Embayment Enhancement Feasibility Study Williston Reservoir

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PART I

INTRODUCTION

1.1 OBJECTIVES

This project was commissioned by the Peace Compensation Program to identify and evaluate enhancement activities for the embayment areas of Williston Lake to increase fish/angler use. This project represents part of a long term program to provide increased recreational opportunities on Williston Reservoir through improved sport fisheries.

1.2 BACKGROUND

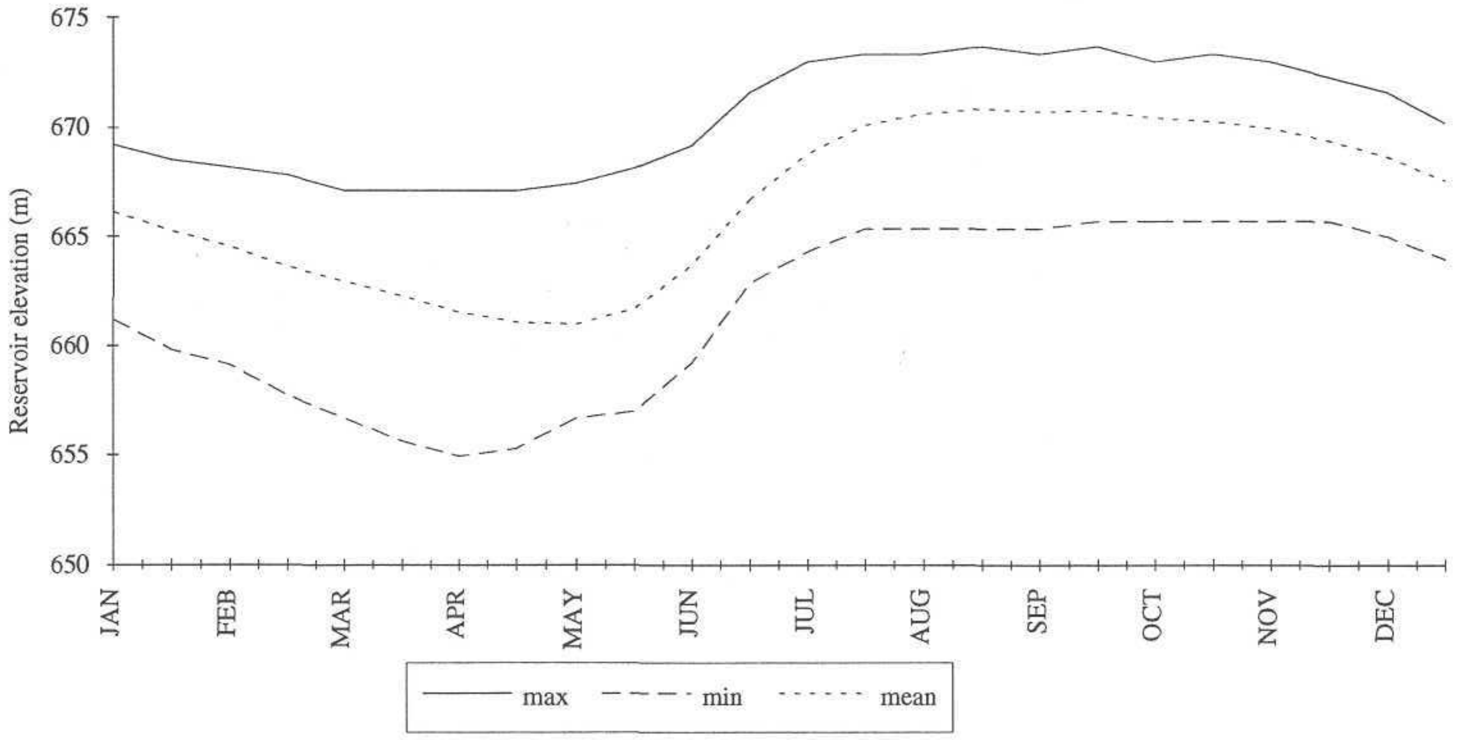
Williston Lake lies in northeastern British Columbia and is the largest lake in the province. It was created in 1968 at the completion of the B.C. Hydro W.A.C. Bennett dam on the Peace River. The Peace Compensation Program was initiated in 1988 as a joint program by the B.C. Ministry of Environment, Lands and Parks (MELP) and B.C. Hydro to compensate for the loss of fisheries values caused by the creation of the lake.

Williston Lake is comprised of flooded portions of the Peace, Parsnip and Finlay Rivers and has a surface area of approximately 1,736 km^2 with a shoreline perimeter of 1,779 km. The Peace Reach runs west to east through the Rocky Mountains and the Parsnip and Finlay Reaches run north and south along the Rocky Mountain trench. The Peace Reach is fjord like with steep sides and therefore limited exposed surface area in the drawdown zone. The Parsnip Reach is relatively shallow with exposed mud flats extending several kilometers out from shore at low water. At low lake levels, the Finlay Reach has extensive flats of sad and mud. The three reaches all have unstable shorelines due to the occasional high winds and heavy wave action.

The annual drawdown is licensed to 30 m but averaged closer to 10 m during the period 1976 to 1988 (Figure 1). Low water is in early spring (April 28 - May 14) with high water attained by late July, although the reservoir is almost full by late June. The high water level varies by up to 6 m.

Temperatures in the area are extreme with winter lows of -40 ^{0}C not uncommon. At MacKenzie there is an average of 77 frost free days per year extending from June 17 to August 29 (30 year standard time period 1951 to 1980; AES 1982). Mean monthly temperatures are above freezing from April to October.

Figure 1
Williston Reservoir Elevation, 1976 - 1988*
* 1979 data unavailable.



The sport fish species in the lake in order of abundance, as determined by a 1988 gillnetting program, are: lake whitefish *(Coregonus clupeaformis)*, bull trout *(Salvelinus malma)*, rainbow trout *(Oncorhyncus mykiss)*, kokanee *(Oncorhynchus nerka)*, burbot *(Lota lota)*, lake trout *(Coregonus clupeaformis)*, Arctic grayling *(Thymallus arcticus)* and mountain whitefish *(Prosopium williamsoni)* (Blackman 1992). It appears that the population of Arctic grayling, mountain whitefish and to a lesser extent rainbow trout have declined since 1974-1975. Bull trout, lake whitefish and kokanee have increased in numbers. Bull trout are the most popular sport fish species in most of the lake, particularly in the Parsnip Reach, while rainbow trout are more commonly caught in the Peach Reach (Blackman 1990). Although lake whitefish are the most numerous species, they are difficult to catch by angling and few are taken.

PART II

METHODS

2.1 INFORMATION COLLECTION

The information contained in this review was collected in two steps: first, through a search of the published literature; and second, through a series of discussions with people engaged in research or other activities relevant to the subject. In general, the search focused on North American information although projects from other temperate areas were investigated when encountered.

2.1.1 Literature search

The literature collection phase included a review of the following journals:

Canadian Journal of Fisheries and Aquatic Science 1989-1992

North American Journal of Fisheries Management 1989-1992

Water Resources Bulletin 1987-1992

Lake and Reservoir Management 1987-1992

Journal articles prior to 1989 were covered by Slaney (1990). Relevant articles from this report were re-examined for their applicability to Williston Lake.

2.1.2 Interview Program

The interview of the data acquisition program was designed to collect information which might be published only in the "gray literature" or as works in progress. Due to a tight report deadline, it was decided, that letters would be ineffective, and solicitation of information was therefore conducted primarily by telephone. From an initial list of government departments, university staff and hydro companies, each discussion led to further contacts. These people are listed in the acknowledgments.

PART III

TECHNIQUES REVIEW

3.1 REVEGETATING DRAWDOWN ZONES

Description

The water level fluctuations typical of most storage reservoirs make it difficult for vegetation to become established in the drawdown zone. As a result, this area is often barren of vascular plants. The wave action, unstable soils, and the alternating periods of flooding and exposure prevent plant species from becoming established in this area. A number of revegetation experiments have been successful in introducing some species of plants in the drawdown zone. Successful revegetation of this zone can provide the cover, and invertebrate forage required by fish, as well as stabilizing the shoreline, increasing wildlife use and improving visual quality (Skeesick and Sheehan 1993).

Applications

There are a few ongoing experiments with a variety of shrubs, trees, grasses and sedges in B.C. and Oregon reservoirs (Carr and Moody 1992; Skeesick 1983; Skeesick 1986; Skeesick 1993; Skeesick and Sheehan 1993).

Oregon Reservoirs. In Oregon, there have been a series of revegetation experiments over the last 22 years (Skeesick 1983; Skeesick 1986; Skeesick 1993; Skeesick and Sheehan 1993). The first experiment was conducted in 1971, another was conducted in 1988-89 and another was conducted in 1991. In these experiments bald cypress, willows and sedges have survived regular flooding in reservoirs where the growing season is limited to six to ten weeks in late summer and fall. The first fall frost in this area occurs in mid-October. Of 46 species planted in 1971, four remain viable in 1992. Columbia sedge *(Carex apertd)* has persisted strongly from depths of O - 15 m below the full supply line with the plugs planted having coalesced into a solid row 1.5 - 4 m wide. The species is considered an unqualified success. Slough sedge *(Carex obnupta)* has spread extensively laterally at depths to 8 m, but has disappeared below that. Bald cypress *(Taxodium distichum)* has survived over a depth range of O - 15 m and has successfully dissipated wave energy and provided juvenile fish cover. The fourth species, silky dogwood *(Comm amomum)* persisted at depths less than 6 m to some degree.

A further ten shrubs and seven tree species were planted in 1988. Of these, green ash *(Fraxinus pennsylvanica)* and bald cypress *(Taxodium distichum)* showed the most promise with a survival rate of 90% at up to 8 m depth and 91% at up to 18m depth after one season, respectively. Of the shrubs, rigid willow and purple willow had a 92% and 85% survival rate, respectively, at depths to 15 m after one season.

In an 1989 experiment, matts and wattles of willow whips were stacked to an unstable beach in various ways to test their effectiveness at preventing erosion. Willow mattings were found to be most effective at stabilization of the soil. They also provided a site acceptable to native pioneering species. The willow whips did not develop shoots and re-vegetate as was hoped however.

In another experiment conducted in 1991, Columbia sedge *(Carex aperta)* exhibited a 64% survival rate after two inundations (seasons) to a depth of 15 m and 80% at a depth of 8 m (Skeesick 1993).

Upper Arrow Lake Studies. An Upper Arrow Lake dust control program in B.C. has tested both the establishment of a temporary cover crop and a permanent wetland/riparian ecosystem (Carr and Moody 1992). The techniques were developed as methods for reducing soil erosion and dust problems in the drawdown zone but are also thought to provide benefits to local fish populations although this aspect has not been closely examined. Fall rye, planted in mid-March, reached heights of 1 m before inundation in late July, 1992. The fall rye resulted in successful reduction of both dust and soil erosion. It also led to increased nutrients in the lake and improved the visual aspect. The rye remained in place after one year of inundation as stubble and appeared to provide several benefits: increased surface roughness and soil protection until the next crop could be established; increased soil organic content and thus increased soil resistance to erosion; and it acted as a seed trap for native plant material. It was also found that drill seeding was more effective than helicopter seeding. While the experiment was solely designed to reduce dust and increase soil stability, the rye would provide cover and nutrients to fish and benthic fauna.

Planting trials conducted in Upper Arrow Lake using willows and wetland plant species have also shown promising results (Carr and Moody 1992). Of 14 species of wetland plants established in 1991, four showed reasonable survival rates through 1992. Of these, slough sedge *(Carex obnupta)* exhibited most success with a survival rate of 92% at approximately 4 m depth and 31% at 8 m. Water sedge *(Carex aquatilus)* had a 79% survival rate at 5 m depth and 25% at 8 m. Beaked sedge *(Carex rostrata)* and sitka sedge *(Carex sitchensis)* showed reasonable survival rates at depths to 7 m, but not at 8 m. Columbia sedge *(Carex aperta)* did not perform well at any elevation.

Four species of willows were planted in spring of 1991 with variable results (Carr and Moody 1992). Plumas sitka willow *(Salix sitchensis)* fared the best with a

15% to 55% survival rate at depths between 5 and 8 m over the first year. Survival rates between sites varied widely.

Upper Campbell Lake. A small revegetation experiment is being conducted in the Upper Campbell Reservoir on Vancouver Island. No information was yet available on the outcome of the project.

Application to Williston Lake

The results of revegetation experiments in southern reservoirs are encouraging. A number of plant species have been successfully grown in the drawdown zone of several reservoirs. However, there do not appear to have been any revegetation programs as far north as Williston Lake. Thus, any attempts to establish vegetation in the drawdown zone would be experimental. However, if re-vegetation were successful, there could be substantial benefits. The drawdown zone in Williston Lake may be particularly difficult to re-vegetate because of several factors:

i. The drawdown zone is large and can extend to a depth of 32 m below the high-water mark;

ii. High water levels are irregular and occur from late July to September/October, covering much of the growing season. There is little or no growing season in the fall after the waters recede;

iii. The winters are long and cold with temperatures reaching -40° C on occasion;

iv. Many areas are subjected to high wave action.

Breakup in Williston Lake occurs between mid-April and early May (Blackman 1990). On average, reservoir levels reach a minimum in late April, peak in late July, and remain high until November (Figure 1). The potential growing period, between spring breakup and late July, could be as long as 12 weeks for plants high in the drawdown zone. Although the growing season is short, the number of hours of daylight each day are longer than in more southern locations. Some species of plants were successfully grown in the drawdown zone of Oregon reservoirs where altitude limits the growing season to 6 -10 weeks (Skeesick and Sheehan 1993).

Spring and early summer would be the main growing period as once the reservoir is full, levels remain high until the fall. In Oregon reservoirs, there were two periods for growth; one in the spring and one in the fall. The fall period allows tree species to set bud and prepare for the winter. Tree species lower down in the drawdown zone may not do well due to lack of a fall growing season.

Experimental design

Indigenous species of plants would be the most suitable candidates for a revegetation experiment. There may be species that are naturally encroaching into the drawdown zone that could be used. Most if not all of the species that were successful in southern reservoirs are not native to the Williston Lake area and possibly would not survive the more northern climate. However, as they have been shown to survive the rigors of the drawdown zone in other areas these species should be tried, particularly the willows and sedges. Additional flood tolerant plants species and species noted to colonize reservoir drawdown zones are listed by Hill (1984).

Fall rye, used to control dust in the Upper Kootenay Reservoir, is planted by some Peace River farmers in mid-late April. Although this species has to be planted annually, it was found to facilitate the colonization of native species by trapping seeds and adding organic material to the substrate (Carr and Moody 1992). It may therefore be useful to experiment with fall rye as the first step in establishing a succession of species in the drawdown zone.

Little research has been done on how re-vegetated drawdown zones affect fish. If plant species can be established in the drawdown zone, then studies should be conducted to determine whether inundated re-vegetated areas are used for cover by fish and if fish production is increased. One experimental design would be to re-vegetate the opposite sides of adjacent bays and to compare fish densities and size in vegetated and unvegetated areas. A near by but unvegetated bay could be used as a control. A Gee trapping or trap net program may be effective in determining relative densities of juvenile fish or could be used for mark and recapture to determine fish growths.

3.2 ARTIFICIAL REEFS, SUBSTRATES AND STRUCTURES

Description

Artificial reefs, substrates and structures have been used in lakes and reservoirs to enhance fish habitat in a number of ways (e.g. Brown 1986, Haley 1987, Prince and Maughan 1978). First, artificial spawning habitat may be needed when spawning habitat is limited due to siltation, water level fluctuations or lack of relief in the reservoir basin. Second, structures and artificial reefs have been used as breakwaters (Clady et al. 1979). Wave induced turbulence, moves shoreline material to deeper water, destroys or prevents vegetation from becoming established, decreases primary and benthic production and can increase turbidity which can also negatively impact on fish. Third, the addition of structure is an established method of enhancing fish by increasing protection from predation and increasing surface area for food production (Pardue and Nielson 1979).

Floating, submerged and suspended artificial habitat has been constructed out of a range of material including: vessels, automobiles, gravel, rock and concrete debris, Christmas trees, tires and brush piles (Envirowest 1990; Prince and *Maughan* 1978; Wight 1988; Martin 1955).

There are several potential problems with artificial habitats. Siltation can render them ineffective, although this should not be a problem in Williston Lake where silt levels are generally low (with the possible exception of upper Finlay reach). Another problem is that it can be difficult to establish these structures in deep or steep sided reservoirs. Thirdly, structures that are placed in the drawdown zone become ineffective and a navigation hazard as waters recede. If structures are placed below the drawdown zone, they may be below the zone used by many fish, particularly juveniles.

Secured floating reefs can provide fish cover year round and also act as a breakwater to decrease shoreline erosion. Unfortunately, there are several problems with this type of cover:

there is less opportunity for benthic invertebrates to colonize.

structures can be a navigation hazard and can present aesthetic problems.

artificial structure may serve as an attractant to fish and anglers alike. In over fished reservoirs, the artificial structures may concentrate fish and subject them to increased fishing pressure (Wede and Anderson 1979).

Despite some problems, artificial structure provides a surface for increased primary and invertebrate production which would lead to increased growth for some fish species (Brouha and von Geldern 1979). In addition survivals offish may increase due to the added protection from predation that the structure would provides.

Applications

Most experiments and projects involving artificial reefs, substrates and structures have been in more temperate lakes and have involved Centrarchid species such as bass, bluegills and sunfish. An on going program, in a reservoir with some similar characteristics to Williston Lake is being conducted in the Hungry Horse Reservoir (Brian Marotz, Montana Dept. Fish, Wildl and Parks, pers. comm.). This reservoir is part of the Flathead River system in Montana and has a large drawdown of between 55 and 67 m. Fish cover was created using logging slash (tree tops) strapped to a steel frame and anchored with concrete . These structures were placed in the drawdown zone between depths of 10 and 35 m below the full supply level. Initial results indicate the structures increased benthic production by eight times and that juvenile salmonids utilized the structures for cover. However, the structures were not cost effective as the experimental design imposed very awkward shapes and deployment methods. Additional work would be required to develop a practical technique.

Applications to Williston Lake

Williston lake contains large areas of drowned timber and there is thus little requirement for structure placement in deep water. However, many of the embayments have lost their cover.

Spawning habitat. Lake trout and lake whitefish are the only lake spawning sport fish species in Williston Lake that could possibly benefit from the establishment of artificial reefs and substrates for spawning. Lake trout, which spawn on reefs or gravely bottom (Carl et al. 1977), are currently low in numbers. However, judging by the gravel shoreline in many areas the lack of spawning substrate is probably not a problem for this species although there may be less of this type of material below the winter drawdown level. Lake whitefish also spawn in the lake along gravel or rocky shores, but are the most numerous species in the lake.

Shoreline Protection. Exposed shorelines could be protected with boom sticks and log bundles in some areas in an effort to decrease bank erosion and allow benthic organisms and vegetation to become established. The cost/benefit ratio of this type of enhancement project would be questionable at the present time as there are many protected areas that have yet to be re-vegetated. Until the existing unexposed areas are re-vegetated, there would be little point in protecting more shoreline.

Chains of boom sticks or log bundles may help to protect areas where revegetation experiments are being conducted.

Juvenile cover. Possibly the best use of artificial reefs, substrates, and structures would be to provide cover and a surface for food production for juvenile rainbow trout and bull trout. Lake resident bull trout and rainbow trout generally spend one to three years in tributary habitat before migrating into larger bodies of water (McPhail and Murray 1979, Fraley and Shepard 1989, Bjornn 1961, and Oliver 1979). However there is some indication that juvenile trout may enter Williston Lake at an earlier stage (B. Blackman, MELP, pers. comm.). As survivals of juveniles in lake habitat increase with size and age, the placement of the appropriate cover in embayments near spawning streams may increase juvenile survivals by decreasing the success of predators. Additionally increases in cover would lead to increased benthic production possibly leading to increase growth for these two species.

Preliminary results from the Hungry Horse Reservoir project suggest that logging slash anchored with cement provides effective cover for juvenile salmonids and increased benthic production. A similar type of project may be effective in Williston Lake embayments. However, this type of program would be largely experimental as no documented evidence was found to suggest the placement of artificial structures in reservoirs leads to increased production and survivals of juvenile bull trout and rainbow trout or even that these species of juveniles would associate with artificial structures.

The placement of these structures in the Williston drawdown zone would be beneficial for juveniles during the summer. The need for cover may not be as crucial in the fall and winter when the reservoir is drawn down and more debris and standing trees come closer to the surface. Careful placement will be required. If artificial cover in the drawdown zone is still under water during freeze up it may become crushed by ice as the lake level drops over the winter.

Other structures that might be considered for cover are floating rafts of logs and slash. While floating structures generally attract fewer fish than reefs (Slaney 1990), this type of cover would be available for fish throughout the year although bottom cover would tend to be available only at certain water levels. The main problem with floating cover is that it can be a hazard to navigation, it may be aesthetically unpleasant and it may not be as effective at attracting rainbow and bull trout juveniles as submerged cover, especially if far from the shore. Floating cover may have to be far from shore in some areas were the bottom has a low slope due to the large draw down of the lake. This would minimize the potential invertebrate benefits.

Experimental design. Bays that have streams used for spawning by bull trout and rainbow trout or bays with streams that are being stocked would be the best locations for additional cover. Potential sites include Nation Arm, Mason Arm, and the bays at the mouths of Scott, Weston, Carbon and Dunlevy creeks.

The lack of documentation indicates there is a need for more information on the enhancement potential of artificial structures on lake rearing bull trout and rainbow trout juveniles. A study should be designed to determine if cover such as floating rafts of slash or submerged tree tops attract juvenile salmonids and increase survivals and growth over areas with little cover. The study could include an examination of the most effective depth to place structure in the drawdown zone.

3.3 FERTILIZATION

Description

The addition of nutrients to oligotrophic lakes may increase summer primary production which in turn leads to increases in Zooplankton standing stock and fish production (Hyatt and Stockner 1985). In British Columbia, lakes have been enriched by the application of chemical fertilizer from aircraft and boats. Lake fertilization may also be achieved through aeration which causes nutrients locked at deeper levels and in sediment to be carried to the surface, although the success of this technique is limited to relatively small systems. Terrestrial vegetation in the drawdown zone may also add nutrients to a lake system.

Lake fertilization experiments indicate that the addition of fertilizer to oligotrophic systems increases primary and secondary production. Fish production generally increases but lake fertilization does not always have the desired impact on the target species of fish. However, lake fertilization is an effective method in increasing sport fish production in some systems.

Applications

There have been a number of programs in B.C. to study the effect of the addition of inorganic nitrogen and phosphorus to oligotrophic lakes on fish production.

Lake Enrichment Program. Since 1969, the Fisheries Research Branch has conducted an extensive experimental lake fertilization study (Lake Enrichment Program), designed to increase sockeye salmon production (Hyatt and Stockner 1985; Stockner and Shortreed 1985; Wright 1982; Cooke and Cousens 1981). Aircraft (DC6B water bombers) were used to apply the fertilizer to as many 17 coastal lakes. Lake fertilization was found to be a cost effective technique for enhancing sockeye production in some systems. However it does not always produce the desired response in the target species. For example, in some systems rather than increases in juvenile sockeye production there were explosions in the populations of threespine stickleback *(Gasterosteus aculeatus).*

Montane Lakes Study. In another study, fertilization of small coastal montane lakes in southwestern B.C. lead to a doubling in yield of rainbow trout (T. Johnston, MELP, pers. comm.). The increased yields appeared to be from increased growth rates rather than changes in survival.

Mohun Lake. Mohun Lake on Vancouver Island was fertilized to increase kokanee size and production (Perrin et al. 1984). Kokanee growth rates increased but the fish matured earlier and spawned in two years rather than three. As a result there was no increase in the size of fish available to anglers, despite increases in growth.

Kootenay Lake. The 130 km^2 north arm of Kootenay Lake was fertilized in 1992 (Ken Ashley, MELP, pers. comm.). A total of 864 metric tons of liquid fertilizer was delivered bi-weekly by a tug/barge unit. The fertilizer cost was $205,000. The results of the limnological sampling program and the response of kokanee have not yet been reported.

Scandinavia. A bay of the Lake Anjan reservoir was artificially enriched by the addition of chemical fertilizer to an inlet stream (Milbrink and Holmgren 1981). The resulting increases in productivity had major impacts on the composition of the fish community. The high degree of segregation and niche separation, which was evident before enrichment, gave way to niche overlap as food resources became more abundant. This meant that there were 'empty niches' for species such as sticklebacks to exploit.

Application to Williston Lake

Williston Lake is an oligotrophic system whose sport fish populations may benefit from nutrient additions. An experimental program would have to be conducted to determine if there would be a positive impact on desirable sport fish species. Due to its large size and rapid flushing, whole lake fertilization of the Williston reservoir or the fertilization of a reach would be impractical. Fertilization of some bays may be appropriate to help attract and boost fish populations in heavily fished areas. The effectiveness of fertilization is strongly influenced by flushing rates, thus bays without tributaries and those not subject to excessive wind/wave action would benefit most.

Rainbow trout should maybe be the main target of any embayment fertilization program. Although this species feeds on a variety of organisms, ranging from Zooplankton to fish (Carl et al. 1977), fertilization experiments of some small montane lakes increased production by increasing growth rates (T. Johnston, pers, comm.).

Kokanee stocks are currently at low levels in the lake but appear to be building (Blackman 1992). As these fish are likely to be limited more by the size and success of the spawning population rather than food availability, a lake fertilization program may not immediately benefit this species. Lake fertilization would probably increase kokanee growth rates but they are already a good size for anglers as they enter their third year (average fork length = 283 mm at age 3+; Blackman

1992). Increased growth rates may only cause some to spawn at an earlier age as was the case in Mohun Lake.

The production of lake whitefish, on the other hand, may be limited by food availability. Although lake whitefish are numerous, the mean size is too small for a commercially viable fishery (Blackman 1992). A lake enrichment program may increase the size and numbers of lake whitefish enough for a fishery. Lake white fish are primarily benthic feeders (Carl et al. 1977) thus this species may not benefit from lake fertilization as directly as a planktonic feeding species such as kokanee. No information was found on the effects of lake fertilization on lake whitefish.

Experimental Design

A small scale experimental program to test the effect of embayment fertilization on the growth of juvenile rainbow trout and bull trout may prove valuable. Confined bays with reasonable concentrations of rainbow trout would be the best locations. Areas to be considered may include Nation Arm, Manson Arm and the bays at Carbon and Dunlevy Creeks . Two bays in close proximity such as at Carbon Creek and Dunlevy Creek could be used with one bay being fertilized and the other not. Before the fertilization experiment, a sampling program, possibly using gillnets should be conducted in the two bays to determine relative densities and growth rates of fish. After a season of fertilization the two bays could be sampled again to test for differences in abundance and growth.

The benefits of a large scale fertilization program would not likely justify the cost given the current assemblage of fish species in Williston Lake. If kokanee become more numerous and mean size decreases, a large scale program may be worth considering.

3.4 STOCKING

Description

Stocking represents the easiest way to overcome spawning and incubation problems within a reservoir. Hatchery incubation tends to be the principal enhancement technique used in North American reservoirs (Keith 1896, McCammon and Von Geldern 1979, Wydoski and Bennett 1981). Most B.C. reservoirs have been stocked to some degree.

Large ongoing costs and questions of genetic fitness remain problems with hatcheries. Selection of optimum strains of trout has received much attention, but success appears to be system specific (Gann 1983, Fraser 1981, Hurdy 1980, Hepworth and Lepnick 1979, Rawston 1979, Huston 1975, Berst and McCombie 1975, Cordone 1968).

Application to Williston Lake

Stocks of stream resident, lake resident and Gerrard rainbow trout and kokanee are currently being planted into some Williston Lake tributaries (Blackman pers, comm.). The stocking program has been designed to build up the low levels of adult rainbow trout in the rivers and embayments (Blackman 1990). The embayments are the most popular fishing areas in the lake and indications are that rainbow trout and bull trout populations are down in these areas (Blackman 1992).

One option for stocking, which is not currently being done, is netpen rearing of rainbow trout in the embayments. For added production, trout could be reared in netpens during early summer and then released into the lake after they acclimatize to lake conditions and attain a larger size at which survival rates are higher. Netpens for rearing have been used in Sayres Lake and Alouette Lake, two other B.C. reservoirs (Slaney 1990) and are currently being installed in two reservoirs: Buntzen and Hayward lakes (D. Wilson, B.C. Hydro, pers. comm.). The advantages of netpen rearing are that the fish are free of predation and receive a certain amount of wild prey in addition to whatever feed supplements may be required. Providing a suitable location and staff area available, the cost of raising large fish can be lower using netpens than conventional hatchery facilities (Slaney 1990).

Netpen rearing is an option for heavily fished embayments close to more populated areas. The disadvantage over stream stocking is that there is less chance of establishing runs in particular tributaries, thus the program would have to be on going. The advantages are that catchable sized fish would be attained at a much faster rate using less brood stock.

3.5 TRIBUTARY IMPROVEMENTS

As lake dwelling bull trout and rainbow trout generally rear in tributary habitat for some time before migrating into the lake, the modification of tributaries to increase carrying capacity for spawning and rearing fish or to increase juvenile survivals could lead to larger numbers of adults available to anglers in the embayments. As this work is beyond the current terms of reference and may be covered by other MELP programs it is outlined here merely for the sake of completeness. Possible tributary enhancement techniques include fertilization and improving fish access at various stream and reservoir levels as well as improvements in substrate, cover, channel morphology, minimum flows and water temperature. There is extensive literature on tributary improvements in both natural and reservoir systems (Slaney and Ward 1992, Ward and Slaney 1992, Envirowest 1990, Taylor 1986, DFO/MOE 1980, Swales and O'Hara 1980, Parkinson and Slaney 1975).

The advantage of this approach is that stream enhancements tend to maximize production of hardy, naturally reared stocks. In addition, improvement programs are often one-off projects that do not require long term funding commitments. Stream surveys need to be conducted to determine specific stream enhancement projects that would benefit the embayment fisheries.

3.6 INTRODUCTIONS

Description

Introductions of new species of fish can sometimes improve fishing opportunities. A new species may be more successful in utilizing the habitat than the resident species. For instance, the introduction of new species of fish may compensate for poor spawning or rearing habitat. In British Columbia reservoirs containing rainbow trout, the population is sometimes limited because stream spawning and rearing habitat is limited or was inundated. The introduction of lake trout, which are a lake spawning species, to such a system that has adequate reef habitat may produce a successful lake trout fishery.

Populations of sports fish can sometimes be enhanced by the introduction of a forage fish or invertebrate species. For example kokanee, which are efficient Zooplankton feeders, have been stocked into some systems as forage for larger piscivorous fish (Slaney 1990). *Mysis relecta,* an invertebrate herbivore, was introduced into many cool water systems in North America.

While the new species may be able to utilize existing habitat better, introductions can lead to unforeseen complications. First, there can be problems associated with the impacts of the new species and second, there can be problems in establishing a new species.

Introductions can lead to large increases in yield and the dynamic stability of systems but the collapse of a fishery and loss of indigenous fauna can also occur. For example, mysid introductions, initially considered to be a great success, have turned out to be more efficient foragers than salmonid fry and therefore are competitors rather than prey (Lasenby et al. 1986). In another example, kokanee introductions to ultra-oligotrophic systems with restricted littoral production can lead to reduced production of juvenile trout (Stuber et al. 1985). Therefore, due to the often unexpected response, detailed impact assessments of the introductions are now common (Li and Moyle 1981).

The success of the new stock requires very careful assessment of the required and receiving habitat. For example, few lake trout introductions have resulted in naturally reproducing populations (Oliver and Lewis 1977).

Application to Williston Lake

Introductions of new species to Williston Lake are not part of the management plan (Blackman 1990), although non indigenous varieties of rainbow trout and kokanee are being planted into some tributaries (Brian Blackman, MELP pers. comm.).

The creation of marshy dyked embayments may produce habitat suitable for some new species not currently in the area. This type of habitat may be suitable for a number of species such as cutthroat trout, mountain whitefish, northern pike, Arctic grayling and walleye. Before a species is introduced the possible ecological impacts will have to be studied along with which species would maximize sport fishing opportunities.

3.7 COVE CULTURE

Description

Cove culture is a means of stabilizing water level fluctuations in small near-shore portions of storage reservoirs. The technique can be used to make up for the loss of the productive littoral zone which is critical to early rearing success in many sport species.

One type of cove culture is the creation of stable, productive habitat by dyking small bays. Water level fluctuations in the enclosed area are reduced which allows the littoral zone to become a stable environment for benthic invertebrates and vascular plants. These areas can provide productive habitat for fish, fur bearing animals and waterfowl. The main disadvantage of this type of project is the high capital costs.

Another form of cove culture is to isolate areas from the main reservoir using nets. In China this method is used to rear hatchery fingerlings after the predators have been removed (Lin 1982, Xiangke 1986). Natural forage is supplemented by artificial food.

Applications

A dyked bay was created in the LG-2 reservoir in northern Quebec to provide habitat for walleye *(Stizotedion vitreum)*, northern pike *(Esox lucius)* and lake whitefish *(Coregonus clupeaformis)* (Hill 1984). In this project the dyked bay took on the appearance of a natural lake and was found to be productive fish habitat. The cost of the 123 m long dyke at the LG-2 project was $743,000 in 1982.

Application to Williston Lake

There is likely a lot of potential for creation of dyked bays in the Williston Lake embayments, particularly in the Parsnip Reach where there are numerous shallow bays. The creation of dyked bays would stabilize the littoral zone and allow the establishment of vascular plants, algae and invertebrates. These areas would increase the system productivity and provide habitat for rearing juvenile salmonids as well as other species of wildlife that utilize wet land habitat. Fish species that might do particularly well in this type of habitat include cutthroat trout, mountain whitefish, Arctic grayling, pike and walleye.

Potential sites for weir construction include areas near the mouth of Mugaha, Tony and Tutu Creeks. Ducks Unlimited had, at one time, proposed the construction of a weir across the mouth of Mugaha Creek to create duck habitat, although the projected was never carried out (Ken Senner, pers. comm.). The costs can be high with this type of enhancement technique, but the biological benefits can be substantial as it would be beneficial to fish and many other types of wildlife.

PART IV

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

The literature review and interview program conducted indicates that little work has been done in northern hydro reservoirs to enhance fish and fish habitat due to the difficulties and expense involved. Typically, most agencies in North America tend to management the available fisheries rather conducting enhancement programs. Other than stocking programs, most of the enhancement work consists of experimental projects. The results of most of the potential enhancement techniques are thus difficult to predict.

Williston Lake is a large, rapidly flushed, oligotrophic system. It has a large draw down zone which is largely bare of vegetation. In a natural system, the littoral zone can be a productive area even in oligotrophic systems. In a reservoir this zone is typically unproductive due to the instability of the environment in this area. The main focus of a reservoir embayment enhancement program should thus be to provide the missing cover and forage.

Among the types of enhancement programs studied or implemented in other systems, four show the most promise for enhancing fish and fish habitat in the embayment areas:

i Revegetation of the drawdown zone.
ii Creation of artificial structures.
iii Creation of dyked bays.
iv Chemical fertilization.

The enhancement benefits of dyked bays are likely the most predictable. The dyked area will have characteristics very similar to a natural lake or pond similar in depth and area. In the northern setting of Williston Lake, this means that the site should be deep enough to maintain reasonable oxygen concentrations in the water column under winter ice. While this type of enhancement project has the potential to create productive fish habitat in the draw down area, if suitable sites are available, it can be costly. However, this type of project has the potential to benefit many other forms of wildlife, and other agencies and organizations may be willing to contribute funding, equipment and materials. The main problem is to locate suitable sites. A good site would be one that is accessible and where a large sub-impoundment can be created with a small dyke.

The establishment of vegetation in the drawdown zone has the potential to be very beneficial if successful. However, it is uncertain whether plants could be found that could survive the harsh conditions that would be encountered. The advantage of attempting revegetation experiments is that a program could probably conducted with relatively modest funding. The first step in conducting revegetation experiments would be to find what species can survive in the drawdown zone and to refine techniques for establishing them. Once suitable species are found, then studies should be conducted to determine the cost/benefits of a larger scale revegetation program. It should, however, be noted that the linkage between shoreline re-vegetation and increased fish production has be assumed more often than tested.

The creation of artificial structures is another experimental technique which has the potential to benefit juvenile rainbow trout and bull trout. A small scale experimental program could be conducted to determine what associations, if any, these two species would have with various artificial structures and if the benefits justify the cost of a larger scale program.

Lake fertilization program may have positive benefits on fish production but, given the current assemblage of fish in Williston Lake, the benefits may not justify the costs. Planktivorous species of fish such as kokanee and to a lesser extent rainbow trout, stand to benefit the most from lake fertilization. A small scale embayment fertilization program targeted at increasing rainbow trout productivity may be the best option for this type of enhancement technique. Further offshore, both kokanee and rainbow trout are currently low in numbers (Blackman 1992) and the population is probably limited by the size of the escapement and spawning success (Blackman 1992). The numbers of fish available to anglers is not likely to increase significantly with lake fertilization. Growth rates would likely increase but kokanee are already a catchable size by age 3+ (Blackman 1992). Lake whitefish are mainly bottom feeders and at times feed on planktonic organisms (Carl et al. 1977). No information was found on the effects of lake fertilization on this species. However, lake whitefish are not a popular sport fish partially due to the difficulty in catching this species.

4.2 RECOMMENDATIONS

No proven enhancement techniques were found for embayments in northern storage reservoirs with large drawdowns. The best approach to the Williston Lake situation appears to be the development of a small scale experimental program to refine some of the techniques which have shown promise in more temperate locations. There are enough small bays on the Williston Lake shoreline to permit the concurrent testing of several techniques and the monitoring of similar control sites. Techniques to be investigated could include:

i Revegetation of the drawdown zone,
ii Creation of artificial structures,
iii Creation of dyked bays.
iv Chemical fertilization.

Embayments at the mouth of Mugaha, Tony and Tutu Creeks as well as other areas in the Parsnip Reach should be examined for dyked bay creation sites. Engineering studies should then be carried out and a cost benefit analysis done.

As a first step in a revegetation program, planting trials should be conducted to test the survivability and the methodology of introduction of various plant species in the drawdown zone. If species can be found that will survive and spread in the drawdown zone a large scale planting program could be conducted and studies should be done on the benefits to fish and fish habitat.

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APPENDIX

Review of re-vegetation techniques from Hill (1984)

3.4.8 - Revegetation of Reservoir Shorelines and Streambanks

Description

It is usually desirable to revegetate reservoir shorelines and Streambanks to stabilize soils and provide riparian habitat. Trees and shrubs along Streambanks can also keep water temperatures low. A number of herbaceous and woody perennials are noted colonizers of reservoir drawdown zones as listed in Tables 9 and 10. Further information on the flood tolerance of plants is available from the US Army Corps of Engineers (1979c). A general guide is to use native species wherever possible. Willow cuttings (Salix spp) may not establish successfully where beaver, muskrat or deer are abundant (US Forest Service, 1969).

Fowler and Hammer (1976) have outlined some key factors to consider in selecting a revegetation technique for reservoir drawdown areas

- fisheries and wildlife populations, density and potential benefit from seeding
- spatial location and size of inundation zone
- inundation zone slope and time of initial exposure (best time to apply seed is immediately after exposure)
- soil fertility
- agricultural, residential and recreational development near shorelines
- plant species adaptable to ecological condition of inundation zone
- effect of flooded vegetation on fish spawning activities and ecology of reservoir.

Where reservoir water levels fluctuate by many metres, stabilization with synthetic fibre sheets may be required. In this case, seed and fertilizer can be placed under interwoven strips of biodegradable material or, alternatively, seeded concrete gratings are placed over polyester matting (Figures 42 and 43).

APPENDIX
Review of re-vegetation techniques from Hill (1984)

TABLE 9

HERBACEOUS PERENNIALS NOTED AS COLONIZERS OF RESERVOIR DRAWDOWN ZONES (Adapted from Gill, 1977)

Genera/Species	Common Name	Canadian Distribution (Britton and Brown, 1970)
Agropyron repens	Quack grass	Throughout Canada except extreme north
Alisma spp	Water plantain	Nova Scotia to Ontario; B.C.
Carex spp	Sedges	Labrador to B.C.
Cirsium spp	Thistles	Throughout Canada
Deschampsia caespitosa	Hair-grass	Newfoundland to B.C.
Eleocharis acicularis	Spike-rush	Newfoundland to B.C.
Equisetum palustre	Marsh horsetail	Nova Scotia to B.C.
Juneus articulata	Jointed rush	Labrador; B.C.
J. bulbosus	Bulbous rush	Labrador; Newfoundland; Nova Scotia
J. effusus	Common rush	Throughout Canada in swamps and moist places
Littorella uniflora	Shore-grass	Newfoundland; Nova Scotia; Ontario
Men-fha aquatic	Water mint	Nova Scotia
Phalaris arundinacea	Reed canary-grass	Nova Scotia to B.C. in moist or wet soil

APPENDIX

Review of re-vegetation techniques from Hill (1984)

Table 9
Herbaceous Perrenials Noted as
Colonizers of Reservoir Drawdown Zones
(Adapted from Gill, 1977) - 2

Genera/Species	Common Name	Canadian Distribution (Britton and Brown, 1970)
Phragmites communis	Common reed-grass	Nova Scotia; Manitoba, and B.C. in swamps and wet places
Plantago lanceolata	Buckthorn or narrow-leaved plantain	New Brunswick to Northwest Territories; B.C.
P. major	Common or broad-leaved plantain	Nearly throughout Canada
Polygonum amphibian	Willow-weed	In ponds and lakes, Quebec to B.C.
Potentilla anserina	Silver-weed	B.C.
Ranunculus flammula	Creeping spearwort	Newfoundland
R. repens	Creeping buttercup	All provinces except Manitoba and Saskatchewan
Typha latifolia	Broad-leaved cat-tail	Marshes throughout Canada

APPENDIX
Review of re-vegetation techniques from Hill (1984)

TABLE 10

WOODY SPECIES FLOOD TOLERANCE LIST
(Teskey and Hinckley, 1978)

	Common Name	Distribution (Britton and Brown, 1970)
Very Tolerant*		
Fraxinus pennsylvanica	Green ash	New Brunswick to Minnesota
Picea mariana	Black spruce	Throughout Canada
Populus deltoides	Eastern cottonwood	Moist soils, Quebec to Manitoba
Populus grandidentata	Bigtooth aspen	Nova Scotia to Ontario
Salix niqra	Black willow	Along streams and lalces, New Brunswick to western Ontario
Tolerant**		
Abies balsamea	Balsam fir	All provinces except B.C. and territories
Acer negundo	Box elder	Along streams, Ontario to Manitoba
A. rubrum	Red maple	Swamps and low ground, Nova Scotia to Manitoba
A. Saccharinum	Silver maple	Along streams, New Brunswick to southern Ontario
Celtis occidentalis	Hackberry	Dry, rocky soil, Quebec to Manitoba
Nyssa sylvatica	Black gum	Swamps, Ontario
Platanus occidentalis	Sycamore	Along streams, wet woods in Ontario

APPENDIX
Review of re-vegetation techniques from Hill (1984)

Table 10
Woody Species Flood Tolerance List
(Teskey and Hinckley, 1978) - 2

	Common Name	Distribution (Britton and Brown, 1970)
Tolerant**		
Quercus bicolor	Swamp white oak	Moist or swampy soils, Ontario and Quebec
Q. macrocarpa	Bur oak	Rich soil, Nova Scotia to Manitoba
Tilia americana	American basswood	New Brunswick to Manitoba
Ulmus americana	American elm	Moist soils, Newfoundland to Manitoba
Intermediately Tolerant***		
Acer saccharum'	Sugar maple	Newfoundland to Manitoba
Alnus incana	Alder	Wet soils, Newfoundland to Saskatchewan
Betula alleghaniensis	Yellow birch	Nova Scotia; New Brunswick; Quebec; Ontario
Carpinus caroliniana	Hornbeam	Moist woods, Nova Scotia to Ontario
Morus rubra	Red mulberry	Ontario
Picea glauca	White spruce	Newfoundland to B.C. and territories
P. rubens	Red spruce	Newfoundland; Nova Scotia, New Brunswick

APPENDIX
Review of re-vegetation techniques from Hill (1984)

Table 10
Woody Species Flood Tolerance List
(Teskey and Hinckley, 1978) - 3

	Common Name	Distribution (Britton and Brown, 1970)
Intermediately Tolerant***		
Pinus resinosa	Red pine	Newfoundland to Manitoba
P. strobus	Eastern white pine	Newfoundland to Manitoba
Populus tremuloides	Quaking aspen	Newfoundland to B.C. and territories

Very tolerant: Can withstand flooding for periods of two or more growing seasons

** Tolerant: Can withstand flooding for most of one growing season.

***Intermediately Tolerant: Can survive flooding for periods between 1 to 3 months during growing season.

APPENDIX

Review of re-vegetation techniques from Hill (1984)

Methods used to seed reservoir shorelines include hydroseeders (tank truck or barge), fixed-wing aircraft, helicopters and air cushion vehicles. Most of these methods have been used by the Tennessee Valley Authority with good success (Fowler and Hammer, **1976).** Further guidance on revegetation of reservoir shorelines is available from Gill (1977) and Teskey and Hinckley (1978).

Along streambanks where quick stabilization is required structural measures (Section 3.1.13) and/or selected grasses with an organic fiber mulch and fertilizers are appropriate. Grass mixtures recommended for coastal climates of British Columbia include alsike clover (Trifolium hybridum), white dutch clover (Trifolium repens), perennial ryegrass (Lollurn perenne), timothy (Phleum pratense), reed canary grass (Phalaris arundinacea), creeping red fescue (Festuca rubra variety),and fall rye (Elymus species), (Fisheries and Oceans Canada, 1980). Provincial ministries of highways, environment or natural resources can most likely assist with local requirements. A general guide entitled "Bioengineering for Land Reclamation and Conservation" by Schiechtl (1980) is also a useful **reference.**

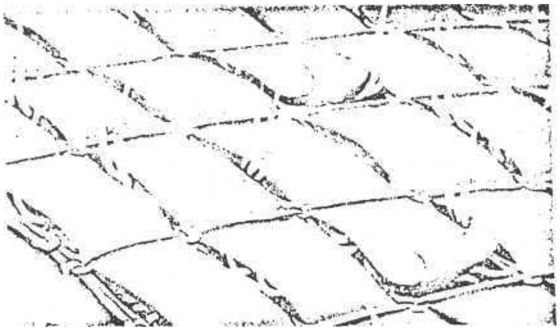

Figure 42 - Biodegradable Material Provides Soil Stabilization Until New Growth is Established (Anco Chemicals Ltd, Maple, Ontario)

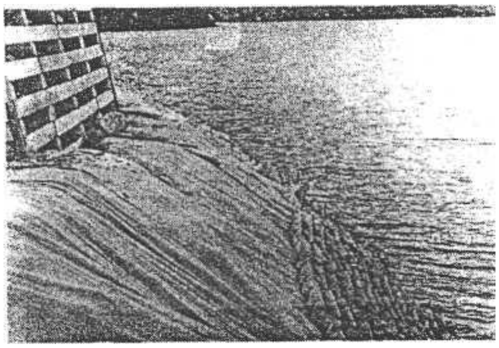

Figure 43 - Seeded Concrete Gratings Over Polyester Matting (Schiechtl, 1980)

Applications and Effectiveness

Location	Description of Measure	Effectiveness
Opinaca Reservoir (northern Quebec)	Planting and seeding of 150 ha along new reservoir shoreline to restore habitat	Considered very successful by Societe d'energie de la Bale James, 1983)

APPENDIX

Review of re-vegetation techniques from Hill (1984)

Location	Description of Measure	Effectiveness
Churchill Falls (Labrador)	Seeding of 116 ha by fixed-wing aircraft for downstream slope protection of diKes	Vegetation stabilized dike slopes in most areas and dramatically decreased costs of slope repairs; also attracted some wildlife to feed in newly planked areas
Upper Salmon (Newfoundland)	Mechanical seeding, hydroseeding, fertilizing and mulching of downstream slopes of dams and dikes, and north cut slope of power canal (approximately 10 ha); also, seeding, fertilization and mulching of disposal areas (53 ha), temporary roads (25 ha) and borrow areas (35 ha)	Not yet implemented as of 1983
Brazeau Reservoir (Alberta)	Grass seeding along canal for erosion prevention; maintenance cutting required every 4 years to keep natural growth down	Considered very effective in controlling erosion (Keyes, 1983)
Arrow Lake/ Keenleyside Dam (British Columbia)	Reseeded drawdown area to reduce effects of dust storms on local community	Unknown

Limitations

Soil, slope and moisture conditions will limit adaptation of certain plant **species.** Where shoreline plantings will be inundated, ensure that water quality and fisheries habitat are not adversely affected.

Fixed-wing aircraft are not practical for seeding in mountainous terrain surrounding some **reservoirs.** Helicopter rotor blade vortices did not adversely affect seeding by the Tennessee Valley Authority; however, air cushion vehicles would not negotiate high grass, brush, or rough terrain (Fowler and Hammer, 1976).

APPENDIX
Review of re-vegetation techniques from Hill (1984)

Costs and Benefits

Costs for a 3-yr revegetation program of 116 ha at the Churchill Falls hydro scheme were $2,100/ha (adjusted to 1982) which included seed and fertilizer, labor and operation of fixed-wing aircraft (Waters and Weston, 1976). The total cost of $243,600 compares very favorably with the estimated annual cost of $73,800 for structural slope repairs at this site. Benefits other than economics and successful soil stabilization included improved aesthetics and the availability of feed for wildlife, particularly Canada geese (*Branta canadensis*).

At the Upper Salmon hydro site in Newfoundland, seeding, fertilizing and mulching costs for approximately 24 ha are estimated at $9,800/ha (adjusted to 1982). Not included in this price are laboratory and field plant growth trials, preparation of a seeeding tender document and field supervision by a reclamation consultant.