A TECHNICAL AND ECONOMIC FEASIBILITY STUDY OF THE BEAVER LAKE/CREEK ENHANCEMENT PROJECT

HATFIELD CONSULTANTS LTD
environmental and pollution management

A TECHNICAL AND ECONOMIC FEASIBILITY STUDY OF THE BEAVER LAKE/CREEK ENHANCEMENT PROJECT

Prepared For

The Vancouver Board of Parks and Recreation

and

The Department of Fisheries and Oceans

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1.0 INTRODUCTION

Subsequent to the salmonid enhancement studies carried out on the Beaver Lake/Creek system during 1984, it was decided that additional technical and economic information would be required to assess the feasibility of the proposed enhancement project. The technical areas identified for further study included lake modelling, system hydrology (hydraulics and additional water sources) and sediments (lake excavation) and costing for proposed enhancement alternatives. This document serves as a brief report on the findings of these supplementary studies. In addition to the cost estimates for the enhancement alternatives, a preliminary budget has been prepared for the detailed design phase of the project.

Prior to the preparation of this report, a meeting was held with representatives of the Vancouver Board of Parks and Recreation and the Department of Fisheries and Oceans on February 4, 1985 to discuss the results of the supplementary studies. As a result of these discussions, it was concluded that the proposed sediment removal (dredging) from Beaver Lake was not economically feasible and posed some difficult technical problems. In addition, disposal costs had yet to be considered. It was noted that disposal of the inorganic sediment fraction, which constitutes approximately two-thirds of the total sediment volume, would be particularly costly since no on-site disposal is possible. Therefore, only partial costing has been provided for this enhancement alternative.

It was also decided at the above-mentioned meeting that it was still important to provide fish access to Beaver Lake through a stepped stream channel constructed to replace the existing twin culverts system. Therefore, this element has been included as part of the stream enhancement plan.

2.0 LAKE MODELLING

2.1 Objectives

Two of the enhancement alternatives proposed as part of the Beaver Lake/Creek Project involve lake restoration and the use of the lake as a rearing area for juvenile salmonids. In order to achieve these goals, lake sediment removal and possibly increased water flow through the system will be necessary. From the viewpoint of salmon propagation, it is important to be able to predict water quality changes that may occur as a result of the sediment removal. Therefore, an effort was made to assess potential physical and chemical changes based on several removal scenarios.

2.2 Findings

Water quality conditions in the lake are strongly influenced by mixing and water residence time (hydraulic detention time). To assess potential mixing characteristics, calculations using heat loss equations were made to determine heat transfer through each metre of lake depth on an average summer day. Initially, instantaneous heat fluxes at the lake surface were calculated and then utilized to determine temperature changes with depth, as outlined in Fischer et al. (1979)*.

Lake water residence times were calculated based on existing inflow-outflow characteristics. In its present form, Beaver Lake has a water residence time of approximately 5.94 days. Assuming that the entire lake was dredged to a mean depth of 3 m, which would include a sizeable segment having a depth of 5 m, then the residence time would increase to 45.67 days, an eight-fold increase. If the sediment removal were to proceed, it is likely that only half of the lake would be dredged. In this case, the lake water residence time would be approximately 20 days.

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* Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in inland and coastal waters. Academic Press, New York.

Results of the heat transfer calculations indicate that the lake may intermittently or weakly stratify between 4 and 5 m during the late summer period, if dredging is carried out. Wind-induced mixing, convective mixing from surface cooling at night, and other factors, such as inflow and outflow energy would act to break down this stratification.

If stratification did occur, oxygen demand would be low in the hypolimnion, at least during the first five years, after sediment removal, because the substrate would contain very little organic matter. Inflow water would most likely provide additional dissolved oxygen to the system.

Based on the results of the preliminary lake modelling exercise, several predictions regarding potential water quality changes that may occur after the lake dredging can be made. During the sediment removal process, dissolved and particulate compounds, such as nitrates and phosphates, which act as plant nutrients, will be released. If these releases occur during the summer period when water temperatures and levels of solar radiation are comparatively high, then there may be a temporary bloom of phytoplankton in the system. Once the dredging activities have been completed and the lake has had a chance to flush completely, it is unlikely that there will be a nuisance problem with aquatic plants. The clay bottom that will be exposed as a result of the dredging will contain essentially no organic matter or plant nutrients.

Plans to increase water flow through the system by tapping groundwater supplies will elevate the flushing rate through the lake which in turn should act to minimize the availability of plant nutrients in the system. A potential reduction in nutrient load to the creek downstream of the lake most likely will not have a substantial impact on productivity in the system. In the case of Beaver Creek, productivity appears to be limited more by the availability of light rather than nutrients.

Long-term changes in lake water pH will be dependent on the chemical characteristics of the sediments exposed during the sediment removal activities.

In summary, it is concluded that the proposed deepening of Beaver Lake by sediment removal would result in an initial short-term increase in plant nutrient availability followed by a subsequent reduction after flushing of the system to pre-removal levels or lower. It is unlikely then that any aquatic plant nuisance problem would occur as a result of the sediment removal activities. Further, it is concluded that intermittent weak stratification could occur near the bottom of Beaver Lake during the late summer period after sediment removal. This stratification could potentially result in oxygen depletion in the lower layer (hypolimnion) of the lake. The hypolimnion would not be used by fish if the oxygen level dropped much below 5.0 $mg.L^{-1}$. Although there is the possibility that a minor amount of oxygen depletion could occur near the lake bottom under these circumstances, the low organic content of the bottom sediments after dredging would tend to minimize the problem. The potential dissolved oxygen problem associated with lake stratification would be further reduced by mixing, as described above. Therefore, it appears unlikely that salmonids residing in Beaver Lake after sediment removal will face any major oxygen depletion problems.

3.0 HYDROLOGICAL CONSIDERATIONS

3.1 Hydrology

3.1.1 Objectives

The objectives for examining the hydrology of Beaver Lake were to:

1. determine the catchment area available to the lake;
2. present the inflow characteristics of the lake; and
3. determine the groundwater capabilities for additional inflow to the lake.

3.1.2 Findings

The catchment area available to Beaver Lake is 0.73 km^2. Runoff coefficients were determined for the catchment using 1984 monthly precipitation data and concurrent creek discharges measured a short distance downstream from the outlet. The precipitation data was recorded at the Vancouver Harbour weather station and the flows were spot readings gauged once a month by Hatfield Consultants Limited.

The runoff coefficients determined for the six months of recorded data ranged from 0.35 to 0.65. The typical value for a forested catchment is 0.3 and the higher values may reflect the fact that the spot discharges were not necessarily representative of the mean monthly flow. The high values also indicate that roadway drainage is not diverting significant flow out of the catchment.

Flood flows at the outlet of the lake were determined using rainfall intensity/duration curves developed at the Vancouver Harbour weather station. The concentration time for the catchment was calcuated to be 30 minutes. This is the average time a drop of rain takes to travel from the upper end of the catchment to the inlet of the lake. The mean annual and 1 in 10 year floods were determined

using appropriate rainfall intensities for a 30 minute duration and runoff coefficient of 0.3. The mean annual flood flow is estimated to be 1 $m^3.s^{-1}$ and the 1 in 10 year flood is estimated at 2 $m^3.s^{-1}$.

The Vancouver Harbour weather station records indicate a mean annual precipitation of 1,500 mm. Ten percent of the annual precipitation is estimated to be available for recharging the groundwater system. This is equivalent to a continuous yield of 3.5 $L.s^{-1}$.

3.2 Hydraulics

3.2.1 Objectives

The hydraulic objectives were to:

1. characterize the lake outflow control;

2. determine typical creek velocities; and

3. assess the capacity of the creek to convey extra flow.

3.2.2 Findings

A 0.7 m wide trapezoidal concrete overflow weir forms the present outflow control for the lake. Discharge from the weir passes through a drop structure and culvert into the creek. There is also an adjacent concrete pipe situated below the crest of the weir. The pipe has been blocked at the lake end and was only passing a small amount of leakage during the site visit of January 18, 1985. The pipe has not been considered as part of the lake outflow control.

The weir is estimated to have a capacity of 0.6 $m^3.s^{-1}$ when the lake is level with the top of the structure. A flow of 1 $m^3.s^{-1}$ is estimated to cause the lake to overtop the pathway which passes over the drop structure and culvert. Flooding of the pathway and subsequent transport of pathway gravel into the creek could be expected to occur on average every two years.

A typical creek and gulley cross-section was surveyed approximately 30 m upstream of the upper bridge (Pipeline Road) where the pathway is adjacent to the stream. Velocities through the cross-section were calculated at 0.3 $m.s^{-1}$ for base load flows of 0.02 $m^3.s^{-1}$ and 1.0 $m.s^{-1}$ for the mean annual flood flow of 1.0 $m^3.s^{-1}$. The adjacent pathway floods at a flow of approximately 1.5 $m^3.s^{-1}$ and at this point the creek channel is full. The depth of the gulley at this cross-section provides ample capacity to convey considerably higher flows.

3.3 Water Sources for Stream Enhancement

3.3.1 Objectives

The objective was to assess the capability of providing additional base flow to the lake from three possible sources:

1. runoff from a diverted catchment;
2. groundwater pumped from wells; and
3. purchase of water from Greater Vancouver Water District (GVWD).

3.3.2 Findings

Beaver Lake catchment is the higher of two catchment basins within Stanley Park. The other basin discharges into Lost Lagoon and runoff from the remainder of the park discharges directly into the sea. It is not possible to capture runoff from outside the Beaver Lake catchment basin and divert the flow into Beaver Lake without pumping, which would be impractical.

There are two possible groundwater-bearing zones present in the Beaver Lake area. The shallowest aquifer would be the sands and gravels that may separate bedrock from the overlying till. If this unit is 4 m to 6 m thick, it could supply significant amounts of groundwater to properly designed and constructed wells. The second possible aquifer is the fractured basalts. The Stanley Park basalts have not been tested for their groundwater potential.

The continuous groundwater yield as discussed above is estimated at approximately 3.5 $L.s^{-1}$. This flow rate could be increased for the peak demand period by mining the aquifer. A flow of up to 14 $L.s^{-1}$ could be provided over a three-month period with the aquifer allowed to recharge over the remainder of the year.

There are several locations for the drilling of test holes. The first possible location would be in the area of Beaver Lake to test for the presence of the sands, silts and gravels that may lie between bedrock and till. A second well location would be to the west of the parkway where the basalts are known to be present. A well at this location would have a projected depth of 75 m and be free from the possibility of saltwater intrusion.

There is estimated to be a 50% chance of discovering an aquifer in the Beaver lake area that could produce up to 14 $L.s^{-1}$ over a three-month period. Drilling and testing will be required to substantiate this estimate.

The third option of purchasing water from the GVWD would require aeration to remove the dissolved chlorine. Aeration?

4.0 SEDIMENTS

4.1 Geomorphology and Sediments

4.1.1 Objectives

The objectives in describing the geomorphology were as follows:

1. to describe the general geology of the area;

2. to describe the creek geomorphology, gradients, sediments, natural flow controls and erosion potential associated with increased flows;

3. to describe the lake sediments, extent and depth of organics and the underlying mineral deposits.

4.1.2 Findings

The predominant geologic units in the Beaver Lake area are the Newton stoney clay and Surrey till. These units are evident along the creek banks. The Surrey till is a sandy to silty till with minor amounts of substratified drift totalling up to 20 m in thickness but generally less than 6 m thick. The till is overlain in most places by the Newton stoney clay which consists of glacio-marine stoney clay silt with narrow interbeds of marine silts, clays and sands ranging from 8 m to less than 3 m in thickness. Sands and gravels are known in places to separate the bedrock from the overlying till.

Two bedrock types are exposed on the Stanley Park Peninsula. These are sedimentary rocks consisting of sandstones, shales, and conglomerates and volcanics which consist of basalt flows and sills. The basalts, where exposed in other locations (Sentinel Hill, West Vancouver), are highly fractured.

The creek draining from the lake has incised deeply into the clay and till, forming a narrow gulley. The general bed slope in the upper reaches is moderately steep with a gradient of 2%.

The surface bed material is primarily angular to sub-angular gravel apparently derived from the fill material used for pathway construction. This is especially so immediately downstream of the lake outlet where the pathway is known to overtop during flood flows. There is little natural armouring sediment available in the bank material and the armouring effect of the pathway gravel has probably reduced the rate of stream bed erosion.

Outcrops of large glacial lag boulders occur at several locations in the creek bed. These outcrops form natural flow controls where the stream must negotiate a path through the boulders. The effect of the boulders is to cause erosion which results in a local widening of the gulley.

The potential for erosion is only likely when velocities are sufficient to erode the cohesive bank material. This is only likely to occur during annual floods when the velocities are estimated to be in the order of 1 m/s. Increasing the base flow of the stream for fish enhancement will have little effect on the erosion process.

The surface lake sediments consist of poorly consolidated organic muds varying in thickness from 0.3 to 2.6 m. The total volume of these organics is estimated at 48,000 m^3. The organic deposits are underlain by a blue clay layer of unknown depth. The blue clay which is presumably also a glacio-marine deposit overlying the Newton stoney clay forms the seal for the lake. The Newton stoney clay with its interbedded sand may not form as effective a seal as the blue clay and deepening of the lake may be limited by the depth of the blue clay layer.

4.2 Lake Excavation

4.2.1 Objectives

The lake excavation objectives were to:

1. assess the technical constraints in excavating a portion of the lake to a depth of 5 m;

2. provide means of leaving a portion of the lake untouched; and

3. examine possible excavation construction methods.

4.2.2 Findings

Deepening of a central portion of the lake to a depth of 5 m would result in side slopes in the clay of between 1:10 to 1:12.

Such flat slopes in the clay would not require stabilization. However, the overlying organic layer which is likely to fluidize would require some form of support around the perimeter of the excavated basin. A gravel dyke or coffer dam could provide this support and be simply constructed by placing suitable material directly into the lake bottom so that it sinks through to the clay layer.

The shallow, marshy area along the south and west shores could be left untouched, assuming suitable fish access to the inflow streams can be provided.

Three construction methods were examined for excavation of the lake bed. A small cutter suction dredge is available and would be ideally suited for the excavation task. The organic material could be dredged and pumped over the surrounding area. However, the blue clay would need to be exported from the site. The clay will be in the form of a slurry and would be difficult and costly to export if it could not be pumped to a disposal site. The other major problem with dredging is the need for a substantial water supply as lake water is continually removed from the site as part of the slurry.

A second approach, similar to open cut mining, could be used to excavate the lake bed in the dry. With the lake de-watered, the clay could be excavated by loaders or backhoes and trucked to a disposal site. A roadway capable of supporting the equipment would need to be constructed in the basin as the excavation proceeded and there would be a continual need for de-watering.

Finally, a dragline could excavate the basin without the need for de-watering and the clay would be trucked from the site as for the open pit method. A roadway extending into the lake and capable of supporting the equipment would be required to provide access for the dragline.

5.0 PRELIMINARY COST ESTIMATE FOR PROPOSED ENHANCEMENT MEASURES

The proposed enhancement measures have been grouped into two project components, based on geographic location within the Beaver Lake/Creek system.

The first group includes those measures proposed for sites located downstream of Beaver Lake. These Group I enhancement activities include the modification of the stoplog cascade, the construction of the fish passage structure in place of the falls under the road bridge, the placement of spawning gravel and possibly boulders for rearing habitat improvement, the modification of the Beaver Lake outflow to allow for fish passage into the lake, the development of a nature walk and, finally, the construction and maintenance of a live trap for downstream migrants near the marine outfall to Beaver Creek. It is recommended that Group I activities also include the drilling of a well to provide supplementary water to the Beaver Lake/Creek system. An additional measure that can be considered for the future is modification of the marine outfall to improve adult fish access to the creek from the sea, and smolt out-migration during low tide periods.

Group II activities, those located upstream of the Beaver Lake outflow, include sediment removal from Beaver Lake, and minor habitat improvements to Prospect and Zoo Creeks.

Cost estimates for each proposed enhancement measure are provided below. Labour costs are based on an average rate of $20.00/hour, which takes into consideration the range of rates paid to the different trades people required for the work.

5.1 Group I Activities

1. Live-Trapping of Downstream Migrants

   In order to assess juvenile out-migration and ensure that smolts are leaving Beaver Creek during high tide periods, a strategy which should increase survival, live-trapping should be carried out in Beaver Creek near the marine

outfall. Timing for the trapping should correspond to out-migration period observed for the donor stock. Initially, it is recommended that the trapping be carried out during only one out-migration period.

Construction and Operating Costs

Materials and Construction Costs for Trap	$1,000.00
Operating Costs	1,600.00
Total	$2,600.00

2. Modification to Stoplog Cascade

The modification to the stoplog cascade will involve the construction of a small step pool to provide a more gradual drop. This step pool, which will improve fish passage conditions, will be relatively straightforward to construct and require a minimum of equipment and materials.

Construction Costs

Equipment Rental (bobcat with backhoe, chainsaw)	$500.00
Labour	1,000.00
Materials	250.00
Environmental Supervision (15% of above)	250.00
Contingency (20% of above)	400.00
Total	$2,400.00

3. Fish Passage Structure Under Road Bridge

It is proposed that a concrete fish ladder, consisting of approximately five steps, be constructed in place of the falls under the road bridge. During

the construction period, it will be necessary to install a temporary culvert to divert the flow past the ladder site. It is anticipated that the short-term (within five years) maintenance costs will be negligible.

Construction Costs

Labour (installation of culvert, concrete work, etc.)	$2,000.00
Concrete and Other Materials	1,500.00
Equipment Rental (bobcat with backhoe, etc.)	500.00
Environmental Supervision (15% of above)	600.00
Contingency (20% of above)	900.00
Total	$5,500.00

4. Gravel and Boulder Placement

Spawning and rearing habitat can be created by the placement of properly sized gravel and boulders, respectively. Coho spawn in gravel ranging from 1.3 to 10.2 cm (0.5 to 4.0 inches) in diameter. An appropriate composition is 80% 1.3-3.8 cm diameter to 20% 3.8-10.2 cm diameter gravel. Placement sites for both gravel and boulders will be selected during the detailed design phase. If boulders are necessary, sizing will not be a critical factor due to the flow stability in Beaver Creek. A bobcat with backhoe attachment will be used to remove existing substrate material from the designated areas in the creek. These areas will then be backfilled with gravel.

Construction Costs

Materials (gravel, boulders)	$1,000.00
Labour	1,600.00
Equipment Rental (bobcat with backhoe, etc.)	1,000.00
Environmental Supervision (15% of above)	550.00
Contingency (20% of above)	800.00
Total	$4,950.00

5. Fish Passage to Beaver Lake

Two basic approaches are possible: the first involves backing water up the existing culverts as described in the report; the second, and most effective approach, involves the removal of one series of culverts to create a stepped stream channel as shown in Figures 1 and 2. In addition to the creation of a new stream channel, two foot-bridges must be constructed to connect existing trails. A cost estimate is provided below for the second approach only as agreed at the meeting of February 4, 1985.

Construction Costs

Equipment (bobcat with backhoe, truck, etc.)	$2,000.00
Labour	4,000.00
Materials (bridge materials, boulders, etc.)	2,500.00
Environmental Supervision (15% of above)	1,275.00
Contingency (20% of above)	2,000.00
Total	$11,775.00

6. Well Drilling for Supplementary Water Supply

Developing a well to supplement flows through the Beaver Lake/Creek system will be a two stage process involving the actual drilling of the well, followed by completion activities. Completion activities will entail the installation of physical structures associated with the well. The drilling site will be located adjacent to the path that runs parallel to Zoo Creek. Drilling at this site will virtually eliminate any environmental concerns relating to the use of the drilling rig in the Beaver Lake area. The probability of striking an aquifer at this location appears to be comparable to other potential sites in the area that are far less accessible.

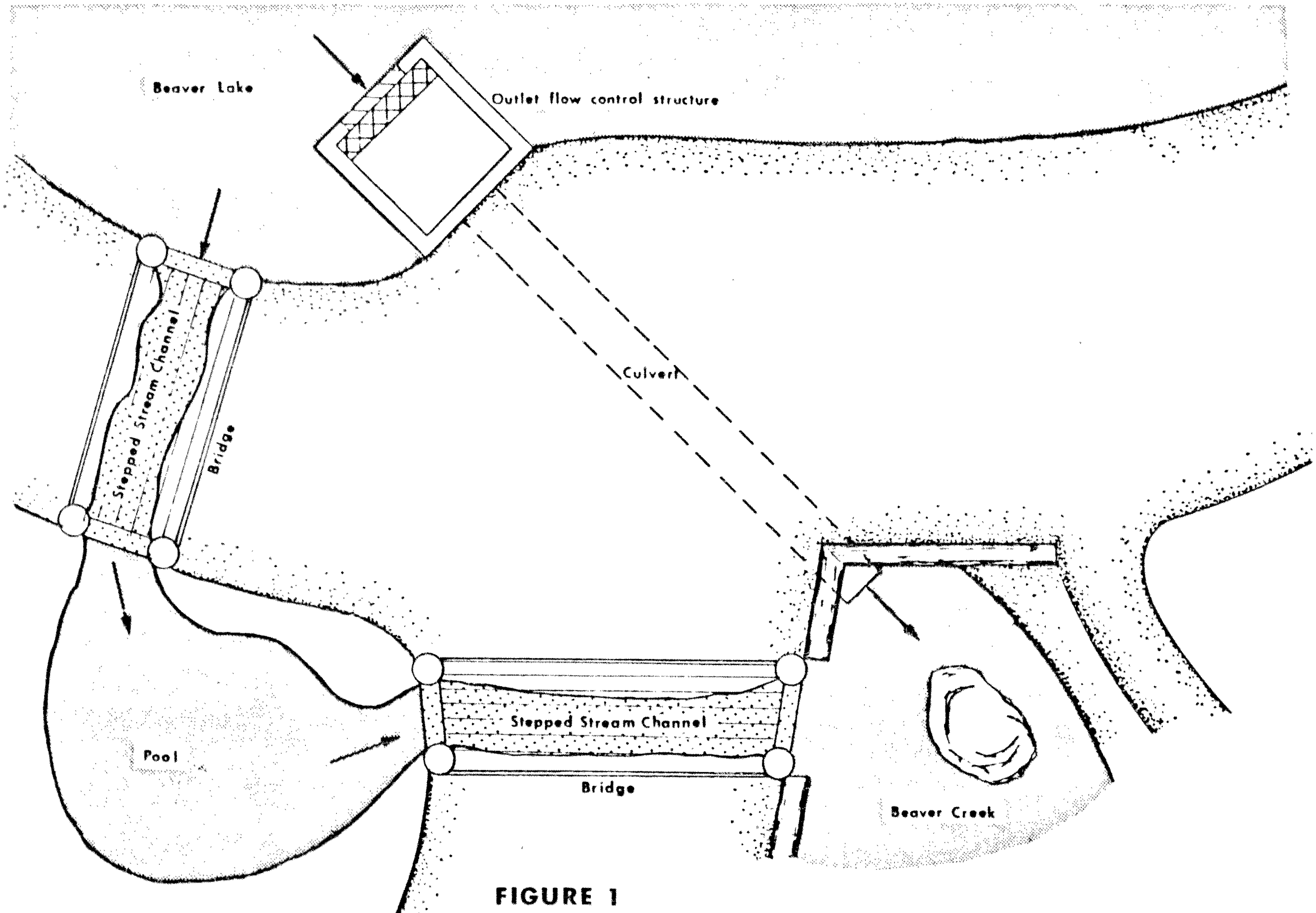

FIGURE 1
Proposed design for the mitigation of the fish passage obstruction between Beaver Lake and Beaver Creek.
Top view.

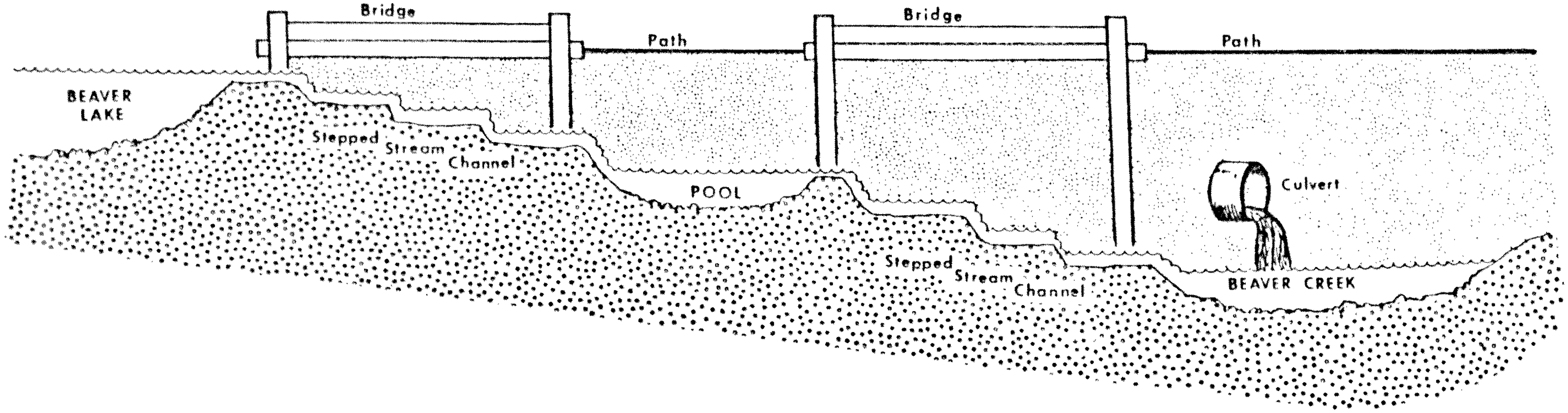

FIGURE 2
Proposed design for the mitigation of the fish passage obstruction between Beaver Lake and Beaver Creek. Side view.

Drilling Costs

Mobilization costs + the first 3 m of drilling	$1,500.00
$100.00 per meter after 3 m (additional 15 m)	1,500.00

Completion Costs

Installation of physical structures	2,500.00
Environmental Supervision (10% of above)	550.00
Contingency (20% of above)	1,200.00
Total	$7,250.00

7. Development of Nature Walk

A nature walk would be developed to highlight the enhancement features and local ecology of the Beaver Lake/Creek system. Cost estimates are provided for two alternatives. The first approach would involve the use of permanent signs on display boards installed in selected locations along the walk. The second alternative would be to provide a small brochure at the beginning of the walk that serves as an illustrated guide to the visitor.

Approach 1. Permanent Signs:

Materials (lumber, sign posts, etc.)	$750.00
Labour (construction and installation of signs)	3,000.00
Equipment	500.00
Development of Sign Text and Graphics	1,200.00
Contingency (20% of above)	1,020.00
Total	$6,470.00

Approach 2. Brochures:

Development of Brochure Text	$1,500.00
Production of Brochures (10,000)	1,000.00
Construction and Installation of Brochure Container	200.00
Contingency (20% of above)	540.00
Total	$3,240.00
Total for Group I Activities	$37,715.00 - $40,945.00

5.2 Group II Activities

1. Sediment Removal

Sediment removal will contribute significantly to the restoration of Beaver Lake as well as provide a much more suitable environment for salmonid rearing. Two basic approaches are under consideration for the lake sediment removal: the first approach involves the use of a hydraulic cutter/suction dredge and pipeline; the second approach involves draining the lake and using a dragline to remove the sediments. Total cost and time requirements would be approximately equal for both methods.

A cost estimate for sediment removal by hydraulic dredge is presented in the text that follows. These numbers are based on estimates provided by Can-Dive Services Ltd., which operates a portable dredge. A second company, Island Dredging Ltd., which also operates a portable dredge, has submitted a similar estimate for the work.

The cost estimate was based on dredging approximately half the lake to a maximum depth of 5 metres, with a mean depth of 3 metres. Since half of the lake area is 1.98 hectares, the total quantity of sediments to be removed is approximately 59,400 cubic metres. Based on an average production capacity of 60-70 cubic metres per hour, plus a 20% contingency for downtime, clogging, etc., it is estimated that the time required for the dredging is 1,020-1,200 hours.

Cost Estimate

Mobilization and Demobilization	$20,000.00
- transport of dredge	
- crane operation	
- set-up and dismantling of dredge and pipeline	
- support equipment and labour	
Operation	
- base hourly operating rate $160.00/hour for 1,020-1,200 hours	$163,200.00 - $192,000.00
Total Cost =	$183,200.00 - $212,000.00

Cost per cubic metre = $3.08 - $3.57

Per cubic metre cost range from Island Dredging = $2.62 - $4.91

These figures make no allowance for sediment disposal or any additional equipment needs.

2. Gravel Placement in Feeder Streams

Salmon spawning habitat can be created in Prospect and Zoo Creeks by the installation of properly sized gravel in selected locations.

Construction Costs

Materials (gravel)	$500.00
Labour	1,000.00
Equipment (bobcat with backhoe, etc.)	500.00
Environmental Supervision (15% of above)	300.00
Contingency (20% of above)	450.00
Total	$2,750.00

Total for Group II Activities (with no allowance for sediment removal from the site)	$185,950.00 - $214,750.00

6.0 BUDGET ESTIMATE FOR DETAILED DESIGN PHASE

Prior to the implementation of the Group I enhancement measures planned for Beaver Creek, detailed technical drawings must be produced. The work will include a brief site visit to obtain final design specifications prior to the preparation of the detailed design drawings. A brief report will accompany the drawings and serve as a bid document in the event that the construction activities are contracted out rather than carried out directly by Parks Board staff.

A budget estimate for this detailed design phase is presented below.

Professional Costs		
J. Villamere (Senior Engineer)	12 days @ $500.00/day	$6,000.00
D. Hay (Senior Hydrological Engineer, Sub-Consultant)	1.5 day @ $500.00/day	750.00
A. Stockwell (Biologist)	4 days @ $375.00/day	1,500.00
Drafting and Graphics		
K. Foley	12 days @ $225.00/day	2,700.00
Clerical and Word Processing		1,110.00
TOTAL:		$12,060.00

7.0 SUMMARY AND CONCLUSIONS

The following points provide a brief summary of the findings contained in this report.

1. Preliminary lake modelling results indicate that weak or intermittent stratification would occur during the late summer period in Beaver Lake if the maximum depth was increased to 5 m by sediment removal activities. A number of factors that would act to break down this stratification, such as wind-induced and convective mixing, were identified. It was concluded that oxygen availability would not be a major problem for salmonids in Beaver Lake after sediment removal.

2. It was determined that nutrient releases from the sediments would not be a major problem after completion of the proposed dredging activities in Beaver Lake. Sediment removal would expose a clay bottom which contains no organic matter and most likely limited amounts of inorganic nutrients. Further, it is proposed to increase the flushing rate through Beaver Lake by tapping groundwater supplies, which would also act to reduce nutrient availability.

3. Long-term changes in lake water pH will be dependent on the chemical characteristics of the clay exposed during the proposed sediment removal process.

4. Assuming that ten percent of the annual precipitation (1,500 mm - Vancouver Harbour) is available for recharging, it was estimated that a continuous yield of 3.5 $L.s^{-1}$ is possible from the groundwater. A flow of up to 14 $L.s^{-1}$ could be provided over a three-month period.

5. It was determined that Beaver Creek provides ample capacity to convey considerably higher flows, if additional water were to be added to the system.

6. From a geomorphological perspective, it was noted that increases in base flow for fish enhancement will have little impact on the stream erosion process.

7. Field observations on Beaver Lake sediments revealed that the surface sediments of poorly consolidated organic muds, varying in thickness from 0.3 to 2.6 m (approximate volume of 48,000 m^3), are underlain by a blue clay layer of unknown depth.

8. Any sediment removal activities proposed for the lake must not completely penetrate this blue clay layer since it forms the seal for the lake.

9. Three methods are available for the removal of sediments from Beaver Lake: dredging; dry excavation; and wet removal with a dragline. A number of major technical problems are associated with each method and preliminary cost estimates for the work are in the $200,000.00 range, exclusive of any spoils disposal costs.

10. Preliminary cost estimates are provided for the proposed Beaver Lake/Creek enhancement measures. Enhancement activities are divided into two groups based on their location within the system. The first group includes those measures proposed for sites located downstream of Beaver Lake, whereas the second group includes measures proposed for the lake (i.e. sediment removal) and associated feeder streams. Total budget for Group I activities is estimated to be between $37,715.00 and $40,945.00. The budget estimate for Group II activities is between $185,950.00 and $214,750.00, exclusive of any spoils disposal costs that would be incurred during lake dredging.

11. Finally, a preliminary budget is provided for the detailed design phase of the Beaver Lake/Creek Enhancement Project. It is estimated that costs for this component of the project will be $12,060.00.

Based on the study results, the preliminary cost estimates, and discussions with the Vancouver Board of Parks and Recreation and the Department of Fisheries and Oceans, it was concluded that Group II enhancement activities (i.e. lake sediment removal, and habitat improvement in the two feeder streams) would not be carried out at the present time. Instead, efforts would be centred on the implementation of Group I activities

which include enhancement measures in Beaver Creek. As outlined in the report, a number of relatively low cost modifications can be made to the existing creek to provide a suitable environment for salmon spawning, egg incubation, and rearing. These modifications can be carried out in an environmentally sensitive fashion which allows for appropriate construction methods and a finished product that is aesthetically consistent with the surroundings.

BEAVER LAKE-CREEK
ENHANCEMENT STUDY

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BEAVER LAKE-CREEK ENHANCEMENT STUDY

Prepared For

Parks and Recreation Board
City of Vancouver

and

The Salmonid Enhancement Program
Fisheries and Oceans Canada

Prepared by

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West Vancouver, B.C.
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1.0 INTRODUCTION

In 1982, Hatfield Consultants Limited approached representatives of both the Vancouver Board of Parks and Recreation and the Salmonid Enhancement Program (SEP) with a proposal to carry out an enhancement project on the Beaver Lake-Creek system in Stanley Park which would have, as an ultimate objective, the creation of an interpretative/ educational program. It was intended that the interpretative program have the ecology and life history of salmonids as a focus, but also highlight other important aquatic and terrestrial processes in the system. The rationale and basic approach of the proposal were viewed positively by representatives of both agencies who subsequently agreed to fund the project on a cooperative basis. A three-phase approach was adopted in the project design. The first phase involved the collection of biological, physical and chemical baseline data on the Beaver Lake-Creek system which was used in the formulation of a proposed enhancement strategy and conceptual design. Phase II will entail the production of detailed designs for proposed enhancement measures and the development of a conceptual interpretative program. Construction of the enhancement facilities and implementation of the interpretative program will take place during Phase III of the project. To ensure adequate communication between the various parties involved in the project, a steering committee, consisting of one member each from both the Parks Board and SEP, and two members from Hatfield Consultants Limited, was established. A total of three steering committee meetings were held during Phase I of the project.

This document contains the results of the work carried out during Phase I. Subsequent sections outline the general and specific project objectives, materials and methods employed during the Phase I studies, study results and discussion, recommendations based on the findings of the Phase I work, and finally a proposed enhancement strategy and conceptual design.

2.0 STUDY OBJECTIVES

2.1 General Objectives

The overall objectives established for the project were two-fold: first, to restore and enhance the natural habitat of the Beaver Lake-Creek system with particular emphasis on salmonids; and second, to use the enhanced facilities to establish an interpretative program aimed at educating the general public on various aspects of the local ecology.

2.2 Specific Objectives

More specifically, the objectives of the Beaver Lake-Creek Project were:

1. to survey the existing biological, physical and chemical environment of the system;

2. to assess the extent of existing limitations to salmonid use in the system;

3. to formulate an enhancement strategy based on the results of the biological, physical and chemical assessment of the Beaver Lake-Creek environment;

4. to design and implement necessary physical habitat improvement measures that are consistent with park planning objectives; and

5. to design and implement an interpretative program centred around the lake and creek that utilizes this enhanced environment to highlight ecological processes in the system.

As was briefly mentioned in the introduction, this report contains the results of the environmental inventories and a proposed enhancement strategy for the system. Completion of these segments of the study constitutes the fulfillment of objectives 1, 2 and 3. Subsequent phases of the project will address objectives 4 and 5.

3.0 STUDY METHODS

This section of the report has been divided into two segments, one describing materials and methods used in assessing the physical, chemical and biological characteristics of Beaver Lake; and a second outlining Beaver Creek assessment methodology. Originally, the sampling program was designed to be carried out over a nine to twelve month period, but data collected from both the lake and the creek during the first six months of the study provide a sufficiently detailed picture of environmental conditions in the system. To ensure that important seasonal patterns were assessed, additional monitoring of various parameters, such as water temperature and dissolved oxygen concentration, was continued through until September of 1984.

A limited amount of historical information concerning the Beaver Lake-Creek environment was obtained from the Vancouver Archives and through interviews.

3.1 Beaver Lake

Biological, physical and water quality parameters were quantified during the lake assessment. The biological program involved the collection of zooplankton and macrobenthic samples, vegetation mapping and observations on resident fish, waterfowl, reptiles and amphibians. Zooplankton and benthic grab samples were collected monthly during the winter and spring sampling period from the deepest point in the lake, which is located adjacent to the outflow structure (Figure 1). During the late spring and summer period, representative plankton and benthos sampling was not possible, due to dense macrophyte growth in most areas of the lake. Zooplankton samples were obtained in short ($<$20 m) horizontal tows with a No. 20 (75 um) mesh, 13 cm diameter mouth Wisconsin Plankton net. After collection, samples were preserved in 5% formalin for subsequent identification and enumeration. Since plankton concentrations were low throughout the sampling period, all organisms were counted in each sample. Benthic samples were collected with a standard Ekman-Birge grab sampler. Each grab sample was passed through a U.S. Standard No. 30 mesh screen and the material remaining on the screen was collected and preserved in 10% formalin and stained with Rose Bengal for macroinvertebrate identification and enumeration.

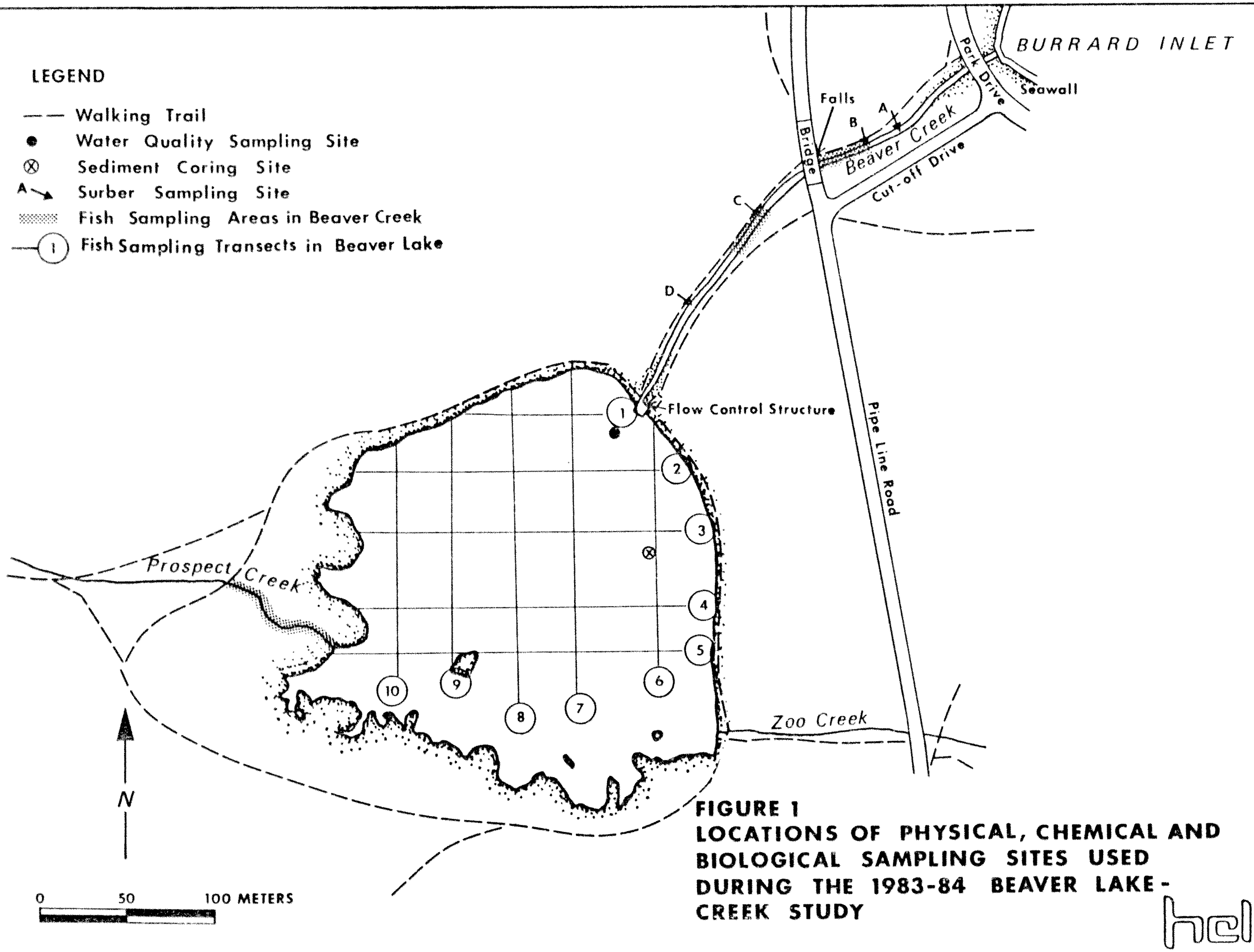


FIGURE 1
LOCATIONS OF PHYSICAL, CHEMICAL AND BIOLOGICAL SAMPLING SITES USED DURING THE 1983-84 BEAVER LAKE - CREEK STUDY

A vegetation map showing general distribution and abundance of major emergent macrophyte species was prepared from observations made during several site visits in mid-June and early July, 1984. Due to the shallow depth and abundant macrophyte growth, conventional fish sampling techniques such as trapping and netting could not be employed in Beaver Lake. Instead, a limited amount of electrofishing was carried out using a Smith-Root Type VII Backpack Electrofisher. The electrofishing was conducted from a small inflatable boat along 10 lake-wide transects (Figure 1) during the month of March prior to the annual macrophyte emergence. Opportunistic observations of waterfowl, reptiles and amphibians were made throughout the study period.

Physical sampling in Beaver Lake consisted of bathymetric mapping and an evaluation of the extent and rate of sediment deposition in the basin. To determine lake bathymetry, a series of transects were established along which water depths to the sediments were measured with a rigid probe. Since water depths in the lake do not exceed 2 m, this method proved effective. Sediment probing, with a narrow steel rod, was also carried out along the established transects to provide a general assessment of unconsolidated sediment deposits in the basin. A single 1 m sediment core, extracted from a point near the centre of Beaver Lake (Figure 1), was used to assess sediment deposition rate in the system. A Brown sampler (Mott 1966), fitted with a 5 cm diameter, clear plastic tube, was used to raise the core, which was kept vertically oriented and transported to Simon Fraser Unversity (SFU) where it was stored at 4°C for several weeks. Palynological (plant pollen), physical and chemical analysis of the core sample was carried out by Dr. Rolf W. Mathewes of SFU, according to the methods outlined in Faegri and Iversen (1975) and Mathewes and D'Auria (1982).

Parameters assessed during the water quality monitoring program on Beaver lake included temperature, dissolved oxygen, pH, conductivity, and a number of water chemistry parameters. All water quality sampling was carried out in the north east section of the lake (Figure 1), where the water depth is greatest. Spot measurements were also made elsewhere in the basin for comparative purposes. All measurements and water samples were collected from mid-depth at the

sampling station (approximately 0.75 m). Surface water temperatures were also obtained during the lake sampling. Temperature and dissolved oxygen were measured with a Yellow Springs Instrument (YSI) model 51A portable dissolved oxygen meter. Specific conductivity was determined with a YSI model 33 portable salinity-conductivity-temperature meter. pH determinations were made in the field with a Lisle-Metrix model PT-70 portable pH meter, and during laboratory analysis of water chemistry samples. Temperature, dissolved oxygen, conductivity and pH sampling of Beaver Lake was carried out on either a bi-weekly or monthly basis from January to September, 1984.

Water chemistry samples from Beaver Lake were collected during February, March, May and June, 1984. Samples were taken from mid-depth in a 4 L Van Dorn bottle, stored in darkness at approximately 4°C, and analyzed within 24 hours of collection. The following parameters were assessed:

pH
colour
non-filtrable residues
filtrable residues
hardness
alkalinity
sulfide - S
phosphorus - Total - P
- Total dissolved - P
- Ortho - P
nitrate - N
nitrite - N
ammonia - N
silicate - SiO_2
tanin and lignin

Details of methods used for chemical analysis of the water samples are presented in Appendix 1.

3.2 Beaver Creek

The stream assessment consisted of three basic components: an evaluation of physical habitat characteristics; biological sampling; and water quality sampling. Procedures used in the physical habitat assessment are outlined in De Leeuw (1981). Therefore, only a brief description of these methods is provided below.

To evaluate existing physical habitat, streams are first divided into reaches based on gross morphometry and/or stream gradient. In the case of Beaver Creek, the relatively short length and morphometric consistency of the stream allowed for the creation of only one reach encompassing the entire creek. Generally, 12 representative hydraulic units are sampled within each reach. Six different hydraulic units (macro-habitat types) are recognized: pools, riffles, glides, falls, ditches and sloughs. Because of its relatively short length, it was unnecessary to select 12 hydraulic units for habitat assessment in Beaver Creek. Instead, all stream units were sampled. Within individual hydraulic units, 21 parameters were measured, describing the overall dimensions of the unit and quality/quantity of fish habitat available. Results from the habitat assessment were then compiled and compared to the data collected during the fish sampling to evaluate habitat utilization. The physical habitat assessment of Beaver Creek was carried out on December 20-21, 1983. Normally, this type of work should be performed during the summer low flow period but, in this particular instance, the actual time of sampling was not a major factor, since Beaver Creek flows exhibit only minor seasonal variation. To supplement the habitat inventory, depth-velocity measurements were made periodically throughout the duration of the sampling program to allow for the calculation of stream discharge. Velocity estimates were made with a Gurley No. 625 Pygmy Current Meter.

In addition to the physical habitat assessment of Beaver Creek, preliminary work was undertaken on a technical survey of the creek bed which will provide accurate slope and elevation data necessary for the detailed enhancement design. To date, bench marks have been established and a baseline surveyed down the creek bed. Additional work to tie-in the baseline with the bench marks will be carried out during the next phase of the project.

The biological component of the creek study consisted of macrobenthic invertebrate sampling and fish sampling. Stream benthos was sampled at four locations (Figure 1) in the creek during December, 1983, and January, March, May and June of 1984. Two benthic sampling sites were established downstream of the road bridge and falls (Sites A and B), and two upstream of this point (Sites C and D). Substrate characteristics at the four sample sites are as follows:

	Site A	Site B	Site C	Site D
% fines	25	10	10	15
% small gravel	60	20	65	30
% large gravel	15	35	20	35
% cobble	0	25	0	5
% boulder	0	10	5	15
% bedrock	0	0	0	0

All benthic sampling sites were located in riffle or riffle-glide areas. A Surber square foot sampler was used to collect replicate samples at each sampling site. Material collected was preserved in 10% formalin and stained with Rose Bengal for sorting, identification and enumeration.

Fish sampling in Beaver Creek was carried out first, to establish presence and diversity, and second, to generate data for the calculation of salmonid population estimates. All fish sampling was performed with a Smith-Root Type VII Backpack Electrofisher. A multiple-step removal-depletion method, based on the work of Moran (1951) and Zippin (1958), was used to provide an estimate of salmonid population density in Beaver Creek and Prospect Creek (Platts et al. 1983). Briefly, this method first involves isolating a representative stream segment using stop nets or natural barriers such as waterfalls. Fish are then successively removed from the enclosure during several passes with the electrofisher. After each pass, the captured fish are enumerated, measured and weighed, and retained until all the passes have been completed. In Beaver Creek, two stream segments were sampled for fish, one downstream of the road bridge and falls, and a second upstream of this point (Figure 1). In Prospect Creek, a single stream segment, located between the lake and a small foot bridge, was sampled (Figure 1). Population estimates for

salmonids in each creek were determined using the removal-depletion maximum-likelihood model described in Platts et al. (1983). This model uses the successive depletion of catch sizes to estimate the actual population size by determining the likelihood of possible population sizes greater than or equal to the total catch. Population estimates were carried out twice (December, 1983 and June, 1984) in Beaver Creek and once (December, 1983) in Prospect Creek.

Water quality sampling in Beaver Creek entailed water chemistry analysis and monitoring of temperature, dissolved oxygen, conductivity, and pH. Methods used to assess these parameters were essentially identical to those described in the previous section on lake sampling. Chemical analysis of creek water was carried out twice (February and June, 1984) during the study whereas the other parameters were assessed on a bi-weekly or monthly basis.

4.0 RESULTS AND DISCUSSION

4.1 Beaver Lake

4.1.1 Physical Sampling

Morphometry and Bathymetry

Table 1 lists the major morphometric characteristics of Beaver Lake. With a surface area of 3.95 hectares, Beaver Lake is probably more accurately termed a pond. Shoreline development (SLD) is an index of the regularity of the lake shoreline with a perfectly circular lake having an index of 1.0. Although this index may not have a great deal of application in the case of Beaver Lake, it is often of some interest to limnologists as it relates to the age of a lake - older lakes have usually had more shoreline erosion and are therefore more regular in outline.

The bathymetry of Beaver Lake is outlined on the map in Figure 2. Depth to the sediments does not exceed 2 m in any area of the lake, and is generally 0.5 m or less in approximately 80 to 90% of the system. The deepest portion of the lake is located near the outflow at the northeast corner of the lake, where a maximum depth of 1.8 m was recorded. Finite lake depths were difficult to obtain due to the substantial build-up of unconsolidated sediments.

Lake Sediments

The extent of lake sediments was estimated by probing with a thin metal rod at 10 m intervals along a transect running through the centre of the lake in an east-west direction (Figure 2). Since the probing was carried out by hand, the results presented here represent only an approximation of sediment depth to hard pan. A more accurate determination of the extent of sediment deposits in Beaver Lake would most likely necessitate the use of expensive geophysical instrumentation. This type of approach was considered beyond the scope and budget of the present study.

Table 1 Beaver Lake morphometric characteristics.

Parameter	Value
Surface Area, A_o (hectares)	3.95
Perimeter, L (m)	918
Shoreline Development, SLD (units)	1.3
Maximum Depth, Z_{max} (m)	1.8
Mean Depth, z (m)	0.3
Volume, V (cubic meters)	11,847

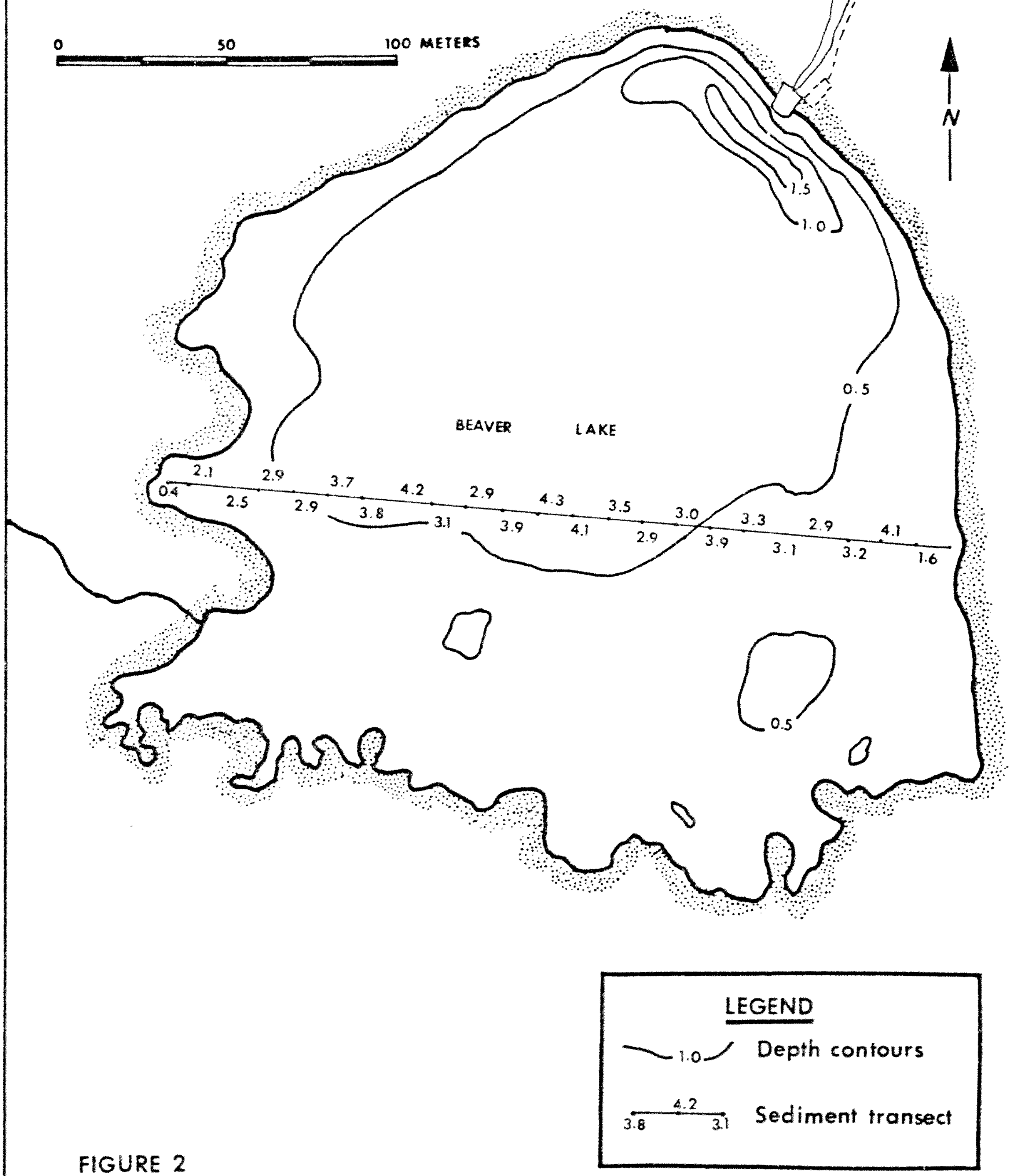


FIGURE 2
Bathymetry and sediment deposition in Beaver Lake.

Values are in meters for both lake and sediment depths.

Results of the probing revealed a maximum sediment depth of approximately 4 m in several locations along the transect. Nearshore (1 m from shore) sediment depths were generally around 0.5 m, with depths increasing rapidly to greater than 2 m within 10-15 m of the shoreline. Sediment depths between the 20 m point on the eastern end of the transect and the 20 m point on the western end of the transect varied between 2.5 and 4.2 m, with a mean depth of 3.4 ± 0.6 m (SD).

The sediment probing in Beaver Lake has demonstrated that deposits in Beaver Lake are extensive, with an unconsolidated sediment layer of between 3 and 4 m existing in approximately 75% of the lake basin. Although there is no doubt that deeper sediment deposits exist in the lake, it was not possible during this study to determine the extent of these deposits.

A number of methods are available for estimating sedimentation rates in lakes. In relatively deep lakes, a variety of collection devices can be used to trap sediments over a certain time period. Quantitative analysis of material collected in this fashion can be carried out to establish sedimentation rates. In shallow water systems such as Beaver Lake, where a number of factors may act to disturb the deposition process as well as existing sediment deposits, sediment collection devices are not appropriate. Instead, an alternative approach involving the analysis of stratographic distribution of plant pollen and spores in a sediment core was employed. By establishing the presence or absence of various plant species through pollen analysis, environmental changes in and around the lake basin can be identified. Often these changes can be linked to historical events in the system which in turn allows for the calculation of sedimentation rates.

Figure 3 summarizes the stratigraphy of the core and the changes in pollen and spore frequency with depth (percent abundances of main pollen types are shown to convey only the essential features of the environmental record). Two main pollen zones that correspond well with changes in core stratigraphy are apparent.

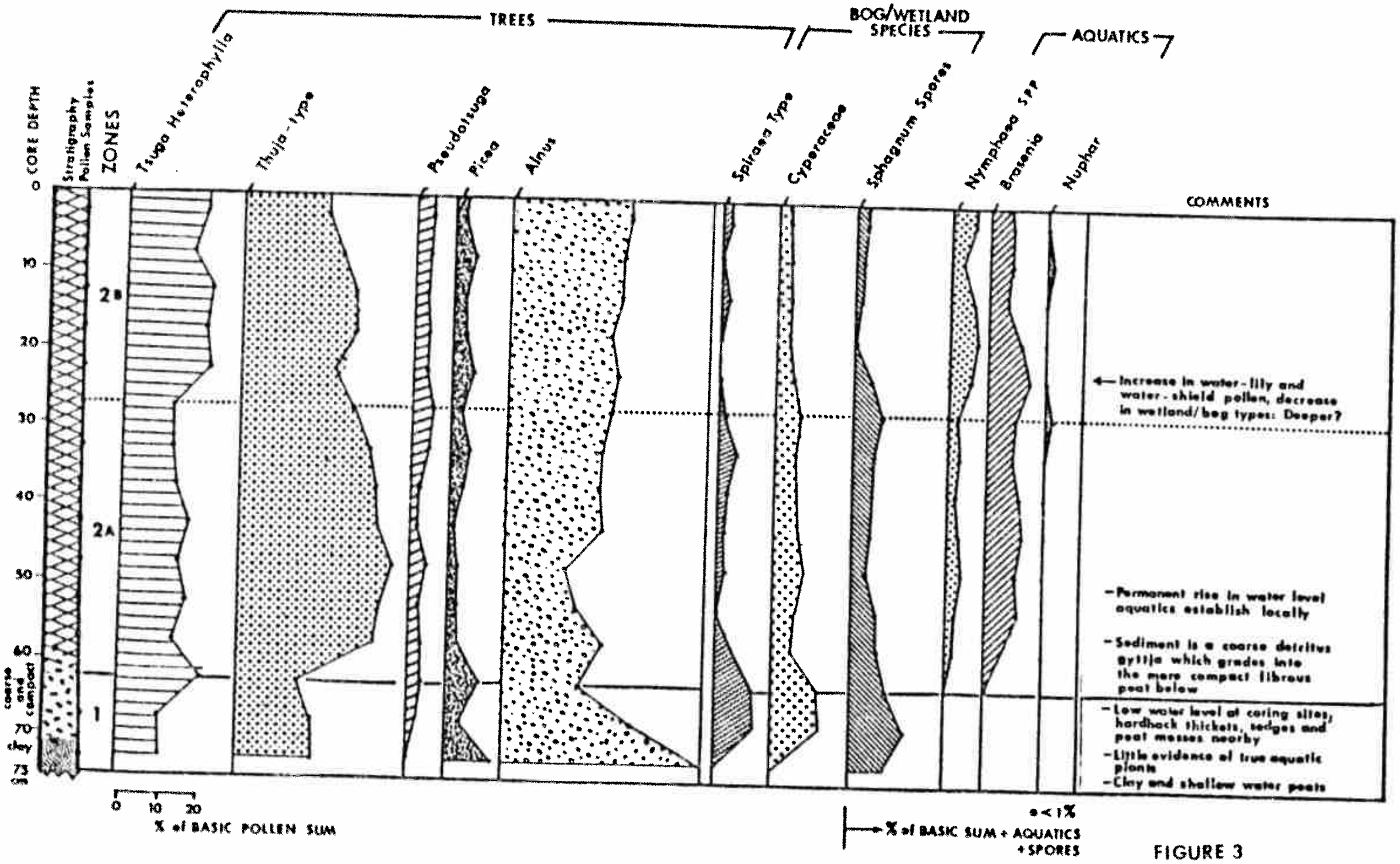


FIGURE 3

Pollen diagram developed from Beaver Lake sediment core.

In Zone 1, the sediments at the base are sandy clay at 70-75 cm, overlain by 10 cm of a compact, fibrous detrital peat. The clay sample contains the highest recorded values of alder, spruce and pine pollen. Pollen of wetland and aquatic plants is rare, although peat moss spores (Sphagnum) are common. An interpretation of this assemblage would be a shoreline on nearshore environment with very shallow water or mudflat-like conditions, surrounded by forest, with some peat mosses nearby. The accumulation of detrital peat on top of the clay suggests a small rise in the water table near the site, promoting the growth of shrubs such as hardhack (Spiraea), sedges (Cyperaceae) and peat mosses. At this point in the history of the lake, the water level may have been fluctuating, and not high enough in the vicinity of the core site to allow for the local establishment of true aquatic plants.

A dramatic shift occurred around the 60 cm depth in the core. The compact detrital peat becomes looser and finer, and could be termed a "coarse detritus gyttja", typical of open water conditions. Pollen and spores of the "Bog/Wetland" types decline in abundance, and the true aquatic species begin to increase. Especially prominent is the rapid appearance of the native water shield (Brasenia) and the introduced water lily (Nymphaea). The native yellow pond lily (Nuphar) also appears in low frequencies in every sample, beginning at 57.5 cm in the core. These findings indicate that a permanent rise in lake level took place during this interval, allowing aquatic plants to occupy the area of the coring site which was previously unsuitable for their establishment. Since no permanent records of modifications to the Beaver Lake system have been kept, it is difficult to establish a date during which this lake level change took place.

One related event which was recorded, is the year of water lily (Nymphaea) introduction into Beaver Lake. According to a newspaper article, published in the "Province" on July 2, 1940, the lilies were introduced into the system during 1938 and first bloomed in the summer of 1940. Pollen from Nymphaea first appears in the sediment core at approximately 60 cm. Assuming that lily pollen production began during the summer of 1940, then there appears to have been 60 cm of sediment deposited during the last 44 years. A sedimentation rate of 1.36 $cm.y^{-1}$

results from a calculation using these data. Although the sediment accumulation rate will vary according to a number of biological and physical factors which are not consistent throughout the lake, it is apparent that this representative rate is comparatively rapid. Mathewes and D'Auria (1982), working on Deer Lake in Burnaby, British Columbia, found that sediment accumulation rates were relatively constant in the system from human settlement until 1963 at 0.3-0.4 $cm.y^{-1}$, increasing to 1.06 $cm.y^{-1}$ since that time. Assuming a mean water depth of 0.5 m in Beaver Lake and a sedimentation rate of $1.36.y^{-1}$, it can be projected that any remaining standing water in the system will be displaced by saturated sediments within a period of 36.8 years. Although this is a very rough calculation, it does provide an indication of how rapidly the lake is filling in.

A second event which may be significant appears to occur around the 27.5 cm depth in the core. A decline in bog/wetland species, and a corresponding increase in aquatic plant pollen in Zone 2B may signify a second change in water level. Again, this change in water level is not apparent in any historical records of the Beaver Lake system. A number of short-term changes in lake level, often resulting from modifications to the outlet flow control scructure at the northeast corner of the lake, have occurred during the last 30-40 years (pers. comm. Don Van Dyke and Herb Johnson), but the timing and impact of these changes is unclear at present.

Occasional pollen of weeds and ornamentals, such as Plantago lanceolata, Rumex acetosella (common dock), Castanea (hazel), and Fraxinus (ash), was found scattered down to 42.5 cm in the core, suggesting the effects of urbanization during this interval of Zone 2. If higher pollen counts were used in any further analysis of the Beaver Lake core, some of those cultural indicators would be expected to occur also in the earliest portions of Zone 2A.

Small variations in the upland trees apparent in Figure 4 do not appear to relate to forest changes in the vicinity of Beaver Lake, with the possible exception of higher alder, spruce and pine in the clay at the base of the core. Based on the sums counted, the fluctuations within Zone 2 do not indicate any significant upland forest shifts.

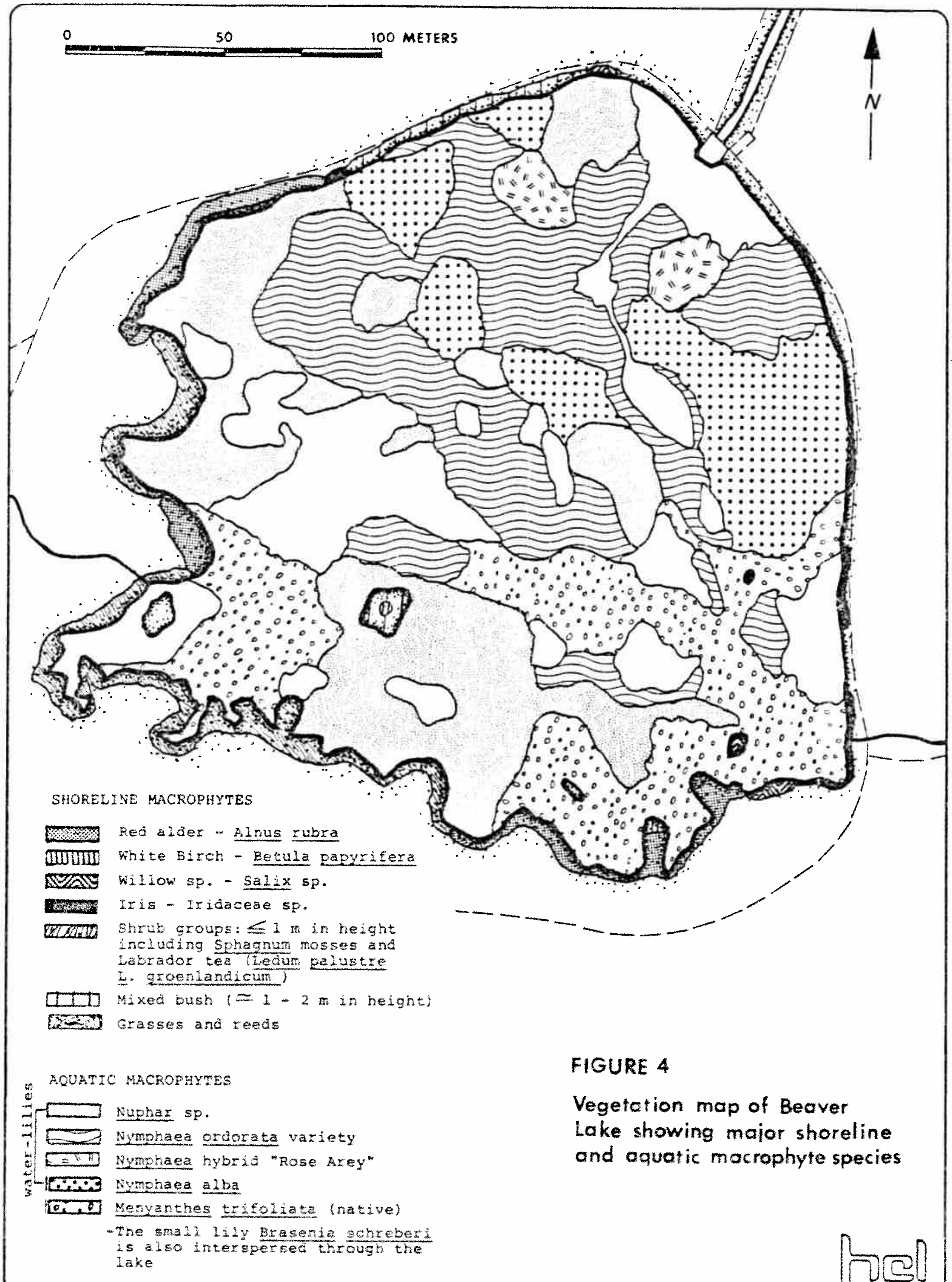


FIGURE 4

Vegetation map of Beaver Lake showing major shoreline and aquatic macrophyte species

4.1.2 Biological Sampling

Plankton

Since Beaver Lake exhibits as marsh type environment, emergent and floating-leaved macrophytes are responsible for the majority of primary production in the system. During the period from April to November, approximately 75-80% of the lake surface is covered with macrophyte growth which severely limits the availability of light and nutrients for phytoplankton production. During the winter months, ambient light levels and Beaver Lake water temperatures are low, which again act to limit macrophyte and phytoplankton primary production in the system. Although no phytoplankton sampling was carried out during the study, efforts were made to assess zooplankton levels in the lake. Zooplankton samples were collected during the months of January, February, March, April and May of 1984. Additional zooplankton sampling during the summer period was not carried out due to extensive macrophyte growth.

The results of the Beaver Lake zooplankton sampling are presented in Table 2. Major groups found in the samples include cyclopoid and harpacticoid copepods (adult, copepodids and nauplii) and the two cladocerans genera Bosmina and Daphnia. Very low numbers of chironomid larvae, an organism more commonly associated with the benthic environment, were also present in the samples. The absence of calanoid copepods from the Beaver Lake plankton samples may be due in part to the shallow lake depth, which is better suited to the littoral copepods of the sub-orders Cyclopoida and Harpacticoida. The majority of species from both of these groups are found in the littoral zones of lakes, and in the case of Harpacticoid copepods, all species are found in association with macrophytes and/or sediments (Wilson and Yeatman 1959). In general, zooplankton concentrations were low throughout the study period with total concentrations ranging from 0.74 organisms.L^{-1} during January, 1984 to 1.61 organisms.L^{-1} in February, 1984. The mean total zooplankton concentrations during the sampling period was 0.97 ± 0.36 organisms.L^{-1} (SD). Although zooplankton populations diversity and abundance may undergo some modifications during the summer months, it is unlikely that the environmental conditions existing in Beaver Lake (i.e. abundant macrophyte growth

Table 2 Results of zooplankton sampling (numbers·L^{-1}) on Beaver Lake during the winter and spring of 1984.

Group	Sampling Data				
	Jan.	Feb.	Mar.	April	May
COPEPODA					
Nauplii	0.24	0.53	0.34	0.28	0.25
Cyclopoida (adults and copepodids)	0.12	0.16	0.36	0.47	0.30
Harpacticoida (adults and copepodids)	0.02	0.02	0.06	0.05	0.07
CLADOCERA					
Bosmina sp.	0.33	0.82	0.08	0.09	0.10
Daphnia sp.	0.02	0.01	0.01	0.01	0.02
DIPTERA					
Chironomidae	0.01	0.07		0.01	0.02
TOTAL:	0.74	1.61	0.85	0.91	0.76

and low nutrient concentrations) can support substantially larger numbers of zooplankton during the period of higher lake temperatures. Zooplankton are important food organisms for juvenile salmonids residing in lacustrine environments. If Beaver Lake is to be used as a rearing area for salmonids, then modifications that result in the creation of additional open water areas must be considered. These areas would allow for increased phytoplankton production, which in turn should elevate zooplankton concentrations in the lake.

Benthos

Further sampling problems caused by the abundant Beaver Lake macrophyte community were encountered during the benthic sampling program. The extensive anchoring system of rhizomes, even in the open water areas, made it very difficult to obtain suitable benthic grab samples. Despite this problem, benthic samples were collected from Beaver Lake during the months of January, March, May and June of 1984. Concentrations of major macrobenthic invertebrates in these samples are presented in Table 3.

Most prominent amongst the groups are chironomid larvae, trichopteran larvae (caddisfly larvae), oligochaete worms, nematodes, and cyclopoid and harpacticoid copepods. The latter group (copepods) are also present in the lake plankton and are more characteristically epibenthic in habit when associated with the sediments. The most notable seasonal variation apparent in the results was with trichoptera larvae, which exhibited a steady decline in numbers as the season progressed from winter to summer, and with cyclopoid copepods, which increased during the warmer months of May and June. Declining concentrations of caddisfly larvae during May and June may be due in part to adult emergence which normally takes place over the warmer periods of the year, often from overlapping cohorts (Mackay and Wiggins 1979). Increases in cyclopoid concentrations may be a result of more favourable environmental conditions associated with the spring and summer months. In general, macrobenthic invertebrate concentrations were quite high in Beaver Lake. Total concentrations exhibited only minor seasonal variation, ranging from a high of 13,023 organisms.m^{-2} in January to a low in May of 10,591.m^{-2}. The mean total concentration was 12,096 $\pm$ 1,098 organisms.m^{-2} (SD).

Table 3 Macrobenthic invertebrate concentrations determined from Beaver Lake grab samples. Values given in number of organisms per square meter of substrate.

Group	Sampling Dates Jan 31/84	Mar 7/84	May 15/84	June 25/84
INSECTA				
Diptera				
Chironomidae	2889	3561	2400	2870
Ceratopogonidae	439	386	241	2870
Other Diptera				
Larvae	489	295	241	184
Pupae				
Ephemeroptera				
Plecoptera				
Trichoptera	2400	2117	241	105
OLIGOCHAETA	1911	2271	1207	2870
NEMATODA	2889	3476	2896	2870
COPEPODA				
Cyclopoida	489	295	2400	1541
Harpacticoida	1467	386	965	1541
TOTAL	13,023	12,787	10,591	11,981

Macrobenthic invertebrates, particularly the epibenthic varieties, can serve as an important food source for juvenile salmonids and therefore must be given consideration in any enhancement program for the Beaver Lake system.

Macrophytes

A preliminary assessment of aquatic and shoreline macrophyte diversity and distribution was carried out on Beaver Lake during July of 1984. The dominant aquatic macrophytes in Beaver Lake fall into two main groups based on the classification of Sculthorpe (1967). The first group includes emergent macrophytes attached to the substratum. These generally occur on water-saturated or submersed soils from the point at which the water table is about 0.5 m below the soil surface to where the sediment is covered with approximately 1.5 m of water; they are primarily rhizomatous or cormous perennials (e.g. Typha - cattails; and Pontederia - pickerel weed). The second group includes floating-leaved macrophytes such as the lilies Nuphar and Nymphaea. These are primarily anigiosperms that occur attached to submersed sediments at water depths from about 0.5 to 3 m. A third group, the submersed macrophytes, is less important in Beaver Lake due to the shallow water depth.

A vegetation map outlining the general distribution of major shoreline and aquatic macrophytes species in Beaver Lake is provided in Figure 4. Although the shoreline vegetation consists of numerous plant species, major representatives include red alder (Alnus rubra) and iris (Iridaceae). From the viewpoint of wildlife management, many of these plants serve as refuge and nesting habitat for various birds, and as such, play an important ecological role in the Beaver Lake system.

Dominant aquatic macrophytes in Beaver Lake include a number of pond lilies such as Nuphar sp. (yellow water lily) and Nymphaea spp. (white water lily). Although previous information regarding the diversity, abundance and distribution of aquatic macrophytes in the lake is very limited, it is apparent from written and verbal accounts of the lake environment that in the early part of this century, macrophyte abundance was much less extensive compared to present conditions.

This is particularly true for the pond lilies that presently cover approximately 50% of the lake's surface, since a major lily introduction program was carried out in 1938 in an effort to enhance the aesthetics of the lake. Although there is no doubt that the lilies do add to the aesthetic quality of the lake, they are also a major contributor of organic sediment which is gradually reducing the lake depth. The life cycle of these macrophytes includes an active growth phase during the summer months followed by a dormant period during the winter. Although a certain amount of the summer production is absorbed by the root or rhizome system during the fall period, a substantial portion of the biomass is lost to the environment and eventually accumulates on the lake bottom. An estimate of this sediment build-up is provided in a subsequent section (4.2). The presence of these macrophytes in Beaver Lake is an indication that the system is in the final stages of its ontogeny or successional development. The shallow lake conditions that were observed by early residents in the Vancouver area in the late 19th century have succeeded to a shallow, marshy environment which presently exists in the system. Continued sediment build-up in the system will eventually result in the elimination of the lake. Regardless of whether or not fish enhancement is a priority in the lake, steps must be taken to reverse the sedimentation process if the lake is to be retained.

Fish and Wildlife

Results of electrofishing in Beaver Lake are presented in Table 4. Limited numbers of four fish species were found in the lake. The most numerous species was the threespine stickleback (Gasterosteus aculeatus), which was taken during shocking on six of the ten transects. Although several individuals were caught along transects in the mid-lake area, the majority of stickleback were taken near the Prospect Creek mouth. The carp, Cyprinus carpio, was the second most numerous fish taken during the sampling, with catches made along five of the ten transects. Although no effort was made to estimate the carp population in the lake, groups of 10-15 individuals were regularly sighted during the study period indicating a sizeable population. No individuals were retained for length-weight measurements,

Table 4 Results of fish sampling in Beaver Lake.

Transect No.	Fish Species			
	Carp	Stickleback	Sculpin	Cutthroat Trout
1	1	4	1	
2	2	2		
3	4		2	
4		1	1	
5		5	1	2
6	4			
7	1	3		
8				
9				
10		5		
TOTAL	12	20	5	2

but carp up to approximately 75 cm in length were observed in the lake during the months of May and June, 1984. The majority of carp taken during the study were found in the eastern portion of the lake where the water depths are generally greater than in the central or western areas. A limited number of prickly sculpins (Cottus asper) were also captured during the electrofishing transects, primarily along mid-lake transects. Two juvenile cutthroat trout were taken during electrofishing near the mouth of Prospect Creek at the west end of Transect 5. These fish were 57 and 64 mm in length. No cutthroat were taken in other areas of the lake.

The Beaver Lake fish community is dominated by the sizeable population of large carp which at some point in the lake's history were introduced into the system. Although the fish sampling in the lake was far from exhaustive, it appears as though few, if any, cutthroat trout truly reside in the lake. In one respect, this finding is not surprizing, since the environmental conditions in Beaver Lake (e.g. relatively high summer water temperatures) are not well suited for salmonid residence. On the other hand, no large cutthroat trout were captured during the fish sampling in the Beaver lake inflow streams, indicating that any adult fish in the system should be lake residents. Prior to the design and implementation of any detailed lake and/or stream enhancement program, further fisheries work should be carried out to resolve this enigma.

Observations of waterfowl diversity and abundance revealed that a number of species, such as the mallard ducks, Anas platyrhynchos, and the wood duck, Aix sponsa, are common residents of the Beaver Lake system, whereas other species, such as the Canada goose (Branta canadensis) and the pie-billed grebe (Podilymbus podiceps) appear more sporadically. The Canada goose, for instance, is far more numerous during the early spring period prior to the emergence of the lake macrophytes in April. Table 5 provides a list of waterfowl species observed during the field studies. In addition to these waterbirds, a number of other bird species, such as the red-winged blackbird (Agelaius phoeniceus), are found in and around the shoreline vegetation associated with the lake.

Table 5 Waterbirds observed on Beaver Lake during the study period (January-September, 1984).

Common Name	Scientific Name
Canada Goose	Branta canadensis
Mallard Duck	Anas platyrhynchos
Wood Duck	Aix sponsa
Lesser Scaup	Aythya affinis
Blue-Winged Teal	Anas discors
Great Blue Heron	Ardea herodias
Pie-Billed Grebe	Podilymbus podiceps
American Coot	Fulica americana
Herring Gull	Larus argentatus

4.1.3 Water Quality Sampling

Results of temperature and dissolved oxygen monitoring in Beaver Lake are presented in Figure 5 and include readings taken from early January through early September, 1984. Mid-depth water temperature in Beaver Lake reached a minimum of approximately 4.2°C during early January and a maximum of 18.5°C during the third week in August, 1984. Surface temperatures exhibited a broader range, due to the influence of freezing and solar heating. During the study period, Beaver Lake was ice-covered for approximately two weeks from late December, 1983 to early January, 1984. Solar heating during the summer months produced a maximum surface temperature of approximately 22°C during parts of July and August, 1984.

After a very moderate increase from January through mid-March, lake temperature began to increase steadily through until mid-July, when levels remained relatively constant until the end of August, 1984. The first two to three weeks of September saw a 3°C decline from 18.5 to 15.5°C which will continue at a gradual rate throughout the fall season.

Due to the shallow water depth ($<$50 cm in most of the lake), no significant thermal stratification was detected during any of the temperature monitoring of Beaver Lake. Although wind-driven mixing of the water in Beaver Lake is most likely of minor importance, particularly during the summer months when most of the surface is covered with macrophyte leaves, several other factors act to break down any thermal stratification that may develop in the system. Most importantly, the action of the carp and water fowl that are concentrated in the deeper segment of the lake tends to mix the lake water and re-suspend bottom sediments. Thermal mixing in the shallower areas of the lake ensures a relatively consistent temperature with depth.

Seasonal variation in Beaver Lake mid-depth oxygen concentrations is also presented in Figure 5. Maximum oxygen concentrations were recorded during January and February, 1984, when levels were approximately 11.0-11.5 $mg.L^{-1}$, 90-95% of saturation values. As lake temperatures started to increase in March, oxygen concentrations began to gradually decline to a seasonal low of approximately 3.0 $mg.L^{-1}$ during the month of August. Spot measurements near the

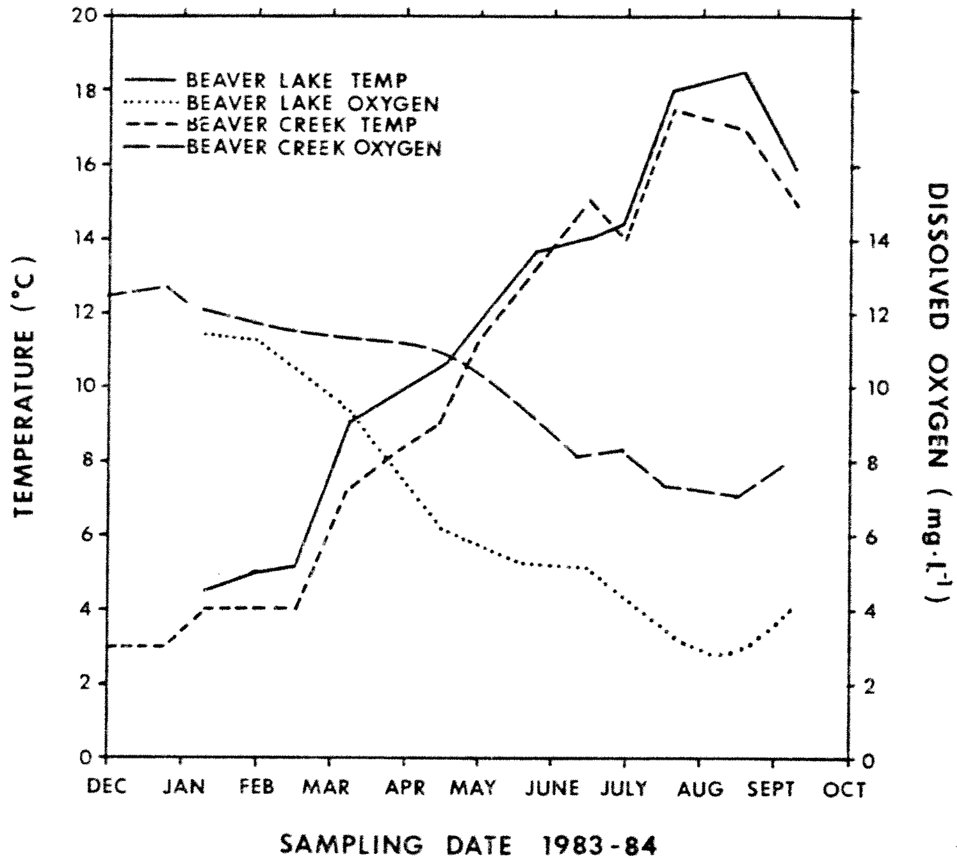


FIGURE 5

Results of temperature and oxygen monitoring in Beaver Lake and Creek. All lake measurements were made at mid-depth (approximately 75 cm below the surface)

hel

lake sediments (within 10 cm of the lake bottom) revealed that oxygen concentrations in that layer were even lower than the overlying water (< 2.0 mg.L^{-1}). This low oxygen layer results in part from the oxygen demand exerted by bacteria involved in sediment decomposition. Although cyprinid fishes, such as carp, are capable of functioning quite well in low oxygen environments, the low summer oxygen concentrations in Beaver Lake are generally below tolerance levels for most salmonids.

Conductivity is a simple and rapid measure of the ionic strength of water. In Beaver Lake, conductivity levels ranged from a low of approximately 35 micromhos.cm^{-1} (micro Siemens.cm^{-1}) to a high of 50 micromhos.cm^{-1}. Although there appeared to be a minor increase in conductivity with increasing temperature during the summer months, no real seasonal variation was noted during the study.

Results of pH monitoring in Beaver Lake are listed, along with the data collected on the other water quality parameters, in Table 6. pH levels in Beaver Lake during the study period were consistently acid, ranging from a low of 6.05 in March to a May high of 6.38. Additional pH monitoring during site visits throughout the study period produced results consistent with those listed in Table 6. In general, little seasonal variation in pH level was detected, although conditions appeared to be slightly more acidic during the winter months. There are a variety of factors in natural water systems that can influence pH. In Beaver Lake, important factors may include the chemical characteristics of surface inflow water which comes primarily from the municipal water supply, particularly during low rainfall periods; humic acids leaching from decaying vegetation in the lake; and the metabolic activities of biological organisms (i.e. bacteria and plants) that affect carbon dioxide concentrations in the lake water.

pH is an important consideration when assessing potential salmonid enhancement opportunities. If a water supply is to be used for intensive salmonid culture or hatchery operations, then it is recommended that the pH fall within the range of 6.5 to 8.5 (Department of Fisheries and Oceans 1983). Although the pH level in Beaver Lake falls slightly outside of this range, the general enhancement

Table 6 Results of chemical analysis of water samples collected from Beaver Lake and Beaver Creek (with the exception of pH and colour, all results are expressed as $mg \cdot L^{-1}$).

Parameter	Feb. 16/84 Lake	Feb. 16/84 Creek	March 27/84 Lake	May 15/84 Lake	June 20/84 Lake	June 20/84 Creek
pH	6.16	6.62	6.05	6.38	6.19	6.74
Colour (cu)	20	20	20	10	5	5
Nonfiltrable Residue Total	62.0	50.0	6.4	2.8	2.8	6.0
Fixed	2.4	1.0	1.6	1.1	1.0	3.0
Volatile	2.4	1.0	4.8	1.7	1.8	3.0
Filtrable Residue Total	55	50	52	51	30	28
Fixed	43	40	40	40	25	20
Volatile	12	10	12	11	5	8
Hardness ($CaCO_3$)	15.0	14.0	16.0	16.0	12.0	14.0
Alkalinity ($CaCO_3$)	17.6	22.0	13.3	14.6	14.3	13.7
Sulphide - S	$<$0.010	$<$0.010	$<$0.010	$<$0.010	$<$0.010	$<$0.010
Phosphorus Total P	0.010	0.013	0.016	0.125	0.016	0.016
Total Dissolved	0.008	0.013	0.015	0.004	0.016	0.014
Ortho - P	0.002	0.011	0.012	0.018	0.010	0.011
Nitrate - N	0.33	0.36	0.25	0.008	0.003	0.022
Nitrite - N	0.008	0.001	0.020	0.003	0.001	0.001
Ammonia - N	$<$0.010	$<$0.010	$<$0.010	$<$0.010	0.021	0.015
Silicate - SiO_2	7.8	6.4	6.7	2.6	3.1	3.2
Tannin and lignin	1.3	1.1	1.3	2.0	1.3	1.2

strategy under consideration for the system does not involve hatchery or intensive fish culture development. A less intensive enhancement approach generally allows for greater flexibility with respect to water quality criteria.

Residue (solids) determinations were carried out on lake water samples collected during February, March, May and June, 1984. With the exception of the February sample, non-filtrable residue (suspended solids) levels were generally low in Beaver Lake (Table 6) and within the acceptable limits for salmonid rearing (< 25 mg.L^{-1}). Since both the lake and creek samples exhibited high non-filtrable residue levels in February, it is unlikely that the comparatively high lake concentrations during this period can be attributed to contamination or analytical error. It is possible that wind or biological activity in the lake (e.g. fish movement), around the time of the February lake and creek sampling, may have re-suspended shallow bottom sediments in the area of the outflow.

Although filtrable residue (dissolved solids) levels were generally higher than non-filtrable concentrations in Beaver Lake, this parameter is usually less of a concern with respect to salmonid enhancement. Filtrable residue levels in Beaver Lake should not present any significant barriers to salmonid enhancement activities.

Hardness is a measure of the concentration of dissolved divalent cations, primarily Ca^{++} and Mg^{++}. Since Ca^{++} is usually the dominant ion, hardness values are generally expressed in mg.L^{-1} $CaCO_3$, with soft water having low hardness and hard water having high hardness. In an intensive culture situation, it appears that soft water may have a negative influence on disease susceptibility in salmonids (Warren 1963; McLean 1979). Although this may be true for intensive culture systems, such as hatcheries, there is little or no evidence to indicate that a low hardness level in natural waters is a major factor limiting fish production. Hardness levels in Beaver Lake are comparatively low, indicating soft water conditions (Table 6). Lake water hardness remained relatively constant throughout the winter and spring period at 15-16 mg.L^{-1} $CaCO_3$, but showed a minor decline to 12 mg.L^{-1} $CaCO_3$ in June. This decline in hardness may be due in part to increased biological activity (i.e. primary production) during the summer period.

Alkalinity is the ability of water to neutralize acid and, therefore, is a measure of the buffering capacity of water. The highest Beaver lake alkalinity of 17.6 mg.L^{-1} $CaCO_3$ was recorded during February, 1984. During the remaining sampling period, alkalinity in Beaver Lake varied between 13.3 and 14.6 mg.L^{-1} $CaCO_3$.

Hydrogen sulphide (H_2S), measured as sulphide-S, is a highly poisonous and soluble gas which, in natural systems, is produced by anaerobic decomposition of organic material or by the biochemical reduction of sulphates. In Beaver Lake, the substantial deposits of organic bottom sediments provide an excellent substrate for anaerobic decomposition. During most of the year, dissolved oxygen concentrations in the Beaver Lake water column limit anaerobic activity and, therefore, H_2S production. This condition is reflected in the Beaver Lake monitoring results which show H_2S levels to be below the detection limit of 0.016 mg.L^{-1} throughout the study period (Table 6). During periods when the lake is ice-covered, anaerobic conditions will develop rapidly and, as a result, H_2S levels could reach biologically harmful levels. During the 1983-84 season, Beaver Lake was ice-covered for approximately two weeks. The odour of H_2S was quite apparent in the lake outflow waters entering Beaver Creek during this period.

Phosphorous, nitrogen and silica compounds are generally monitored in freshwater systems due to their role as important plant nutrients. In natural waters, the concentration of these nutrients often varies with the level of primary production, particularly for those chemical species such as orthophosphate and ammonia, that are readily utilized by phytoplankton and aquatic macrophytes. With the exception of winter nitrate-N levels, phosphorous and nitrogen concentrations were generally low throughout the study period and did exhibit a certain amount of seasonal variation. In particular, nitrate-N levels declined substantially from a February high of 0.330 mg.L^{-1} to a low of 0.003 mg.L^{-1} during June, 1984.

Silica is an important nutrient for a group of microalgae called diatoms that utilize this element in the construction of the cell wall or furstule. In Beaver Lake, both planktonic and epiphytic diatoms are present. Silica levels in the lake were

generally high throughout the study period, particularly during the winter months when primary production is low. During May and June, when biological activity is increasing in the system in response to higher water temperatures and greater solar radiation availability, silica concentrations dropped to less than one-half of February and March values.

From the viewpoint of fisheries enhancement, the nutrient levels in Beaver Lake do not appear to be a problem at present. Any physical or biological modifications to the system that may be carried out as part of an enhancement program (e.g. lake sediment removal) will undoubtedly alter the chemical characteristics of the lake water. The potential impact of these chemical changes must be considered in the detailed design process leading up to a comprehensive enhancement plan.

4.2 Beaver Creek

4.2.1 Physical Habitat Assessment

Physical habitat characteristics of Beaver Creek are summarized in Table 7. A more detailed listing of habitat characteristics is presented in Appendix 6 where individual descriptions for each hydraulic unit are provided.

The overall reach or, in the case of Beaver Creek, the overall stream length is 301.1 m. This distance encompasses the area from the lake outflow at the upstream end to the marine outfall at the downstream end. The overall stream gradient, calculated from a 1:12,000 scale topographic map of the park, is approximately 1.3%. During the study period, a series of hydraulic units consisting of pool, riffles, and glides covered an estimated total wetted area of 644.0 m^2. Several small falls are also present on the system, one of which exists as a substantial barrier to fish migration. Glide sections made up 47.8% of the total stream area, whereas pools and riffles were 19.7 and 32.4% respectively. Average wetted stream width ranged from 2.1 m in riffles and glides, to 2.6 m in pool sections, with an average depth of 0.27 m in pools, 0.09 in riffles, and 0.11 in glides.

Table 7 Summary of Beaver Creek physical stream habitat characteristics.

Hydraulic Unit	Pools		Riffles		Glides		Falls	
	Value	%	Value	%	Value	%	Value	%
Size								
Total # of Units	7		12		12		3	
Avg. Length (m)	5.6	17.1	6.0	33.9	10.1	48.0	1.0	1.0
Avg. Wetted Width (m)	2.6	-	2.1	-	2.1	-	0.95	-
Avg. Channel Width (m)	9.1	-	8.9	-	9.0	-	6.3	-
Avg. Depth (m)	0.27	-	0.09	-	0.11	-	0.67	-
Avg. Area (m^2)	17.8	19.7	17.2	32.4	25.7	47.8	0.95	0.01
Total area of unit in Reach (m^2)	124.7	19.7	206.4	32.4	308.0	47.8	2.85	0.01
Cover								
Avg. Area Log Debris (m^2)	0.43	2.4	0.48	2.8	0.33	1.3	0.17	17.9
Avg. Area Boulder (m^2)	1.17	6.6	0.97	5.6	0.29	1.1	0.27	28.4
Avg. Area Instream Veg. (m^2)	0	0	0	0	0	0	0	0
Avg. Area Overstream Veg. (m^2)	1.29	7.3	1.00	5.8	1.48	5.8	0	0
Avg. Area Cutbanks (m^2)	1.32	7.4	0.55	3.2	1.13	4.4	0	0
Avg. Area Total Cover (m^2)	4.21	23.7	3.00	17.4	3.23	12.6	0.44	46.3
Substrate Type								
Avg. % Fines	-	30.7	-	16.7	-	36.7	-	0
Avg. % Small Gravel	-	29.0	-	38.7	-	33.3	-	0
Avg. % Large Gravel	-	14.6	-	21.3	-	17.5	-	1.6
Avg. % Cobble	-	5.7	-	6.7	-	6.3	-	13.3
Avg. % Boulder	-	20.0	-	16.3	-	5.9	-	33.3
Avg. % Bedrock	-	0	-	0	-	0	-	0
Avg. Compaction	0.5	-	0.7	-	0.6	-	0.9	-

Date: December 20, 1983
Reach Length: 301.1 m
Reach Area: 644.0 m^2
Reach Gradient: 1.3%

Water Temperature: 3.5°C
Specific Conductance: 42 umhos.cm^{-1}

In addition to the small falls mentioned above, fish movement into Beaver Lake fom the creek is also blocked due to the culvert and flow control installations positioned at the lake outflow. Creek access from the ocean is limited to periods of high tide, when seawater reaches the creek outfall that passes under the seawall.

In general, stream cover in and over Beaver Creek is substantial. Large coniferous trees that are growing in close proximity to the entire stream channel provide a relatively dense canopy that limits the amount of available light at creek level. A number of habitat cover parameters were assessed during the study including: instream log debris - both area and depth provided to salmonids; instream boulders - boulder area; instream vegetation - area of submerged vegetation, not including algae; overstream vegetation - the area of overhead (organic) cover within 1 m (vertical) of the stream surface; and cutbanks - area of undercut or subsurface eroded streambank. Although there is substantial canopy cover over the entire length of Beaver Creek, the average area of overstream cover (within 1 m of the stream surface) was less than 5% of the total stream area during the time of the assessment. Since the assessment was carried out during the winter season, it is certain that overstream vegetation cover is greater during the summer months. No instream vegetation cover was noted during the study period. Other instream cover parameters are low in Beaver Creek. At the time of the study, the water transparency was high with the stream bottom being visible throughout the creek, despite the shaded conditions and the brownish water colour.

Particle size ranges listed for the substrate types in Table 7 are 0.0-0.1 cm for fines, 0.1-4.0 cm for small gravel, 4.0-10.0 cm for large gravel, 10.0-30.0 cm for cobble, and greater than 30.0 cm for boulders. In general, the substrate in Beaver Creek is dominated by fines and small gravel. From the viewpoint of potential salmon spawning sites, the substrate in most of the creek is not suitable, due to this small particle size. Coho, for instance, require spawning gravels in the size range between 2.5 and 10.0 cm (Burner 1951; Hamilton and Buell 1976), whereas the resident Beaver Creek cutthroat trout would be expected to utilize small gravels ranging in size between 1.0 and 6.0 cm (Hickman and Raleigh 1982).

Beaver Creek discharge measurements were made thoughout the study period and are displayed in Figure 6. Discharge ranged from a seasonal high of 0.032 cubic meters per second ($m^3.s^{-1}$) in January to a low of approximately 0.022 $m^3.s^{-1}$ during June. Due to the flow control structure positioned at the Beaver Lake outflow, creek discharges generally do not vary substantially. The mean seasonal discharge calculated from the measurements taken during 1984 was 0.025 ± 0.003 $m^3.s^{-1}$ (SD). Any fluctuations in creek discharge are generally a result of increased runoff during periods of high precipitation. Supplemental water is provided to the Beaver Lake system from the municipal water supply. Changes in this supply could also influence discharge levels in Beaver Creek.

4.2.2 Biological Sampling

The biological assessment of Beaver Creek involved macrobenthic invertebrate and fish sampling.

Stream Invertebrates

Stream invertebrate sampling was carried out to provide a general idea of benthic production and food availability for salmonids in the system. Seasonal variation in total macrobenthic invertebrate concentrations at the four Beaver Creek sampling stations is displayed in Figure 7. Appendices 2, 3, 4 and 5 provide a breakdown of these results by important invertebrate groups. A more in-depth assessment of the macrobenthic invertebrate community involving biomass estimates and drift studies, was beyond the scope of this study.

In general, Beaver Creek appears to be a relatively productive system with the highest invertebrate concentrations occurring during the month of June, 1984. Levels at Stations B and C were particularly high during this period in the sampling program. A closer examination of the invertebrate data shows that, in most instances, these high values can be attributed to an abundance of either chironomid or simulid larvae. Although seasonal variability can be difficult to detect in stream invertebrate communities, due to overlapping cohorts (Radford and Hartland-Rowe

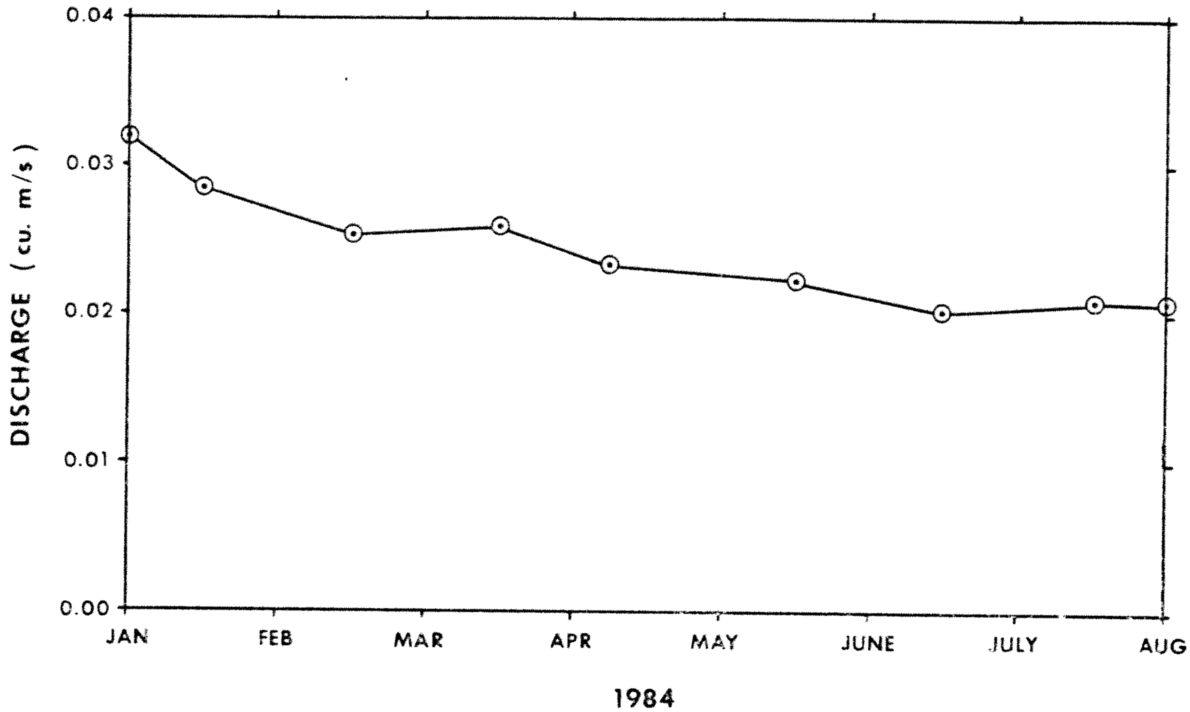


FIGURE 6
BEAVER CREEK DISCHARGE

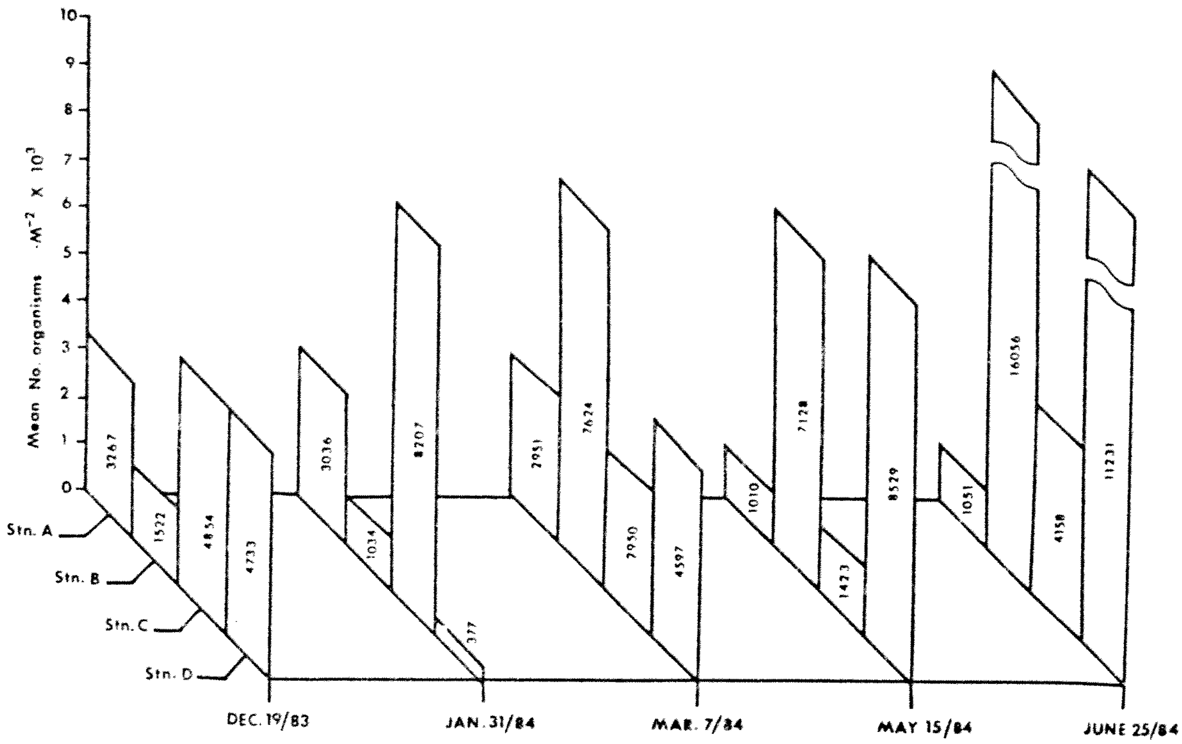


FIGURE 7

Seasonal variation in total macrobethic invertebrate concentrations at four sampling stations in Beaver Creek.

1971), there appears to be a strong seasonal influence in the case of these dipteran groups. Large concentrations of up to 50,000 chironomids.m^{-2} are not unusual in streams, particularly in small to medium size systems (Coffman 1978). Both simulids and chironomids are available as fish food in the stream drift and on the stream bottom.

From the viewpoint of species diversity, the results obtained from Beaver Creek appear to be generally consistent with conditions existing in other similar west coast streams. One possible exception is the complete absence of plecoptera (stoneflies) in the Beaver Creek samples. The absence of stoneflies from Beaver Creek may be related to habitat and feeding requirements of this group. Factors, such as stream order (Stahler 1957), geomorphic and vegetational setting, and the annual hydrograph pattern, exert important controls on biological function (Cummins 1979). The influence of hydrology is minimized in Beaver Creek due to the flow control structure in place at the lake outflow. Therefore, it is likely that biological factors have a greater influence on invertebrate community structure in Beaver Creek.

Based on the P/R, or the ratio of gross photosynthesis to community respiration, Beaver Creek can be considered hetertrophic because of restricted light, a consequence of shading by riparian or overhanging vegetation. Since Beaver Creek is a detritus-based ecosystem rather than an autotrophic system, based on periphyton primary production, the macrobenthic invertebrate community should be dominated by organisms ecologically suited to the Beaver Creek environment. The predominant food sources in the creek include attached bacteria and fungus, and coarse and fine organic detrital material. These food types may not be appropriate for the majority of plecopteran species that are mostly predators and shredders, feeding on decomposing vascular plant tissue (Cummins 1978). Ephemeropterans are primarily gathering collectors, feeding on fine detrital deposits, and scrapers that graze on mineral and organic substrates. Trichopterans are well represented in all feeding groups.

Macrobenthic invertebrate concentrations in Beaver Creek also showed some variation with substrate and current speed type. Concentrations were generally

lowest at sampling site A (Figure 1), with a mean total macrobenthic invertebrate concentration of 2,263 organisms.m^{-2}. Mean concentrations at sites B, C and D were 6,673, 4,318 and 5,893 respectively. The dominant substrate types at site A are fines and small gravels, whereas the other three sampling sites have substrates composed primarily of small and large gravel. Sampling site A was located in a riffle-glide area, whereas sites B, C and D were situated in riffle areas. The comparatively low invertebrate densities measured in the relatively low energy and small substrate habitat of sampling site A are consistent with findings from other studies (Cummins and Lauff 1969; Williams 1978). Although a considerable amount of variability exists, it is generally believed that small to medium size gravel in riffle areas exhibits the highest level of stream invertebrate production.

Beaver Creek is a relatively low gradient (1.3%) system with pools and glides making up approximately 70% of the total stream area (see section 4.2.1). Fines and small and large gravel are predominant throughout the system. From the viewpoint of gradient and substrate particle size, Beaver Creek can be considered generally good habitat for macrobenthic invertebrates and, as a result, the system should be capable of supporting relatively high numbers of fish.

Biological production in Beaver Creek may be limited by low light availability. A number of studies designed to compare shaded streams with streams having open or clear-cut sections revealed that open systems had higher microbial respiration associated with organic matter; greater standing crop of aufwuchs (microscopic plant and animal forms which encrust submerged surfaces of living organisms and non-living substrates), benthic invertebrates, trout and other vertebrates; greater diversity of drifting invertebrates; and greater production of trout than did shaded old-growth and second-growth sites (Albrecht 1968; Erman et al. 1977; Hunt 1978; Murphy and Hall 1981; Murphy et al. 1981). Although these findings could be applied to Beaver Creek as part of an enhancement program, the enhancement objectives that have been established do not include efforts at significantly increasing fish production levels in the creek. The preliminary assessment of invertebrate production in Beaver Creek, carried out during this

study, indicates that the system can most likely sustain a limited number of additional salmonids on existing food resources. Therefore, it is unlikely that any modifications intended strictly to increase macrobenthic invertebrate production in the system will be necessary.

Fish

Fish sampling in Beaver Creek was carried out twice during the study period, once in December, 1983, and again in June, 1984. Capture-removal methodology was applied to two 30 m segments of the stream, one above the main set of falls under the road bridge, and a second below the falls (Figure 1). Although these stream sections contained representative fish habitat from both stream reaches, the habitat conditions in the sampling sections is generally of a slightly higher quality than in the remaining stream sections. During the sampling program, five fish species were captured: cutthroat trout (*Salmo clarkii*); coho salmon (*Oncorhynchus kisutch*); carp (*Cyprinus carpio*); threespine stickleback (*Gasterosteus aculeatus*); and the western brook lamprey (*Lampetra richardsoni*). The two most abundant species were cutthroat trout and coho salmon. Carp and lamprey catches were incidental amounting to a total of 1 and 2 specimens, respectively, during both sampling efforts. A total of 12 sticklebacks were captured during the study, but no population estimates were calculated for this species.

Salmonid population estimates for both stream sections during the month of December are presented in Table 8. In the downstream section of the creek, population estimates for cutthroat and coho were 17 and 13, respectively. Assuming an area of 50.4 m^2 in the sampling section, these population estimates equate to an overall stream density of 0.34 cutthroat.m^{-2}, and 0.26 coho.m^{-2}. Therefore, total salmonid density is 0.60 fish .m^{-2}. These estimates can be further broken down be size classes to produce the following densities:

	cutthroat	coho
50-99 mm	0.08.m^{-2}	0.06.m^{-2}
100-149 mm	0.16.m^{-2}	0.20.m^{-2}
150-199 mm	0.08.m^{-2}	
350-399 mm	0.02.m^{-2}	

Table 8 Salmonid population estimates for Beaver Creek during December, 1983 using the removal-depletion maximum-likelihood formula (Platts *et al*. 1983).

Catch Statistics	Reach and Salmonid Species: Downstream of Falls — Cutthroat	Downstream of Falls — Coho	Upstream of Falls — Cutthroat
Total Catch	17	13	27
Population Estimate	17	13	28
Population Estimate Standard Error	0.6858	0.8750	1.8305
Lower Confidence Interval	17	13	27
Upper Confidence Interval	18.3443	14.7150	31.5877
Chi Square	3.3161	4.9294	1.3880
Capture Probability	0.7391	0.6842	0.6279
Capture Probability Standard Error	0.1143	0.1458	0.1103
Lower Confidence Interval	0.5151	0.3984	0.4117
Upper Confidence Interval	0.9632	0.9701	0.8441
Removal Pattern	11 6 0	7 6 0	18 5 4

In the upstream section, no coho salmon were captured. The cutthroat population estimate for the sampling segment was 28, with a population density of 0.44 fish.m^{-2}, based on a sampling area of 63.8 m^2. Based on size distribution, the following densities were calculated:

50-99 mm	0.25.m^{-2}
100-149 mm	0.17.m^{-2}
150-199 mm	0.02.m^{-2}

A salmonid population estimate was also carried out in Prospect Creek during the month of December, 1983. Results of the catch analysis are presented in Table 9. A total of 38 cutthroat trout were captured in three passes during the electrofishing. Based on a removal pattern of 25, 10 and 3, the population estimate is 39. Since the sampling area was 85.8 m^2, then the cutthroat density in the creek was 0.45 fish.m^{-2}. Densities based on size distribution of the cutthroat caught in Prospect Creek are:

0-49 mm	0.01.m^{-2}
50-99 mm	0.40.m^{-2}
100-149 mm	0.05.m^{-2}

Results of population estimates generated fom the fish sampling in Beaver Creek during June of 1984 are presented in Table 10. In the downstream section, fish densities were considerably higher in June than during December of the previous year. This difference can be attributed to the influx of coho fry that entered the stream during April, 1984. Since no coho spawning activity or redds were observed during the study period, it is uncertain whether the appearance of O+ juveniles in the system is a result of creek spawning. Population estimates for cutthroat and coho in the downstream sampling segment during June were 49 and 94 fish, respectively. In terms of population densities, these values are equivalent to 0.97 cutthroat.m^{-2} and 1.81 coho.m^{-2}, which produces a total salmonid density of 2.84 fish.m^{-2}. This value is approximately five times greater than the total density figure calculated for the December sampling, and is only representative of conditions in the system for a relatively short period of time each year.

Table 9 Salmonid population estimates for Prospect Creek during December, 1983 using the removal-depletion maximim-likelihood formula (Platts *et al*. 1983).

Catch Statistics	Salmonid Species Cutthroat
Total Catch	38
Population Estimate	39
Population Estimate Standard Error	1.6973
Lower Confidence Interval	38
Upper Confidence Interval	42.3266
Chi square	0.2531
Capture Probability	0.6667
Capture Probability Standard Error	0.0870
Lower Confidence Interval	0.4961
Upper Confidence Interval	0.8373
Removal Pattern	25 10 3

Table 10 Salmonid population estimates for Beaver Creek during June, 1984 using the removal-depletion maximum-likelihood formula (Platts *et al.* 1984).

Catch Statistics	Reach and Salmonid Species: Downstream of Falls – Cutthroat	Downstream of Falls – Coho	Upstream of Falls – Cutthroat
Total Catch	42	81	53
Population Estimate	49	94	57
Population Estimate Standard Error	6.2371	8.1578	3.5590
Lower Confidence Interval	42	81	53
Upper Confidence Interval	61.2248	109.9892	63.9756
Chi Square	2.6045	0.3356	0.9240
Capture Probability	0.4667	0.4765	0.5761
Capture Probability Standard Error	0.1114	0.0790	0.0849
Lower Confidence Interval	0.2484	0.3217	0.4098
Upper Confidence Interval	0.6850	0.6313	0.7424
Removal Pattern	20 17 5	45 22 14	31 17 5

In the upstream section of Beaver Creek, a population estimate of 57 cutthroat trout was calculated from the fish sampling data collected in June. This population estimate is equivalent to a cutthroat density of 0.89 fish.m^{-2}. This value is approximately twice as high as the cutthroat density determined during December. This difference can be attributed to recruitment and changes in the pattern of fish distribution.

With the exception of the very high salmonid densities recorded in the downstream section during June, the population densities calculated for Beaver Creek appear to be consistent with results produced elsewhere. A number of stream systems ranging in wetted width from 3.16 to 8.09 m, in the Salmon River Drainage, Vancouver Island, were studied by Ptolemy et al. (1977). Salmonid population densities varied from a high of 1.67 fish.m^{-2} to a low of 0.19.m^{-2} (n = 8).

Additional data relating to Beaver Creek salmonid length, weight, age and condition factors are presented in Appendices 7 and 8. These data apply to salmonids taken during the December, 1983 sampling. Only limited length-weight data were recorded from fish taken during the June sampling effort, therefore no listing is provided. In the downstream section of Beaver Creek, the majority of cutthroat trout were in the 100-149 mm length range, whereas in the upstream section, two major size classes (50-99 mm and 100-149 mm) were evident. The coho salmon captured in the downstream section showed only minor variation in fork length ranging from 88 to 119 mm.

Length-weight distribution for cutthroat trout taken from Beaver Creek during December, 1983 is presented in Figure 8. Results are presented separately for the upstream and downstream sections. Condition factors listed in Appendix 7 appear to be within the normal range reported in other studies carried out on west coast salmonid populations (Carlander 1969; Tripp and McCart 1983).

It is apparent from the preliminary fisheries assessment work carried out during this study that Beaver Creek contains suitable habitat for both cutthroat trout spawning and rearing and coho salmon rearing and possibly spawning. Although no concrete evidence is available to support the possibility of coho

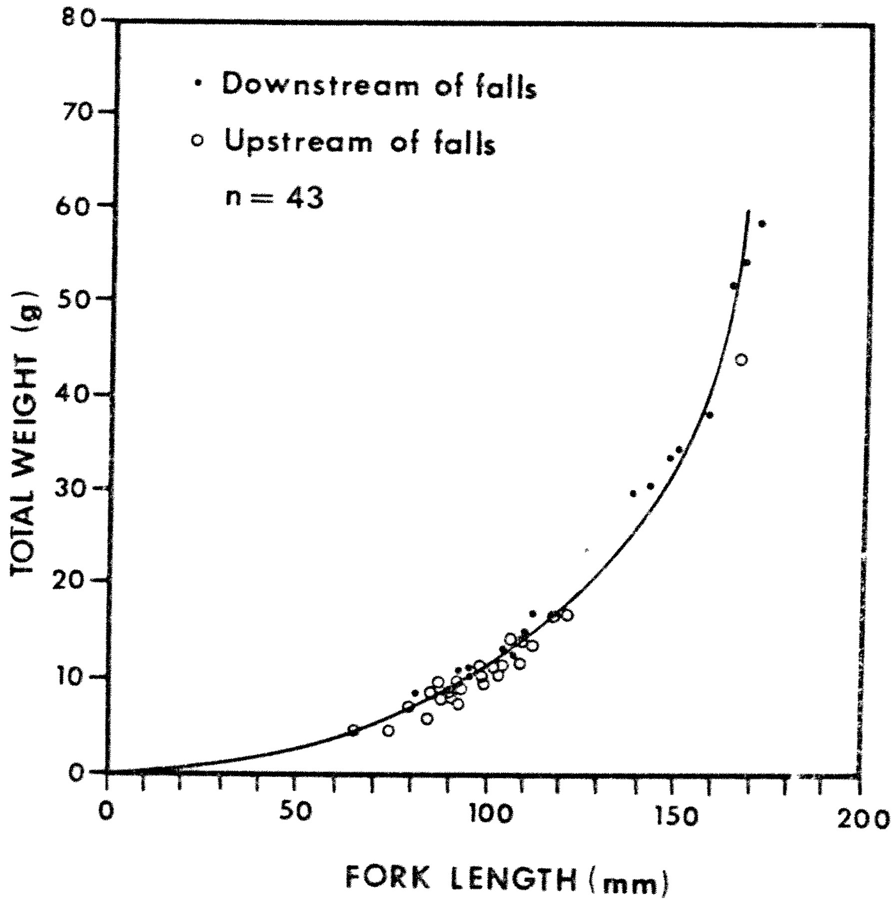


FIGURE 8
Length-weight distribution for cutthroat trout taken from Beaver Creek during December, 1983.

spawning in the lower creek section, it is unlikely that fry from another stream entered Beaver Creek from the marine environment. With respect to salmon enhancement, the presence of coho fry in Beaver Creek is encouraging, since this is an indication of favourable environmental conditions. Because the existing creek environment contains all the essential habitat requirements for salmon production, enhancement measures should be limited to relatively minor habitat improvement activities and upgrading stream access.

4.2.3 Water Quality Sampling

Water quality assessment in Beaver Creek entailed a limited water chemistry analysis program, and monitoring of temperature, dissolved oxygen, conductivity and pH. In general, water chemistry parameters and pH in Beaver Creek varied little from levels measured in Beaver Lake (Table 6). Conductivity levels were also similar to those determined for Beaver Lake, generally falling within the 30-50 micromho.cm^{-1} range. Considering the relatively short length of the creek, it is not surprising that the levels of these water quality parameters are relatively consistent from the lake to the creek environment.

Results of temperature and dissolved oxygen monitoring in Beaver Creek are presented, along with the monitoring results from the lake, in Figure 5. Although variation in creek temperatures followed a pattern that was very similar to that which occurred in Beaver Lake, oxygen concentrations were consistently higher in the creek than in the lake. Creek oxygen concentrations varied from a high of 12.6 mg.L^{-1} in January to an August low of approximately 7.0 mg.L^{-1}. These concentrations are sufficient to sustain all salmonid species.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 Summary

The following points provide a brief summary of the results contained in this report.

Beaver Lake

1. Beaver Lake has a surface area of 3.95 hectares and the water depth to the sediments does not exceed 2 m in any area of the lake. It is generally 0.5 m or less in depth in approximately 80 to 90% of the system.

2. Bottom probing revealed that maximum sediment depth in the lake is approximately 4 m. The probing demonstrated that sediment deposits in Beaver Lake were between 3 and 4 m in approximately 75% of the lake basin.

3. A sedimentation rate of 1.36 $cm.y^{-1}$ was calculated from results of pollen analysis carried out on a sediment core extracted from Beaver Lake. Assuming a mean water depth of 0.5 m in Beaver Lake, it was calculated that the remaining standing water in the system will be relaced by saturated sediments within a period of 36.8 years. It was noted that this is a very rough calculation since this sedimentation rate cannot be applied consistently to all areas of the lake.

4. Low concentrations of zooplankton were found in the lake. Dominant groups were cyclopoid and harpacticoid copepods and two cladoceran species (Bosmina and Daphnia).

5. Dominant macrobenthic invertebrates in Beaver Lake were chironomid larvae, trichopteran larvae (caddisflies), oligochaete worms, nematodes and copepods. Total concentrations of these organisms exhibited only minor seasonal variation, ranging from a high of 13,023 $organisms.m^{-2}$ in January to a low in May of 10,591 $organisms.m^{-2}$.

6. Dominant aquatic macrophytes in Beaver Lake include a number of pond lilies such as Nuphar sp. (yellow water lily) and Nymphaea spp. (white water lily). These lilies, most of which were introduced into the system, presently cover approximately 50% of the lake's surface. These macrophytes are the major contributors of organic sediments into the lake.

7. Four fish species were captured in Beaver Lake during the study - threespine stickleback, carp, prickly sculpin, and cutthroat trout. The lake supports a large carp population, but only two cutthroat were taken during the sampling; these were captured near the mouth of Prospect Creek.

8. A number of waterfowl species were observed at various times on Beaver Lake. The majority of resident waterfowl appeared to be mallard ducks.

9. Mid-depth water temperature in Beaver Lake reached a minimum of 4.2°C during early January, and a maximum of 18.5°C during August, 1984.

10. Maximum oxygen concentrations were recorded during January and February, 1984, when levels were approximately 11.0-11.5 $mg.L^{-1}$ (90-95% of saturation). A seasonal low of approximately 3.0 $mg.L^{-1}$ was recorded in August. It was concluded that these low oxygen levels are unsatisfactory for most salmonid species and life history stages.

11. Other water quality parameters in Beaver Lake were found to be within acceptable limits for salmon survival. It was noted, however, that any modifications to the physical or biological make-up of the system will undoubtedly alter the chemical characteristics of the lake water.

can this be predicted ahead of construction activity

<u>Beaver Creek</u>

1. The overall length of Beaver Creek was found to be 301.1 m, at a slope of 1.3%, with a total wetted area of 644.0 m^2. Glide sections made up 47.8% of the total stream area, whereas pools and riffles were 19.7 and 32.4%, respectively. With respect to fish passage, it was noted that there is a major impass in the form of a set of falls under the road bridge which passes over

the stream approximately halfway upstream. In addition, creek access from the marine environment is limited by the seawall to high tide periods. Several other minor obstructions to fish migration were noted.

2. The dense overstory, provided by mature coniferous trees and smaller deciduous species at the creek bank, provides good fish habitat. Instream cover for salmonids varies with stream location, but is generaly less than 5% of the wetted area of each hydraulic unit (i.e. pool, riffle, glide).

3. In general, the Beaver Creek substrate is dominated by fines (0.0-0.1 cm) and small gravel (0.1-4.0 cm). There appears to be a number of suitable spawning areas in the system for cutthroat trout, but substrate characteristics are generally unsuitable for salmon spawning.

4. Beaver Creek discharge ranged from a seasonal high of 0.032 cubic meters per second in January, to a low of approximately 0.022 $m^3.s^{-1}$ in June.

5. Macrobenthic invertebrate production appeared to be relatively high, particularly during the month of June, 1984, when concentrations of either chronomid or simulid larvae were present. Some correlation was noted between substrate size and macrobenthic production. The substrate dominated by fines had consistently lower production than the larger substrate sections sampled. It was noted that biological production in Beaver Creek could be limited somewhat by the low light availability.

6. Five fish species were captured during the creek sampling - cutthroat trout, coho salmon, carp, threespine stickleback, and western brook lamprey. Coho were found only downstream of the road bridge falls. In general, salmonid densities were similar to those measured for a number of other coastal streams in British Columbia. The presence of very early fry stage coho in the downstream section of Beaver Creek during April of 1984 is a good indication that limited coho spawning has occurred in the creek. This factor is encouraging from an enhancement viewpoint.

7. Beaver Creek water temperature exhibited a similar seasonal variation to that which took place in Beaver Lake. Creek oxygen concentrations, on the other hand, were consistently higher than in the lake. Oxygen concentrations in Beaver Creek varied from a high of 12.6 $mg.L^{-1}$ in January to an August low of approximately 7.0 $mg.L^{-1}$.

5.2 Recommendations

Based on available information relating to the Beaver Lake-Creek environment, much of which is contained in this report, the following recommendations regarding the restoration and enhancement of the system are presented.

1. A detailed restoration and enhancement design should be developed that is consistent with park planning objectives and effectively integrates all the specific recommendations listed below.

2. In an effort to restore the aquatic habitat of Beaver Lake, it is recommended that dredging activities be carried out on at least one-half of the lake. Aquatic macrophytes should be retained in the remaining section of the lake. This process will effectively reclaim a portion of lake habitat which, under the correct circumstances, could be used by resident and migratory salmonids. In addition, valuable aesthetic features (i.e. water lilies) and waterfowl habitat will be retained. Based on the results of sediment probing in the lake, and the habitat requirements of lake resident salmonids, it would seem appropriate to remove approximately 4-5 m of bottom sediments. The extent of sediment removal will be dependent on technical and logistic factors that will be addressed in the design phase of the project.

3. Salmonid enhancement efforts in the Beaver Lake-Creek system should be two-phased. Initial work should be directed at establishing a self-sustaining salmon run in Beaver Creek. Salmonid enhancement in Beaver Lake and its associated tributaries should be included in a second phase.

4. It is recommended that Beaver Creek enhancement activities include the following:

   a) improving creek access for salmon from the marine environment (i.e. modification of the culvert under the seawall);

   b) developing some form of fish passage facility to allow salmon to move past the road bridge falls and utilize the upstream habitat;

   c) alleviate any other minor fish passage problems that exist in the creek at present (e.g. stoplog structure under foot bridge in lower section); and

   d) install additional salmon spawning gravel in both the upstream and downstream sections of the creek; at the same time, minor improvements to salmon rearing habitat can be carried out if necessary (e.g. increasing instream cover).

5. Since coho are presently using the downstream section of Beaver Creek, it is recommended that enhancement efforts be focused on this species. Several alternatives for increasing coho numbers in the creek are discussed in section 6.0. Consideration must be given to the increased potential of cutthroat trout - coho salmon interaction.

6. It is recommended that Beaver Lake enhancement activities include the following:

   a) providing lake access to stream salmonids, particularly migrating salmon;

   b) improving fish access to the two small feeder streams that flow into Beaver Lake;

   c) establishing self-sustaining salmon (i.e. coho) runs in the small feeder streams; and

   d) increasing the quality and quantity of salmonid rearing habitat in Beaver Lake.

7. A follow-up assessment of the effectiveness of the creek and lake enhancement activities should be carried out. This assessment can be done in conjunction with activities associated with the proposed interpretative program that is recommended below.

8. Finally, it is recommended that an all-encompassing interpretative program be developed which would be designed to incorporate various enhancement features as they come on stream. It is proposed that the plan be composed of the following components:

    a) initially, an unobtrusive nature walk that follows the Ravine and Beaver Lake Trails, which includes information on both the aquatic and terrestrial environment of the system;

    b) once the creek and lake enhancement work has been carried out, the new features should be incorporated into the nature walk; and

    c) depending on public interest and planning objectives, a number of organized interpretative programs can be developed around the nature walk facility.

6.0 PROPOSED ENHANCEMENT STRATEGY AND DESIGN CONCEPTS

The basic strategy behind the proposed restoration and enhancement of the Beaver Lake-Creek system is to ensure that the final plan has a substantial level of interpretative or educational value. This is a particularly critical consideration when designing the salmonid enhancement component of the project, since a different strategy would be necessary in the development of a high volume salmon production plan. Although the salmonid enhancement component of the project is of primary concern, it is intended that all aspects of the Beaver Lake-Creek environment be considered in the final enhancement plan design. These considerations are to be incorporated into an interpretative program that consists initially of a nature walk that will highlight various aspects of the local aquatic and terrestrial environment. This nature walk concept can then be expanded to include the lake-creek enhancement features as they are developed.

It is intended that the nature walk be unobtrusive but informative. A number of design options are possible, but one that appears to have been successful in other locations in British Columbia involves the use of a written guide, in the form of a brochure or pamphlet, that provides a description of natural features along the walk. In addition to being unobtrusive, this type of facility requires a minimum level of effort during installation and maintenance, and the potential for vandalism is reduced.

A number of design alternatives are possible for the specific enhancement features listed in the previous section under Recommendations. With respect to salmon enhancement in the Beaver Lake-Creek system, a number of important objectives must be addressed in the final enhancement plan. These objectives include: maximizing the interpretative quality of the system, while at the same time ensuring that the natural and aesthetic qualities of the area are retained; establishing a self-sustaining salmon run in the system; eliminating barriers to fish movement in the system; ensuring an appropriate amount of salmon spawning and rearing habitat is created; and finally, ensuring that all modifications to Beaver Creek are as natural as possible, and require a minimum of maintenance.

From the viewpoint of fish migration barriers, there are three locations in the Beaver Creek system that could potentially disrupt fish movement. The first is the culvert structure under the seawall. In its present state, the structure restricts fish access to Beaver Creek from the marine environment to the highest tide periods. To ensure that migratory salmon are able to have free access to the creek during the spawning season, it may eventually be necessary to modify the culvert in some fashion. This modification can be carried out subsequent to the more urgent instream changes that are needed to eliminate migration barriers in Beaver Creek.

The second migration barrier in the system is a small stoplog cascade located under the downstream footbridge. Figures 9 and 10 provide a view of the existing structure and two design alternatives for elimination of the barrier. These alternatives involve the raising of the water level in the plunge pool below the cascade by stepping with logs or damming with small boulders.

The third, and most substantial, barrier to fish movement within Beaver Creek is the water control structure under the road bridge, which creates a set of small falls and a cascade below (Figure 11). Fish passage alternatives are presented in Figures 12 and 13. The first alternative involves the construction of a stepped fishway. The second possibility is to redirect the creek flow through a series of drop boxes that are also stepped.

Salmon habitat improvement in Beaver Creek must be directed primarily at increasing the amount of available spawning gravel. This can be done by replacing the existing gravel in selected riffle areas with appropriate sized salmon spawning gravel (e.g. for coho 2.5 to 10 cm), or by creating new riffle-pool habitat that contains the necessary gravel. A secondary habitat improvement measure could be directed at increasing salmon rearing habitat. This can be accomplished in a number of ways, but in Beaver Creek boulder placement may be the best approach (Figure 14).

Once habitat and migration problems have been resolved, a decision must be made regarding the appropriate method of initiating or enhancing the salmon run in the creek. Several alternatives exist, including the construction of an egg incubation box on the system, the planting of eggs in the creek gravel, or the release of hatchery-reared

STOPLOG CASCADE UNDER FOOT BRIDGE

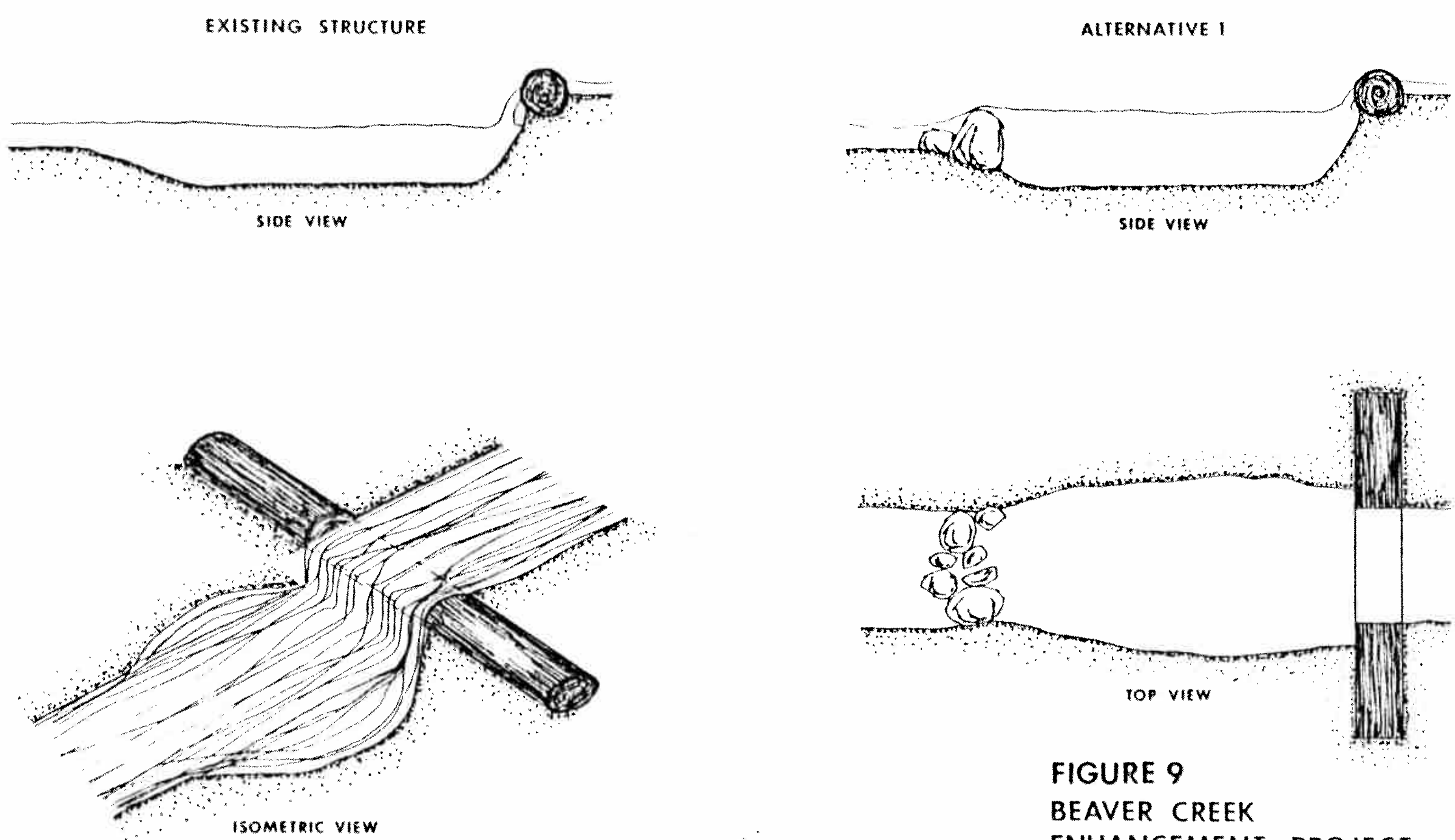


FIGURE 9
BEAVER CREEK
ENHANCEMENT PROJECT

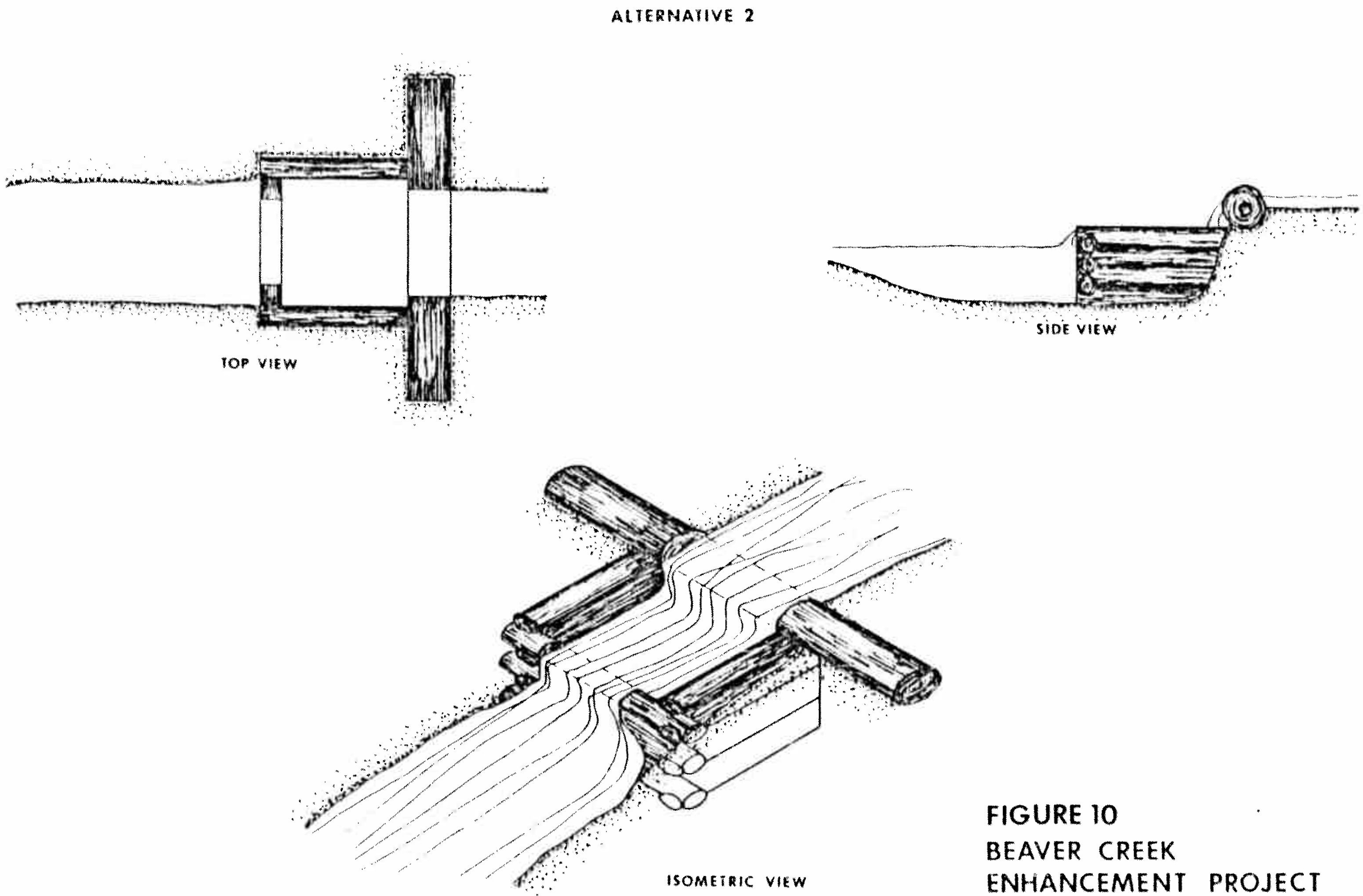


FIGURE 10
BEAVER CREEK
ENHANCEMENT PROJECT

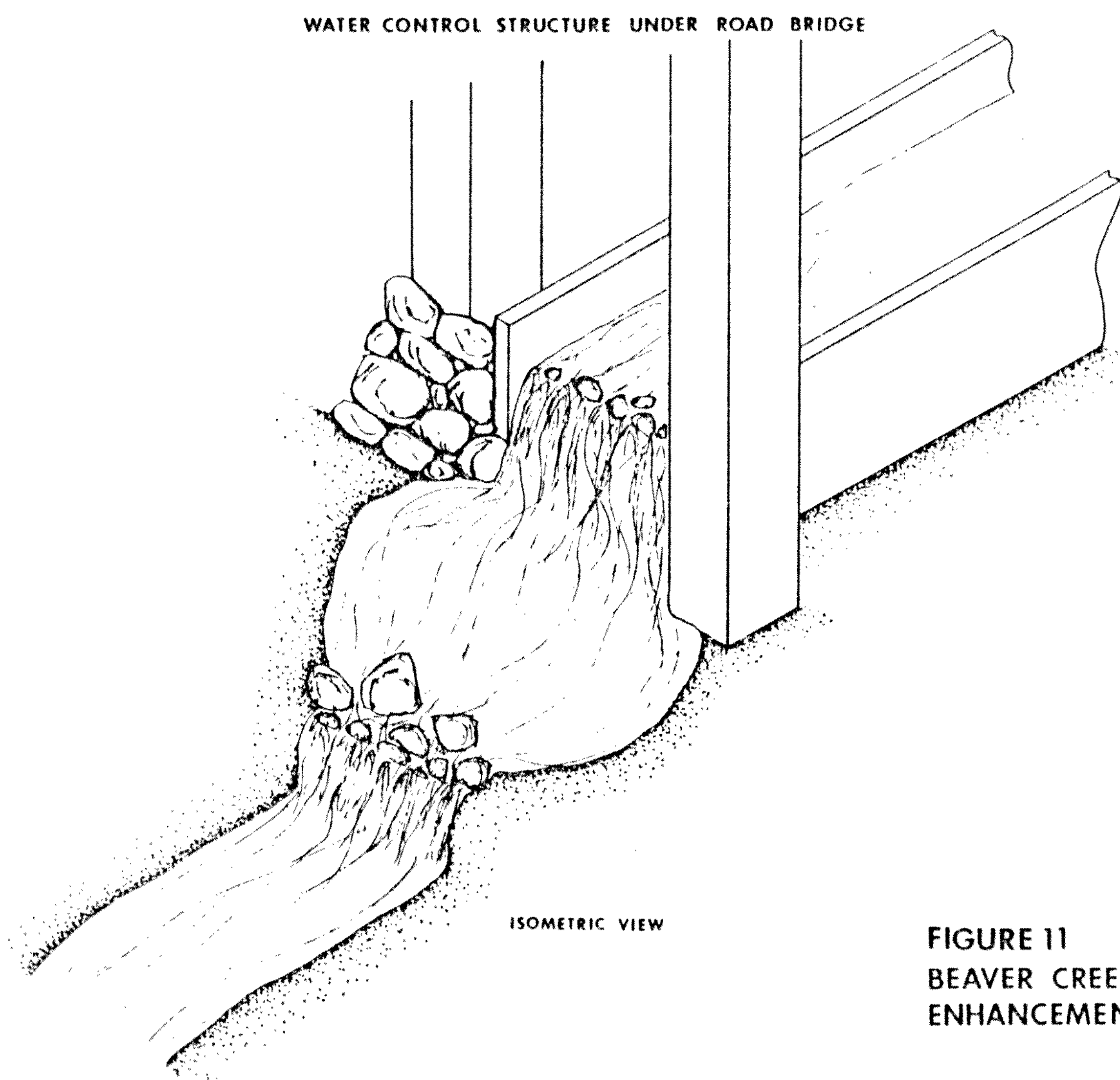
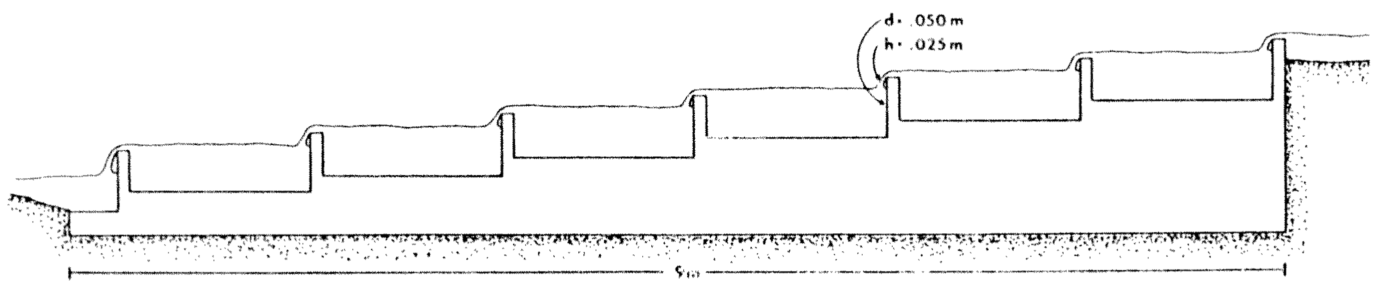


FIGURE 11
BEAVER CREEK
ENHANCEMENT PROJECT

FISH PASSAGE ALTERNATIVES

ALTERNATIVE 1 REDESIGN OF EXISTING WATER CONTROL STRUCTURE



SIDE VIEW

FIGURE 12
BEAVER CREEK
ENHANCEMENT PROJECT

ALTERNATIVE 2 ADDITION TO EXISTING WATER CONTROL STRUCTURE

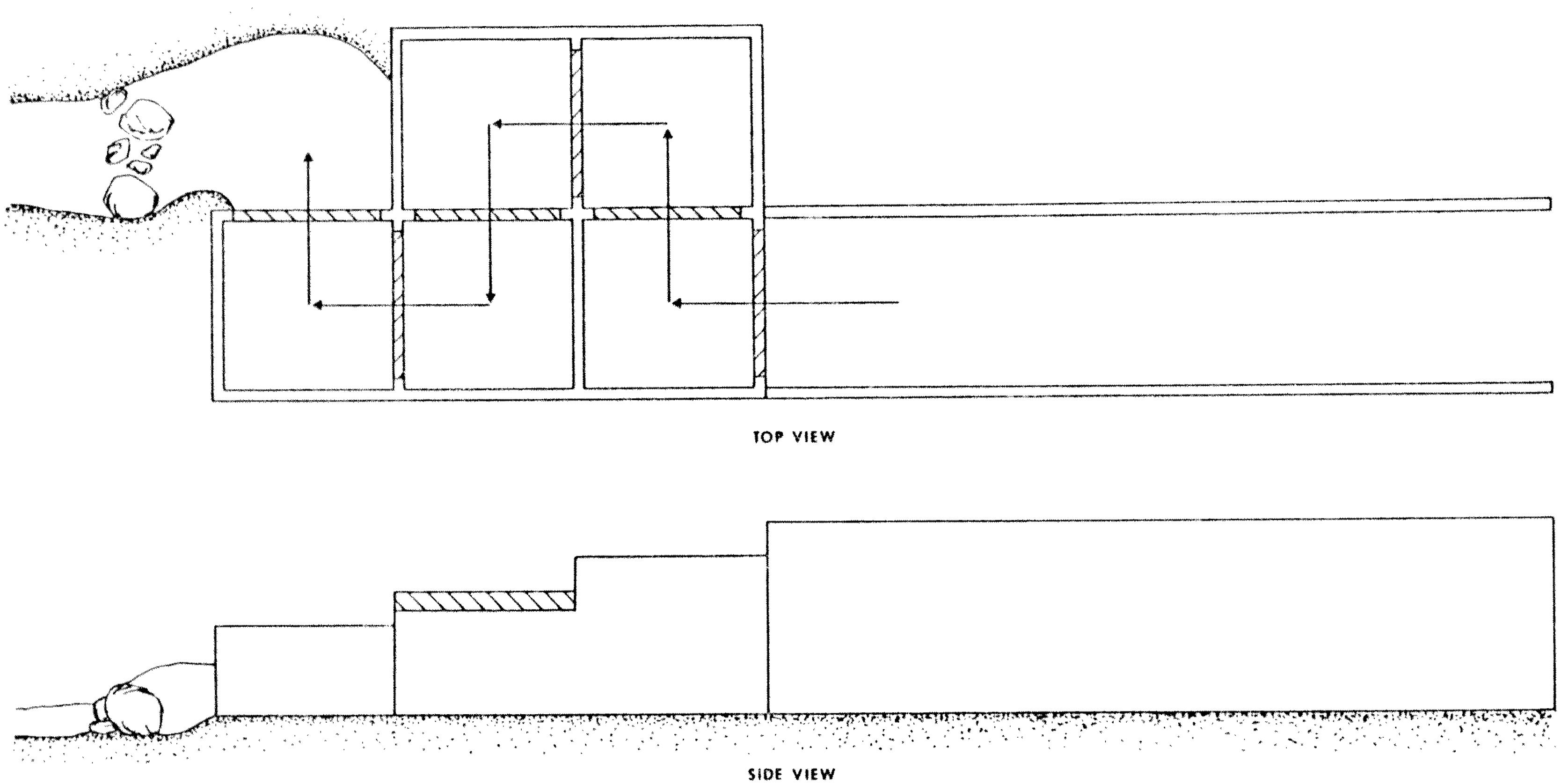


FIGURE 13
BEAVER CREEK
ENHANCEMENT PROJECT

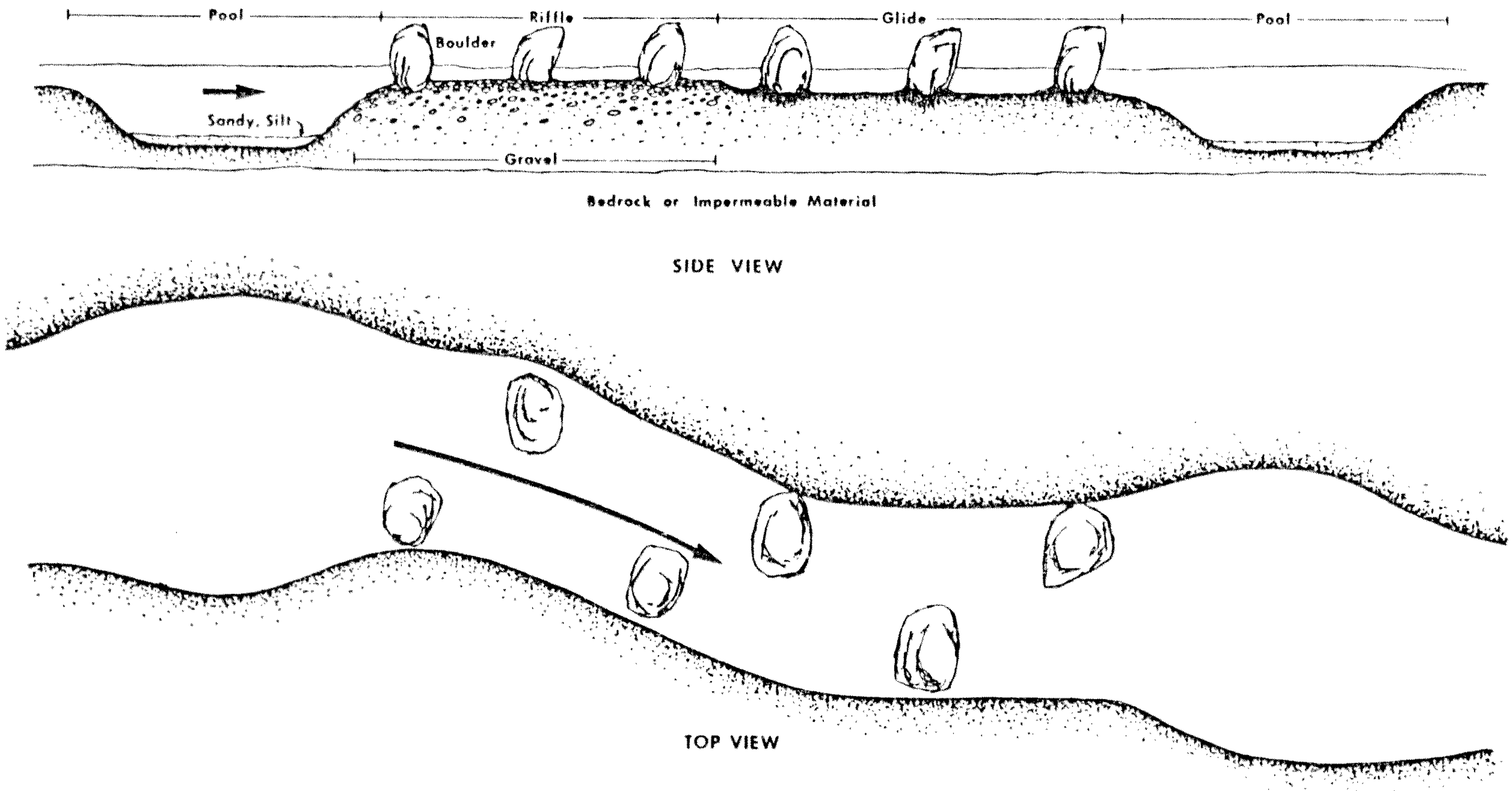


FIGURE 14
BEAVER CREEK
ENHANCEMENT PROJECT

salmon fry or smolts. Although the labour and maintenance costs associated with an egg incubation box are substantial, the educational value of such an installation must be considered. If possible, eggs should come from wild stock, and preferably from any salmon that are entering Beaver Creek.

At present, upstream migrants are unable to access Beaver Lake and its associated inflow creeks due to the outlet flow control structure which consists of a dropbox culvert configuration (Figure 15). Access could be provided by increasing the water level immediately downstream of the outfall, which would back water up the culvert to lake level (Figure 16). A second alternative would be to excavate an open stream channel in the location of the secondary outlet culvert (Figure 15) which would link the lake and creek.

Assuming the necessary measures are taken to create appropriate rearing habitat for salmon in Beaver Lake, a number of possibilities exist for the use of the two small feeder strams (Prospect and Zoo Creeks) for salmon rearing and spawning. With the necessary habitat improvements and egg or fry introduction programs, the systems could supplement the interpretative process planned for Beaver Creek.

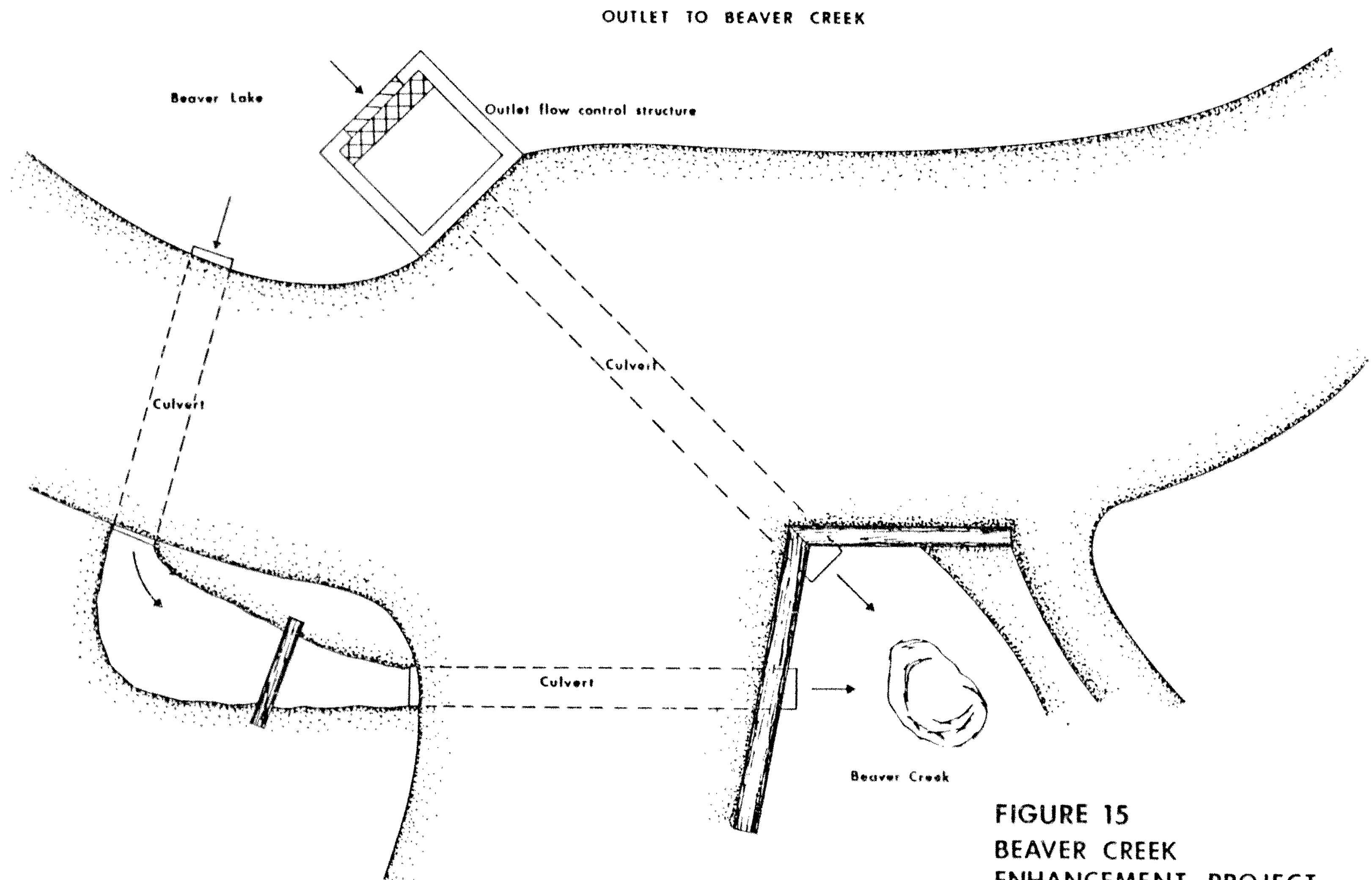
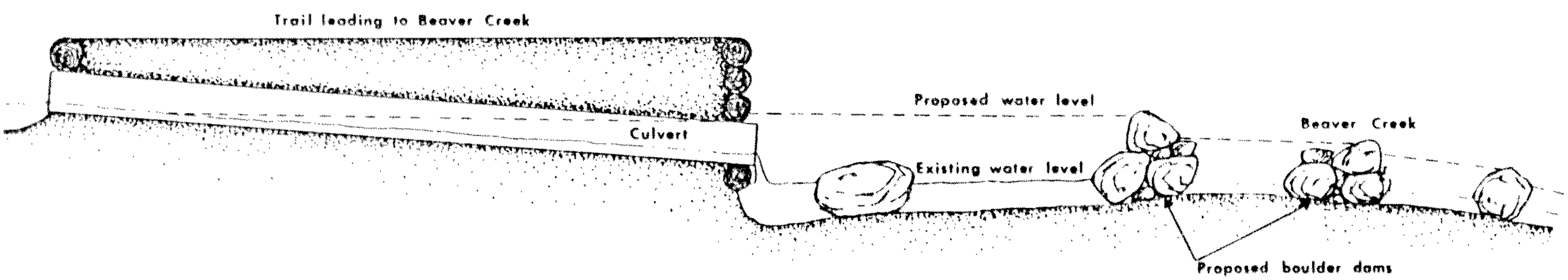


FIGURE 15
BEAVER CREEK
ENHANCEMENT PROJECT

OUTLET TO BEAVER LAKE



SIDE VIEW

FIGURE 16
BEAVER CREEK
ENHANCEMENT PROJECT

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APPENDIX 1. SUMMARY OF ANALYTICAL METHODS USED TO QUANTIFY WATER CHEMISTRY PARAMETERS

In general, analytical procedures followed those outlined in Standard Methods for the Examination of Water and Wastewater (American Public Health Association 1976). Therefore, only a brief summary of each method is provided below.

Alkalinity

Titration with standardized sulfuric acid using a pH meter to monitor end point. Final result expressed as bicarbonate (HCO_3).

Reactive Silicate

Molybdosilicate colorimetric method, expressed as $Si0_2$.

Ammonia Nitrogen

Indo-phenol colorimetric analysis, expressed as N.

Nitrite Nitrogen

Diazotization colorimetric analysis, expressed as N.

Nitrate Nitrogen

Cadmium reduction method, expressed as N.

Total Nitrogen

Kjeldahl persulfate digestion, final analysis by specific ion electrode.

Organic Nitrogen

Obtained by calculating the difference between kjeldahl nitrogen and ammonia nitrogen.

Phosphorus

Ascorbic acid colorimetric method, expressed as P.

Total Hardness

Disodium ethylenediamine tetraacetate (Na_2EDTA) titration, reported as $mg.L^{-1}$ $CaCO_3$.

Tanin and Lignin

Tungstophosphoric and molybdo-phosphoric acids colorimetric determination.

Colour

Platinum-Cobolt method, expressed in chloroplatinate units.

Dissolved Solids (filtrable residue)

Filtration and evaporation of filtrate

Suspended Solids (nonfiltrable residue)

Filtration and weighing of the filter.

Appendix 2   Macrobenthic invertebrates collected in Surber samples from Beaver Creek Station A during the study period. Values given in mean number of organisms per square meter of substrate.

Group	Sampling Data				
	Dec. 19/84	Jan. 31/84	Mar. 7/84	May 15/84	June 25/84
INSECTA					
Diptera					
Chironomidae larvae	144	732	43	178	129
Simuliidae larvae	48		1109	11	75
pupae					
Ceratogonidae larvae	48				
other Diptera larvae	24	194	65	33	86
pupae				11	
Ephemeroptera larvae (mayflies)		151	11	259	129
Trichoptera larvae (caddisflies) adult	48	172	205	38	11
Homoptera larvae				11	
Coleoptera larvae					11
OLIGOCHAETA	1009	538	1152	269	420
NEMATODA	1802	1033	366	119	135
HIRUDINAE	24	129		11	22
PELECYPODA *Pisidium* sp.	120			43	22
ACARINA		22			11
AMPHIPODA		65			
ISOPODA				27	
Total:	3267	3036	2951	1010	1051

Appendix 3 Macrobenthic invertebrates collected in Scuba samples from Beaver Creek Station B during the study period. Values given in mean number of organisms per square meter of substrate.

Group	Sampling Data				
	Dec. 19/84	Jan. 31/84	Mar. 7/84	May 15/84	June 25/84
INSECTA					
Diptera					
Chironomidae larvae	240	344	377	431	684
Simuliidae larvae	10	22	6502	5662	13270
pupae				65	127
Ceratogonidae larvae					20
other Diptera larvae			65	124	458
pupae					
Ephemeroptera larvae (mayflies)	144	97	54	237	406
Trichoptera larvae	240	215	108	129	186
(caddisflies) adult				11	
Homoptera larvae				11	32
Coleoptera larvae					
OLIGOCHAETA	648	269	420	253	618
NEMATODA	192	43	65	70	197
HIRUDINAE		11		32	22
PELECYPODA					
Pisidium sp.	24		11	65	
ACARINA		11	11	38	16
AMPHIPODA					20
ISOPODA	24	22	11		
Total:	1522	1034	7624	7128	16056

Appendix 4 Macrobenthic invertebrates collected in Surber samples from Beaver Creek Station C during the study period. Values given in mean number of organisms per square meter of substrate.

Group	Sampling Data				
	Dec. 19/84	Jan. 31/84	Mar. 7/84	May 15/84	June 25/84
INSECTA					
Diptera					
Chironomidae larvae	961	2954	1184	409	1863
Simuliidae larvae	120	62	97	119	108
pupae					
Ceratogonidae larvae	48	21		11	11
other Diptera larvae	96	369	140	22	307
pupae					11
Ephemeroptera larvae (mayflies)		21	75	102	366
Trichoptera larvae	1394	1026	161	11	22
(caddisflies) adult					
Homoptera larvae					
Coleoptera larvae					11
OLIGOCHAETA	384	492	646	145	700
NEMATODA	913	3097	517	571	624
HIRUDINAE	48		43	11	27
PELECYPODA					
Pisidium sp.	433	123	65		75
ACARINA		21		11	22
AMPHIPODA	24		11	11	
ISOPODA	433	21	11		11
Total:	4854	8207	2950	1423	4158

Appendix 5 Macarobenthic invertebrates collected in Surber samples from Beaver Creek Station D during the study period. Values given in mean number of organisms per square meter of substrate.

Group	Sampling Data				
	Dec. 19/84	Jan. 31/84	Mar. 7/84	May 15/84	June 25/84
INSECTA					
Diptera					
Chironomidae larvae	144	118	2217	4916	8273
Simuliidae larvae	120		517	143	11
pupae					11
Ceratogonidae larvae					
other Diptera larvae			377	143	425
pupae				41	17
Ephemeroptera larvae (mayflies)			97	194	313
Trichoptera larvae	96	22	140		49
(caddisflies) adult					
Homoptera larvae					
Coleoptera larvae				41	32
OLIGOCHAETA	4301		527	2050	1297
NEMATODA		86	129	286	162
HIRUDINAE	72	140	97	459	318
PELECYPODA					
Pisidium sp.		11	474	225	237
ACARINA					
AMPHIPODA					11
ISOPODA			22	41	75
Total:	4733	377	4597	8529	11231

Appendix 6 Physical habitat characteristics of Beaver Creek. Assessment was initiated at upstream end of reach.

Habitat Unit	Pool	Riffle	Glide	Falls	Pool	Riffle	Glide	Riffle	Glide
Unit Size									
Unit #	1	2	3	4	5	6	7	8	9
Length (m)	8.0	9.5	7.5	1.0	3.1	9.8	4.2	7.1	7.0
Avg. Width (m)	3.5	2.9	1.8	0.75	2.0	1.8	2.4	2.2	2.0
Avg. Channel Width (m)	7.0	11.0	12.0	10	12.0	13.0	11.0	9.0	10.0
Avg. Depth (m)	0.4	0.08	0.12	0.4	0.25	0.06	0.1	0.1	0.1
Area (m^2)	28.0	27.6	13.5	0.75	6.2	17.6	10.1	15.6	14.0
Cover									
Log Debris (m^2)	0	0.5	0.25	0.5	0.5	0	0	0.5	0.25
Boulder (m^2)	0.5	0	0.25	0.05	0.5	1.0	0.5	1.0	0.25
Instream Veg. (m^2)	0	0	0	0	0	0	0	0	0
Overstream Veg. (m^2)	1.5	2.0	2.0	0	3.0	1.0	4.0	0.2	1.0
Cutbanks (m^2)	4.0	2.0	4.0	0	1.0	0	3.0	1.5	0
Total Cover (m^2)	6.0	4.5	6.5	0.55	5.0	2.0	7.5	3.2	1.5
Substrate Type									
Fines %	20	20	50	0	30	15	25	15	20
Gravel - small %	40	39	44	0	30	40	35	30	35
Gravel - large %	20	40	5	5	25	30	25	35	35
Cobble %	5	0	0	40	5	5	5	5	5
Boulder %	15	1	1	55	10	10	10	15	5
Bedrock %	0	0	0	0	0	0	0	0	0
Compaction	0.4	0.5	0.3	0.8	0.4	0.7	0.5	0.7	0.6

Appendix 6 (Cont'd)

Habitat Unit	Riffle	Glide	Pool	Glide	Riffle	Riffle-Pool Sequence	Pool	Riffle-Glide Sequence	Riffle-Glide Sequence
Unit Size									
Unit #	10	11	12	13	14	15	16	17	18
Length (m)	6.0	9.9	4.0	9.1	8.4	28.8	8.5	20.5	22.0
Avg. Width (m)	2.2	1.7	2.0	2.1	2.2	1.5	2.5	2.0	2.0
Avg. Channel Width (m)	13.0	13.0	15.0	15.0	10.0	7.5	6.8	9.5	9.5
Avg. Depth (m)	0.05	0.12	0.25	0.10	0.10	0.15	0.35	0.07	0.07
Area (m^2)	13.2	16.8	8.0	19.1	18.5	43.2	21.3	41.0	44.0
Cover									
Log Debris (m^2)	0.25	0.1	0	0.25	0	4.0	0	1.0	2.0
Boulder (m^2)	0.5	0.1	0.2	0.25	0.5	8.0	2.5	0	0
Instream Veg. (m^2)	0	0	0	0	0	0	0	0	0
Overstream Veg. (m^2)	0.5	3.0	0.25	2.0	2.5	1.0	0.5	0.5	3.5
Cutbanks (m^2)	0.5	2.0	1.0	1.0	0	0.5	1.0	1.5	0.5
Total Cover (m^2)	1.75	5.2	1.45	3.5	3.0	13.5	4.0	3.0	6.0
Substrate Type									
Fines %	25	25	40	35	20	10	20	10	30
Gravel - small %	55	40	30	40	30	30	28	65	55
Gravel - large %	15	25	15	15	20	20	2	20	5
Cobble %	0	5	10	5	20	10	0	0	5
Boulder %	5	5	5	5	10	30	50	5	5
Bedrock %	0	0	0	0	0	0	0	0	0
Compaction	0.6	0.5	0.7	0.6	0.7	0.6	0.4	0.7	0.8

Appendix 6 (Cont'd)

Habitat Unit	Falls	Riffle	Pool	Riffle-Glide Sequence	Riffle-Glide Sequence	Glide	Falls	Pool	Riffle
Unit Size									
Unit #	19	20	21	22	23	24	25	26	27
Length (m)	1.0	7.0	7.6	20.2	15.5	20.6	1.0	5.2	3.6
Avg. Width (m)	1.3	2.0	2.7	1.8	2.0	1.5	0.8	3.5	2.0
Avg. Channel Width (m)	2.0	5.5	7.0	6.0	6.0	3.5	1.0	8.5	7.0
Avg. Depth (m)	1.0	0.15	0.20	0.10	0.08	0.17	0.6	0.30	0.05
Area (m^2)	1.3	14.0	20.5	36.4	31.0	30.9	0.8	18.2	7.2
Cover									
Log Debris (m^2)	0	0.5	0.5	0.5	0.25	1.0	0	0	0.1
Boulder (m^2)	0.25	2.5	0	3.5	0.75	0	0.5	0.5	0
Instream Veg. (m^2)	0	0	0	0	0	0	0	0	0
Overstream Veg. (m^2)	0	1.0	3.0	3.5	1.0	2.0	0	0.2	0
Cutbanks (m^2)	0	0.5	2.0	0.5	1.2	3.0	0	0	0
Total Cover (m^2)	0.25	4.5	5.5	8.0	3.2	6.0	0.5	0.7	0.1
Substrate Type									
Fines %	0	5	25	10	20	85	0	70	20
Gravel - small %	0	5	45	15	40	5	0	0	60
Gravel - large %	0	5	20	25	20	5	0	0	20
Cobble %	0	5	5	20	10	5	0	0	20
Boulder %	25	80	5	25	10	0	20	25	0
Bedrock %	75	0	0	0	0	0	80	0	0
Compaction	1.0	0.9	0.4	0.8	0.6	0.4	1.0	0.4	0.8

Appendix 6 (Cont'd)

Habitat Unit		Glide	Glide
Unit Size			
Unit #		28	29
Length (m)		23	22
Avg. Width (m)		2.0	3.6
Avg. Channel Width (m)		9.0	3.6
Avg. Depth (m)		0.10	0.15
Area (m^2)		46.0	79.2
Cover			
Log Debris (m^2)		0.75	0
Boulder (m^2)		0	0
Instream Veg. (m^2)		0	3.5
Overstream Veg. (m^2)		0.5	0
Cutbanks (m^2)		1.5	0
Total Cover (m^2)		2.75	3.5
Substrate Type			
Fines	%	35	95
Gravel - small	%	25	0
Gravel - large	%	30	0
Cobble	%	10	5
Boulder	%	0	0
Bedrock	%	0	0
Compaction		0.6	0.4

Appendix 7 Lengths, weights and condition factors determined for salmonids taken in Beaver Creek during December, 1983.

	Size Class	Length (mm)	Weight (g)	Condition Factor (K)
A. Downstream of Falls				
1. Cutthroat Trout				
	50-99 mm	94	11.7	1.41
		96	10.0	1.13
		82	8.6	1.56
		97	11.1	1.22
	100-149 mm	139	30.0	1.12
		150	34.8	1.03
		149	34.5	1.04
		108	12.8	1.02
		110	15.0	1.13
		143	31.6	1.08
		112	17.6	1.25
		106	13.1	1.10
	150-199 mm	173	59.9	1.57
		167	56.5	1.21
		165	51.1	1.38
		158	38.4	0.97
	350-399 mm	359	530.5	1.15
			mean K (n = 17) =	1.20
2. Coho Salmon				
	50-90 mm	95	10.9	1.27
		98	11.2	1.19
		88	8.3	1.22
	100-149 mm	114	16.8	1.13
		102	12.9	1.22
		109	14.8	1.14
		106	14.7	1.23
		119	18.6	1.10
		104	11.6	1.03
		104	12.8	1.14
		113	16.6	1.15
		112	16.4	1.17
		109	15.1	1.17
			mean K (n = 13) =	1.17

Appendix 7 Cont'd.

	Size Class	Length (mm)	Weight (g)	Condition Factor (K)
B. Upstream of Falls				
1. Cutthroat	50-99 mm	90	7.9	1.08
		88	9.5	1.39
		93	9.9	1.23
		99	11.5	1.19
		90	8.0	1.10
		80	6.8	1.33
		88	7.8	1.14
		91	8.9	1.18
		85	8.0	1.30
		91	8.8	1.17
		74	4.9	1.21
		98	10.9	1.16
		85	7.0	1.14
		99	10.0	1.03
		67	4.7	1.56
	100-149 mm	100	11.4	1.14
		108	14.3	1.14
		110	14.1	1.06
		119	17.2	1.02
		109	14.2	1.10
		108	12.7	1.01
		111	14.4	1.95
		122	17.6	0.97
		102	11.7	1.10
		102	11.4	1.07
		104	12.6	1.12
	150-199 mm	167	44.2	0.95
				mean K (n = 27) = 1.15

Appendix 8 Results of scale sample analysis from Beaver Creek cutthroat.

	Fish #	Weight (g)	Length (mm)	Years of Growth
A. Upstream of Falls				
	1	2.5	72	1 + *
	2	6.9	85	1 +
	3	7.9	92	2
	4	9.6	95	2
	5	9.3	103	2
	6	11.5	108	2 +
	7	12.5	110	2
	8	14.4	110	2
	9	16.1	117	2 +
	10	90.1	204	3
B. Downstream of Falls				
	1	9.1	89	2
	2	9.6	94	2
	3	10.0	96	2
	4	17.6	112	2 +
	5	10.4	121	2 +
	6	24.0	131	2 +
	7	25.1	132	3
	8	36.9	153	3
	9	42.9	165	3
	10	81.9	197	3

* '+' refers to current growth in the next year