as Ni	LE	0.20	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
pH	GE	4.5		ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
	LE	9.0		
α– RADIATION, TOTAL	LE	0.02	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
β– RADIATION, TOTAL	LE	0.19	Bq/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
SELENIUM, as Se	LE	0.020	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
SODIUM ABSORPTION RATIO	LT	6		ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
TOTAL DISSOLVED SOLIDS	LE	500	mg/L	ONTARIO MINISTRY OF THE ENVIRONMENT, 1974
VANADIUM, as V	LE	0.10	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033
ZINC, as Zn	LE	2.0	mg/L	ENVIRONMENTAL STUDIES BOARD, 1973, EPA.R3.73.033

REF: Environment Canada 1979, Water Quality Sourcebook.

TABLE 4.6

COMPARISON OF ALTERNATIVE USE RESERVOIR REQUIREMENTS

Use	Water Quality	Shoreline Stability	Floating Debris	Underwater Obstruction	Access
Hydro Power	- H_2S and extreme suspended solids to be avoided - other parameters not important	- stable shores desirable to (a) minimize debris (b) maintain storage volume	- large sized debris damaging to trash racks therefore avoid - small debris acceptable - preferrably little debris because of maintenance expense	- need clearance behind dam for effective operation of intakes	- year round access to dam for maintenance and fire protection
Recreation and Aesthetics	- aesthetically pleasing - safe to drink with minor treatment	- stable shores desirable for shoreline uses and aesthetics	- undesirable as interferes with navigation and is aesthetically unattractive	- hazard to navigation	- dependent upon type of recreation desired, varies from fly-in only to high grade road access to several reservoir points (see Table 3.1)
Fisheries	- good water quality required for most parameters, aesthetic qualities unimportant	- desirable for maintenance of littoral zone and water quality	- not relevant except as affects water quality	- desirable for food production and shelter for fish - can restrict utilization by fishermen - severely limits use of nets	- dependent upon type of fishing (sport fly-in to commercial extraction) - varies from float plane to high grade road to at least one point on reservoir
Wildlife	- as for fisheries	- desirable for use of riparian habitat, and maintenance of littoral zone and water quality	- hazard to some large game - irrelevant to most wildlife - desirable for some water birds	- undesirable for large game in nearshore - can be hazardous to migrations of caribou - desirable for beaver - restricts water access for hunters	- hunter access along low grade roads desirable in some reservoirs - fly-in only preferrable in "wilderness" areas

Table 4.6
Comparison of Alternative Use Reservoir Requirements - 2

Use	Water Quality	Shoreline Stability	Floating Debris	Underwater Obstruction	Access
Domestic Water	- excellent water quality desirable to minimize treatment costs	- desirable as it can deteriorate water quality	- undesirable as it is aesthetically unpleasant and can contribute to coloration of water - can interfere with operation of intake	- undesirable as it contributes to reduced water quality (color, taste, odor, etc)	- road access to intake facility for maintenance - other access (and uses) usually restricted
Irrigation	- as for fisheries	- desirable as it can affect water	- only important as affects operation of intake structure	- not relevant except as affects intake operation	- road access to intake facility for maintenance
Flood Control	- not relevant	- desirable as can reduce storage volume of reservoir	- as for hydro power	- as for hydro power	- as for hydro power

(a) Hand and machine clearing equipment required and areas where each will be used. Equipment may include power saws, wheeled skidders, mechanical limbers, mobile slashers, mower type land clearing machines, brush rakes, barges, boats, winches, etc. Terrain characteristics (e.g. steep slopes, bog areas etc) and timber densities will determine clearing methods.

(b) Time required for clearing operations and labor availability. Local weather conditions will affect timing of operations. Where prescribed burning is carried out, this operation will be limited by the number of suitable days as determined by wind, humidity and degree of fire hazard.

(c) Infrastructure requirements during clearing operation e.g. portable field office, crew quarters and supplies, portable parts depot and field garage, mechanic's truck, passenger buses.

(d) Location and specifications for access roads. Will they be required for extraction of merchantable timber? Road equipment may include bulldozers, front end loaders, pick up trucks, gravel trucks, road graders, sanders and snow plows.

Once these logistics have been determined, the adjustments required to the preliminary clearing strategy should be made and all parties notified prior to preparing a schedule for the work. A typical schedule outlined below has been adapted from Hunter and Associates (1980).

Year 1 - Construction of access roads and infrastructure facilities

Year 2 - Construction of local branch logging roads
- Initiation of logging operations (merchantable timber)
- Initiation of forebay clearing

Year 3 - Completion of logging operations
- Hauling of wood from reservoir
- Initiation of main reservoir clearing operations

Year 4 - Completion of hauling activities
- Completion of clearing activities below first stage flood

Year 5 - Completion of all clearing requirements.

In many cases a 5-year period for clearing is not available or is not required depending on the clearing strategy selected and size of the reservoir area to be cleared. Where an advance in the clearing schedule is required to meet the reservoir operations schedule for water use, alternative measures which can be taken are

- reduction of clearing requirements which may involve clearing of selected areas, e.g. forebay, drawdown zone, and/or other areas

- clearing concurrently with logging operations

- hauling while clearing is underway

- hand felling and floating with helicopter access (reduces or eliminates time required for construction of access/logging roads).

With a no clearing option, it is still necessary to clear some areas such as dam sites, forebays and canals. The logistics outlined above will, therefore, still be required, although to a much lesser degree.

Logistics should also include determination of labor and equipment requirements for postflood clearing and maintenance. This is particularly important where the no clearing option is selected, since floating debris will require the construction of temporary or permanent debris removal and disposal facilities and the necessary labor to be available for this purpose. Postclearing logistics should also clarify whether the maintenance operations will be carried out during summer or over ice. In some areas of Ontario deep, drifting snow accumulations may make winter clearing operations impractical.

4.2.2 - Economics

A step-by-step approach to establishing the economics of reservoir clearing is shown in Figure 4.1. There are basically two approaches to evaluating the economics of reservoir clearing. The primary approach is to determine the costs of all possible clearing strategies on a purely engineering and economic basis without consideration for environmental constraints. On completion of this process, a secondary approach should be followed which incorporates environmental constraints into the costing of the various alternative clearing strategies. A comparison of the final results from each approach will enable an assessment of financial cost versus environmental benefits.

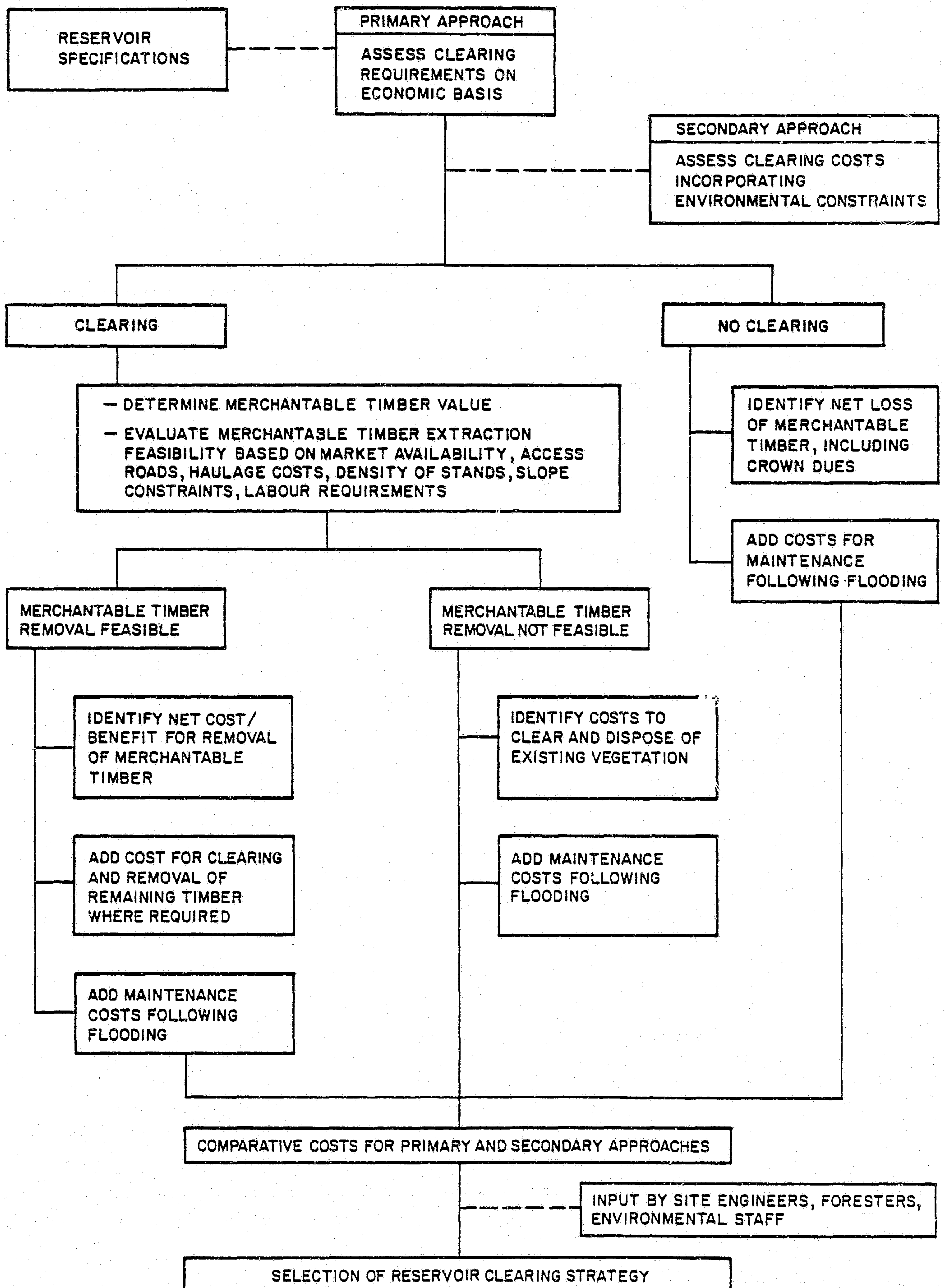


FIG 4.1

APPROACH TO IDENTIFICATION OF RESERVOIR CLEARING COSTS

ACRES

There are many variables that affect the overall cost of clearing. These factors include scale of operation, terrain features, merchantable timber, volume and densities, proximity of markets (and whether they are kraft or high-grade pulp mills or sawmills, i.e., market preference) fluctuations in timber, selling prices as a result of supply and demand, labor availability, scheduling requirements and environmental constraints. Some of these variations are exemplified by hand clearing costs estimated for the Upper Salmon Reservoir in Newfoundland (Kiell 1981).

Clearing Cost/ha	Class	Description
1,600*	1	Flat area (<35 m^3/ha forest biomass)
1,850	2	Flat to moderate slope
2,100	3	Moderate slope (36 to 70 m^3/ha)
2,350	4	Moderate to steep slope
2,600	5	Steep slope (71 to 105 m^3/ha)
0	6	Wetlands and soil barrens

In the above example, the clearing class for islands was raised by one to compensate for difficulty of access.

*All costs quoted in this section of the report have been adjusted to 1981 dollars by assuming a 4 percent annual inflation rate prior to 1974 and a 10 percent annual inflation rate between 1974 and 1981 based on Canadian consumer price indexes.

A survey of the clearing costs for 10 Canadian reservoirs indicates a mean clearing cost of $2,430/ha which excludes merchantable timber sales. This cost is assumed to include labor/living expenses, equipment, access roads, crown dues, haulage of salvageable timber and burning of debris. If there is no salvageable timber, the clearing cost could feasibly be reduced to $1,100/ha based on estimates for the Cat Arm Reservoir in Newfoundland (Hunter and Associates 1980).

The cost of access roads will depend on whether timber products are to be hauled out of the area. Where extraction roads are required, one estimate quotes $18,000/km including culverts but excluding major bridges. This cost can be reduced considerably ($9,000/km) if no timber products are to be hauled. These estimates are based on those given by Eddy Forest Products Limited for the proposed INCO power development near Espanola.

Only one estimate was available for the clearing strategy involving complete stump removal. The cost in 1981 dollars was $4,811/ha based on a reservoir cleared by the Grand River Conservation Authority in 1974.

To winter clear from ice, including extraction and burning of debris, it is predicted to cost $3,700 to $3,900/ha for Muskrat Falls and Gull Island reservoirs in Labrador (Proctor and Redfern 1980).

It takes approximately 25 man-days/ha for the felling and disposal of vegetation from lands ranging from flat areas with 35 m^3/ha forest biomass up to steep slopes with 71 to 105 m^3/ha forest biomass (Kiell 1981).

The cost of clearing debris after flooding a reservoir is dependent on the clearing strategy adopted and accessibility to the site. For example, for the Muskrat Falls and Gull Island reservoirs on the Lower Churchill River, Labrador, no clearing is recommended except at dams and at the confluence of tributaries. It is anticipated that the clearing and burning of debris from these reservoirs will take place over a 5-yr period at approximately $1,100/ha (Proctor and Redfern 1980). This maintenance cost includes an allowance for the amortization of capital expenditures over 5 years.

It is emphasized that the above-mentioned costs must be treated as rough estimates only since there are many site-specific variables.

The cost of postflood clearing and maintenance is not always the responsibility of the reservoir operator. It is common practice for the reservoir operator to carry out postflood clearing if debris interferes with operational requirements. However, where reservoirs are used for recreational activities (boating, fishing, camping, picnicing), the costs to reduce hazards and improve aesthetics in the reservoir are sometimes the responsibility of the provincial forest service or are shared with the reservoir operator.

If the proper clearing strategy is not selected and adequate mitigative measures are not implemented at an early stage, the costs for postflood clearing and maintenance can be exorbitant. In the case of Williston Lake (surface area 177 259 ha) which is the reservoir for Bennett Dam in British Columbia, maintenance costs for clearing and debris control are expected to reach 46.2 million dollars by 1984 (B.C. Hydro 1981). The strategy for this reservoir was to clear an area above the lower water level and leave the material to float. Adding to the debris problem in this reservoir are extremely erodible soils, leading to massive bank slumping..

There are many aspects to consider in reviewing the economics of alternative clearing strategies. By taking a logical approach as outlined in Figure 4.1 and interacting with site engineers and environmental staff, a practical as well as economical clearing strategy is possible.

4.2.3 - Relevant Acts and Regulations

There are a number of provincial and federal acts and regulations that may affect selection of a reservoir clearing strategy. The list of Table 4.7 covers all relevant Ontario legislation as well as federal acts and regulations which apply to Ontario reservoirs.

These statutes and regulations outline specific requirements to be met prior to, during and after the clearing of reservoirs. For Ontario reservoirs, particular attention should be focused on requirements of the Crown Timber Act, the Forest Fires Prevention Act and the Lakes and Rivers Improvement Act.

4.2.4 - Land Use

Current and projected land use within a reservoir area can be a major constraint in the selection of a clearing strategy. Although many of these considerations have been addressed in Section 4.1 in respect of

TABLE 4.7

RELEVANT ACTS AND REGULATIONS

Act/Regulation	Relevant Power/ Requirements of Regulations
CANADA WILDLIFE ACT (Federal)	Provision of protection for endangered wildlife.
Wildlife Area Regulations	Provides specific protection in following areas of Ontario: Big Creek (Norfolk County), Hahn Marsh (Haldimand-Norfolk), Dover Marsh (Kent County), Eleanor Island (Muskoka), Mohawk Island (Lake Erie), Mississippi Lake (Lanark County), Weller (Prince Edward County), Wye Marsh (Simcoe County)
CLEAN AIR ACT (Federal)	Power of Minister of Environment to prohibit emissions to ambient air if they exceed a national emission standard and create a health hazard or violate an international boundary agreement. Failure to comply brings maximum fine of $200,000.
Ambient Air Quality Objectives	Acceptable emissions of suspended particulate matter are 0 to 120 $\mu g/m^3$ average concentration over 24-h period.
CONSERVATION AUTHORITIES ACT (Ontario)	Power to alter flow of water course and restrict use of water from rivers and inland lakes in conservation authority jurisdictions. Conservation authorities have first rights to water power on their lands and may charge an annual fee to Ontario Hydro for use of such water.
CROWN TIMBER ACT (Ontario)	Power to grant licences for cutting and sale of timber. Ministry of Natural Resources may designate trees to be left standing for watershed protection, forest management, fire protection or preservation of landscape and game reserves. Penalties outlined for commencing cutting operations without approval or cutting beyond limits approved by Minister.

Table 4.7
Relevant Acts and Regulations - 2

Act/Regulation	Relevant Power/ Requirements of Regulations
Crown Timber Act (Ontario) (contd)	
Regulation 159	Covers crown charges for timber cut under licence, terms and conditions of licences, and penalties for wasteful practices in forest operations, e.g. not utilizing merchantable logs. A "merchantable tree" means a standing tree containing one or more merchantable logs having a total content of sound wood that is equal to more than one-half of the content of all the logs in the tree.
ENDANGERED SPECIES ACT (Ontario)	Up to $3,000 fine or imprisonment up to 6 months for interfering with or destroying endangered species of fauna or flora or associated habitat as outlined in regulations.
Regulation 33/77	Endangered Species (a) Fauna Blue racer (*Coluber constrictor foxi*) Timber rattlesnake (*Crotalus horridus horridus*) Peregrine falcon (*Falco peregrinus anatum*) Bald eagle (*Haliaeetus leucocephalus alascanus*) West Virginia white butterfly (*Pieris virginiensis*) Lake Erie Island water snake (*Natrix Sipedon insularum*) Piping plover (*Charadrius melodus*) Eskimo curlew (*Numenius borealis*) Golden eagle (*Aquila chrysaetos*) White pelican (*Pelecanus erythrorhynchos*) Eastern cougar (*Felis concolor couguar*

Table 4.7
Relevant Acts and Regulations - 3

Act/Regulation	Relevant Power/ Requirements of Regulations
Endangered Species Act (Ontario) (contd)	
	(b) Flora Small white lady's slipper orchid (*Cypripedium candidum muhl*)
ENVIRONMENTAL ASSESSMENT ACT (Ontario)	Requires certain government agencies and all public corporations and municipalities to submit an environmental assessment prior to an undertaking unless exempt by the Minister of Environment. Failure to comply brings initial fine up to $5,000 and up to $10,000 per day for subsequent convictions.
General Regulations Regulation 836/76	Outlines exemptions.
ENVIRONMENTAL PROTECTION ACT (Ontario)	Certificate of approval required prior to emitting or discharging a contaminant to the natural environment (except water). Minister may authorize studies of the natural environment (including monitoring) as required.
Air Pollution Control (General) Regulations (Regulations 15, 1970, 873/74, 271/77, 834/80)	Restricts air contaminants that may cause discomfort to persons, loss of enjoyment of property, interfere with normal business, or cause damage to property. Limit of suspended particulate concentration at point of impingement: 100 $\mu g/m^3$.
Ambient Air Quality Criteria (Regulations 872/75, 158/75)	Suspended particulate matter 120 $\mu g/m^3$ over 24-h period.

Table 4.7
Relevant Acts and Regulations - 4

Act/Regulation	Relevant Power/ Requirements of Regulations
FISHERIES ACT (Federal)	During land clearing, no slash, stumps or other debris is permitted in waters frequented by marine fish. Failure to comply brings maximum fine of $5,000 for first offence and $10,000 for each subsequent offence. Ontario Fishery Regulations apply.
FOREST FIRES PREVENTION ACT (Ontario)	A work permit is required prior to clearing of any land in or within 300 m of a forest or woodland. A fire permit is also required since the clearing of land requires piling and burning of all brush, debris, nonmerchantable timber and other flammable material cut (except chips). Failure to comply brings $1,000 fine or 3 months imprisonment or both.
GAME AND FISH ACT (Ontario)	Restricts hunting or fishing on land or water bodies where there is written notice not to hunt or fish.
INDIAN ACT (Federal)	Act of parliament of Canada or provincial legislature required prior to use of Indian reserves by province, municipality or corporation.
Indian Timber Regulations	Applies to harvesting, sale and disposal of timber within Indian reserves and surrended lands.
LAKES AND RIVERS IMPROVEMENT ACT (Ontario)	Provides for public rights over waters of lakes and rivers in Ontario; protection of riparian owners; use, management and protection of fish, wildlife and other natural resources on such waters; preservation of natural amenities of such waters and on shores and banks.

Table 4.7
Relevant Acts and Regulations - 5

Act/Regulation	Relevant Power/ Requirements of Regulations
Lakes and Rivers Improvement Act (Ontario) (contd)	Where water has been impounded for power development or storage purposes, the Ministry of Natural Resources may require clearing of timber, slash or debris from flooded lands and removal of any of this material that has escaped from flooded lands to any lake or river. Timber floated down a lake or river must be kept under control and where timber floats out of control or creates a hazard or obstruction, it must be removed from the lake or river. There is a fine of up to $10 for trees cut and felled without lopping off branches and cutting up the trunk into lengths not more than 5.5 m before floating. Up to $5,000 fine for contravening any provision of act and regulations.
MIGRATORY BIRDS CONVENTION ACT (Federal)	In addition to hunting regulations, prohibits taking nests or eggs of migratory birds and provides special protection to wood ducks and eider ducks.
Migratory Bird Regulations	No deposit of wastes is allowed where they may be harmful to migratory birds.
Migratory Bird Sanctuary Regulations	Permit required from federal Minister of Environment prior to disturbing migratory birds, nests, eggs or habitat in a migratory bird sanctuary. Migratory bird sanctuaries in Ontario are - Beckett Creek Bird Sanctuary, Russell County (Cumberland Township) - Chantry Island Bird Sanctuary, Bruce County (Saugeen Township) - Eleanor Island Bird Sanctuary, Muskoka District - Fielding Bird Sanctuary, Sudbury District

Table 4.7
Relevant Acts and Regulations - 6

Act/Regulation	Relevant Power/ Requirements of Regulations
Migratory Bird Sanctuary Regulations (contd)	- Guelph Bird Sanctuary, Wellington County (Guelph/Puslinch Townships) - Mississippi Lake Bird Sanctuary, Lanark County (Drummond Township) - Moose River Migratory Bird Sanctuary, Cochrane District - Pinafore Park Bird Sanctuary, St. Thomas (Elgin County) - Rideau Bird Sanctuary, Merrickville (Lanark County) - St. Joseph's Island Bird Sanctuary, Algoma District (Jocelyn Township) - Upper Canada Bird Sanctuary, Stormont County (Osnabruck Township) - Young Lake Bird Sanctuary, Manitoulin Island
NAVIGABLE WATERS PROTECTION ACT (Federal)	Approval required from federal Minister of Transport prior to construction of works in or across navigable waters. Construction is to commence within 6 months of approval and be completed within 3 years. Failure to comply brings maximum fine of $5,000. Deposit of rubbish which interferes with navigation (or rubbish which sinks in <20 fathoms of navigable water) may bring maximum fine of $5,000.
Navigable Waters Works Regulations	Lights, buoys and other marks are required as specified by federal Minister of Transport. Tools, equipment and vehicles must be removed from navigable waters on completion of project. The federal Minister of Transport may require removal of debris which accumulates on bed or surface of navigable waters. Reservoir owner may be required to install log chutes around works, provide public roads or footpaths around works and furnish Minister with records of flows and elevation of water above and below the work.
ONTARIO HERITAGE ACT	Power of Ministry of Culture and Recreation to manage property of historical

Table 4.7
Relevant Acts and Regulations - 7

Act/Regulation	Relevant Power/ Requirements of Regulations
Ontario Heritage Act (contd)	architectural, archaeological, recreational, aesthetic and scenic interest.
ONTARIO WATER RESOURCES ACT	Ministry of environment has power to control and regulate storms, distribution and use of water for public purposes and examine any surface waters or groundwater in Ontario. Discharge of any material into a reservoir that may impair water quality is an offence subject to fine of up to $5,000 on first conviction and up to $10,000 and/or 1 year imprisonment on each subsequent conviction.
Water Management - goals, objectives, policies and implementation procedures of the Ministry of Environment	Reflects current policies for water management in Ontario and outlines provincial water quality objectives.
PROVINCIAL PARKS ACT (Ontario)	The Ministry of Natural Resources may make agreements for the establishment of works, facilities or services on public lands.
PUBLIC LANDS ACT (Ontario)	Where 25 percent or more of lands fronting on a water body are public lands, those lands comprising at least 25 percent of the frontage shall be set apart for recreational and access purposes by the Ministry of Natural Resources. Where <25 percent of land frontage is public lands, all public lands fronting shall be used for such purposes.
WILDERNESS AREAS ACT (Ontario)	Development or utilization of natural resources is possible in any wilderness

Table 4.7
Relevant Acts and Regulations - 8

Act/Regulation	Relevant Power/ Requirements of Regulations
Wilderness Areas Act (Ontario) (contd)	area that is more than 260 ha in size. Lands and wildlife in designated wilderness areas are controlled by the Ministry of Natural Resources.

reservoir objectives, these and others are summarized below.

(a) Forest Resources - An active forest industry implies both the presence of merchantable timber as well as the equipment and manpower to extract it. It also indicates a probable market for extracted timber.

(b) Historical and/or Archaeological Sites - The presence of culturally valuable "sites of antiquity" can affect the timing of reservoir clearing as well as the actual practices used.

(c) Tourism - Even if the future reservoir is not slated for recreational use directly, if it will be visible to residents and visitors to the area, aesthetic grooming will likely be required.

(d) Access - If current access is poor, this can restrict clearing options both technically and economically. It can put pressure on reservoir operator to improve access or maintain status quo thereby biasing in favor of one strategy over another.

(e) Proximity to Population Centres - Outside of the definition of future reservoir uses, local people provide a source of manpower for clearing purposes. If unemployment is high, major clearing efforts may be viewed as a socioeconomic benefit to the region. Conversely, in sparsely populated areas, manpower may be unavailable for clearing activities.

(f) Ecologically Sensitive Areas - Will restrict clearing options primarily through access and the definition of future use options. It will directly affect clearing strategy for the maintenance of riparian and downstream uses.

5 - RESERVOIR CLEARING METHODS

5.1 - Hand Versus Machine Clearing Methods

Where removal of any part of the reservoir site cover is required as part of the clearing strategy, the most appropriate methods (tools) must be selected. Hand clearing involves the manual use of lightweight power chain saws and is usually employed where physical constraints or economics preclude the use of heavy mechanical cutting methods. Once cut, the trees are mechanically skidded to landings and slashers are used to process and stock tree lengths. Hand clearing may also imply the piling and burning of nonsalvageable timber.

The primary advantages to hand clearing are small capital investment and accessibility to a range of terrains. These advantages are offset to a large degree by the amount of labor and time required to hand clear a reservoir as opposed to heavy machinery operations.

Where terrain permits access for heavy mechanical equipment, large mower type land-clearing machines (e.g. Hydro-ax) and crawler tractors with shearing blades can be utilized.

For uprooting and moving vegetation, a crawler tractor equipped with a land-clearing rake can grub vegetation out of the soil, move it and pile it. In steep or rugged terrain where there is no access for wheeled or tracked equipment, winches can be set up near accessible areas and long cables used to drag felled vegetation out of the cut area (Kloster and Mikucki 1978).

Heavy mechanical cutting equipment is used primarily for large-scale clear cutting operations. The large capital investment required and the difficulty in gaining access to remote areas with rough terrain limits the use of this equipment considerably.

If the selected strategy includes the minimization of residual access, hand methods may be preferred to mechanical techniques because of the overgrowth potential of small contour roads.

5.2 - Criteria for Selecting Clearing Method

The decision as to whether to use manual and/or mechanical cutting methods is dependent on a number of criteria.

(a) Clearing Strategy Recommended

The clearing strategy may involve removal of merchantable timber, piling and burning of slash and debris, cutting and floating, topsoil stripping, etc. A selective clearing strategy often requires manual clearing since heavy mechanical equipment can be impractical in this situation. A complete clearing requirement is often more conducive to the use of heavy mechanical equipment.

(b) Physical Constraints

These will include accessibility to the reservoir site, terrain characteristics (e.g. swamps, bogs, slope steepness) and density of forest stands.

(c) Identification of Archeological Sites

Where these are identified, manual clearing is usually employed to facilitate excavation of a site. Following archeological investigations, it may then be desirable to utilize heavy mechanical equipment.

(d) Economics

Economic feasibility should reflect capital investment, labor requirements, return on merchantable timber, scale of clearing operation and schedule in terms of time required to clear the reservoir.

The environmental and economic criteria affecting selection of a reservoir clearing method is summarized in Figure 5.1. It is emphasized that while one criterion may indicate that hand or machine clearing is clearly preferred, it is important to consider all criteria before making a decision on the method to be used. It may be that a combination of hand and machine clearing methods is the most practical approach.

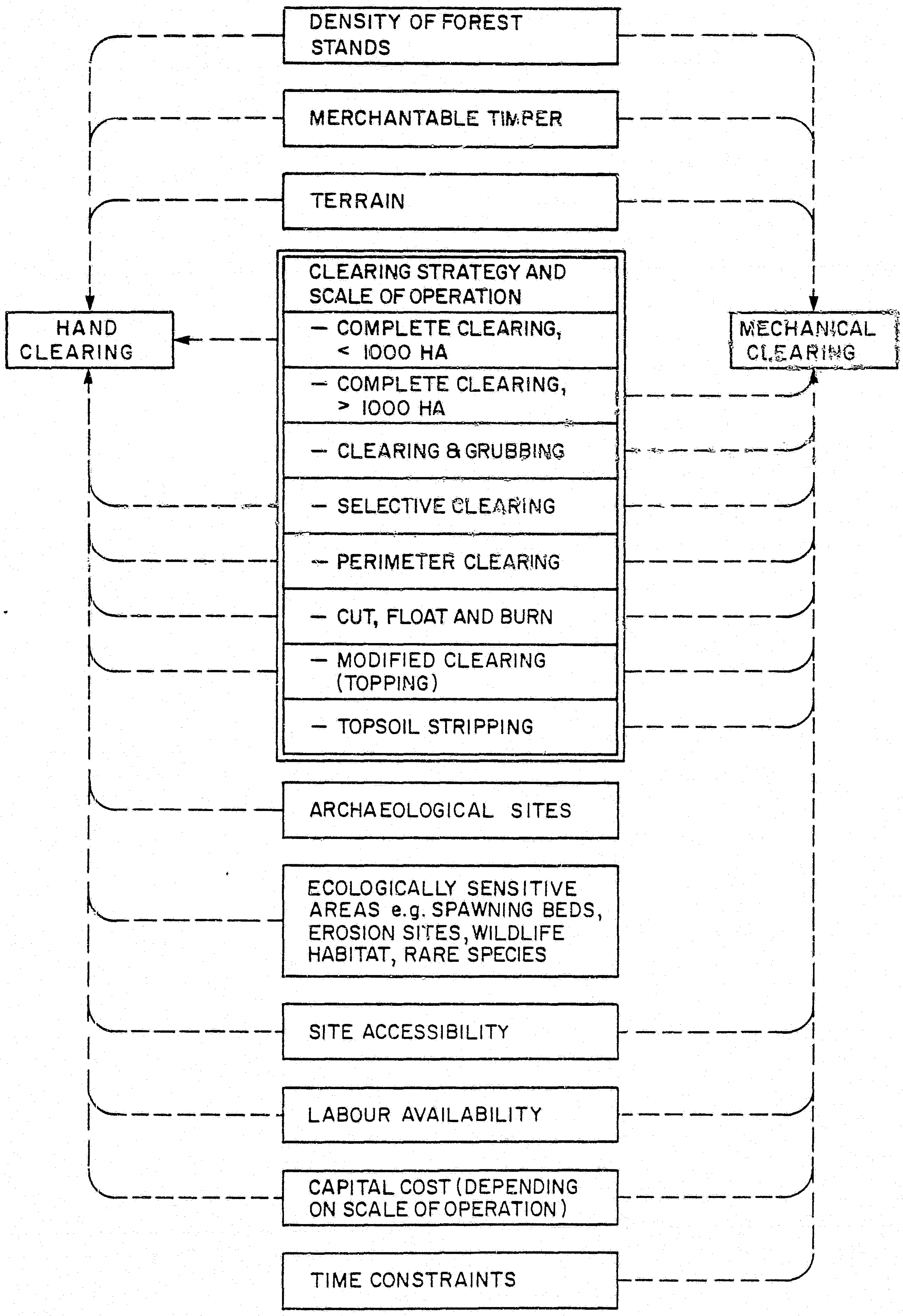


FIG. 5.1

ENVIRONMENTAL AND ECONOMIC CRITERIA
AFFECTING SELECTION OF A RESERVOIR CLEARING METHOD

ACRES

6 - DERIVING A SITE SPECIFIC STRATEGY

In the Introduction an overall process was put forward, by which a clearing strategy could be derived for a given reservoir. Having presented the background material for this process in Sections 2 to 5, this process is now elaborated below.

6.1 - Model Development

The term "model" in this context is simply the structuring of the decision factors and input requirements for the reservoir under considerations. It involves the first 4 boxes in the logic diagram presented in Figure 6.1.

1 - Description of Baseline

The system in which the reservoir will be created, must be described and understood. From this, the physical properties of the reservoir can be predicted. The project objective - power generation - forms part of this baseline so that reservoir operational limitations must be described.

2 - Definition of Constraints

Using the baseline data, constraints to secondary uses are defined. This includes topographic, social and economic, biological, physico-chemical features, as well as legal and jurisdictional limitations, etc, that can eliminate or restrict secondary uses.

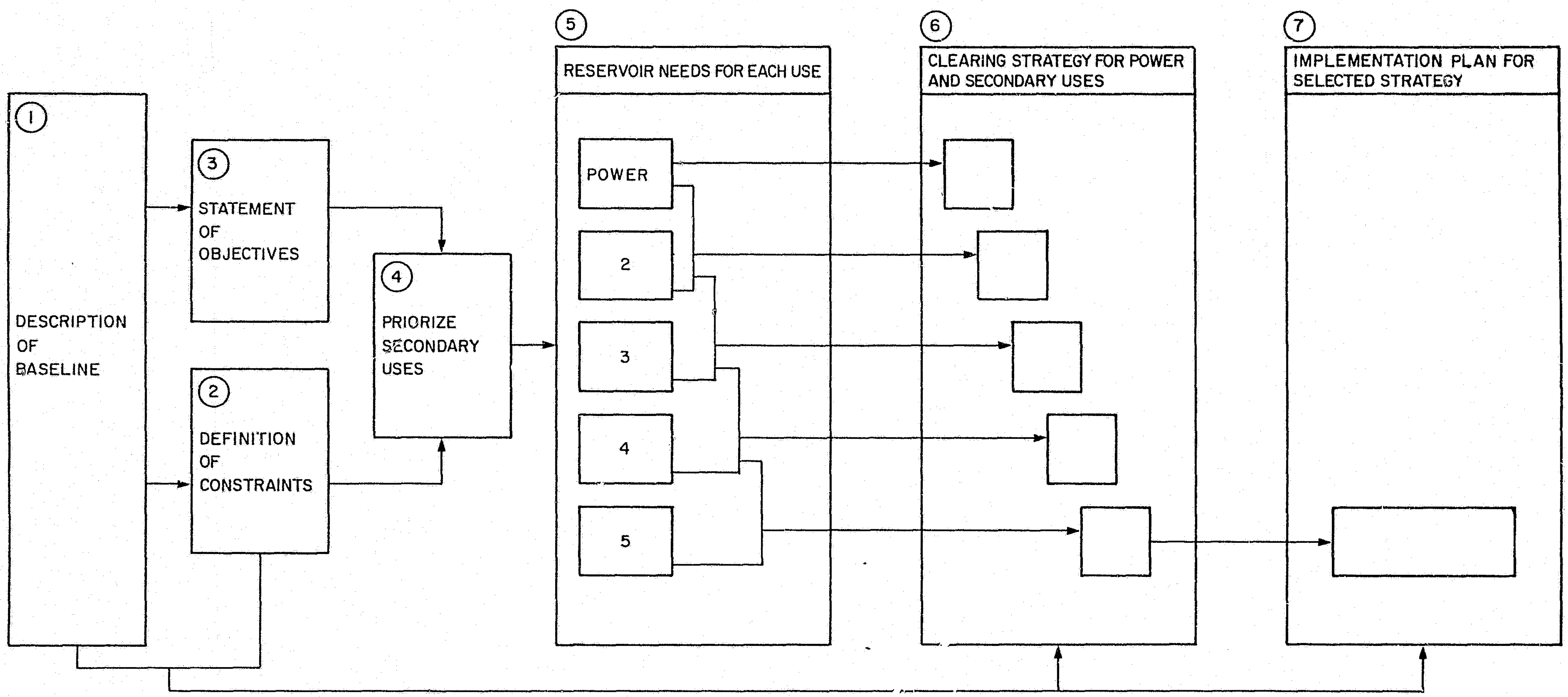


Fig 6.1

ONTARIO HYDRO
RESERVOIR CLEARING & PREPARATION – ENVIRONMENTAL PROTECTION STRATEGIES
RESERVOIR CLEARING DECISION FRAMEWORK

3 - Statement of Objectives

Through discussion with MNR, local people, and whoever else may fruitfully contribute to, or be affected by the decision, the secondary needs the reservoir may fill, over and above the primary power producing goal, are derived. The aim is to include only those uses which have a reasonable probability of success. This selection has three components

- anticipated regional or local needs
- area constraints and limitations
- compatibility with hydro power generation

4 - Priorize Secondary Uses

Having assembled a list of possible secondary uses, rank these, placing those deemed most desirable at the top. Uses for immediate implementation should rank above those which, although not required at the present time, may become so at some future date (i.e. those options which are not to be specifically excluded or foreclosed).

These first 4 steps are executed without specific consideration of reservoir clearing needs per se. Reservoir preparation is a tool. The clearing strategy finally derived is designed to meet projected needs not vice-versa.

6.2 - Decision Framework

The remainder of the decision process depicted in Figure 6.1 relates to reservoir clearing specifically. Having established and ranked secondary uses (objectives) for the reservoir.

5 - For each reservoir use, describe those reservoir characteristics (needs) for which reservoir preparation can be seen to be an assisting tool. Start with the primary objective of power production. This is in fact, the base case - the minimum and absolute need. The remainder of the decision process is premised on this point.

6 - Examine the possible approaches to reservoir preparation (Section 3.2) and outline what strategy or combination thereof, would best meet the power-producing goals of this specific reservoir. Then progressively incorporate each of the secondary uses and see how their reservoir needs alter the strategy. The Use 1 (power) plus Use 2 combination produces a new strategy. This is then revised to incorporte the needs of Use 3, etc. When completed, there will be list of ranked use combinations with associated strategies for each. This list is reviewed. Some cutoff must be selected, i.e., in the illustrated example in Figure 6.1, there are 4 secondary uses depicted. In view of the clearing requirements, should all 4 be retained, or some lesser number?

7 - Whichever level is decided on, an implementation plan is outlined to execute the indicated strategy. There is more than one way to "skin the cat". Economics, logistics, site constraints, etc, will be used to determine which methods will best serve for any given reservoir.

Some Points of Consideration

Having briefly reviewed the decision framework as presented, there are some points which warrant expansion.

- Because of the many variables involved, a reservoir clearing selection methodology cannot be generated that will tell the operator precisely what to do for a specific reservoir.

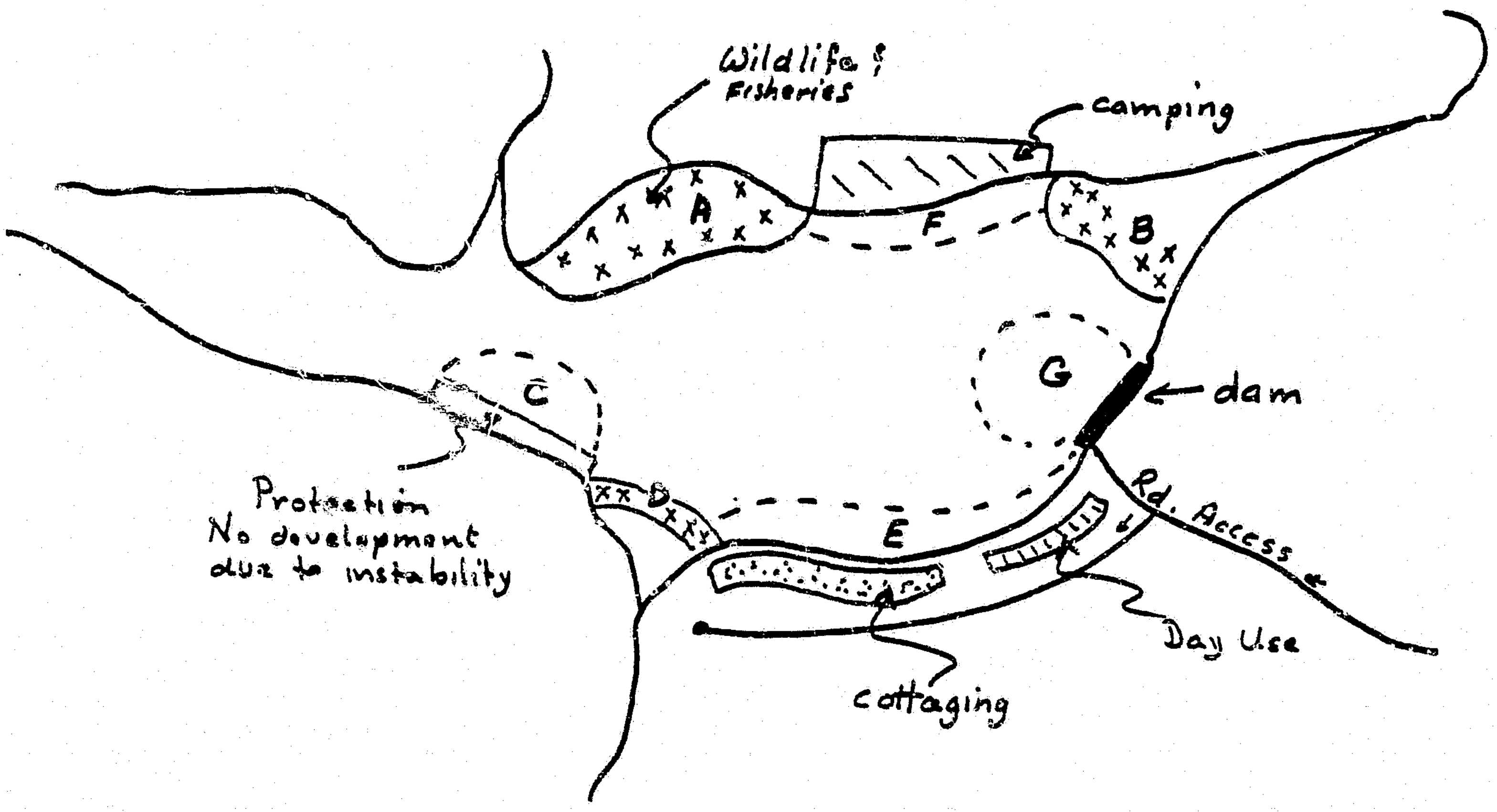
- Many subjective decisions must be made, particularly in the model development where reservoir objectives are laid down.

- The premise upon, which this framework is built, is that the hydropower objective is unquestionably first and that and other uses remain secondary and that it is indeed possible to rank the secondary uses in order of priority.

- Some secondary uses such as flood control and irrigation are completely compatible with storage for power generation (re: reservoir preparation). Other uses vary to differing degrees. More conflicts arise between secondary uses in some cases, than with power generation. For example, high intensity recreational usage and wildlife enhancement are rarely compatible. These conflicts should be identified in the selection and ranking phase.

- The only uses for which a reservoir can be viewed holistically are power, flood control, irrigation and domestic water supply. For other uses, the reservoir can and should be subdivided, with clearing treatment designed for each section according to its designated use. Many of the apparent conflicts between uses, can thus be resolved through separation.

- Step 6 - selection of strategies - would probably involve the preparation of a reservoir management plan showing where specific shoreline developments could take place and what level of clearing effort should be used for that purpose, e.g.



- Removal of deadfall throughout reservoir and shoreline back 2 m above TWL.

- Select cut and remove softwoods below TWL.

- Topping to designated elevation except in zones A, B, C, and D.

- All clearing roads below bottom operating level except as shown.

- Complete clearing and grubbing zones E, F, and G.

- The design of an implementation plan should be reserved for that single overall strategy finally selected e.g. the decision as to whether to burn or to haul material away from the reservoir is relevant to implementation in fact - not to strategy. As long as the material is removed, the strategy requirements are met. If it is logistically or economically impossible or environmentally too disruptive to haul - burning may be the only way to dispose of unwanted material. Decisions of this sort should be deferred to the implentation phase and as there will be many of them - it would only "make work" to go through the process for more than one strategy.

- Economics - the actual cost of clearing is included directly only in the selection of an implementation plan. If the best way to implement a strategy from all other viewpoints turns out to be exorbitantly expensive, a different strategy (i.e., lower level or different combination of uses) may have to be considered. In other words, one may have to retrace some steps.

7 - CONCLUSIONS AND RECOMMENDATIONS

This study has been an overview exercise aimed at examining all aspects of the reservoir clearing question. In so doing, it has become apparent that there is much conflicting evidence reported both in the literature and by power utilities, regarding the effectiveness and impacts of different reservoir preparation strategies. Some of the problems attributed to lack of clearing in some reservoirs may in fact be functions of other factors upon which the level of preimpoundment preparation could have little influence. Likewise some of the apparent successes could well be a function of good luck rather than good planning. The supporting science is lacking as are complete reservoir case histories involving direct assessment of reservoir clearing practices.

Nevertheless, the major issues, clearing strategies available, and criteria used in deriving site specific approaches to preimpoundment preparation have been addressed. Nearly a hundred reservoir case histories have been reviewed. Hundreds of literature references have been searched for relevant material and a framework for decisionmaking, is put forward.

The many variables that can affect and be affected by, reservoir clearing practices made it impossible to devise within the scope of this study, a detailed clearing selection manual. Indeed, several aspects require considerable further work before such an undertaking can even be considered.

Major deficiencies in the data are seen to be as follows.

(a) No detailed approach or guidelines are available in Canada for reservoir clearing. Brief guidelines are available for MNR reservoirs and those reservoirs proposed by Newfoundland and Labrador Hydro. In the USA the US Army Corps of Engineers also has a brief set of guidelines.

(b) There has been little or no monitoring of environmental effects of alternative clearing strategies. Only reservoirs constructed in the last 10 years have been monitored on a continuing basis. Much of the environmental monitoring currently carried out concentrates on water quality/fisheries effects as a result of reservoir configuration (surface area, volume depth, drawdown) and changes in stream flows. Specific effects of clearing strategies are rarely documented.

(c) There is a lack of cost data for alternative clearing strategies. A good set of cost data were available for general clearing and burning operations but not for other strategies such as cut and float, stump removal, topsoil stripping, prescribed burning of all vegetative material, and modified clearing (topping). Comparative costs for post-flood clearing were not available for underwater clearing and reservoir sweeping in relation to preflood clearing strategies utilized.

Recommendations

(a) Detailed Examination of Erosion/ Bank Stability Question

An understanding of the complex interrelations between erosion, bank stability and vegetation are fundamental to the design of a reservoir clearing strategy. Every soil type behaves differently in a given set of conditions and it was outside the scope of this program to analyze all the variables of importance. This particular aspect more than any other, requires detailed investigation. Field measurements and possibly experimentation will be required to quantify rates of erosion, revegetation possibilities and status of existing reservoirs.

(b) Monitoring of Environmental Effects of Clearing

The lack of information regarding the impacts of various clearing strategies was evident from this survey. In future, this documentation should be sought. It can be accomplished during regular post-flood monitoring but should clearly distinguish, wherever possible, between the effects of clearing and inundation and subsequent operation of the reservoir. The post-clearing analysis should include an evaluation of any mitigative measures such as revegetation of banks and construction of protective works, as well as general effects of the clearing strategy on the local environment, i.e., fisheries, water quality, wildlife habitat and distribution, social/cultural opportunities, recreation, navigation, and aesthetics.

(c) Long-Term Debris Problems

In many of the reservoir case histories, the surfacing of tree-length debris was reported as a continuing problem. The mechanisms whereby flooded material is released to the surface, should be clarified. Some speculation was put forward in this report but as there is a continuing economic expenditure, not to mention the potential hazard, generated by this phenomenon, it deserves further attention. In situ examination of floating debris should be carried out to determine the controlling factors.

(d) Cost Analysis for Alternative Clearing Strategies

Comparative cost analyses for different clearing strategies or a given reservoir have not until recently, been reported. In future the presentation of these comparative costs should be encouraged as they are very useful in assessing future reservoir clearing options.

(e) Preparation of a Detailed Guideline for Assessing Reservoir Clearing Requirements

The decision framework developed from this study is a general one, based on general information collected in an overview capacity. With some infilling of the data gaps already identified, a more detailed guideline for the selection of appropriate clearing strategies and implementation plans, should be formulated.

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APPENDIX A

CASE HISTORIES OF RESERVOIR CLEARING PRACTICES IN CANADA AND THE UNITED STATES

NOTES RE APPENDIX A - CASE HISTORIES

The table in this appendix provides a record of clearing practices for 80 reservoirs in Canada and 12 in the United States. All reservoirs listed are in the temperate region of North America with the exception of reservoirs operated by the Tennessee Valley Authority. Much of this information was obtained from a previous reference (Efford, 1975) and through discussions with utilities and government agencies.

During the survey it was discovered that documentation was usually available on clearing strategies but follow-up studies on the environmental effects of clearing or not clearing were not undertaken except for recent projects. As a consequence, the environmental effects are documented only for 50 of the 92 reservoirs listed, although predictions are being made or studies are currently underway for an additional 10 reservoirs as specified in the table. One of the difficulties in reviewing the environmental documentation that was available was that on many occasions it was not clear whether the effects resulted from clearing or flooding of the reservoir or a combination of both.

Prior to the 1950's the trend was toward no clearing, particularly in remote areas (especially north of N60° latitude) and where the reservoir site encompassed a particularly large area. Clearing and burning was carried out only where the reservoir area could accommodate hand tools (e.g., small stands of timber, flat areas, small reservoir sites). With increased mechanization and more emphasis on recreation, the trend moved toward complete clearing of many reservoirs in the 1960's. In the 1980's the trend appears to be reversing. For remote areas of Canada the no clearing option has been recommended recently (Lower Churchill River project, Labrador) where there is little recreational value and since no significant long-term adverse impacts are expected to the aquatic ecosystem.

In more southerly locales of Canada where recreational and commercial interests are of more importance, the trend is often toward selective clearing to alleviate environmental, socioeconomic and aesthetic concerns as much as possible.

In addition to the references noted in Appendix A, information from the following utilities and government agencies is gratefully acknowledged:

- B. C. Hydro
- Grand River Conservation Authority
- Great Lakes Power
- Hamilton Region Conservation Authority
- Hydro Quebec
- New Brunswick Power
- Newfoundland and Labrador Hydro
- Northern Canada Power Commission
- Ontario Hydro
- Tennessee Valley Authority
- TransAlta Utilities
- U.S. Army Corps of Engineers (Walla Walla and Seattle, Washington; Waltham, Massachusetts).

APPENDIX A

CASE HISTORIES OF CLEARING PRACTICES IN CANADA AND THE UNITED STATES

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Newfoundland (170 km southwest of Gander)	Upper Salmon (1982?)*	Hydro, recreation	11 100	Selective clearing and salvage of merchantable timber	Recreational potential; caribou migration routes	Reservoir not filled as of October 1981
Newfoundland (Great Northern Peninsula)	Cat Arm (198_)	Hydro, recreation	5 300	Selective clearing; salvage of merchantable timber in entire reservoir zone; small trees protruding into drawdown zone removed by ice	Rugged, rocky terrain, site remoteness, availability of labor	Predict floating debris after flooding will create recreational hazard (Hunter and Associates, 1980)
Newfoundland (West central)	Hinds Lake (1980)	Hydro, recreation		Complete clearing of all woody vegetation taller than 1 m within impoundment zone, extending 2 m above full supply level. Merchantable timber salvaged; remaining vegetation piled and burned	Wet slash (due to machine handling) made burning difficult; forest fire started during burning of slash in summer of 1979	Project not complete as of September 1980
Newfoundland (Western)	Grand Lake (1925)	Hydro	49 210	No clearing		Impacts on water quality, fisheries or aquatic furbearers not noticeable. Local residents harvested firewood and pulpwood from reservoir zone for

*Approximate date of flooding

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Newfoundland (Western) (contd)						8 to 10 years after flooding (wood was still sound and saleable) [Hunter and Associates (1980)]
Newfoundland (Labrador) (Lower Churchill River)	Muskrat Falls/ Gull Island (198_)	Hydropower		No clearing recommended except at dams and confluence of tributaries (prospects of recreational activities remote)	No road access in merchantable timber areas; steep slopes; merchantable timber recovery uneconomical	Construction of reservoir not commenced as of 1981. Predict no significant effect on water quality, fish on other acquatic organisms. Anticipate slumping of banks due to sandy/silty valley. Clearing of debris required over 5-yr period at 1,100/ha* (Proctor and Redfern, 1980).
Newfoundland (Labrador) (53 - 55°N Lat/ 63 - 66°W Long)	Smallwood (1971)	Hydro; potential for commercial/ sport fishery	569 818	No clearing except around civil works. Approximately 2,600 km^2 of taiga, low bogland and spruce forest were flooded	Bogs, noncontinuous permafrost zone, cost of clearing	Changes in water quality slight (LCDC, 1980). Little evidence of trophic upsurge following flooding (Duthie and Ostrofsky, 1974) but removal of some spawning beds and habitat. Low levels of dissolved nutrients but shallowness compensates resulting in good fishery (Bruce, 1974)

*1981 dollars

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 3

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Newfoundland (South central)	Bay D'Espoir (1968)	Hydro	66 500	No clearing based on economics and limited use for recreation. Subsequent limited selective clearing at low water level by cutting tree tops standing above ice	Primarily economics	Impacts based on evaluation 7 years after flooding: - no major differences in water quality, phytoplankton, zoo-plankton, or fishery - poor reservoir aesthetics due to drowned forest - recreational activities hazardous (Airphoto/Beak, 1976; Emberley et al, 1974)
Nova Scotia (northeast Cape Breton)	Wreck Cove reservoirs (6) (1978)	Hydro, recreation	2 489	Complete clearing with chain saws and burning of slash in reservoir zone. Clearing to 3 m above high water level. Merchantable timber salvaged	Difficulty with slash burning due to high humidity and precipitation. Fire control also a problem. Cost of harvesting exceeded market value	Significant change in water quality in Surge Lake (lowest lake in chain) and moderate change in remaining lakes after 2-1/2 years monitoring. Relative rates and amounts of revegetation of exposed soils key factors in changes in water quality (Kelly et al, 1980)
Nova Scotia (Mersey River)	Lake Rosignol (1928/29)	Hydro	17 600	No clearing except for some merchantable timber	Isolated area	Water quality appears good. Problem with floating debris

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
New Brunswick (Tobique River)	Sisson Branch (1952)	Hydro, sport fishery	1 345	No clearing	Remote area with no road access	Water quality monitored 28 years following flooding. Well buffered reservoir with high potential productivity. Reservoir supports brook trout, land-locked salmon and rainbow smelt (NB Environment, 1981)
New Brunswick (Saint John River)	Mactaquac (1968)	Hydro, boating, swimming, sport fishery	8 347	Complete clearing using cut and burn method	Steep slopes	
New Brunswick (Saint John River)	Beechwood (1957)	Hydro, recreation (boating)	1 157	Complete clearing using cut and burn method	Steep slopes	
New Brunswick (Saint John River)	Grand Falls (1929)	Hydro, recreation (boating)	1 421	Complete clearing using cut and burn method	Steep slopes	Water quality varies only with upstream inflow
New Brunswick (Tobique River)	Tobique Narrows	Hydro, boating, fishing	415	Complete clearing using cut and burn method	Steep slopes	No data
New Brunswick (Tobique River)	Trousers Lake (1952)	Hydro, sport fishery (brook trout)	1 007	No clearing	Remote area with no road access	Poorly buffered humic lake with low potential productivity

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 5

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
New Brunswick (Tobique River)	Serpentine Lake (1953)	Hydro storage, sport fishery	495	No clearing	Remote area with no road access	Poorly buffered humic lake with low potential productivity
New Brunswick (Tobique River)	Long Lake (1952)	Hydro, sport fishery (trout)	910	Completely cleared and burned	Poor road access; site remoteness	Poorly buffered humic lake with low potential productivity
Quebec (east of James Bay)	LG2 (1979)	Hydro	401 450	Only 1 percent of total reservoir area cleared (forested lands of little commercial value). Clearing of access ramps at fishing sites and areas suitable for spawning at mouth of tributaries (Therrien-Bolullo, 1980)	Remoteness; inaccessibility	Negligible changes in physical/chemical conditions and chlorophyll pigments after filling. Slight mineralization after second winter. Increase in zooplankton biomass after flooding. Increase in fish captures in 1979 in La Grande River but then returned to capture levels of 1977/1978. Appearance of drowned forest expected for many decades (Societe d'energie de la Baie James, 1980; Environment Canada, 1975)

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Quebec (east of James Bay)	Desaulnier (1977)	Hydro		Minimal selective clearing (forested lands of little commercial value)	Remoteness; inaccessibility	Extreme changes in physical/chemical conditions and then stabilization. Almost reached benthic state of equilibrium in fourth year after flooding. Fish production increased; results particularly elevated in 1980 for certain principal species (see reference above)
Quebec (east of James Bay)	Opinaca	Hydro	130 795	Minimal selective clearing (forested lands of little commercial value)	Remoteness; inaccessibility	Some variation in physical/chemical conditions but generally insignificant. Zooplankton stayed same from year to year. Little mineralization and poor in nutrients (Societe d'energe de la Baie James, 1980; Environment Canada, 1975)

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 7

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Quebec (Cote Nord)	Manic 3	Hydro	20 720	Perimeter clearing from 3 m below full supply level to 1.5 m above FSL. Topping of trees in bottom of reservoir. Merchantable timber previously recovered	Cost of clearing versus timber market value	No floating timber. Shoreline colonized by shrubs and herbaceous vegetation. Abundant waterfowl populations. Little change in water quality
Quebec (north shore St. Lawrence -Baie Comeau)	Manic 5 (1970)	Hydro	195 027	Approximately 15 percent of merchantable timber harvested; remainder not cleared before flooding		
Quebec (north shore St. Lawrence -Labrieville)	Bersimis 1 (1956)	Hydro	79 254	Merchantable timber recovered; partial clearing before flooding		
Quebec (Cote Nord)	Outardes 2	Hydro	3 969	Clearing from former water level to 1.5 m above full supply level. Merchantable timber partially recovered. Debris buried or burned	Cost of clearing versus timber market value	Floating debris recovered and burned. No floating timber now. Shoreline colonized by shrubs and herbaceous vegetation. Abundant waterfowl population. Little change in water quality
Quebec (Cote Nord)	Outards 3	Hydro	1 235	Complete clearing to 1.5 m above full supply level. Timber left on site	Not economic to recover timber	Floating timber. Shoreline vegetation relatively scarce; some high shrubs. Associated waterfowl scarce. Little change in water quality

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 8

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Quebec (north shore St. Lawrence -Baie Comeau)	Outardes 4 (1969)	Hydro	65 268	Approximately 20 percent of merchantable timber cut; remainder not cleared		
Quebec (south central -Maurice)	Beaumont (1958)	Hydro	440	Approximately 200 ha cleared before flooding		
Quebec (south central -Maurice)	Rapide Blanc (1934)	Hydro	8 288	Approximately 4,150 ha cleared before flooding		
Ontario (Spanish River)	Inco Head Pond (198_)	Hydro, recreation	Approx. 4 500	Perimeter clearing to 3 m above high water level and 7 m below high water level. Slash and debris to be piled and burned; stumps 10 cm. Merchantable timber to be harvested where economical	Low density of forest stands; rough terrain; high road construction costs	Predict temporary disturbance to fish due to increased sedimentation of habitat. Minimal changes in water quality expected. Initial trophic surge in reservoir expected to peak in 3 to 5 years with stabilization in about 10 years (Acres, 1978)
Ontario (Muskoka District)	Lake Orillia (1948/49)	Hydro, recreation	2 590	Completely cleared; no stumps removed. Merchantable timber logged, and small trees burned		Good fishing and general recreational capability

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 9

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Ontario (Montreal and Michipicoten rivers)	Great Lakes Power reservoirs (8)	Hydro, recreation	9 638 (total)	Hand clearing and burning to 1 m above high water level, 46-cm high stumps left. Merchantable timber salvaged		Improved boating and fishing opportunities
Ontario (Timiskaming District)	Lower Notch (1971)	Hydro	1 256	Completely cleared before flooding		
Ontario (junction of Madawaska and Ottawa rivers)	Arnprior	Hydro	931	Clearing to high water level. Merchantable timber salvaged. Stump heights 10 cm except in bottom of reservoir where they are 30 to 45 cm		Riprap bank protection required in sensitive areas along shoreline
Ontario (Cochrane District)	Otter Rapids (1961)	Hydro	932	Complete clearing before flooding		
Ontario (Renfrew District)	Centennial Lake (1967)	Hydro	3 445	Complete clearing before flooding (similar to specifications for Arnprior)		Good angling potential
Ontario (Algoma District)	Aubrey Falls (1969)	Hydro, recreation (boating, fishing)	2 217	Complete clearing to 3 m above high water level before flooding		Good fishing
Ontario (Cochrane District)	Harmon (1965)	Hydro	251	Complete clearing before flooding		

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Ontario (Cochrane District)	Kipling (1966)	Hydro	142	Complete clearing before flooding		
Ontario (Cochrane District)	Little Long (1963)	Hydro	7 615	Complete clearing before flooding		
Ontario (Hamilton Region)	Christie (1972)	Flood control, recreation, irrigation, low flow augmentation	60	Clearing and slash burning to recreation level. Recreation surface cleared and excavated to bedrock (0 to 2 m of muck soil)	Little merchantable timber	Excavation improved water quality and increased reservoir capacity. Algal blooms not a problem. No continuing maintenance. Some islands created for wood ducks
Ontario (Hamilton Region)	Valens (1966)	Flood control, recreation (swimming, boating, fishing), low flow augmentation	76	26 ha cleared of bush; upper 8 ha left standing in water as habitat on advice of MNR wildlife personnel; remainder wet pasture. Limited burning of slash, remainder left	Limited funds for complete clearing. Difficult road access in muck soils	Nonremoval of slash and muck soils contributed to reservoir nutrients causing large algal blooms and poor water quality in early years. Trend reversed with 5 years (1970-1975) of destratification. Water quality now good
Ontario (Grand River)	Guelph (1976)	Flood control, low flow augmentation, recreation	445	Clearing of trees and stumps		Water quality similar to inflow characteristics
Ontario (Spanish River)	Agnew Lake (1920's)	Hydro, recreation		No clearing		Good boating and fishing, only a few floating stumps, aesthetics excellent

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 11

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Ontario (Grand River)	Conestogo (1958)	Flood control, low flow augmentation, recreation	735	Clearing to stump level; stumps removed as they floated to surface or after drawdown when easier to extract		Water quality similar to inflow characteristics
Ontario (Grand River)	Belwood (1940's)	Flood control, low flow augmentation, recreation	758	Clearing to stump level; stumps removed as they floated to surface or after drawdown when easier to extract		Water quality similar to inflow characteristics
Ontario ( )	Marmion Lake	Hydro, recreation		No clearing		
Manitoba (Nelson River)	Kettle Rapids (1970)	Hydro	33 722	285 ha of forebay area cleared; rest uncleared before flooding		
Manitoba	Southern Indian Lake	Hydro, potential commercial fishery		Hand and machine clearing of selected sites; replacement of riparian vegetation with more preferred wildlife habitat at selected sites		
Manitoba (northern)	Rat-Notigi	Hydro, recreation		Hand and machine clearing of channel areas; cut and float in some areas; trees <5 cm diameter inundated		

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 12

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Manitoba (northern)	Burntwood	Hydro		Selective clearing of coniferous and deciduous trees less tolerant to flooding; willows and cottonwood left standing to enhance soil stability and provide wildlife habitat. Clearing boundary 0.6 m above high water level		
Manitoba (Nelson River)	Long Spruce (1977)	Hydro	2 383	Completely cleared before flooding		
Manitoba (Saskatchewan River)	Cedar Lake (1965)	Hydro	349 391	5,232 ha of forebays cleared; rest uncleared before flooding		
Manitoba (Nelson River)	Kelsey (1960)	Hydro	70 785	<26 ha of forebay cleared; rest uncleared before flooding		
Saskatchewan (Saskatchewan River)	Tobin Lake (1963)	Hydro	30 044	Merchantable timber removed. Other tree growth cut but burning unsuccessful		Floating material requires continuous removal
Saskatchewan (South Saskatchewan River)	Lake Diefenbaker (1968)	Hydro, Irrigation	42 994	Completely cleared of trees and brush before filling		

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 13

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Alberta (Brazeau River)	Brazeau (1965)	Hydro, limited recreation	4 533	No clearing except near diversion structure and reservoir outlet works. Subsequent clearing in visible areas by cutting from winter ice, clearing after drawdown and reservoir sweeping	Soil composition; road access; clearing cost judged to exceed recreational value	Water quality adequate; bank erosion not a problem. High maintenance costs for floating debris. Debris is problem to hunters, fishermen and boaters
Alberta (North Saskatchewan)	Bighorn (1971)	Hydro, campsites	5 569	Complete clearing and grubbing before flooding	Minimal	Water quality outflow similar to natural flow; erodible banks due to lack of tree protection; suspended glacial silt imparts aquamarine coloring; boating hazardous due to high winds
Alberta (Kananaskis River)	Upper Kananaskis Lake (1933)	Hydro, recreation (fishing, boating, hiking)	868	Hand clearing and burning	Accessibility; steep, rocky terrain, excessive snowpack; strong winds, timber deterioration	Clear and potable water; tree stumps a problem from erosion along shoreline
Alberta (Bow River)	Bearspaw Forebay (1952)	Hydro, recreation (boating)	251	Hand clearing and burning		

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Alberta (Bow River)	Ghost (approx 1927)	Hydro, recreation (boating, skating)	1 155	Probably hand cleared and burned; few trees, primarily open grassland		
Alberta (Kananaskis River)	Barrier (1946)	Hydro, recreation (fishing, boating)	308	Hand clearing and burning	No merchantable timber	Eutrophic conditions due to leaf litter on reservoir bottom. Silt in spring runoff of 1948 buried litter and oligotrophic species became dominant (Nursall, 1952)
Alberta (Cascade River, Banff National Park)	Lake Minnewanka (1941)	Hydro, recreation (fishing, boating, camping, scuba diving)	2 226	Hand clearing and burning; grubbing in upper drawdown zone	Accessibility; park restrictions; economics of timber salvage	Water is clear and green; shoreline is tidy. Little change in physical/chemical conditions after flooding. Initial decrease in benthic organisms. Size of lake trout reduced after separation from whitefish prey (Cuerrier, 1954)
Alberta (Kananaskis River)	Lower Lake Kananaskis (1955)	Hydro, recreation (boating, fishing)	646	Hand clearing and burning; merchantable timber salvaged for cribwork during construction	No significant constraints	No adverse effects on water quality reported

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Case Histories of Clearing Practices
in Canada and the United States - 15

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Alberta (Spray River)	Spray Lake (1950)	Hydro, recreation (boating, fishing)	2 006	Hand clearing and burning; machine clearing in flat areas; some waste piles buried below low supply level; stump height 30 cm	Accessibility and steep slopes, limited merchantable timber salvage	Trout fishery suffered from inundation of spawning beds; tree stumps are problem to boaters and fishermen
British Columbia (Revelstoke)	Revelstoke (1983)	Hydro, recreation	11 534	Clearing entire reservoir from low to high water level. Burning except in inaccessible areas where wood is floated	Steep slopes	Environmental studies under way and mitigation measures undertaken
British Columbia (north of Revelstoke)	Kinbasket Lake (Mica Dam) (1972)	Hydro, recreation (fishing, boating and camping)	43 181	Selective clearing and burning. Low water level exposes shoreline of tree stumps and other debris. Debris disposal still under way and to be completed by 1985.	Steep slopes (mountainous)	Extensive debris accumulation expected to continue for 6 to 10 years. Waterfowl habitat limited by deep water, few marshlands and fluctuating water levels. Logging in area due to availability of reservoir to float timber.
British Columbia (between Revelstoke and Trail)	Arrow Lakes (1969)	Flood control, power storage for U.S.A., recreation	51 802	Complete clearing and stump removal	Mountainous with some agriculture along old valley; three villages relocated	Bank slumping seeding of drawdown areas in low water years. Water fowl habitat poor due to lack of marshland, deep water and heavy drawdowns. Shoreline areas important for ungulates

Appendix A
Case Histories of Clearing Practices
in Canada and the United States - 16

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
British Columbia (Peace River)	Williston Lake (Bennett Dam) (1967)	Hydro, recreation	177 259	Cut and float above low water. Debris clearing to 1984. Total maintenance costs estimated at $46.2 million	Remote area; poor access	Slumping of banks. Good fishing with potential for enhancement of fish stocks. Shoreline important for ungulates. Boating and fishing hazards from floating debris
British Columbia (north of Kalso)	Duncan Lake (1967)	Flood control, storage for downstream power, recreation (boating, fishing)	7 163	Downstream portion cleared between high and low water level. Upper portion boomed off and eventually cleared. Standing timber in drawdown area cleared	Inaccessible and remote	Debris no longer a problem. Loss of spawning areas; new spawning areas restricted; reservoir supports many ungulates and large furbearers. Waterfowl habitat restricted due to deep water, little marshland and extensive drawdown
British Columbia (Cheakamus River)	Daisy Lake (1957)	Hydro	425	Complete clearing		
British Columbia (Bridge River)	Carpenter Lake (1960)	Hydro	4 920	No clearing before flooding. Clearing of reservoir margins during drawdown. Floating debris boomed and burned.		

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Case Histories of Clearing Practices
in Canada and the United States - 17

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
British Columbia (Jordan River)	Bear diversion (1913) Elliot Lake (1971)	Hydro		No clearing before flooding; reservoir to be completely cleared after flooding		
British Columbia (Campbell River)	Buttle Lake (1958)	Hydro		Cleared to ground level and burned before flooding		No major changes in water quality. Draw-down zone became little more than large, sterile gravel bar as a result of wave action and erosion. Absence of amphipods associated with disappearance of rooted aquatic plants (Sinclair, 1965)
British Columbia (Campbell River)	Lower Campbell Lake (1949)	Hydro	2 590	Clearing of large trees around lake; secondary growth left to decay and beakdown under water		No major changes in water quality. Erosion less serious than Buttle Lake because zone of regulation not completely ________ of vegetation (Sinclair 1965)
British Columbia (Stave River)	Hayward Lake (1930)	Hydro	297	No clearing before flooding - underwater clearing still carried out		
Yukon	Canyon Lake	Hydro, recreation	890	Perimeter clearing of of 24 ha		

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Yukon	Aishihik Lake	Hydro, recreation	15 379	No clearing		Bank erosion and adverse effect on fish primarily a result of drawdown and flooding
Yukon	Wareham Lake	Hydro	368	No clearing		
Yukon	Marsh Lake	Hydro	50 020	No clearing		
N.W.T.	Big Spruce Lake	Hydro	12 950	No clearing		
Yukon	Mayo Lake	Hydro	10 320	No clearing		
N.W.T.	Nonacho Lake	Hydro	89 439	No clearing		
Idaho (Orofino)	Dworshak	Flood control, hydro, recreation	6 644	Perimeter clearing; timber in bottom of reservoir left standing	Very steep, no access roads	

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Case Histories of Clearing Practices
in Canada and the United States - 19

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
British Columbia/ Montana (Kootenay River)	Lake Koocanusa (Libby Dam) (1976?)	Hydro, flood control, recreation, navigation	18 818	In Canada Complete clearing and burning In USA Removal of merchantable timber prior to perimeter clearing to 1 m above maximum pool and 1.5 m below 10-yr frequency low pool. Trees topped in reservoir bottom and floatable material removed.	Steep forest-covered mountains; relocation of railroad and highway	Impacts relate primarily to flooding of reservoir and changes in river flows rather than clearing; also affected by chemical wastes from upstream smelter, fertilizer plant and pulpmill.
Maine (St. John River)	Lincoln School Lake (198_?)	Hydro, recreation (fishing)	1 060	Recommend complete clearing to 0 to 1 m above high water level	Archaeological sites	Reservoir not cleared as of 1981. Anticipated effects: reservoir should support marginal cold-water sport fishery; sedimentation not expected to be a problem; zooplankton and benthic pops should be high; mercury not expected to exceed natural conditions

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Maine (St. John River)	Dickey Lake (198_?)	Hydro, recreation	34 814	Perimeter clearing plus complete clearing within 1.6 km of main dam structure or primary public use area; log boom to be placed 120 to 180 m upstream of forebay	Archaeological sites; relocation of 162 families	Reservoir not cleared as of 1981. Expect short-term enrichment and anaerobic condition in lake bottom. Expect chemical stablity in 6 to 9 years. Mercury may be a problem. Navigation hazards from debris
Colorado (Fryingpan River)	Ruidi (1969)	Flood control, recreation, municipal/ industrial use, irrigation	400	Clearing by chain saws and D6B tractor with brush rake. Winch lines used to pull trees down steep slopes. Burning as prescribed by US Forest Service	Steep slopes; unstable cut slopes required realignment, rock bolting, chain-link meshing; relocation of 2.7 km road	Currently being analyzed by Bureau of Reclamation
Tennessee (Little Tennessee River)	Tellico (T.V.A.) (198-?)	Hydro, navigation, flood control, recreation	6 678	Selective clearing to enhance commercial navigation, recreational boating, and provide optimum sport fishing. Use of logs and brush to construct fish attractors	Careful skidding of logs to minimize siltation and turbidity; historical and archaeological sites	Project halted in 1977 due to harming of habitat of snail darter. Work commenced again in 1979.

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Tennessee (Elk River)	Tims Ford (T.V.A.) (1970)	Hydro, flood control	6 252	Perimeter hand and machine clearing, including piling and burning	Relocation of 215 families; highway, railroad and utility adjustments; steep slopes; low, swampy lands; relocation of 318 graves	
Tennessee (Tennessee River)	Nickajack (T.V.A.) (1967)	Hydro, navigation, recreation (boating)	4 423	Complete clearing, representing 14 percent of total reservoir area - remainder agricultural. Hand and machine clearing; six areas cleared and graded for future commercial fishing	Relocation of 82 families and 7 cemeteries; highway, bridge and railroad relocation; historical/ archaeological sites	
Tennessee (Clinch River)	Melton Hill (T.V.A.) (1963)	Hydro, commercial navigation	2 315	Complete clearing to maximum pool except on steep slopes and very flat areas where adjustments were made to clearing contour. Hand clearing in inaccessible areas	Relocation of 89 families; relocation of highways, railraods and bridges; steep slopes; bank clearing difficult	

Appendix A
Case histories of Clearing Practices
in Canada and the United States - 22

Province/State	Reservoir	Use	Surface Area (ha)	Clearing Practice	Constraints	Environmental Effects
Tennessee (South Fork Holston River)	Fort Patrick Henry (T.V.A.) (1953)	Hydro, recreation (boating)	361	Perimeter clearing. Below lower limit of clearing buoyant material tied down	Malaria control required timber clearing, relocation of 22 families; desire to designate shore areas as state park	
Tennessee/ Kentucky (Tennessee River)	Kentucky (T.V.A.) (1944)	Hydro flood control		Complete clearing involving hand clearing, machine piling and burning	Relocation of 2,609 families; malaria control required forest clearing	
North Carolina (Little Tennessee River)	Fontana (T.V.A.) (1944)	Hydro, flood control, recreation		Perimeter clearing to 0.6 m above maximum pool; topping below low water level; 870 ha wired down, merchantable timber recovered where economical	Shortage of manpower during war; relocation of 1,311 families; relocation of highways/ railroads; mine access; mountainous and rugged terrain	

APPENDIX B

EXAMPLE CLEARING GUIDELINES

CLEARING SPECIFICATIONS FOR THE HEAD POND OF THE ARNPRIOR GENERATING STATION 1972
(Ontario Ministry of Natural Resources)

1 - Jurisdiction - All private lands purchased by Ontario Hydro are to be considered Crown Lands for the purpose of clearing, but shall not imply that Crown timber dues are to be paid.

2 - Notification - All clearing, burning and salvage shall be carried out only with the full knowledge and to the satisfaction o the District Forester.

3 - Elevation for Determining Clearing Boundaries - The upper contour limit of clearing shall be the regulated high water level.

4 - Removal of Dead Trees - The Hydro Electric Power Commission of Cntario will, during the 10 years following looding, remove all trees above the regulated high water mark deemed by the District Forester to have been killed as a result of flooding.

5 - Slasb Disposal - All slash, debris, timber refuse, etc, is to be burned. No push outs, burial plots or stake-down of slash permitted.

6 - Timber Salvage - All timber deemed to be merchantable by the District Forester is to be salvaged. Disposition of timber shall be the responsibility of Ontario Hydro, its agents, or subcontractors.

All salvaged woods, shall be removed from the land to be flooded prior to flooding.

7 - Stump Height

(a) In areas between the regulated high water level and 12 ft below the regulated high water level, stumps are not to exceed 4 in. in height.

(b) In areas 12 ft below the regulated high water level and deeper, stumps shall not exceed 12 in. in height where the stump diameter is 18 in. or less, and shall not exceed 18 in. in height where the stump diameter exceeds 18 in.

8 - Fences and Other - Wooden fence posts and poles shall be disposed of as per Clause 5, or removed from the area. Metal fence posts, wire and wire fencing, old cars, and other metals, etc, shall be removed or disposed of by burning, burying or otherwise to the satisfaction of the District Forester.

9 - Burning - Burning shall be done under the authority of a burning permit.

10 - Sweeping - The Hydro Electric Power Commission of Ontario will carry out a sweep of the head pond within 1 month of the initial lood to the regulated high water level, and will boom and then remove within 4 months all floating debris into a bay approved by the District Forester. Subsequent sweeps and removals will be carried out when, in the opinion of the District Forester, free floating debris constitutes a safety hazard in using the waters of the head pond.

11 - <u>Cutting Operations</u> - Trees shall not be felled into standing timber above the clearing contour and clearing shall be so carried out that as little damage as possible is done to the trees at or above the clearing contour.

12 - <u>Responsibility for Operations</u> - Primary responsibility for clearing operations rests with Ontario Hydro, subject to final approval by the District Forester or his representative.

PROPOSED CLEARING SPECIFICATIONS FOR INCO HEAD POND NORTH OF AGNEW LAKE, ONTARIO

(Ontario Ministry of Natural Resources, 1976)

1 - All clearing, burning and salvage shall be carried out only with the full knowledge and to the satisfaction of the Ministry.

2 - The upper level of clearing shall be hand cleared and shall continue 10 ft in linear distance above the regulated high water level and 23 ft in linear distance below the regulated high water level.

3 - To reduce the effects of erosion and trees falling into the lake, Ministry of Natural Resources (MNR) may direct that additional clearing be carried out.

4 - Slash and debris may be piled and buried but not within 10 ft (elevation) of the regulated high water level.

5 - No stump shall be left higher than 4 in. above ground level between the regulated low water level and 4 ft (elevation) below the regulated low water level during open water season.

6 - All wood shall be salvaged where this can be done without monetary loss.

7 - Nonsalvageable standing trees and brush shall be felled and removed from the area to be flooded so as not to present a hazard for fishing or navigation.

8 - All wood, including felled trees, floodwood and windfalls, and material, such as cull logs, tops, booms and dam timber, left by logging operations, shall be burned, buried or otherwise disposed of to the satisfaction of MNR. Any ashes from burned wood shall be bured to the satisfaction of MNR. INCO shall be requred to sweep the lake of all wood as required by MNR after flooding has taken place.

9 - Burning shall not be carried out on areas where salvaged wood is piled.

10 - All salvaged wood shall be removed from the lands to be flooded prior to flooding.

11 - Trees shall not be felled into the standing timber above the clearing contour. Clearing and burning shall be so carried out that as little damage as possible is done to trees at or above the clearing contour.

12 - INCO shall be charged Crown dues for all trees of merchantable quality as determined by a timber estimate made under the direction of the District Forester as follows

(i)	Spruce, Balsam and Jack Pine	3.5 in. dbh and
(ii)	all other species	8.0 in. dbh and up.

CLEARING GUIDELINES
SOUTHERN INDIAN LAKE RESERVOIR, MANITOBA
(Slaney, 1973)

Suggested Sites for Clearing in Order of Priority

1 - Hand clear (pile and burn) identified archaeological sites according to priorities and specifications of the archaeologists.

2 - Hand and machine clear all foreshore areas of identified recreational or park sites designated within about 20 mi of Leaf Rapids.

3 - Clear (pile and burn) all fire-killed stands to elevation 852 ft within about 20 mi of South Indian Lake Village and the town of Leaf Rapids.

4 - Hand clear (pile and burn) all woody material over 1 in. in diameter or 4 ft tall to elevation 852 ft within about 10 mi of South Indian Lake Village. (Operate during periods of minimum fire hazard.)

5 - Clear, as above, for all lands to elevation 852 or 50 ft horizontally from el 850 ft, whichever includes the least area, from Leaf Rapids to Opachuanau Lake.

6 - Clear for mitigation purposes, sites identified by biologists for special significance to fish or wildlife.

7 - In accordance with wildlife interests, clear selected sites above elevation 850 ft for replacement of riparian vegetation with more preferred wildlife habitat.

8 - Circumstances will alter cases and clearing priorities should be reassessed before embarking on a post flooding clearing and cleanup operation. Use of both water-based equipment and complementary units operating over the ice is envisaged.

CLEARING AND TIMBER SALVAGE STRATEGY
CAT ARM RESERVOIR, NEWFOUNDLAND
(Hunter and Associates, 1980)

Salvage of all productive timber including that in nonmerchantable stands greater than 10 cm DBH is recommended for the entire reservoir zone if favorable contract prices and a willing buyer may be obtained. This strategy is only practical within nonmerchantable stand areas where felling, limbing and topping may be undertaken manually with portable power saws and tree length or shorter logs may be floated, boomed and removed from the future flooded reservoir at centralized haul-out zones. As an alternative to booming, tree length logs will float and eventually will be caught along the eastern shore of the reservoir. Collection of the logs from the shore, however, is a tedious task. Float salvage of timber from the drawdown zone near FSL is more complicated and logs must be hauled to a point where they can be floated. Conventional machine logging of merchantable timber zones will allow sale of logs to generate short-term revenue in contrast to a float method, which would delay return and increase working capital costs.

Total clearing of scrub is recommended for the drawdown zone, but not for the submerged portion of the reservoir. After timber salvage, the entire drawdown zone from LSL to and elevation of 3 m above FSL should be cleared of all vegetation greater than 2 m high or 5 cm at the base. Clearing above the FSL allows for freeboard and improved shore zone habitat for wildlife. However, severe windfall may be expected along this abrupt forest edge. Merchantable timber salvage of the drawdown zone would be undertaken as part of the contract for salvage in individual blocks. Clearing of the drawdown zone would be undertaken under separate contract following logging. Hand clearing and burning methods are recommended for the upper drawdown or "freeboard" zone, due to the general rugged and rocky nature of the terrain.

Total clearing after timber salvage of the submerged reservoir zone below LSL is not recommended as the remaining brush will be less than 10 cm DBH, and usually less than 5 m tall and poorly rooted. Scrub and small trees protruding into the drawdown zone will be removed by the winter ice. Considerable small size floating debris originating from uprooted shrubs, small trees, and logging slash will result after flooding. Smaller material will be abraded by waves on the rocky shores and wood fragments will collect in the easterly embayments as a result of wind and current action.

It is unlikely that post flood winter clearing at Low Supply Level would be feasible in the Cat Arm Reservoir environment, as a result of deep drifting snow accumulations, blown from the adjacent uplands and across the frozen reservoir.

The high humidity of the reservoir area will make burning of stacked debris difficult. The burning season will be short, probably through late July to September. Even then, care will have to be taken to avoid including saturated mosses, peat, and other wet ground cover in the debris piles, and these will have to be well aerated for effective burning to take place. Bulldozer methods of "pushing debris" into piles should be discouraged to ensure that burning may be completed in the short time available prior to flooding.

RECOMMENDED CLEARIG STRATEGY
MUSKRAT FALLS/GULL ISLAND RESERVOIR, LABRADOR
(Proctor and Redfern, 1980)

The finding of this study is that the forest need not be cleared for any environmental reason, except in the vicinity of the dams, and at the confluence of tributary streams.

This finding is based on the following environmental considerations.

(i) There was no evidence that submergence of the forest would have a significant effect on water quality, fish or other aquatic organisms'

(ii) Plants will be killed and birds, mammals and other animals presently occupying the flood zone will be displaced or possibly killed regardless of the strategy.

(iii) The prospects for substantial recreational and tourist activities (except of a local nature) on and in the vicinity of the reservoirs are considered remote. Hence, the need for special preparations in the interests of appearance, safety of watercraft or the use of beaches is not a high priority consideration.

There is, however, an important consequence of not clearing and that is the disposal of the debris broken from dead and uprooted trees which will float towards the dams and shores. Experience elsewhere suggests that over the initial 2 or 3 years of flooding, large rafts of trees will appear and will have to be disposed of. This will probably be

ENVIRONMENTAL MATRIX

Strategy	Gull Island Biological Parameters* 1	2	3	4	5	6	7	8	9
1 No clearing	M	N	NA	N	mE	mE	mD	mE	ID
2 Complete clearing	mD	N	NA	N	mD	N	mE	mD	IE
3 Partial clearing									
- clear perimeter only	N	N	NA	N	mE	N	mE	N	mE
- clear by timber class	N	N	NA	N	mE	N	mE	mD	N

Strategy	Muskrat Falls Biological Parameters* 1	2	3	4	5	6	7	8	9
1 No clearing	N	N	NA	N	mE	mE	mD	mE	mD
2 Complete clearing	mD	mD	NA	N	mD	N	mE	mD	IE
3 Partial clearing									
- clear perimeter only	mD	N	NA	N	mE	N	mE	N	mE
- clear by timber class	N	N	NA	N	mE	N	mE	mD	N

*Biological Parameters

1 Bank stability and sediment transport
2 Water quality
3 Terrestrial vegetation
4 Mammals
5 Birds
6 Aquactic vegetation
7 Fish
8 Other aquatic life
9 Recreation and aesthetics

Matrix Rating

Disruptive - MD - Major
- ID - Intermediate
- mD - Minor
- N - None

Enhancement - ME - Major
- IE - Intermediate
- mE - Minor
- N - None

Not applicable - NA

followed by a number of years when lesser volumes will have to be removed. Slumping of the banks will, from time to time, contribute more dead trees. In itself, this will not have an environmental impact provided that the debris is extracted and disposed of and provided none is permitted below Muskrat Falls. This finding is conditional on these steps being taken.

An outline assessment of environmental impacts is in the attached table.

RECOMMENDATIONS FOR CLEARING
UPPER SALMON RESERVOIR
(Northland Associates, 1979)

Three options were considered for preparing the Upper Salmon Reservoir: no clearing; complete clearing; and, complete clearing in selected areas. The options were evaluated based on the environmental analysis, cost of clearing in relation to the environmental benefit accrued, and engineering variables such as project scheduling and manpower requirements.

The no-clearing option was rejected because of the future recreational potential of the reservoir. Although the area is not intensively used at present, the potential use was judged significant enough to protect. Data indicated that the Grey River caribou herd crosses in the area of the reservoirs and that a no-clearing option would present a major barrier to such movement.

Complete clearing was also rejected as an option because of the high cost relative to the environmental benefit.

The third option, a program of clear cutting selected areas on the reservoir was recommended by the consultants. The following recommendations were made

1 - Clear selected areas on the reservoir to enhance caribou migration.

2 - Clear forest areas underlain by gravel material to create salmonid spawning in the reservoir.

3 - Clear Cold Spring Pond to encourage and preserve recreational potential in the reservoir zone (198 ha).

4 - Clear a 200-m strip between Great Burnt Lake and Crooked Lake to enhance movement of boats between these lakes (5.1 ha of productive forest, 22.8 ha of scrub forest, and 600 man-days).

5 - Clear a 200-m strip through the diversion channel areas (2 ha of productive forest, 5.5 ha of scrub forest and 188 man-days).

All recommendations were agreed to by regulatory agencies except one (Kiell, 1981). Clearing of part of the reservoir to increase the amount of salmonid spawning habitat was considered costly given the uncertainty as to whether fish would use and spawn successfully in such areas.

APPENDIX C

REGIONAL CONSIDERATIONS

APPENDIX C

C1 - PRECAMBRIAN SHIELD

The Canadian Precambrian Shield can be divided into a number of structural provinces related to folding, lithologies and radiometric age. The area of interest here is the part of the Severn-Abitibi Uplands of the Superior Province which is found in Northern Ontario (see Figure C.1). This area comes under the authority of both the Northwest and Northeast Ontario Planning Regions.

Geology

The geology of the shield is extremely complex. In early Precambrian (Archean) times, orogenies produced greenstone belts or metamorphosed, complex folded, volcanic and sedimentary and intrusive rocks separated by large expanses of banded gneiss and granitic rocks. It is within the greenstone belt that most of the economic minerals are found.

Thick, relatively flat-lying sedimentary and volancic rocks found in the Thunder Bay-Nipigon area are related to sedimentation and vulcanism during the middle and late Precambrian (Proterozoic) times. Iron-ore, lead, zinc and silver are associated with the Proterozoic rocks.

Glacial erosion has turned the Archaen rocks to a rolling topography of low relief and the Proterozoic rocks into strongly broken topography.

Surficial Geology and Soils

Till deposits are found over much of the area but they are discontinuous and mainly thin (less than 1 m deep). These deposits are generally composed of a sandy till mixed with large boulders, stones and gravel and little clay. Bedrock outcrops through out the region.

Postglacial lakes filled many of the low-lying areas depositing deep layers of clays and silts interrupted by sand ridges. These deposits have a relatively high productivity. The farming areas of Kenora and Rainy River, Thunder Bay, Sault Ste Marie-Sudbury, New Liskard are found in these clay and sand areas. The Cochrane Clay Belt is the largest of these areas and least developed. These deposits would be easily eroded if forming the shoreline of a reservoir. Where the bedrock outcrops, there is little or no soil development and thus, would provide good shorelines. On the clay-silt soils agricultural use will probably be given first priority over any other development.

Eskers and moraines occur throughout the region and usually provide the best source of aggregate material.

Topography and Drainage

Generally, surface elevations vary from 900 to 1,200 ft. The land is gently rolling to the west and north and is more broken to the south and east. The highest area is to the west of Lake Superior where 2,000 ft is reached in a few places.

There are a large number of rivers and lakes with over 10 percent of the region covered by water. There are three major watersheds. The northern half drains to Hudson Bay. The southwest drains to the Winnipeg River and the southeast flows into the Great Lakes system (Figure C.2). There is a gentle rise in elevation to almost 1,500 ft from Hudson Bay to the water divide between north and south drainage. The southeast flowing rivers have a more rapid decent to Lake Superior which is 600 ft above sea level.

The rivers have been dammed in several places and water diverted from one watershed to another for hydro development. Most of the watersheds are at least partially controlled. The water supply varies both annually and seasonally. The winter minimum to spring maximum may be of the order of 1:20.

Water Quality

Environment Canada has carried out water quality sampling from 1967-77 on a number of watersheds. They found that the waters have low total dissolved solids with concentrations ranging between 23 mg/L and 61 mg/L. All water was soft (17-60 mg/L hardness as $CaCO_3$) and mostly unsaturated with respect to calcite. Stability index calculations indicate that these waters are extremely corrosive. The nature of the underlying shield bedrock is evident in the low concentrations of calcium and bicarbonates. The majority of the waters were classified as alkaline-earth bicarbonates.

The watersheds of the Precambrian Shield are extremely sensitive and are easily disturbed by atmospheric and geochemical inputs. The waters have a very poor buffering capacity and would be extremely sensitive to acid rain (see Figure __). It has been found to be advantageous to leave as much living organic matter in the lakes as possible. The NO_x in acid rain tends to be taken in by the vegetation. Thus, the hydrogen ion component of NO_x is lessened reducing the possibility of lowering the pH in the reservoir.

Various impurities have been found in the waters of the Canadian Shield. Mercury, in particular, has given cause for concern. This has been released by both industry and from natural sources. Fishing waters have been affected, these include Rainy Lake, Lac Seul, Lake St. Joseph, parts of the English River and the Thunder Bay area of Lake Superior. Major water quality problems have resulted from discharges from the pulp and paper industry, from mining operations and from community waste.

Climate

The continental type climate of the region is modified by the presence of both Hudson Bay and Lake Superior. Their moderating effect is most marked in the fall and early winter when minimum temperatures are raised. Annual temperature ranges in the south, around Lake Superior, are 30°C and in the north, in the Patricia region, are 35°C. January temperatures range from -25°C in the north to -10°C in the south. In July there is less variation, 15°C in the north to 20°C in the south.

Precipitation is low in the winter and shows a summer maximum. There is an increase in precipitation from west to east (600 mm in Kenora to 820 mm at Lake Timiskaming) with the least in the extreme northwest (500 mm). Snow depths can reach 1,500 mm and are usually greater than 300 mm. Northeast winds predominate in winter and southwest in summer.

Vegetation

In the very south the Great Lakes--St. Lawrence forest region is found which includes sugar maples, pine, birch, hemock and poplar. In the far north, there is very stunted growth. Small black spruce, tamarack and bog conditions are found bordering the Hudson Bay Lowlands. The central belt is covered by Boreal forest with the dominant species being black spruce, tamarack, aspen, jack pine and white birch, and with white spruce, balsam fir and red pine being well represented.

Wildlife

Terrestrial wildlife includes those species associated with a forest habitat. Furbearers such as otter, mink, muskrat, beaver and fish are common, as are bear and moose. Deer and caribou have a more restricted distribution.

Due to the large number of lakes, there is an abundance of waterfowl. Over 80 different fish species have been identified. Warm water species are found in the lakes north of the water divide and cold species to the south.

Population and Employment

The northwestern Planning Region had a population of __*__ and the northeastern had __*__ people. The construction of the railway has clearly influenced the settlement pattern of the area and its economic development. The majority of the population north of the CNR mainline is Indian, either

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*Awaiting data from most recent census.

Cree or Objibwa, living in numerous small isolated communities. The main urban areas are found in the south along the east-west rail links and highways.

Indian groups carry on their traditional sustenance activities of hunting and fishing and also engage in commercial trapping, fishing, tourism and wild rice gathering. These activities do not support the whole population and many are dependent on welfare.

The rest of the population is employed mainly by the primary industries in the resource field, mining and forestry industries being the primary employers. The tourist industry is important especially on a seasonal basis.

Resources

(a) Mining

The region is rich in mineral deposits. The mineral potential of the area is high especially in the greenstone belts and the nickel belt around Sudbury.

(b) Agriculture

The land capable for agricultural is that associated with the deep clay soils laid down in the postglacial lakes. The only area not developed extensively is the northern clay belt where the climate can impose serious constraints on crop production. However, with the introduction of hardier varieties, agricultural expansion can be expected.

Wild rice is an important cash crop for Indians. During the 2- to 3-week harvesting period up to 1,000 people can be employed.

With any reservoir development the agricultural potential of the area must be considered as well as any detrimental effect it might have on wild rice paddies.

(c) Forestry

The forest industry is the major employer in Northern Ontario. South of 52°N about 50 percent of the land has a high to moderate forest capability. The northwest region of Ontario contains about 40 percent of Ontario's merchantable timber.

The demands by the forestry industry may influence reservoir development and clearing practices.

(d) Recreation

The recreational potential of the region is high. The southern area is the most attractive to the majority of tourists, the potential decreases farther north, but numerous fly-in camps exist and wilderness outfitters service this area. Recreational activities include picnicing, bathing, angling, hunting, camping, canoeing and boating. The majority of the tourists stay in cottage accommodation. Again, conflicts of interests may occur between reservoir development and recreational needs.

(e) Fish and Wildlife

Moose, deer, bear and small game are the main animals hunted. Commercial fur trapping involves about 3,000 people and of these half are probably Indians. Beaver is the most important species trapped. Waterfowl and grouse are also hunted.

Sport fishing is probably the most important element in the tourist industry. It is also an important source of recreation and food supply for the local population. Walleye, northern pike and bass are the fish favored by the tourist while the locals prefer walleye, pike, lake and brook trout. There are a large number of lake trout waters in the region, these are being fished to capacity and are very sensitive to overuse.

Commercial fisheries are active in over 200 lakes, competing with the sport fishermen. The bait fish industry is growing in importance.

Unfortunately, the discovery of mercury in fish above the acceptable minimum of 0.5 ppm is having a noticeable effect on the tourist industry and the lives of the Indians.

Reservoir Clearing Considerations on the Canadian Shield

Generalized recommendations for reservoir clearing on the Shield cannot be made due to the heterogeneity of this large region. Listed below, however, are some of the key features which can influence the section of a site-specific strategy for Shield reservoirs.

- Much of the area is covered with very thin (<1 m) till deposits. This implies shallow root systems for standing timber.

- Some areas have deep layers of clays and silts which are easily eroded along shore, although deeply rooted trees would be found.

- Surface waters are very poorly buffered and are therefore sensitive to acid precipitation. The presence of organic materials aids in reducing pH depression by absorbing the NO_x function of acid rain.

- Natural mercury levels are high in some areas. Removal of mercury-laden soils may be warranted in these area.

- There is a general trend from hardwood to softwood dominance as one proceeds north along the Shield reaching stunted Boreal and bog at the lowlands. The floatability of hard US software is a determining element.

- Generally speaking, waterfowl habitat is not lacking due to the high density of water bodies on the Shield.

- The forest industry is the major employer in the Shield. Clearing equipment and manpower likely available.

- There is a high recreational potential, particularly in the southern parts of the Shield.

- Sport fishing is very important to tourist industry (walleye, pike and bass). Locals prefer trout. Reservoir encouragement of warm water fishing could relieve pressure on trout lakes.

- 200 Shield lakes support commercial fisheries. There could be a demand for net use in new reservoirs.

C2 - THE HUDSON BAY LOWLANDS

The Hudson Bay Lowlands are a distinct physiographic unit occupying the coastal plain area to the south and west side of James and Hudson Bays from the Nottaway River in Quebec to the Churchill River in Manitoba (see Figure C.1). These flat, swampy lowlands contrast sharply with the rocky outcrops of the Precambrian rocks which bordered them.

Geology

The area is underlain by Palaeozoic rocks of Ordovician, Silurian and Devonian age and consists of sandstones, shales, limestones, dolomite and evaporite deposits. In places, a low escarpment marks the boundary between these rocks and the Canadian Shield but in other locations boulder clay deposits make delineation of the area more difficult. The Sutton Inlier is an outcrop of Precambrian rock providing the only relief to the otherwise very gently dipping Paleozoic rocks.

Surficial Quaternary deposits cover the area in the form of till sheets, lacustrine deposits, buried soils and marine beds. These deposits could present engineering problems; in particular, the postglacial marine clays (Skinner, 1973). The Pleistocene deposits are mainly fine grained and generally do not provide aggregate material suitable for road construction.

Topography and Drainage

The highest elevations, of about 500 ft, occur in the areas bordering the Shield and from here drop to sea level giving a gradient of about 3.4 ft/mi. The major rivers flow in a southwest-northeast direction draining into Hudson and

James Bays (see Figure C.2). Drainage is poor due to the flat nature of the ground; over most of the region are rivers and lakes with extensive areas of swamp and muskeg. There is little dry land and this is related to some glacial deposits, riverbanks or the old strand lines which encircle Hudson Bay. These old beaches indicate that the area is still rising under isostatic rebound, which is reducing the gradient and encouraging even poorer drainage. Any proposed reservoir in this area would be very shallow, large areas would be exposed to wave action and shorelines would have gentle slopes.

Water Quality

All the rivers drain the Canadian Shield in their headwaters and the water chemistry reflects the amount of Palaeozoic-carbonate or Precambrian-silicate which makes up the watershed. The total dissolved solids vary from 61 to 94 mg/L, calcite units are from -1.1 to 0.5. The stability indices ranged from 8.5 to 9.5 pH units. The rivers are all classified as alkaline-earth bicarbonate. The waters are harder than those of the Shield and they have an excellent buffering capacity.

During high runoff periods solute dilution occurs. Trace element and nutrient data are limited but concentrations are always low and exhibit no evidence of human activity. The color is often very dark (50 to 100 relative units), the result of runoff and leaching of organic materials in peat.

Climate and Permafrost Distribution

The continental climate is modified by the presence of Hudson Bay which delays heating in the summer. Average temperatures are 0 to -4°C with an annual range of as much as 40°C. Precipitation is about 450 mm/yr with a summer maximum. Snow depth rarely exceeds 30 cm.

Permafrost distribution appears to be directly related to temperatures (see Figure C.4). A narrow strip of continuous permafrost exists around the southern shore of Hudson Bay where annual temperatures are less than 25°F (-4°C). Permafrost is generally not found south of the 30°F (-1°C) isotherm. Between 30°F and 25°F (-1°C and -4°C) permafrost is discontinuous and related to drainage. If the water table is at the surface, permafrost is absent. Its formation appears to be dependent on an insulating layer of dry material which prevents summer thawing. The active layer varies from 1 ft to 3 ft and the thickness of the permafrost may be as much as 100 ft near Hudson Bay. Permafrost features include palsas to elevated peat platforms, the latter which are greater than 10 ft high and may cover several acres.

Soils and Vegetation

Weathering of the soft bedrock produced fine grained material, which when reworked by ice sheets produce fine textured sediments (sands and silts) with restricted internal drainage. The marine sediments are mostly silty loams which are also almost impervious. These conditions, plus the gentle gradient, produce continual waterlogging and have given rise to the greatest peat accummulations in Canada (Figure C.5). Peat deposits are generally greater than 2 m and can reach 10 m, becoming progressively thinner toward Hudson Bay. Peat is easily eroded and would provide poor shorelines for reservoirs. Massive slumping can also be expected where permafrost underlies the peat. The reservoir water would cause the permafrost to melt and thus remove the support for the overlying material.

Vegetation shows a gradual change from boreal conditions in the south to tundra in the north (Figure C.6), however, the poor drainage interferes with usual plant development. On the peatlands in the south a closed black spruce-moss community is found, on the permafrost peatlands - an open spruce - lichen forest and a shrubby tamarack fen grows on the unfrozen areas. Tree growth is much improved on the better drained peat plateaus and palsas where trees may reach 15 cm diameter and their height may be twice that of trees growing on the fens.

Near Hudson Bay there are true tundra conditions with sedge and heath.

On the better drained soils and in the protected valleys, white and black spruce and balsam poplar grow. These are larger trees, maybe 22 m in height and 50 cm in diameter.

Wildlife

The coastal lowlands of Hudson and James Bay are internationally significant as a nesting and staging area for waterfowl.

Along the Hudson Bay coast, whales, seals, polar bear, barren ground caribou, arctic fox, lemmings, blue geese and ptarmigan are found. The muskeg provides nesting sites for the sandhill crane. Moraine and beach ridges are ecologically important areas for caribou and denning areas for bears, wolves and foxes. Brook trout, northern pike common sucker and sturgeon are the predominant fish species.

Social Structure

The total population in 1971 was 5,810; 76 percent were Indians (Cree) and many of the remainder were Metis. The population is found in small communities along the coast (Moosonee, Moose Factory, Albany, Attawapiskat, Fort Severn, Winisk, Moose River Crossing). The lowlands represent the traditional hunting, trapping and fishing territories of these coastal Indians. The travel routes of the Indians are along the rivers and lakes. Although many of the Indians are wholly or partially dependent on welfare for their economic well being, they do continue their traditional activities and way of life and these must be respected when any development in the area is considered. There are no effective land links between the communities and access to the Lowlands is mainly by plane. The only land route to the south is the railway to Moosonee.

The recreational potential of the area is just beginning to be exploited. Moosonee is developing into the center of the tourist trade which is based on wilderness activities. The Indian community has been incorporated in this recent tourist development. For instance, they have been trained to run six goose camp operations.

Two provincial parks are located on the lowlands. An extensive part of the Hudson Bay coast is included in the Polar Bear Provincial Park and the Winisk Wild River Park extends 238 miles along the lower reaches of the Winisk River to within 32 miles of the coast.

Resources

Forest

The physical conditions of the region make exploitation unfavorable. The environment is extremely fragile. For instance, it appears that the removal of trees from the peat plateaus, where better growth occurs, can cause melting of the permafrost and collapse and disappearance of the plateau. Much of the forest comes under the "Protection" class. Thus, capability of the area plus the distance from market all impose very restricting conditions on forest development.

Mineral

Mineral deposits of lignite, gypsum, silica, kaolin, and niobium are found in the area. There is a potential for lead and zinc in the Palaeozoic rocks and iron in the Precambrian inlier. Oil and gas drilling exploration is underway in the Palaeozoic rocks.

Reservoir Clearing Considerations in the Hudson Bay Lowlands

The two major problems that are encountered in the lowlands are the inaccessibility of the area and the fragility of the muskeg permaforst environment.

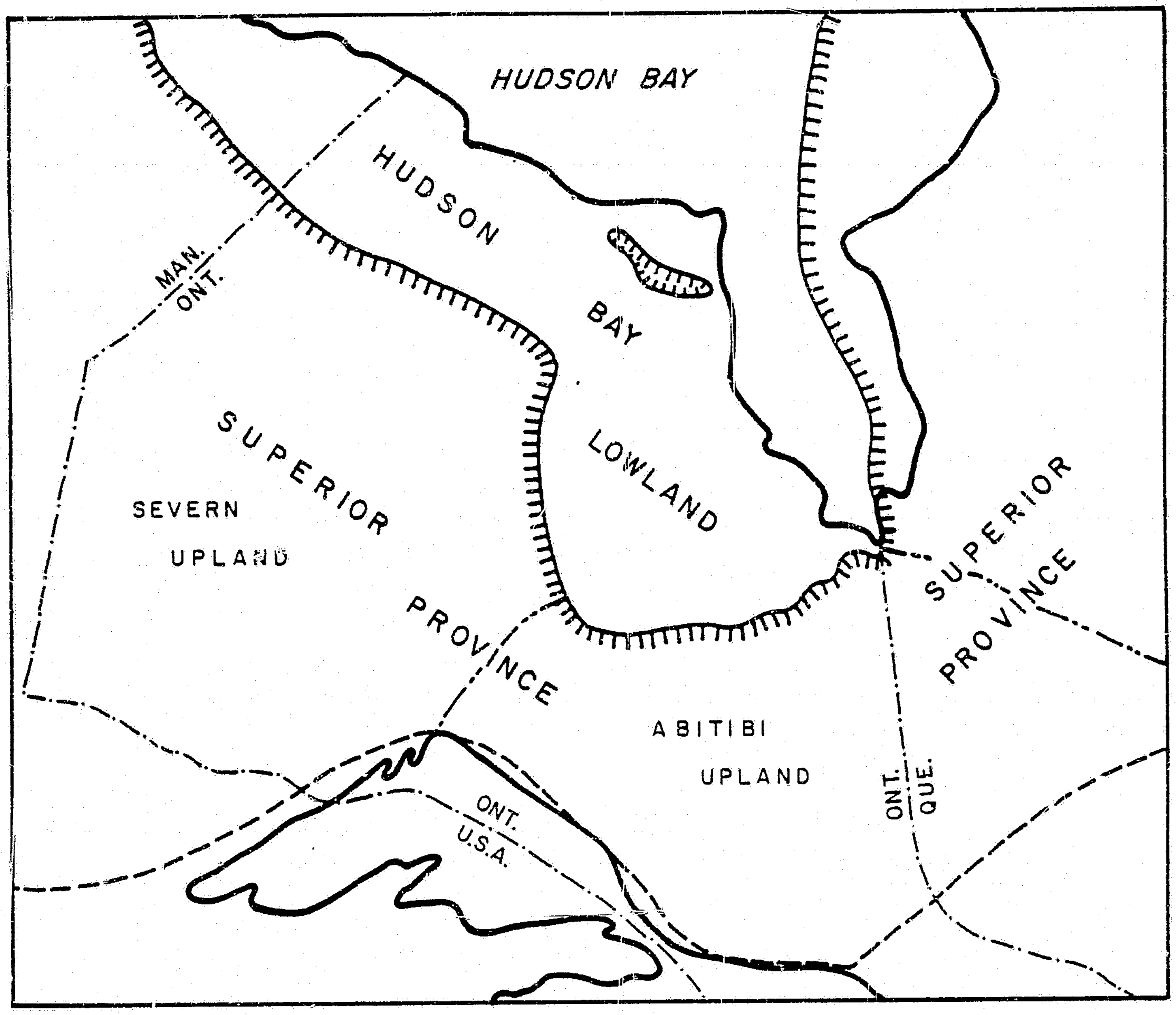
Muskeg patterns and drainage can be destroyed by movement of heavy equipment. Machinery exerting over 5 lb/sq in. can only be used when the ground is frozen to at least a depth of 20 cm and covered with 20 cm of snow. Cutting operations if required would probably be of small scale involving hand clearing which would reduce the effects of heavy machinery.

The creation of reservoirs will cause melting of the adjacent permafrost and slumping of the banks. The presence of trees and other vegetation cover may slow bank erosion and thus perimeter clearing is not generally recommended.

By flooding peat areas the water quality will be changed. There will be an inflow of acidic lummus, (phosphorus) and nitrogen will rise and an oxygen deficit will develop, especially near the bottom. These changes will last for a number of years. The present color content is so high that any increase from the peat will probably be insignificant. Clearing of the peat before flooding is not a practical solution. Peat soils can reach a depth of 10 m. and there would be considerable environmental damage wrought by both its removal and dumping. Floating peat islands may form in the newly flooded areas. These may have to be removed, since they may persist for years, if they affect the use of the reservoir. Clearing cost at Gull Island in Newfoundland ran to $1,100/ha ±20 percent and this could be the same order of magnitude for this area.

If the reservoirs are constructed near communities, some aesthetic clearing may be necessary. The local population must be consulted on any development and their requirements incorporated into any decision taken.

In general, it would appear that minimal clearing is preferable in reservoir construction in the Hudson Bay Lowlands. The inaccessibility of the area and the fragile nature of the environment pose considerable problems to any development. Depending on reservoir size and location, minimal clearing may not be possible due to the necessity of large-scale clearing of floating muskeg and timber following flooding to prevent problems with reservoir operation. One alternative may be to tow floating islands ashore where they can be anchored as refuges for wildlife and waterfowl. This possibility has been considered by the Société d'énergie de la Baie James (1978). Also, fine mesh screens should be installed near the intake gates and cleared on a regular basis. Additionally, it is expected that reservoir sweeping would be required on a more frequent basis than is necessary in other areas of Ontario.



LEGEND

BOUNDARY OF CANADIAN SHIELD AND INLIERS

BOUNDARY OF STRUCTURAL PROVINCE

BOUNDARY OF SUB - PROVINCE

(SIMPLIFIED MAP AFTER DOUGLAS 1970)

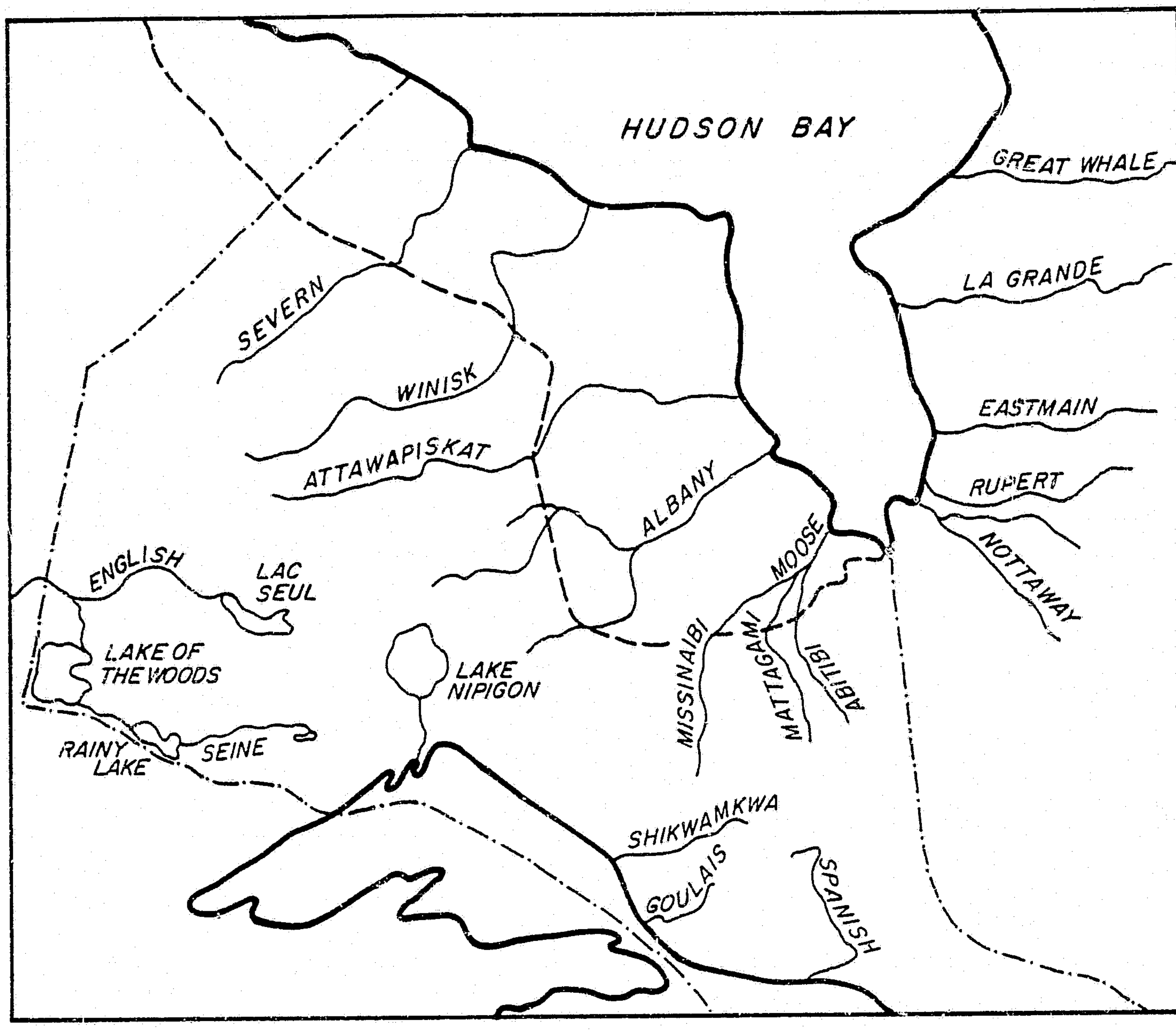
FIG. C.1

ONTARIO HYDRO

RESERVOIR CLEARING & PREPARATION - ENVIRONMENTAL PROTECTION STRATEGIES

LOCATION MAP

ACRES



LEGEND

—·—— BOUNDARY OF HUDSON BAY LOWLAND

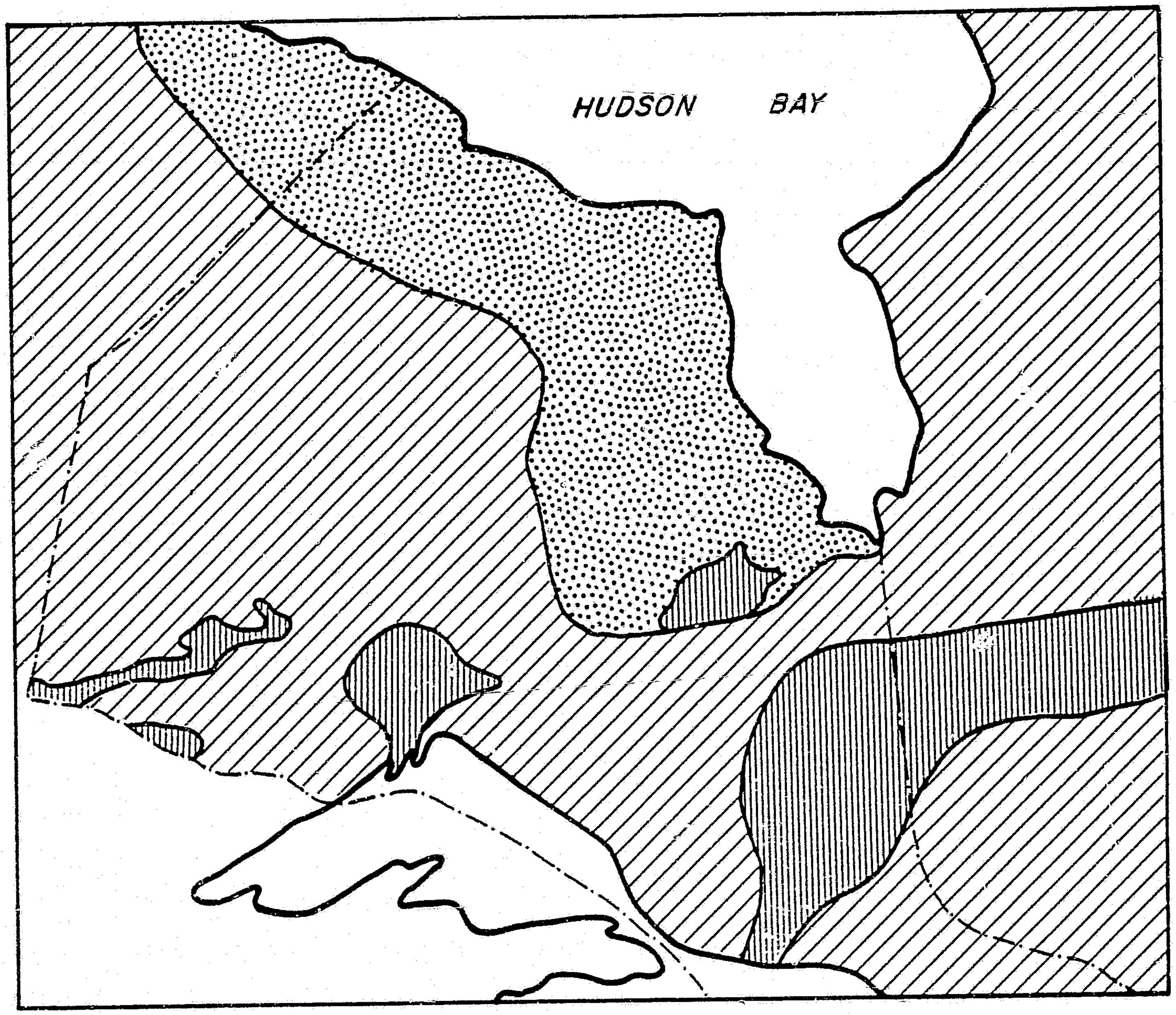
FIG. C.2

ONTARIO HYDRO

RESERVOIR CLEARING & PREPARATION – ENVIRONMENTAL PROTECTION STRATEGIES

DRAINAGE PATTERN

ACRES



LEGEND

SENSITIVITY OF BEDROCK AND DERIVED SOILS

- LOW SENSITIVITY - HIGH BUFFERING CAPACITY - *MAINLY BY CARBONATE ANION*
- INTERMEDIATE SENSITIVITY - *LOW OR UNCERTAIN BUFFERING MAINLY BY CATION EXCHANGE IN CLAY AND SILT SIZED DETRITUS*
- HIGH SENSITIVITY - LOW TO INSIGNIFICANT BUFFERING CAPACITY - *IF ANY, MAINLY BY CATION EXCHANGE WITHIN CLAY AND SILT SIZED DETRITUS*

(SIMPLIFIED MAP AFTER GEOLOGICAL SURVEY OF CANADA, 1981 MAP 1551A & 1550A SENSITIVITY OF BEDROCK AND DERIVED SOILS TO ACID PRECIPITATION)

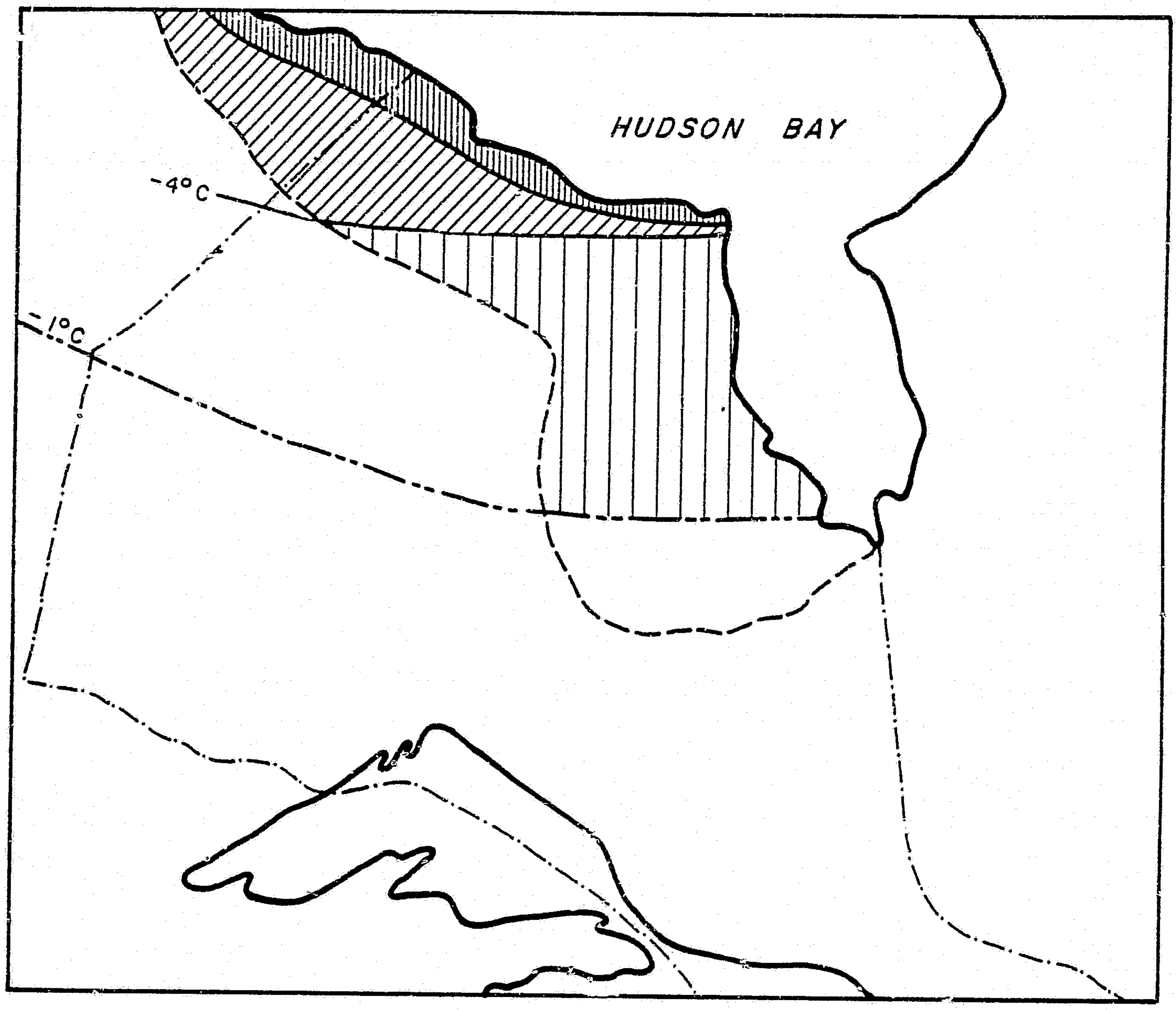
FIG. C.3

ONTARIO HYDRO

RESERVOIR CLEARING & PREPARATION - ENVIRONMENTAL PROTECTION STRATEGIES

SENSITIVITY TO ACID RAIN

ACRES



LEGEND.

- – – – BOUNDARY OF HUDSON BAY LOWLAND
- CONTINUOUS PERMAFROST ZONE
- WIDE SPREAD PERMAFROST
- SOUTHERN FRINGE OF PERMAFROST
- ——— SOUTHERN LIMIT OF CONTINUOUS PERMAFROST
- –·–·– SOUTHERN LIMIT OF PERMAFROST

(AFTER BROWN, 1973)

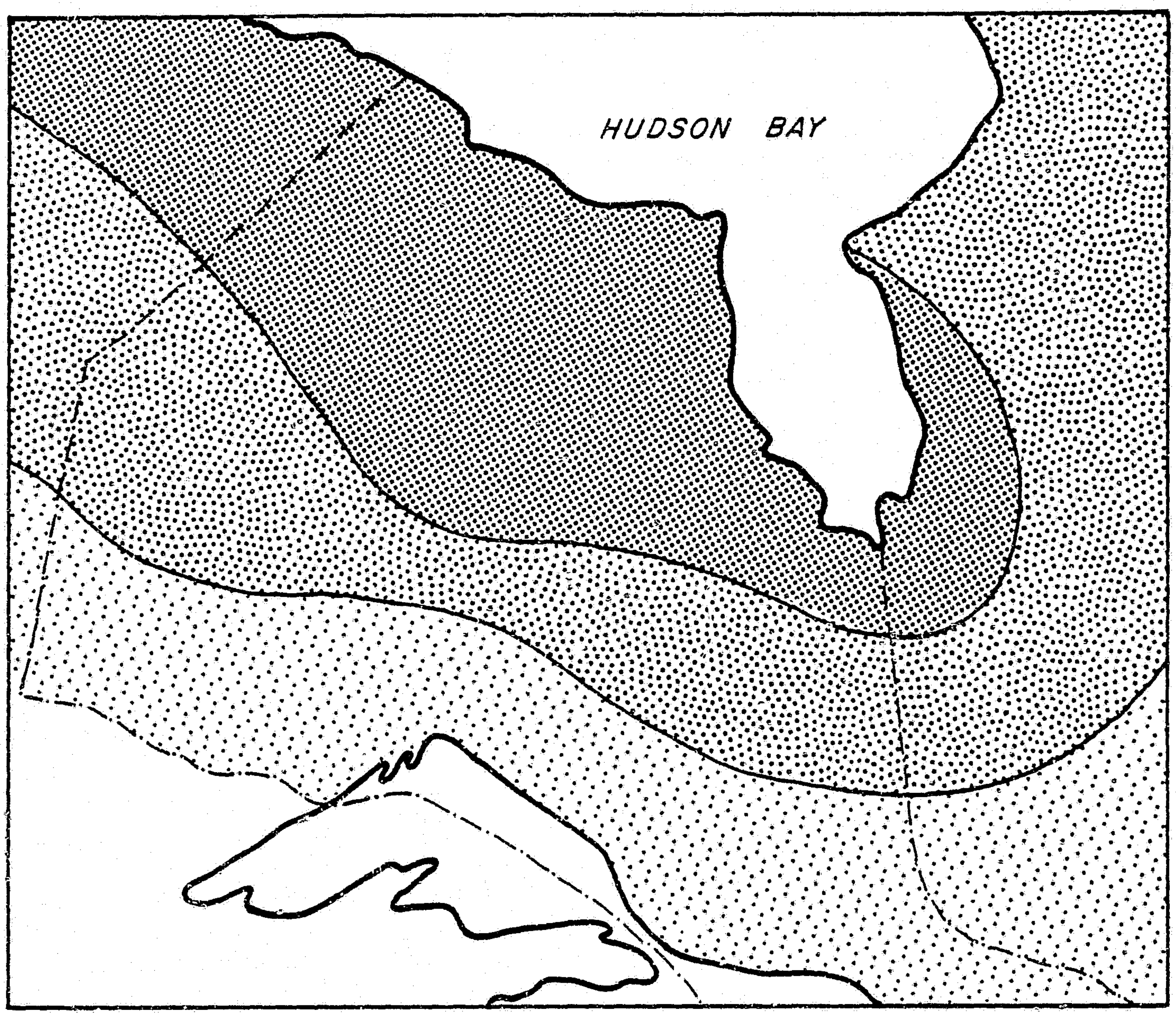
FIG. C.4

ONTARIO HYDRO

RESERVOIR CLEARING & PREPARATION – ENVIRONMENTAL PROTECTION STRATEGIES

PERMAFROST IN HUDSON BAY LOWLAND

ACRES



LEGEND

FREQUENCY OF OCCURRENCE OF MUSKEG

HIGH

MEDIUM

LOW

(AFTER RADFORTH 1966, MUSKEG MAP OF CANADA)

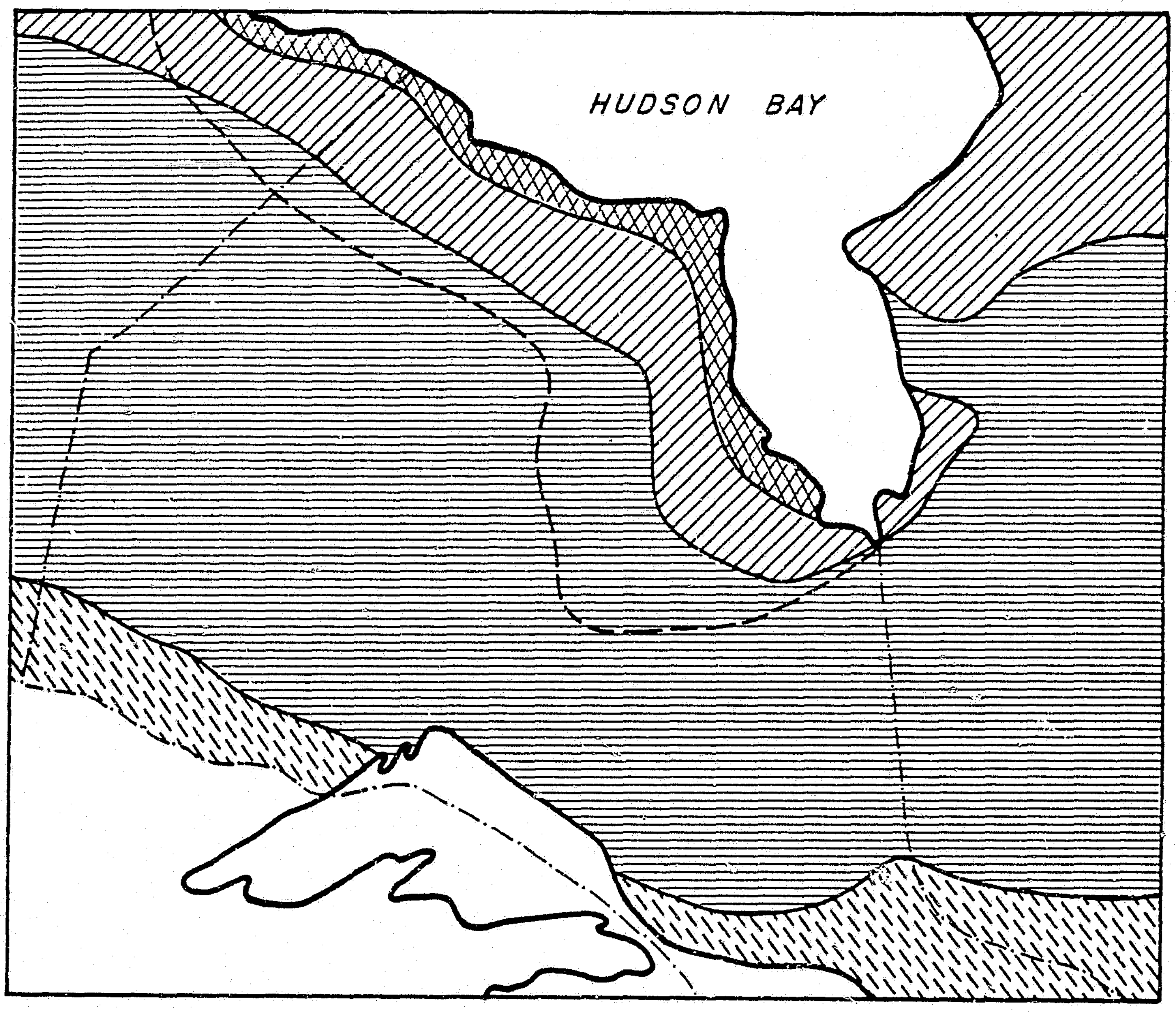
FIG. C.5

ONTARIO HYDRO

RESERVOIR CLEARING & PREPARATION – ENVIRONMENTAL PROTECTION STRATEGIES

OCCURRENCE OF MUSKEG

ACRES



LEGEND

- — — — BOUNDARY OF HUDSON BAY LOWLAND
- HEATH - FENLAND
- OPEN SUBARCTIC FOREST
- BOREAL FOREST
- SOUTHEASTERN MIXED FOREST (GREAT LAKES - ST. LAWRENCE FOREST)

(MODIFIED MAP AFTER ZOLTAI, 1973 AND ROWE 1972)

FIG. C.6

ONTARIO HYDRO

RESERVOIR CLEARING & PREPARATION - ENVIRONMENTAL PROTECTION STRATEGIES

VEGETATION ZONES

ACRES