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IMPACTS OF THE OPERATION OF EXISTING HYDROELECTRIC DEVELOPMENTS ON FISHERY RESOURCES IN BRITISH COLUMBIA

VOLUME II

INLAND FISHERIES

by

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The report reviews the main features of 46 hydroelectric dams and diversions in B.C. and summarizes available information on the inland sport fish resources within and below the impoundments. Forty of the dams and diversions are owned and/or operated by B.C. Hydro, four by West Kootenay Power and two by Cominco. The projects are collectively responsible for generation of about 95 percent of the electrical power used in the province.

Eight of the projects are located within the Columbia River basin, nine in the Kootenay River basin, two in the Peace River system, ten within the Fraser River basin, and nine are located within various watersheds on Vancouver Island. A further four are located on small lakes in coastal areas. The oldest plant still operating is Upper Bonnington (63 MW) on the lower Kootenay River, constructed in 1908. The most recent project is Revelstoke (1843 MW) on the Columbia River, completed in 1984. The impoundments cover a total area (at full pool) of nearly 6200 km^2 and regulate a total river length of about 591 km. Impoundments vary in size from 60 ha (Wokas Lake) to 177,870 ha (Williston Lake), mean depths range from 3 m (Wokas Lake) to 97 m (Seton Lake), annual maximum drawdowns range from less than 1 m (Seton Lake) to 35 m (Downton Lake), and mean water retention periods range from less than 1 day (Waneta) to longer than 19 months (Williston Lake).

All the hydroelectric impoundments reviewed, with the possible exception of some small headponds, support sport fish populations. Rainbow trout, bull trout and kokanee are the most common species in reservoirs, while cutthroat trout are common in Vancouver Island and some lower mainland reservoirs. Mountain whitefish are significant population components in reservoirs in the Columbia, Kootenay and upper Fraser watersheds. Lake whitefish are significant components in the Peace River reservoirs. Lake trout, brook trout, burbot and white sturgeon occur locally in a few impoundments.

Angling effort and catches have been measured at various times and at various intensities for 16 of the impoundments. Mean catches per unit effort range from highs of just over 2 fish/angler/day (Elsie, Lower Campbell, Daisy lakes) to as low as 0.1 fish/angler/day (Alouette Lake). Recreational angling quality, a criterion based roughly on sport fish population abundance, lake access and aesthetic qualities, is considered good for about one-quarter (9 of 34) of impoundments for which information is available. Angling quality is considered moderate for another quarter (8 of 34) and poor for the remaining half (17 of 34). All the impoundments having good quality angling were natural lakes prior to hydroelectric development. Low population density is the dominant reason for poor angling quality. Extensive drawdowns, snags and floating debris are common impediments to recreational angling. All reservoirs developed after 1968 have been cleared of standing timber within the drawdown zones, while post-impoundment removal of debris has occurred in some.

Size and depth of reservoirs, mean water retention times and maximum annual drawdowns of less than 10 m appear to have little relationship by themselves to sport fish stock densities. Drawdowns exceeding 10 m annually and/or low water retention times in reservoirs with minimal tributary habitats are significant impediments to sport fish stock densities. Some degree of maturation takes place but is as yet poorly documented for B.C. reservoirs. Availability of spawning and rearing habitats within reservoir tributaries is the major factor sustaining viable sport fish populations. Competition from coarse fish species is a significant impediment to sport fisheries in mainland reservoirs, but the nature of the interaction is not consistent. All hydroelectric reservoirs, with the possible exception of one (Daisy Lake), are classified as oligotrophic.

Periodic enhancement has been applied to four of 11 reservoirs with relatively high sport fish stock densities, three of seven with moderate stock densities and one of 14 with low stock densities. Stocking with hatchery-bred fingerlings is currently applied to six of eight enhanced reservoirs. Kokanee spawning channels are the major enhancements for the larger impoundments (Kootenay and Arrow lakes) and were provided as compensation measures for the impacts of development. Based on comparisons, four of the 11 enhanced reservoirs could not otherwise support high or moderate sport fish densities. Only two run-of-river reservoirs (Dinosaur and Hayward lakes) have been enhanced, both with poor results. Reservoirs and regulated rivers having good potential for improved recreational fisheries under enhancement programs include Kootenay, Whatshan, Stave, Buntzen and Jones lakes, and the Shuswap, Cheakamus and Puntledge rivers.

Because of serial development within the same river systems, half of the reviewed reservoirs and diversions (23 of 46) discharge into the headponds of other projects, the remainder regulate the discharges and hydrologic conditions within river systems used by sport fish. Although very poorly studied and documented, sport fish populations and habitats appear to be of generally low densities and qualities in regulated systems below reservoirs. Notable exceptions are regulated reaches of the Shuswap, Cheakamus and Puntledge rivers. About one-half of the projects which discharge to river systems have some form of discharge constraints as conditions to their water licences or in the form of written agreements between the utility and the Department of Fisheries and Oceans (DFO). Operational constraints currently in effect are all aimed at the protection of anadromous salmon resources.

Although hydroelectric development has taken place in the province since near the turn of the century, compensation for impacted resources commenced only in 1954 for anadromous fisheries and in 1968 for inland fisheries. To date compensation has been provided for losses to inland fisheries within three systems - Duncan River (spawning channel, hatchery), Columbia River on the Arrow lakes and at Revelstoke (spawning channel, hatchery), and Peace River at Peace Canyon (pilot hatchery - now discontinued). Studies on a fisheries compensation program for Williston Lake were initiated in 1988. Evaluation of compensation programs is complicated by unavoidable consideration of unlike pre- and post-project conditions. Superficial comparisons suggest that in most cases compensation programs to date have not replaced impacted fishery resources.

Recommended measures to improve sport fishery resources in and below hydroelectric impoundments include evaluation of the efficacy of ongoing compensation programs, improvements to impact assessment procedures to ensure adequate documentation of pre- and post-project conditions, and enhancement of several systems through stock or nutrient supplementation.

RÉSUMÉ

Hirst, S.M. 1991. Impacts of the operation of existing hydroelectric developments on fishery resources in British Columbia. Volume II. Inland fisheries. Can. Manuscr. Rep. Fish. Aquat. Sci. 2093: 200 p.

Le présent rapport passe en revue les principales caractéristiques de 46 barrages hydro-électriques et canaux de dérivation en Colombie-Britannique et résume les renseignements disponibles sur les ressources de pêche sportive de l'intérieur dans les bassins de retenue et en aval de ceux-ci. La B.C. Hydro possède ou exploite 40 de ces barrages et canaux de dérivation, la West Kootenay Power, quatre et la Cominco, deux. Ensemble, ces installations fournissent environ 95% de l'énergie électrique utilisée dans la province.

Huit des installations sont situées dans le bassin du fleuve Columbia, neuf dans celui de la rivière Kootenay, deux dans le système de la rivière de la Paix, dix dans le bassin du fleuve Fraser et neuf dans divers bassins versants de l'île de Vancouver. Quatre autres installations sont situées sur de petits lac dans des régions côtières. La plus ancienne usine en fonctionnement, construite en 1908, est celle d'Upper Bonnington (63 MW) sur le cours inférieur de la rivière Kootenay. Le projet le plus récent, achevé en 1984, est celui de Revelstoke (1843 MW) sur le Columbia. Les bassins de retenue couvrent une superficie totale (lorsqu'ils sont pleins) de près de 6 200 km^2 et permettent la régularisation sur environ 591 km de longueur totale. La taille des bassins de retenue varie de 60 ha (lac Wokas) à 177 870 ha (lac Williston), les profundeurs moyennes de 3 m (lac Wokas) à 97 m (lac Seton), les rabattements annuels maximums de moins de 1 m (lac Seton) à 35 m (lac Downton) et les périodes moyennes de rétention d'eau de moins d'un jour (Waneta) à plus de 19 mois (lac Williston).

Tous les bassins hydro-électriques étudiés, à l'exception peut-être de quelques petits bassins de retenue d'amont, font vivre des populations de poissons de pêche sportive. La truite arc-en-ciel, la Dolly Varden et le kokani sont les espèces les plus courantes dans les réservoirs; la truite fardée est courante dans l'île de Vancouver et dans certains réservoirs de la partie continentale inférieure (le Lower Mainland) de la Colombie-Britannique. Le ménomini des montagnes constitue une part importante des espèces peuplant les réservoirs des bassins du Columbia, de la Kootenay et du cours supérieur du Fraser. Le grand corégone est une espèce courante dans les réservoirs de la rivière de la Paix. Dans quelques bassins, on observe la truite fardée, l'omble de fontaine, la lotte et l'esturgeon blanc.

Les efforts et les prises de pêche sportive ont été mesurés a divers moments et diverses intensités dans 16 des bassins de retenue. Les prises moyennes par unité d'effort varient de plus de 2 poissons/pêcheur/jour (lacs Elsie, Lower Campbell et Daisy) à un minimum, très bas, de 0.1 poisson/pêcheur/jour (lac Alouette). La qualité de la pêche récréative, critère fondé grosso modo sur l'abondance des populations de poissons de pêche sportive, sur la facilité d'accès au lac et sur les qualités esthétiques est considérée comme étant bonne dans environ un quart (9 sur 34) des bassins de retenue pour lesquels on dispose d'information. On considère la qualité le la pêche sportive moyenne pour un autre quart (8 sur 34); pour les 17 autres bassins, on considère la qualité comme étant faible. Tous les bassins pour lesquels la qualité de pêche sportive est dite bonne étaient des lacs naturels avant d'être aménagés pour la production d'hydro-électricité. La faible qualité de la pêche sportive s'explique surtout par une faible densité de population de poissons. Des rabattements considérables, la présence de souches et de débris flottants constituent souvent des entraves à la pêche récréative. Dans tous les réservoirs créés après 1968, on a arraché les souches des zones de rabattement; dans certains des réservoirs, on a aussi enlevé les débris après le remplissage.

La taille et la profondeur de réservoirs, les temps moyens de rétention de l'eau et les rabattements maximums annuels inférieurs à 10 m semblent avoir, seuls, peu de rapport avec les densités des stocks de poissons de pêche sportive. Il y a un certain degré de maturation, encore cependant mal étudié pour les réservoirs de la C.-B. C'est surtout grâce à la présence de zones de fraye et d'élevage dans les tributaires des réservoirs, qu'il y a des populations viables de poissons de pêche sportive. La concurrence exercée par les espèces de poissons communs est un handicap marqué, mais variable, pour la pêche sportive dans les réservoirs de la partie continentale de la Colombie-Britannique. Tous les réservoirs hydro-électriques, à l'exception peut-être de celui du lac Daisy, sont classés comme étant oligotrophes.

On a pratique le repeuplement périodique dans quatre des 11 réservoirs à potentiel relativement élevé de stocks de poissons de pêche sportive, dans trois des 7 reservoirs à potentiel de densité moyen et dans un des 14 réservoirs à potentiel de densité faible. On empoissonne à l'heure actuelle six des 8 réservoirs à potentiel élevé avec des fingerlings d'écloserie. Dans les plus importantes retenues (lacs Kootenay et Arrow), l'aménagement de frayères artificielles pour les kokanis constituent les principales améliorations; celles-ci servaient de mesures de la compensation nécessaire pour

contrer l'impact du développement. D'après des comparaisons, quatre des 11 réservoirs à potentiel élevé n'auraient pu maintenir des densités élevées ni même moyennes de poissons de pêche sportive s'ils n'avaient été ensemencés. Seuls deux réservoirs au fil de l'eau (lacs Dinosaur et Hayward) ont fait l'objet d'enrichissements; les résultats ont été médiocres dans les deux cas. Les réservoirs et cours d'eau régularisés dont le potentiel d'amélioration pour les pêches sportives est bon dans le cadre de programmes de mise en valeur, comportent les lacs Kootenay, Whatshan, Stave, Buntzen et Jones et les rivières Shuswap, Cheakamus et Puntledge.

A cause de développement en série dans les mêmes réseaux hydrographiques, la moitié des réservoirs et canaux de dérivation étudiés (23 sur 46) se déversent dans les retenues d'amont d'autres projets; les autres régularisent les débits et les conditions hydrologiques des réseaux hydrographiques utilisés pour la pêche sportive. Bien qu'ils aient été encore très peu étudiés, les habitats et les populations du poisson de sport semblent avoir des densités et des qualités généralement faibles dans les systèmes régularisés en aval des réservoirs; des exceptions notables: les secteurs régularisés des rivières Shuswap, Cheakamus et Puntledge. Dans environ la moitié des cas, les installations qui se déversent dans des réseaux hydrographiques sont soumis à des contraintes inscrites sur le permis d'utilisation de l'eau ou qui font l'objet d'accords écrits entre le service public et le ministère des Pêches et des Océans (MPO). Les contraintes d'exploitation en vigueur à l'heure actuelle visent toutes la protection des ressources en saumon anadrome.

Même si le développement hydro-électrique s'observe dans la province presque depuis le début du siècle, ce n'est qu'en 1954, pour les poisons anadromes, et en 1968, pour le secteur de la pêche intérieure, qu'on a commence à assurer des compensations à trois réseaux hydrographiques: la rivière Duncan (chenal de ponte, écloserie), le fleuve Columbia sur les lacs Arrow et à Revelstoke (chenal de ponte, écloserie) et la rivière de la Paix à Peace Canyon (programme d'écloserie pilote, interrompu à l'heure actuelle). Des études sur un programme de compensation pour les pêches pour le lac Williston ont été entreprises en 1988. L'évaluation des programmes de compensation est compliquée par le fait que les conditions antérieures au projet sont différentes des conditions postérieures. D'apres des comparaisons superficielles, dans la plupart des cas, les programmes de compensation n'auraient pas à ce jour permis de remplacer les ressources touchées.

Les mesures recommandées pour améliorer les ressources de poissons de pêche sportive dans les basins de retenue hydro-électriques et en aval de ceux-ci comportent: l'évaluation de l'efficacité des programmes actuels de compensation, des améliorations aux méthodes d'évaluation de l'impact afin de recueillir un grand nombre de données permettant de documenter les conditions avant le projet et après sa réalisation et l'amélioration de plusieurs réseaux grâce à l'apport en éléments nutritifs ou à l'empoissonement.

INTRODUCTION

Hydroelectric power generation is the most important source of electricity in British Columbia due to relatively low costs per unit electricity produced and the abundance of potential hydroelectric source. About 85 percent of total electrical capacity in B.C. is presently generated by B.C. Hydro and approximately 10 percent by West Kootenay Power and Cominco. This situation might change in the long-term future as private development of hydroelectric projects is encouraged.

A review (Hirst 1991) undertaken for the Department of Fisheries and Oceans (DFO) summarized available information on the effects of 25 B.C. Hydro dams and diversions on anadromous salmon resources in B.C. Numerous negative impacts caused by the operation of these facilities were documented, including restricted spawning migrations and restricted mainstem spawning and rearing due to flow fluctuations, low flows and/or high water temperatures; flooding and sedimentation causing loss of eggs, rearing fry and habitats; fluctuating water levels leading to stranding and exposure of fry and eggs; migrating spawners being delayed at powerhouse tailraces or dam spillways; and smolt and fry mortalities occurring during passage through powerhouse turbines. The quantitative and/or economic extent of these impacts has seldom been determined. Only six of the 25 dams or diversions reviewed have requirements for flow releases written into the conditional water licences.

The following report presents a similar review for inland fisheries affected by hydroelectric projects and their operation in B.C. All of the hydroelectric projects within the Fraser River system and on Vancouver Island which affect anadromous salmon also affect resident sport fish habitats and populations. In addition, the Columbia, Kootenay and Peace river systems, which contain large proportions of the province's sport fish populations, have been extensively developed for hydroelectric power production. The regulated river reaches below the impoundments are subject to flow and water quality changes similar to those described for salmon (Hirst 1991) while the impoundments above the dams or diversions constitute variable and varying environments for sport fish populations.

The overall objective of the following review is to provide a quantitative overview of the existing impacts of operating B.C. Hydro, West Kootenay Power and Cominco facilities on inland recreational fish populations and habitats. These facilities encompass at least 95 percent of all hydroelectrically regulated systems in B.C. The specific objectives are to:

a. document all B.C. Hydro, West Kootenay Power and Cominco hydroelectric projects and their salient features as they relate to inland fishery resources;

b. review all available information on the status of inland fishery resources within reservoirs and regulated river systems;

c. determine the potential for improving fish habitats and populations in hydroelectrically regulated river systems;

d. provide recommendations on how the existing situation might be improved in general and for specific installations.

METHODS

All information presented in the review was obtained from archived and published sources. New information generated within the review is limited to that produced by analysis of existing information on habitats, populations, flows, water quality and other relevant data, and to correlations within and between data obtained from different sources. Field investigations of regulated river systems were not undertaken.

A list of all B.C. Hydro, West Kootenay Power and Cominco hydroelectric installations was compiled from information provided by the controlling corporations. The major features of each dam or diversion were documented, including dimensions, power generating capacity and any features specifically related to fish protection or enhancement. Additional information on the installations and their licence restrictions was provided by the Water Management Branch of the Ministry of Environment.

Sources of information for the review included reports and data held by the respective corporations and by regional and central Ministry of Environment offices throughout the province. B.C. Hydro provided access to plant operational data and to study reports and impact assessments for the various hydroelectric projects. West Kootenay Power provided operational data for their own and Cominco plants in the West Kootenay region. Monthly mean, maximum and minimum turbine, spillway and special discharges (e.g. fish releases) for the 4-year period 1984 through 1987 were taken to be representative of the typical operational mode of the dams. Total power outputs for each month in the same 4-year period were taken to be typical of the electrical generation patterns and contributions to the integrated systems.

Inventory and assessment data for the various reservoirs and the regulated systems were obtained from published and filed material held by the Inventory Section of the Fisheries Branch and by the regional Fish and Wildlife sections of the Ministry of Environment. This material was supplemented by discussions with regional fishery biologists and technicians. Supplemental material on some regulated systems was provided by DFO.

A standard format for reporting the information is provided in the following report. This considers each project in terms of its physical dimensions and the physical and chemical environment created by the reservoir and the regulated river system below it. Summarized information is then presented on sport fish populations and their recreational use and potential. Because of the review nature of the report, available material has been condensed and summarized to confine the report to a reasonable length.

The measure used to quantify sport fish populations in regulated systems and particularly reservoirs is gill net catch per unit effort (CPUE). Gill netting has been the most common method employed to sample sport fish populations in reservoirs and is generally applied in a standard fashion, i.e. a set of five or more nets of various mesh sizes, adequate to sample all fish within the sampling location, placed just below the surface for a period of 12 to 24 hours. Reported gill net catches were standardized by converting all catch rates to numbers /100 m^2 net / 24 hour period. Where gill net catches and angling catch rates were reported for the same reservoir within the same general period, a linear regression between the two variables was computed and used to determine a CPUE for reservoirs where no actual gill netting data were available.

Quantitative data for habitats within reservoirs and their associated tributaries were seldom found. To permit some level of quantitative assessment, categorical values were placed on factors such as spawning and rearing habitat availability, sport fishing catches and angling quality.

The impacts of hydroelectric projects on inland fishery resources and the management of these resources in terms of compensation and mitigation through project modification or habitat and population enhancements have been assessed largely on the basis of comparisons. Comparisons are made between different systems and between the same system before and after hydroelectric development. The latter comparison could be made in relatively few cases because of the absence of pre-impoundment data for many developments.

A list of all fish species mentioned in the following review is given in the Appendix.

A. COLUMBIA RIVER SYSTEM

MICA
(Mica Dam)
(Mica Generating Station)
(Kinbasket Lake)
(McNaughton Reservoir)

PROJECT

Description

Mica Dam (Map A) is a 197 m high, 792 m long concrete and earth fill gravity dam located below the Big Bend of the Columbia River at the outflow of Kinbasket Lake. The dam is served by three gated spillways. The power plant, situated immediately below the dam has a nameplate capacity of 1736 MW, i.e. the third largest generating plant in the province after G.M. Shrum (W.A.C. Bennett Dam) and Revelstoke. Mica is presently undersized in relation to its potential, and further expansion of the generating capacity is planned. The dam was completed in 1973 and the reservoir reached full pool for the first time in 1976. The project is owned and operated by B.C. Hydro. Mica was developed in accordance with the Columbia River Treaty to provide flood and hydroelectric storage for the Columbia River within the U.S.A.

Water Licences and Operational Constraints

Conditional water licences were issued for the Mica project in 1962, 1963 and 1972. Initially, total storage of 8.6 x 10^9 m^3 per annum was permitted, this was subsequently reduced to 6.2 x 10^9 m^3 per annum. Maximum allowable diversion is 1840 m^3/s (65,000 cfs) and maximum allowable storage elevation is 754 m.

Clause "n" of the initial conditional water licence dated 1962 required B.C. Hydro to provide $5000 in each of the years 1962 and 1963 to cover the costs of studies and reporting on remedial measures for fisheries and wildlife. The result of this provision is not known. Clause "o" of the same licence required B.C. Hydro to "undertake and complete ....remedial measures for the protection of fisheries and wildlife...". This requirement has yet to be met and planning for a mitigation and compensation program was initiated in 1990 (B.C. Hydro, pers. com.). The shoreline areas of the reservoir have been cleared although clearing of the reservoir was not a requirement of the water licence.

Electrical Generation

Mica generating plant produces from 45 million to 1.2 billion kWH monthly. Prior to Revelstoke completion, Mica was the second most important producer of electricity in B.C. The plant is now operated in close conjunction with Revelstoke for which Kinbasket provides storage. Monthly power production varies considerably, according to system optimization requirements, from less than 1 to over 28 percent of B.C. Hydro's total electrical output.

Enhancement Facilities

No fisheries mitigation or enhancement facilities were provided.

OPERATIONAL REGIME

Kinbasket Lake provides a high percentage storage capability for the annual run-off within the upper Columbia River watershed, and annual spill from the reservoir is a relatively uncommon occurrence (Figure 1). The reservoir has a large storage capacity and annual drawdowns are correspondingly large (Figure 2). Turbine discharges are very erratic (Figure 1) due to daily and seasonal fluctuations in power production and water availability, and the Columbia River treaty requirement to use Mica storage to stabilize flows lower down the Columbia system.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Prior to project development, Kinbasket Lake had an area of 2250 ha and was simply a 13 km long enlargement of the Columbia River. A preimpoundment survey of the Columbia and Canoe river valleys was undertaken in 1962 -63 (Peterson and Withler 1965a), i.e. about 10 years before completion of the Mica Dam project. All tributaries in the reservoir area were found to be of glacial origin, i.e. heavily silted, and contained minimal amounts of useful spawning gravels. The best fish habitat in the area was provided in the Bush lakes, two shallow lakes of 157 and 144 ha area respectively (Farquharson 1973) near the Bush River confluence which provided about 4500 m^2 of good quality spawning gravels (Peterson and Withler 1965a).

The post-impoundment Kinbasket Lake has a maximum surface area of 43,200 ha, a maximum volume of 24.7 x 10^9 m^3 and a mean depth of 57 m. The mean water retention time is 15 months. The amounts of useful tributary habitats are not recorded although pre-impoundment surveys (Peterson and Withler 1965a) suggested these would be very limited.

Shortly after its formation, Kinbasket Lake (= McNaughton Reservoir) was found to be oligotrophic, slightly alkaline, and of low to moderate hardness (B.C. Research 1977). Dissolved oxygen concentrations were near saturation at all levels, although some oxygen utilization was detected at depth. There was no indication of thermal stratification. Chlorophyll-*a* concentrations and nutrient levels were very low with no indication of nutrient loading from the bottom sediments. Primary producers were dominated by diatoms, while Cladocerans were the dominant zooplankton and the benthos was dominated by Chironimidae, although the latter were scarce in the littoral zone where water levels fluctuated. By 1986, i.e. 10 years after formation, sampling within the reservoir forebay (Fleming and Smith 1988a) indicated that the pH was varying from 6 to 8 through the year, dissolved oxygen levels were still at or near saturation (10-13 mg/l), and the reservoir was ultra-oligotrophic (total nitrogen 0.15 - 0.25 mg/l). Development of a mild thermocline by September with 16.6° C water at the surface and 9.7° C water at 50 m was detected. Chlorophyll-*a* levels were still very low (range <0.5 to 2.2 mg/m^3) and cladocerans remained the dominant form of zooplankton.

Downstream System

See Revelstoke and Keenleyside.

SPORT FISH POPULATIONS

Reservoir

Pre-impoundment fish fauna within the Columbia and Canoe river systems included mountain whitefish, bull trout, Eastern brook trout, rainbow trout and burbot (Maher 1961, Peterson and Withler 1965a). Mountain whitefish were found in most creeks, while bull trout were present in 8 of 27 streams surveyed (Peterson and Withler 1965a). Rainbow trout were scarce in tributary streams but were abundant in the Bush lakes, where spawning and rearing conditions were good. The Bush lakes were stocked with rainbow trout fingerlings from 1955 through 1960 (Peterson and Withler 1965a).

No post-impoundment fisheries studies appear to have been done other than fish population sampling in the reservoir forebay (Smith 1986, Fleming and Smith in prep.) undertaken as part of a long-term monitoring study of Revelstoke reservoir. Gill net catches for sport fish in 1985 and 1987 were 4.3 and 5.0/100 m^2/24 hours respectively. Catch composition has varied considerably: kokanee and mountain whitefish currently dominate the sport fish population, with rainbow and bull trout also present. Sport fish presently make up about two-thirds of the samples (see Revelstoke). The upper Columbia River is considered to provide good spawning habitat for kokanee (Fisheries Branch, pers. com.).

Downstream System

See Revelstoke and Keenleyside.

RECREATIONAL FISHERY

Reservoir

Prior to Mica project development, the best available fishing opportunities were in the relatively small Bush lakes which provided good rainbow trout angling and easy access (Peterson and Withler 1965a, Farquharson 1973). Only very light sport fishing pressure was prevalent in the Columbia River and the tributaries. Rainbow trout and bull trout were fished at the mouths of the tributaries (especially Tsar Creek and Kinbasket River). Total tributary and other stream lengths flooded by the formation of the Mica reservoir were estimated at 445 km (Farquharson 1973).

Present levels of recreational angling in Kinbasket lakes have not been monitored but are believed to be increasing (Fisheries Branch, pers. com.) despite relatively poor access. Catches include rainbow and bull trout and kokanee (Fleming and Smith 1988a) and burbot (Fisheries Branch, pers. com.). Success rates are thought to be good for experienced kokanee anglers (B.C. Hydro, pers. com.).

Downstream System

Mica Dam discharges directly into the Revelstoke reservoir (see Revelstoke). Prior to Revelstoke completion, Mica dam discharges flowed some 150 km into the Upper Arrow Lakes; downstream effects included water quality changes, low flows below the dam, and obstruction of Arrow Lake migrant spawners (see Keenleyside).

REVELSTOKE PROJECT

Description

The Revelstoke project (Map A) is a concrete and earth fill dam at the mouth of Little Dalles Canyon on the Columbia River. Maximum dam height (concrete portion) is 175 m, and the overall length is 1630 m. The gated spillway has two 17 by 13 m gates and a maximum discharge capacity of 6900 m^3/s. The power plant located immediately below the dam presently has a nameplate capacity of 1843 MW and is planned to eventually reach 2700 MW installed capacity. The dam was constructed from 1977 through 1984 and the reservoir filled from late 1983 to mid-1984. The project is owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The conditional water licence dated 1976 permits diversion of a maximum quantity of 2550 m^3/s (90,000 cfs) and storage of 1850 million m^3. The environmental and fisheries provisions of the licence were the most extensive issued for a B.C. Hydro project and included development of environmental guidelines for construction, the monitoring of construction activities, collection of biological data during construction, clearing of the reservoir area and removal of floating debris, and provision of mitigation and compensation measures (determined separately in negotiations between the Minister of Environment and B.C. Hydro). Development of the Mackenzie Creek spawning channel and the Hill Creek hatchery were the primary fishery compensation measures provided (described below).

Electrical Generation

Revelstoke commenced power generation in March 1984 and reached full production by June 1984. The project produces from 436 million to 1184 million kWH electricity per month, i.e. from 10 to 32 percent of B.C. Hydro's total monthly output, with capacities ranging from 14 to 82 percent.

Enhancement Facilities

The fisheries compensation program for Revelstoke received relatively more study and attention than any previously developed B.C. Hydro project, and was intended to cover all project-related fisheries losses (B.C. Hydro 1982a). Target numbers for compensation were 500,000 kokanee, 1000 rainbow trout and 4000 bull trout available to the sport fishery. To provide these replacements a spawning channel and hatchery were constructed at Hill Creek on Upper Arrow Lake by B.C. Hydro at a cost of $3.4 million (subsequent extensions to the hatchery were undertaken as partial compensation for impacts from the Arrow Lakes development - see Keenleyside). The spawning channel is 3.2 km long, 6.1 m wide, provides capacity for 150,000 kokanee spawners (= estimated returns of 500,000 kokanee to the sport fishery), and commenced operations in 1981. The hatchery has a capacity of 80,000 yearling rainbow trout (Gerrard stock), 100,000 bull trout fingerlings, and 1.5 million egg incubation, and commenced major releases in 1980 (rainbow trout) and 1982 (bull trout). From 8 to 23 percent of the monitored rainbow trout catch in Upper Arrow Lake since 1983 has been hatchery fish (Fisheries Branch, Nelson, data files). B.C. Hydro provides annual operating funds for the hatchery and spawning channel. Debris disposal from the flooded reservoir was completed in 1989.

OPERATIONAL REGIME

Revelstoke is operated as a run-of-river reservoir (Figure 3) using storage behind Mica Dam. To date annual operating level fluctuations have declined from 3.96 m in 1985/86 to 3.05 m in 1985/86 to 1.46 m in 1986/87 (Figure 4). The present maximum flood level of 575 m is a specific condition of the water licence related to maintaining stability of the Downie slide.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The Columbia River reach impounded by the Revelstoke reservoir extends 140 km from Mica to Revelstoke between the Monashee and Selkirk mountains along a mean gradient of 0.9 m/km and has a total surface area of 10,125 ha. Mean depth of the reservoir is about 15 m, although the reservoir is 125 m deep at the forebay and less than 10 m near the Mica Dam tailrace. Mean water retention time of the reservoir is about 27 days. Most of the tributaries, including the major ones - Goldstream River, Downie Creek and Bigmouth Creek - are of glacial origin and are meandering, low - and moderate gradient streams. Downie Creek and Goldstream River have good habitat potential, although Goldstream has a major fish blockage (falls), while Bigmouth Creek has a high proportion of glacial fines. Other smaller tributaries are precipitous with moderate gradients, numerous falls and rapids. Access to many tributaries is blocked by falls and rapids. Water quality in the pre-impoundment river was characterized by low temperatures and low total dissolved solids.

The Revelstoke reservoir has been monitored annually since filling (Fleming and Smith 1988a). Water temperatures at the reservoir bottom had declined to 4.3° C by the second year due to stratification. A thermocline develops by June (surface temperature 11° C) with stronger stratification by August and September. Thermocline development and water temperatures in the surface and intermediate layers are affected by cold inflows from Kinbasket Lake (behind Mica Dam) which appear to create interflows.

A short-term increase in nutrient loading in the first year after impoundment was observed, but was absent by the second year. The reservoir has rapidly become ultra-oligotrophic with low concentrations of ammonia nitrogen and dissolved phosphorus. Nitrate nitrogen concentrations are at or below detection level (0.005 mg/l) as are orthophosphates (0.003 - 0.004 mg/l). The location of the reservoir, i.e. immediately below a large oligotrophic reservoir (Kinbasket Lake) has influenced the rate at which Revelstoke itself has stabilized. The reservoir is turbid during snow melt, Downie Creek being the major source of sediments. Dissolved oxygen has remained near saturation at all sampling stations and levels for the first three years (Fleming and Smith 1988a, in prep.).

Downstream System

Revelstoke discharges directly into the Upper Arrow Lake (see Mica).

Gas supersaturation of the Revelstoke spillway releases in 1986 was measured at 104 to 120 percent of total saturation levels (Fleming and Smith 1988a). Total dissolved gas levels (measured 1 to 8 km downstream of the dam) increased as spill discharges (range 0 to 1983 m^3/s) increased, but the relationship was not linear.

SPORT FISH POPULATIONS

Reservoir

Resident sport fish in the Columbia River below Mica Dam prior to impoundment (Hooton and Whately 1972) included bull trout, rainbow trout, cutthroat trout, brook trout, burbot, white sturgeon and mountain whitefish. Kokanee moved into the reach from the Arrow Lakes. At least 7 species of non-sport fish were documented. The mainstem reach in general provided abundant habitat of low to moderate quality for spawning and rearing (Martin 1976). Downie and Bigmouth creeks had abundant spawning and rearing habitat. Cutthroat trout were recorded in Goldstream River (Paish 1974) and in Carnes, Holdich and La Forme creeks (Hooton and Whately 1972). Rainbow trout occurred in Seymour and Fortynine creeks while the upper reaches of other smaller creeks were considered likely to hold bull trout, rainbow trout and cutthroat (Martin 1976). Two bull trout tagged near the dam site were recaptured south of Keenleyside Dam (126 km from the point of tagging, B.C. Hydro 1982b), indicating the wide-ranging distribution of species within the Columbia system.

A significant increase in fish species diversity (based on gill netting samples) was measured to occur in the Revelstoke reservoir within the first two years of impoundment (Fleming and Smith 1988a). Rainbow trout, bull trout, burbot, mountain whitefish and suckers were recorded at numerous sites within the reservoir, while kokanee, lake whitefish, northern squawfish and peamouth were not recorded. By the third year declines in rainbow trout and mountain whitefish were apparent (Fleming and Smith in prep.) while bull trout and long-nose sucker were found to be increasing along with a very marked increase in coarse fish species. Kokanee appeared in limited numbers by the third year of monitoring (Fleming and Smith, in prep.), possibly due to entrainment out of Kinbasket Lake (Fisheries Branch, pers. com.).

Downstream System

See Keenleyside.

RECREATIONAL FISHERY

Reservoir

Creel censuses at Revelstoke in 1986 (based on voluntary information provided by anglers) indicated a relatively low success rate of 0.11 fish/hour (Fleming and Smith 1988a). The success rate for rainbow and cutthroat trout, the preferred species, was only 0.09 fish/hr., and for 0.01 fish/hr. The average angler caught 0.44 rainbow trout per day, while the average fishing party caught 1.1 trout/day.

Population monitoring based on gill netting (Fleming and Smith 1988a, in prep.) indicated a drop in catch per unit effort rates from 11.3 fish/100 m^2 net/24 hr. in 1985 (first year after filling) to 7.1 in 1986 to 5.7 in 1987. Sport fish species comprised 98 percent of the catch for the first year, and rainbow trout made up 7 percent, bull trout 36 percent and mountain whitefish 61 percent of the catch respectively. Catches varied very significantly in proportion between various sampling sites in the reservoir. Rainbow trout ranged from 3 to 10 years of age, with about one-third being age 5.

Downstream System

See Keenleyside.

KEENLEYSIDE
(Hugh Keenleyside Dam)
(Arrow Lakes)

PROJECT

Description

Keenleyside near Castlegar in the west Kootenays (Map A) is a Columbia River Treaty project designed to provide hydroelectric storage and flood control for the benefit of downstream projects within the U.S.A. It consists of a 58 m high, 869 m long, concrete dam across the Columbia River at the lower end of Lower Arrow Lake. The dam is provided with four dissipater spillways, eight low-level sluices and a small boat lock. The dam has no fishway. The project has no power-plant although plans to install one are being considered by B.C. Hydro. Keenleyside was completed in 1967 and the water level in the Arrow Lakes raised to the maximum operating level for the first time by mid-1969.

Water Licences and Operational Constraints

The conditional water licence, issued in 1962, permits B.C. Hydro to store up to 8.8 x 109 m^3 of water to a maximum permissible elevation of 440.7 m. Three clauses to the licence relate to fisheries concerns:

- an amount of $5000 per annum for two years was to be made available to the Department of Recreation and Conservation for reporting on remedial measures required for fish and wildlife;
- B.C. Hydro was to undertake and complete remedial measures for fish and wildlife protection;
- the reservoir was to be cleared as directed by the Ministry of Forests.

Enhancement Facilities

Protracted negotiations between B.C. Hydro and the Ministry of Environment over a 20-year period following project completion led to the provision of $3 million in 1986 to the Ministry for fisheries compensation. A proposed fish ladder at Inonoaklin Falls was abandoned in 1986 as a fisheries compensation measure because of agricultural water use conflicts. Instead, a financial contribution was made to double the capacity of the Hill Creek hatchery which was initially built as compensation for Revelstoke project impacts (see Revelstoke Enhancement Facilities). The hatchery presently has a capacity of 80,000 yearling rainbow trout, 100,000 bull trout fingerlings and space for incubation of 1.5 million eggs. Boat launching ramps were constructed at Shelter Bay, McDonald Park, Burton, Fauquier and Edgewood as part of the Arrow Lakes compensation program. Forest debris disposal was completed in the early 1970's.

OPERATIONAL REGIME

Keenleyside is used to optimize water storage in the middle Columbia system for the benefit of hydroelectric power generation and flood control within the Columbia River system in the U.S.A. The reservoir is operated to capture as much of the annual freshet flood as possible within the constraints of a maximum reservoir operating level of 440.7 m (Figure 5). As much water as possible is then released over the remaining period for downstream uses. Annual evacuation of the reservoir is 60 to 85 percent, with correspondingly large drawdowns, typically reaching 15 to 20 m below full pool (Figure 5). Filling and drawdown occur on a cyclical and predictable basis.

Water is normally passed though the low-level ports only while the hydraulic head is less than 10 m and the associated flows are less than 1400 m^3/s (B.C. Hydro, operations data). Above these levels, the spillway is used in conjunction with the ports - this operational mode is significant for downstream dissolved gas concentrations (see below).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Prior to impoundment at Keenleyside Dam, the Arrow Lakes had a maximum surface area of 39,310 ha. This was increased to 52,600 ha following impoundment (Lindsay 1987). The maximum pre-impoundment elevations ranged from 420 to 427 m. Present maximum post-impoundment elevations are permitted to go to 440.5 m (B.C. Hydro operations data). The range of seasonal water level fluctuations in Upper Arrow Lake were 7-8 m (Fulton and Pullen 1969); the present range is approximately 20 m (Figure 5). The lakes are steep-sided and narrow, with rocky shorelines and narrow gravel beaches. The pre-impoundment lakes had extensive flats at the northern end and fairly extensive bottom lands between the upper and lower lakes. The post-impoundment mean depth is approximately 18 m.

Tributaries flowing into the Arrow Lakes are generally precipitous, except for their lower terminal reaches. The latter provided the best spawning habitat available to lake fish populations; about 20-30 percent of such habitats were lost due to flooding (Lindsay and Seaton 1978). Based on a reconnaissance survey, most tributary reaches were considered to be unstable and non-productive (Peterson and Withler 1965b), the best habitats being found in Mosquito Creek (24 km), Halfway River (10 km) and Kuskanax Creek (9 km).

Total dissolved solids content of the pre-impoundment Arrow Lakes was 110-127 ppm (Northcote and Larkin (1956). Ten years after impoundment the dissolved solids content was measured at 50-60 ppm (B.C. Research 1977). Filterable residue measured at the north end of Upper Arrow Lake in 1986 (20 years after impoundment) was 54-108 mg/l (Fleming and Smith 1988a). The pre-project lakes were probably oligotrophic and this appears to still be so, with total phosphorus levels ranging from 0.005 to 0.019 mg/l and total nitrogen from 0.15 to 0.24 mg/l. The lakes are slightly alkaline, of low to moderate hardness, low metals and chlorophyll-*a* content, and there is no indication of nutrient loading from bottom sediments (B.C. Research 1977, Fleming and Smith 1988a). The lakes do not become thermally stratified, although thermal discontinuities are evident in late summer at the upper end of Upper Arrow Lake due to low level outflows from Revelstoke reservoir (Fleming and Smith 1988a).

Downstream System

Keenleyside dam development reduced the maximum daily and monthly fluctuations in discharge in the lower Columbia River within B.C. by a factor of approximately 2 and increased minimum monthly discharges, also by a factor of 2 (Figure 6). Minimum flows (daily) in any one year were relatively unaffected. The discharge records suggest the possibility of a reduction in mean annual flows following impoundment (Figure 6) but a longer-term record would be required to provide clear statistical evidence of this.

The river gradient below Keenleyside increases with distance from the dam, from about 0.2 m/km to more than 7 m/km; flow velocities increase proportionately (Ash et al. 1982). The main river channel is relatively deep (10-18 m) with 3-10 m banks of glacial till and rock and heavily silted substrates of boulder and cobble; spawning habitats for sport fish are limited but the shorelines are extensively used by non-sport fish (Ash et al. 1982).

Very high levels of gas supersaturation occur in the Columbia River below Keenleyside (Clark 1977, Water Investigations Branch 1979, Ash and Hildebrand 1985). From 1972 through 1977 about 70 percent of samples taken below Keenleyside exceeded 120 percent saturation, and 36 percent exceeded 140 percent (highest values recorded in any river in B.C.). The design of the dam whereby water is passed through the ports to depth and then rerouted by the energy dissipaters back into the plunging water stream is partly responsible for the high levels. Much higher supersaturation levels (>130 percent) occur when the spillway is in use (Ash and Hildebrand 1985). Despite the high concentrations only 1.5 percent of fish sampled below the dam have been found to show sign of gas-bubble disease (Ash and Hildebrand 1985). Sub-lethal effects of gas supersaturation (e.g. area avoidance, depth preferences) and direct mortality rates from gas-bubble disease in the lower Columbia have not been determined.

SPORT FISH POPULATIONS

Reservoir

The fish populations of the Arrow Lakes were not studied in detail prior to construction of Keenleyside and the species composition and population characteristics were known only from general surveys and from angling information (Maher 1961, Peterson and Withler 1965b). Angler access to the lakes was limited prior to project development and overall angling pressure was correspondingly very light. Rainbow trout (spring and early summer), bull trout (fall and early winter) and kokanee (summer) were taken in small numbers. Bull trout were recorded in Burton and Caribou creeks in August and September, while rainbow trout were known to anglers in Kuskanax Creek and Halfway River. Kokanee were reported to enter lake tributaries in the third week in August (i.e. earlier than in Kootenay lake) and to spawn in September - October (Martin 1976). It had been generally assumed that sport fish in the Arrow Lakes system moved over fairly large distances; this was confirmed in 1981 when two bull trout tagged at the Revelstoke dam site were recaptured below Keenleyside Dam (126 km from tagging site) (B.C. Hydro 1982). Migrant spawners, especially bull trout, were severely impacted by the closing of the Revelstoke diversion tunnel in 1978. Kokanee presently comprise almost one-half of all fish sampled in the northern end of Upper Arrow Lake in summer (Fleming and Smith, in prep.), while bull trout are relatively abundant (about one-quarter of total gill net catches) and rainbow trout and mountain whitefish each comprise small proportions of samples.

Population enhancement of Arrow Lakes sport fish numbers has increased since construction of Keenleyside and more so since development of Revelstoke because of the construction of the Hill Creek hatchery and the Hill - Mackenzie Creek spawning channel (Figure 7) in 1980. The 3.2 km channel has a total capacity of 150,000 spawning kokanee, and the number of kokanee using the channel and associated natural stream has risen from 10,000 in 1983 to 75,889 in 1986 to 105,000 in 1987 (Thorp 1987). An associated increase in kokanee catches has been recorded in both Upper and Lower Arrow Lakes (Figures 8 and 9, Lindsay 1987). By 1986 significant numbers of hatchery bred rainbow trout and bull trout were beginning to appear in sport fish catches in Upper Arrow lake (Lindsay 1987). Primary production in the lakes is dominated by several species of diatoms (B.C. Research 1977, Fleming and Smith 1988a). The zooplankton are diverse and dominated by copepods. The benthos is dominated by Chironimidae.

Downstream System

Nearly 90 percent of all fish in the mainstem Columbia River below Keenleyside sampled in 1980 and 1981 were non-sport species, with redside shiners being dominant (Ash et al. 1982). Mountain whitefish were the most prevalent sportfish species, making up about 5 percent of total numbers and apparently using the mainstem plus the local tributaries for spawning. Rainbow trout comprised very small proportions of sportfish numbers and were reported as being limited to tributary habitats for spawning. Later surveys have found mainstem rainbow trout spawning habitats in the lower Columbia (B.C. Hydro, pers. com.). Kokanee occurred in highly variable numbers and appeared to be migrants from Lake Roosevelt on the U.S. portion of the Columbia River although some local spawning in tributaries was recorded. Bull trout occur in small numbers near Keenleyside Dam. Later studies and angling reports in 1989 and 1990 (Fisheries Branch, pers. com.: B.C. Hydro, pers. com.) indicate that sport fish, including walleye, sturgeon and rainbow trout are now more prevalent. Kokanee are increasing, due to increased migrations from Lake Roosevelt and/or increased entrainment through Keenleyside Dam.

Significant numbers of fish are passed through the sluices and ports in Keenleyside Dam (Smith 1984), apparently in a passive manner. From June to October 1983 97,827 fish were entrained through the dam, while 45,099 were entrained from April to October 1984. Kokanee contributed 17 and 8 percent of total fish numbers, bull trout 4 and 0 percent, rainbow trout 2 and 0 percent, and mountain whitefish 3 and 2 percent respectively. Most fish entrained were non-sport fish.

Rates of fish entrainment were found to be dependent on discharges, rates of change in discharge, mode of operation (ports or sluices), season of year, and (possibly) the overall fish standing crop in Arrow lake (Smith 1984). *Mysis* sp. shrimp were introduced to the Arrow Lakes in 1973 to provide additional food resources for sport fish, and significant numbers are entrained through Keenleyside and passed to the lower Columbia River from Arrow Lake (Ash and Hildebrand 1985).

RECREATIONAL FISHERY

Reservoir

Angling in the Arrow Lakes prior to Keenleyside completion was apparently of high quality but fishing pressure was very light (Maher 1961). Causes for this low interest by anglers at that time were likely the poor access available to the lakes and the availability of better angling within the same region (Kootenay Lake). Rainbow trout, bull trout and kokanee were the principle species sought by anglers. Angling activity was reported for Drimmie and Mulvehill creeks, Akolkolex and Illecillewaet rivers and other smaller tributaries. The most extensive sport fishery took place in the mainstem Columbia below Castlegar towards the U.S. border (Peterson and Withler 1965b), probably because of easier access and proximity to regional population centres. Stocking programs involving rainbow trout, kokanee and Eastern brook trout eggs and fingerlings were undertaken from 1938 to 1953 (Peterson and Withler 1965b), although the results are not recorded.

Angling in both the upper and lower Arrow Lakes has been monitored on a periodic basis (Lindsay 1987), although different approaches are used in the two lakes and the results are not always comparable. Angling effort in Lower Arrow Lake for rainbow trout and bull trout has decreased in the decade since Keenleyside completion (Figure 8), probably because of poor returns for these species (Lindsay 1987) and a possible change to kokanee angling. The success rate for trout and char declined from 0.22 fish per angling hour to 0.03 by 1986. The impact of the Revelstoke Dam, completed in 1984, appears to be at least a contributory factor to these declines (mainly by cutting off spawner access to tributary streams). By contrast, angling effort and returns for kokanee have shown a marked increase since 1974 (Figure 8), and the angling success rate has risen from 0.5 fish per angling hour in 1974 to 1.18 by 1987 (Lindsay 1987). These latter high success rates are not in proportion to the gill net sampling catches in Upper Arrow Lake (see Inland Fisheries Resources in Hydroelectrically Regulated Systems: *Quantative Index of Sport Fish Abundance*, pg. 69) and may be limited to areas containing large numbers of kokanee derived from the Mackenzie Creek spawning channel (built as compensation for Revelstoke impacts).

Similar patterns of angling effort and success have been monitored on Upper Arrow Lake (Figure 9). Success rates for rainbow trout and bull trout have remained relatively constant at 0.15 to 0.2 fish per angling hour, but effort for these species has declined, resulting in lower catches. Both angling effort and catch for kokanee have increased since 1982 and the angling success rate for kokanee reached about 1.5 fish per angling hour by 1986. The high production of kokanee has resulted in a decrease in size, however, and the species' value as a sport fish is likely to decline (B.C. Hydro, pers. com.).

Rainbow trout in the Arrow Lakes are sought in spring and summer, bull trout are fished in fall and winter, and kokanee are fished throughout the summer. The Arrow Lakes are unique in terms of angling in large B.C. lakes in that bull trout are actively sought by anglers. Despite the steady decreases in rainbow and bull trout catches, the Arrow Lakes provide lake fishing comparable to that obtained in Kootenay Lake. Although Arrow Lakes fish are smaller than those caught in Kootenay Lake, the numbers caught and success ratios per angler are higher (Lindsay 1987).

Downstream System

The Columbia River below Keenleyside was surveyed for angling use and success in 1980 and 1981 when construction of the Murphy Creek Dam was under consideration (B.C. Fish and Wildlife Branch 1981). Angling interest in the reach is highest in July and August, varies greatly from one locale to another, and is directed towards burbot, kokanee, bull trout, rainbow trout and walleye. The total number of angling hours expended per annum within the 35 km reach are estimated to be about 20,000, which is roughly the same level of effort presently directed towards kokanee in either the Upper or Lower Arrow Lakes. Rainbow trout catches per unit effort approximated 0.18 fish per angling hour in 1981, i.e. about the same rates as in the Arrow Lakes. Success rates for bull trout were low (zero to 0.03 fish per hour). About 3000-4000 kokanee were estimated to have been caught over a 3-month summer period in 1980.

SEVEN MILE PROJECT

Description

The Seven Mile project is a 79 m high, 348 m long, concrete gravity dam located on the Pend d'Oreille River, a tributary of the Columbia River in the west Kootenay region (Map A). The 75 m wide 5-gated spillway has a maximum discharge capacity of 10,500 m^3/s. The powerplant is located at the base of the dam and has a nameplate capacity of 607.5 MW. Seven Mile was completed in late 1979 and was operated at maximum reservoir levels less than optimal for full power production until 1988. Seven Mile project lies between two run-of-river projects, i.e. Boundary Dam in the U.S. (upstream) and Waneta (downstream). A 2 km reach of regulated river extends from the Seven Mile tailrace to the headwaters of Waneta reservoir. The project is owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The conditional water licence, issued in 1974, permits B.C. Hydro to divert a maximum quantity of 1020 m^3/s (36,000 cfs). Two conditions attached to the licence relate to fisheries concerns, i.e. clause "l" which requires that the headpond should be cleared, and clause "n" which specifies that "programs for the protection or enhancement of fish and wildlife habitat and for the mitigation of losses of habitat shall be carried out ....".

Clearing of the reservoir was apparently carried out prior to flooding although no specific records have been located. No specific fishery programs aimed at clause "n" of the water licence have been carried out as the Ministry of Environment elected to dedicate all the specified compensation (about $2 million) to wildlife compensation programs (Sigma Engineering Ltd. 1990).

Electrical Generation

Over the sample period 1984 through 1987 the Seven Mile project produced from 91 to 373 million kWH per month and contributed between 3 and 14 percent of B.C. Hydro's total output at capacity factors ranging from 20 to 85 percent.

Enhancement Facilities

No fisheries enhancement facilities were developed for the Seven Mile project in terms of the water licence provisions (see *Water Licences and Operational Contraints*). Following the operational raising of the maximum reservoir level in 1989, B.C. Hydro constructed a low head waterfall at the outlet of the Salmo River to prevent ingress of non-sport fish species (B.C. Hydro, pers. com.).

OPERATIONAL REGIME

Seven Mile operates as a run-of-river project and is located below a series of dams on the U.S. portion of the Pend d'Oreille River, including Boundary Dam which also operates as a run-of-river project and is located some 1.5 km above the headwaters of the Seven Mile reservoir. Live storage of the reservoir is about 80 percent of total storage and full use of this would entail a drawdown of nearly 8 m, but this is seldom used (Figure 10), and drawdown fluctuations are relatively small, averaging 1 to 2 m (Figure 11). Storage capacity is limited within the upstream reservoirs on the Pend d'Oreille and Seven Mile consequently spills water every year, the amounts and frequencies varying considerably (Figure 10).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The reservoir is approximately 370 ha in extent, with a mean depth of 28 m. Mean water residence time is 1-2 days, i.e. a very high flushing rate. The shorelines of the reservoir are generally rocky and precipitous, with limited low-gradient areas and difficult access in most areas.

The Salmo River constitutes the most important tributary to the Seven Mile reservoir and has an annual mean discharge of about 32 m^3/s (Environment Canada 1988). Smaller tributaries include Tillicum, Charbonneau, Nine Mile and smaller creeks, most of which have minimal flows in summer (B.C. Hydro 1987).

The reservoir is well-mixed and isothermal throughout most of the water column (B.C. Hydro 1987). Water temperatures exceed 20° C in late summer and drop close to 2° C in winter. The pH throughout the water column is 7.8 - 8.0, although slightly lower (7.2) near the bottom (B.C. Hydro 1987). The water column is oxygen saturated due to the mixing in the upstream reservoir and constricted channels, but declines to 47 percent at the bottom, possibly due to decomposition which also causes a slight increase in nitrogen and phosphorus levels near the bottom. Nitrogen and phosphorus concentrations in the remainder of the water column are very low (N = 0.213-0.16 mg/l), P =

0.013-0.02 mg/l, B.C. Hydro 1987). Occasional samples from the reservoir show slightly elevated levels of some metals such as copper and lead, a result of extensive mining pollution along the Pend d'Oreille and its tributaries prior to Seven Mile project development (Cope 1969, Envirocon/ Pearse Bowden 1973).

Eurasian milfoil *Myriophyllum spicatum* is a potential problem in the upstream Boundary reservoir, but has not yet become established in Seven Mile reservoir possibly because of the rapidly fluctuating water levels (B.C. Hydro 1987).

Downstream System

A 2 km reach of river connects the Seven Mile tailrace to the Waneta reservoir headwaters (see Waneta).

Prior to construction of the Seven Mile Dam, very high total dissolved gas levels were measured in the Pend d'Oreille River between Boundary Dam and Waneta (Water Investigations Branch 1979). About 69 percent of samples taken over a 4-year period were higher than 110 percent saturation and 25 percent were higher than 120 percent and some as high as 140 percent. No incidence of gas embolism in fish within the Pend d'Oreille River has been reported, although no systematic search has been made to date. The Seven Mile spillway was designed to reduce the incidence of gas supersaturation (B.C. Hydro 1987), but probably passes supersaturated water derived from the Boundary Dam spillway upstream.

SPORT FISH POPULATIONS

Reservoir

Sampling in the reservoir in 1987 by means of gill netting revealed a high incidence of coarse fish species, notably northern squawfish (57 percent), yellow perch (19 percent), peamouth chub (11 percent), longnose sucker (7 percent), redside shiner (3 percent and pumpkinseed (0.3 percent). Sport fish made up very small proportions of the sample catches (mountain whitefish 1 percent and rainbow trout 0.3 percent). Bull trout are present in the reservoir according to local angler reports (B.C. Hydro 1987). Rainbow trout were present in the lower Pend d'Oreille prior to Waneta Dam construction in 1954 which blocked their access from the Columbia River (Cope 1969) and which preceded Seven Mile project development (see Wantea).

Previous surveys of the Salmo River (Envirocon/Pearse Bowden 1975) revealed moderate numbers of rainbow trout and smaller numbers of bull trout, mountain whitefish and suckers. The Salmo River is the primary tributary of the present Seven Mile reservoir which supplies any useful sport fish spawning habitat. Swimming observations in the Salmo River in 1987 and 1988 revealed the presence of moderate numbers of rainbow trout and mountain whitefish, but small numbers of bull trout. Suckers were the most abundant non-sport fish species observed. Rainbow trout and mountain whitefish have increased in abundance since the previous swimming survey in 1974.

Zooplankton densities and abundance within the reservoir are typical of an oligotrophic reservoir, i.e. low numbers of copepods, rotifers and cladocerans, although these may be influenced as well by the high flushing rate and by heavy cropping in reservoirs upstream of Seven Mile (Fisheries Branch, pers. com.). Chlorophyll-*a* content of reservoir water is also low (0.12 - 0.2 mg/m^3, B.C. Hydro 1987).

Downstream System

See Wantea.

RECREATIONAL FISHERY

Reservoir

Prior to Seven Mile development the Salmo River was reported as supporting an excellent rainbow trout fishery (Cope 1969) although the extent of this and the harvests were not measured. Coarse fish catches at the Salmo-Pend d'Oreille confluence outnumbered sport fish taken by a ratio of 25:1 (Envirocon/Pearse Bowden 1973). The lowest 0.8 km of the Salmo were flooded by the Seven Mile reservoir; despite this the river still provides a viable sport fishery for rainbow trout and, possibly, bull trout (B.C. Hydro 1987). No detailed data on actual recreational use are available, fairly intensive use by sport anglers and possible overfishing may be occurring (B.C. Hydro, pers. com.). A size restriction is presently in effect for rainbow trout taken in the Salmo River.

Downstream System

See Waneta.

WANETA

PROJECT

Description

Waneta Dam is a 76 m high, 290 m long, concrete and earth fill dam located on the Pend d'Oreille River immediately above the confluence with the Columbia (Map A). The reservoir is located downstream of Seven Mile Dam (see Seven Mile). The concrete spillway has 9 control gates and discharges the spill over a total drop of 64 m. Maximum capacity of the spillway is 7900 m^3/s. The powerplant is located at the base of the dam and has a nameplate capacity of 373 MW. Waneta was completed in 1954 and additional turbine units added in 1963 and 1966. The project was built and is owned by Cominco and is presently operated as part of the West Kootenay Power system.

Water Licences and Operational Constraints

A total of four final water licences issued in 1961, 1962 and 1977 together permit a total diversion of 680 m^3/s. There are no conditional clauses relating to fisheries or other environmental concerns.

Electrical Generation

Over the sample period 1984 through 1987 Waneta produced from 130 to 262 million kWH per month, i.e. from 41 to 64 percent of West Kootenay Power's total output, at capacity factors ranging from 50 to 95 percent.

Enhancement Facilities

No fisheries enhancement facilities were requested nor provided for the Waneta project.

OPERATIONAL REGIME

Waneta operates as a run-of-river project and is the final reservoir of a series on the Pend d'Oreille which includes Seven Mile in B.C. (10 km upstream) and Boundary, Box Canyon, Albeni Falls, Noxon Rapids and Thompson Falls in the U.S.A. Waneta provides the bulk of the power used in smelting and industrial operations at Trail in the west Kootenays and power output thus varies considerably on a daily and monthly basis according to demand (Figures 12 and 13). The reservoir volume and level fluctuates over a relatively small range on a daily basis. Waneta is undersized in capacity in terms of the available water resources and is one of the few dams in B.C. which spills water on a sustained basis, often for 3-4 months.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The basic dimensions of the Waneta reservoir are not recorded, but it closely resembles that of the Seven Mile project above it, i.e. long and narrow with a relatively small surface area, probably similar mean depth (~ 30 m) and a high flushing rate (1-2 days average residence time). Other morphological features are similar to those of Seven Mile reservoir. Tributaries to Waneta reservoir consist of small creeks with zero to very low flows in late summer.

The reservoir has not been studied in detail, although some limited sampling was done in 1974 as part of the Seven Mile impact assessment (Envirocon/Pearse Bowden 1975). The reservoir is probably well-mixed and isothermal and summer water temperatures are probably fairly high. Temperatures of up to 25° C have been measured in the river below the Dam. The reservoir was classed as oligotrophic on the basis of low phosphorus and nitrogen content (Envirocon 1975).

Downstream System

The Pend d'Oreille River extends only 0.5 km from the Waneta tailrace to the Columbia River confluence. This section is fairly turbulent, especially during periods of spillway discharge. The Pend d'Oreille was a heavily sedimented river prior to Waneta construction (Cope 1969, Envirocon/Pearse Bowden 1973), much of the sediment originating from mine tailings along the Pend d'Oreille and in the upper watershed in both B.C. and Washington.

Prior to construction of the Seven Mile Dam (1979), very high total dissolved gas levels were measured in the Pend d'Oreille River below Waneta (Water Investigations Branch 1979). About 59 percent of samples taken over a 4-year period were higher than 110 percent saturation and 1 percent were higher than 120 percent. Waneta has a high frequency of large spills (Figure 13) and the spilled water enters the plunge pool from a height of more than 60 m. No incidence of gas embolism in fish within the lower Pend d'Oreille or Columbia has been reported. The Seven Mile spillway was designed to reduce the incidence of gas supersaturation (B.C. Hydro 1987), but the efficiency of this in reducing dissolved gas levels of water entering Waneta reservoir has not been examined.

SPORT FISH POPULATIONS

Reservoir

Sampling in the Waneta reservoir in 1974 revealed a predominance of squawfish (46 percent) and redside shiners (41 percent) (Envirocon/Pearse Bowden 1975). The incidence of sport fish was not determined, but was very low. No stocking of the Waneta reservoir has been attempted because of its very high flushing rate and low productivity (Fisheries Branch, pers. com.). Small numbers of rainbow trout and mountain whitefish occur in the Seven Mile reservoir above Waneta and may be passed through to Waneta in small numbers from time to time.

Downstream System

Rainbow trout are reported to have moved between the lower Columbia and the lower Pend d'Oreille rivers prior to the development of Waneta (Cope 1969) - these movements were blocked by dam construction. The present extent of the fishery resource below Waneta has not been investigated.

RECREATIONAL FISHERY

Reservoir

Unlike Seven Mile reservoir, Waneta reservoir has no major tributaries of high fisheries capability to support a recreational fishery. Recreational angling use prior to project construction was not documented but was probably minimal due to the turbulent nature of the river and poor access. Present recreational use is probably very low because of low productivity, poor access and very low numbers of sport fish in the reservoir.

Downstream System

Recreational fishery use below Waneta is not documented but anglers are often observed fishing the large pool near the Columbia River confluence for walleye, sturgeon and other sport fish (B.C. Hydro, pers, com.).

WALTER HARDMAN
(Coursier Lake)
(Cranberry Creek)

PROJECT

Description

Coursier Lake is 143 ha in extent and is the headwaters for the south fork of Cranberry Creek, located west of the northern end of Upper Arrow lake (Map A). The lake was provided with a concrete and earth fill dam in 1959 and used as storage for power and domestic use for the City of Revelstoke. A series of small diversion and saddle dams diverts portion of Cranberry Creek into a headpond (Cranberry Lake) dammed by an 11 m high, 411 m long dam. A 2 km penstock leads to a powerhouse on the western shore of Upper Arrow lake which has a name plate capacity of 8 MW. The project is now owned and operated by B.C. Hydro (acquisition date uncertain). The dams were upgraded in 1974 and a further 6 m of storage added to Coursier Lake.

Water Licences and Operational Constraints

The present conditional water licence permits B.C. Hydro to store up to 790,000 m^3 of water per year and to divert a maximum flow of 3.9 m^3/s. There are no conditions pertaining to fisheries or other environmental concerns.

Electrical Generation

Records of plant and reservoir operations are not kept by B.C. Hydro's central operational centre and were not available for this review.

Enhancement Facilities

No fisheries mitigation or enhancement facilities were provided.

OPERATIONAL REGIME

No data are available from B.C. Hydro. Field observations in 1975 (Northern Natural Resources 1976) indicated that the lake is drawn down by as much as 15 m in winter, and the headpond receives the bulk of Cranberry Creek's water at times leaving minimal flows for downstream uses.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

A limnological survey in 1970 (Ministry of Environment, lake survey data) revealed extensive floating debris and snags within the lake, some derived from logging and some from a lack of clearing when the lake level was raised. Some of this debris was subsequently removed by B.C. Hydro. Total dissolved solids were measured (in 1970) at 24 - 33 mg/l, pH at 7, and surface temperatures at 12° C. Dissolved oxygen was measured at 8 mg/l on the surface and at 5 m depth, but only 3 mg/l at 15 m depth, suggesting the likelihood decomposition in the debris filled lake.

Downstream System

Cranberry Creek below Coursier lake is 21 km in extent and characterized by log jams, velocity chutes and several waterfalls (Lindsay 1976). Only the low gradient terminal 2 km reach is considered normally accessible to migratory fish, the remaining reaches are occasionally accessible depending on flow conditions and the species involved. There are no discharge records available for Cranberry Creek. Substrates in lower Cranberry Creek are mainly cobble and pebble.

SPORT FISH POPULATIONS

Reservoir

Coursier Lake contains some sport fish species, including rainbow trout (Lindsay 1976) but the distribution and numbers are unknown.

Downstream System

The lower 2 km is used as spawning habitat by rainbow trout and kokanee from Upper Arrow Lake. Spawning escapements have not been measured.

RECREATIONAL FISHERY

Reservoir

No angling surveys have been carried out. Some use is made of the reservoir for rainbow trout trolling and fly fishing (B.C. Hydro, pers. com.)

Downstream System

No information available.

WHATSHAN

PROJECT

Description

Whatshan Dam is a 6 m high, 104 m long, earth- and rock fill dam located at the outflow of Whatshan Lake into the Whatshan River, which is a tributary of Lower Arrow Lake (Map A). A 2 km power tunnel leads to the powerhouse on the east shore of Lower Arrow Lake. The latter has a nameplate capacity of 50 MW. Whatshan was built in 1952 by the B.C. Power Commission and is presently owned and operated by B.C. Hydro. Barnes Creek joins the Whatshan River below the dam and studies are presently (1990) under way to establish the feasibility of diverting the creek into Whatshan Lake to increase energy production.

Water Licences and Operational Constraints

Conditional water licences issued in 1948 and 1956 permit maximum storage of 271 million m^3 per annum and diversion of a maximum flow of 12.5 m^3/s from the lake and Barnes Creek. There are no conditions pertaining to fisheries or other environmental concerns.

Electrical Generation

Whatshan generates from 2 to 20 million kWH of electricity monthly and contributes on average about 0.2 percent of B.C. Hydro's total annual output. Monthly capacities range from 5 to 80 percent.

Enhancement Facilities

No fisheries mitigation or enhancement facilities were provided.

OPERATIONAL REGIME

The operation of Whatshan power plant is largely independent of other plants in the B.C. Hydro grid, and the plant is run to the maximum extent possible by the storage volume available. Turbine discharges are erratic from one month to the next (Figure 14) with larger outputs in the winter months and, sometimes, in freshet months when large volumes of water are available. The lake is drawn down to the maximum extent possible each year (Figure 15) with consequent large drawdowns (4 to 6 m) each year. There is seldom any spill over the dam.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Whatshan Lake is approximately 22 km long and 2.5 km wide at the broadest point. Mean depth is approximately 50 m and the maximum surface area is about 1700 ha. The lake is roughly divisible into three sections - the original lake (which existed prior to impoundment), a shallow middle section, and a shallow lower portion presently occupied by extensive mats of aquatic vegetation. Prior to dam construction there were natural rock barriers at the lake outlet which prevented fish access to and from the Whatshan River (B.C. Game Branch 1948) and this barrier to upstream fish migration is still effective (Fleming and Smith 1988b).

Water quality samples taken in Whatshan Lake in 1959 (Ministry of Environment, lake survey data) recorded total dissolved solids content of 58 ppm, indicating that the lake at that time was oligotrophic. The lake has subsequently been sampled as part of a comparative monitoring program (including Revelstoke reservoir, Kinbasket Lake and part of Upper Arrow Lake - Smith 1986, Fleming and Smith 1988a, in prep.). Thermal stratification is apparent in the upper lake in late summer, the thermocline commencing some 6 m below the surface. Dissolved oxygen concentrations decline sharply below 20 m depth, presumably due to high macrophyte densities and possibly decomposition. The lake has remained oligotrophic with low concentrations of dissolved solids (total residue 41-48 mg/l), phosphorous, nitrogen and other nutrients.

Downstream System

No information is available on habitats or chemical and physical characteristics of the Whatshan River below Whatshan Lake. A 10-12 m high falls lies in the Whatshan River about 50 m from its mouth on Arrow Lake and appears to be a complete blockage to upstream fish migrations (Fleming and Smith 1988b).

SPORT FISH POPULATIONS

Reservoir

Rainbow trout, bull trout and kokanee were present in the lake prior to dam construction (B.C. Game Branch 1948). Spawning habitats were available in small tributary streams but migrations from the lower Whatshan River were blocked by natural obstructions at the lake outlet. Totals of 747,000 rainbow trout eyed eggs and fry and 400,000 kokanee eyed eggs were planted in Whatshan Lake over a period of 22 years prior to 1948 (B.C. Game Branch 1948), indicating that natural reproduction in the lake was not high.

Whatshan Lake was sampled by gill netting from 1985 through 1987 (Smith 1986, Fleming and Smith 1988a, in prep.). From 15 to almost 50 percent of gill net catches were sport fish, with rainbow trout and mountain whitefish present in small numbers, and bull trout and kokanee dominating the sport fish numbers, their actual proportions depending in the season of sampling (bull trout higher in fall, kokanee higher in summer). Northern squawfish and peamouth dominated the coarse fish populations, while other coarse species present included both large-scale and longnose suckers. Catch per unit effort (based on gill netting) in Whatshan Lake has ranged from 7.8 to 11.9 fish/100 m^2/24 hr, i.e. as high or higher than in Arrow Lake, Revelstoke Reservoir or Kinbasket Lake. The lake has not been stocked since impoundment, and hence sport fish species appear to be maintaining their numbers through tributary stream spawning. The very large drawdowns in Whatshan Lake would likely preclude any use of littoral areas for spawning by kokanee or mountain whitefish.

Downstream System

Rainbow trout from Lower Arrow Lake used the Whatshan River for spawning prior to project development (B.C. Game Branch 1948) and prior to the raising of Arrow Lakes (see Keenleyside). No useful habitats are now present below the falls (B.C. Hydro, pers. com.). In September 1978 an estimated 1000 kokanee were observed at the mouth of the Whatshan River, below the falls (Fleming and Smith 1988b).

RECREATIONAL FISHERY

Reservoir

Prior to impoundment Whatshan Lake was described as providing excellent recreational angling (B.C. Game Branch 1948). Rainbow trout were taken by fly fishing and by trolling, and bull trout were described as abundant. Good access to the lake was available via an all-weather road.

The present extent of recreational angling is not documented, but some localized angling has been observed to take place (B.C. Hydro, pers. com.). Present angler access to the lake is good.

Downstream System

No information is available on the recreational use of the Whatshan River. Anglers have been observed to fish Barnes Creek upstream of the Whatshan River confluence (B.C. Hydro, pers. com.)

SPILLIMACHEEN

PROJECT

Description

Spillimacheen power plant is located on the Spillimacheen River, a tributary of the upper Columbia below Windermere Lake (Map A). A 9 m high, 42 m long, concrete dam diverts part of the Spillimacheen flow through a 3 km power tunnel to a powerplant with a 4 MW capacity. The project has a free overflow spillway and a gated 1.2 m square low level outlet. The project was constructed by the B.C. Power Commission in 1954-55 and is presently owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The conditional water licence issued in 1956 permits a maximum diversion of 8.5 m^3/s. There are no conditions pertaining to fisheries or other water uses.

Electrical Generation

Spillimacheen is operated independently of the B.C. Hydro integrated system, and no records are maintained by B.C. Hydro's central Operations Control Department.

Enhancement Facilities

No fishery facilities were provided at the project site.

OPERATIONAL REGIME

The operational mode of the plant is not documented. The Spillimacheen headpond has a very limited volume. The Spillimacheen River has a mean annual discharge of 35 m^3/s (Environment Canada 1988), hence the plant operation likely has little influence on river habitats except possibly under conditions of very low flows.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The headpond is very limited in size. No information on the physical and chemical characteristics are available.

Downstream System

No information available.

SPORT FISH POPULATIONS

Reservoir

No information available.

Downstream System

Burbot, bull trout and mountain whitefish are known to use the lower Spillimacheen River (Fisheries Branch, pers. com.).

RECREATIONAL FISHERY

Reservoir

No information available.

Downstream System

Burbot have supported a long-standing fishery (Fisheries Branch, pers. com.) but this has not been quantified.

B. KOOTENAY RIVER SYSTEM

ABERFELDIE

PROJECT

Description

Aberfeldie is a small hydro project located on the Bull River in the East Kootenays (Map A), and consists of a concrete gravity dam 27 m high and 134 m long. A concrete spillway has a maximum discharge capacity of 990 m^3/s and is equipped with 1.5 m flashboards for additional storage capacity in winter. The generating plant, 1 km below the dam and supplied by wooden penstocks, has a nameplate capacity of 5 MW. Aberfeldie was constructed from 1920 through 1922 by the Bull River Electric Power Company and taken over by the East Kootenay Power Company which redeveloped the dam in 1953. The project is now owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The initial water license, issued in 1924, permitted a maximum diversion of 2.6 m^3/s (91 cfs) and no specification as to amounts stored. The licence as amended in 1927 to permit a maximum diversion of 7.4 m^3/s (260 cfs). There are no provisions in the licence for fisheries or other environmental concerns.

Electrical Generation

Data on generation by Aberfeldie are not kept by B.C. Hydro's Operations Control Department and were not available from other sources.

Enhancement Facilities

None provided.

OPERATIONAL REGIME

No information is available on turbine releases or spillway discharges. The average drawdown in the reservoir is about 1 m (B.C. Hydro, pers. com.).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The reservoir has a maximum surface area of 26 ha and an estimated maximum volume of 900,000 m^3 (B.C. Hydro, n.d.). There are no data on physical and chemical characteristics. Water temperatures are normally cold and the reservoir is ice covered throughout the winter (B.C. Hydro, pers. com.). The only tributary habitats available are those in the upstream Bull River - no information is available on these habitats.

Downstream System

The live storage of the reservoir is estimated at less than 0.1 percent of the mean annual volume of the river. WSC gauging data for the Bull River near its confluence with the Kootenay consequently indicate that impoundment has resulted in only very small changes in river discharges, although pre-impoundment discharge data are relatively few (Figure 16). Swimming surveys in the river below the dam indicate the presence of fine sediments (Fisheries Branch, pers. com.), suggesting that the reservoir contains substantial volumes of sediment and is passing them through the turbines.

SPORT FISH POPULATIONS

Reservoir

No quantitative surveys have been undertaken in the Aberfeldie reservoir. Local anglers report the presence of mountain whitefish and the absence of trout species.

Downstream System

As noted for the reservoir, no quantitative surveys have been undertaken in the Bull River below Aberfeldie Dam. Fish are absent for the first 2 km below the dam, possibly due to the presence of dissolved gases at supersaturation concentrations (Fisheries Branch, pers. com.). Cutthroat and bull trout and mountain whitefish in relatively low numbers are reported in the lower reaches by local anglers.

RECREATIONAL FISHERY

Reservoir

Local anglers seldom fish the reservoir because of the absence of trout and very poor catches of other species (Fisheries Branch, pers. com.).

Downstream System

Small numbers of anglers make use of the downstream system for cutthroat trout. No quantitative creel data have yet been collected.

ELKO

PROJECT

Description

Elko is a small hydro project located on the Elk River near its confluence with the Kootenay River (Lake Koocanusa) in the East Kootenays (Map A). The dam is a concrete gravity structure 10 m high and 66 m long supplied with two concrete spillways of 900 m^3/s maximum discharge capacity and two steel gates of 280 m^3/s capacity each. The dam is equipped with flash-boards for additional storage capacity in winter. The generating plant, 1 km below the dam and supplied by a wooden penstock, has a nameplate capacity of 9.6 MW. Elko was constructed in 1924 by the East Kootenay Power Company and the spillway was raised in 1950. The project is now owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The final water license, issued in 1927, permits a maximum diversion of 25 m^3/s (900 cfs). There are no provisions in the licence for storage amounts, nor for fisheries or other environmental concerns.

Electrical Generation

Data on generation at Elko are not kept by B.C. Hydro's Operations Control Department and were not available from other sources.

Enhancement Facilities

None provided.

OPERATIONAL REGIME

No information is available on turbine releases or spillway discharges.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The surface dimensions of the Elko reservoir have not been determined, but the maximum volume is estimated to be about 600,000 m^3 (B.C. Hydro, n.d.). There are no data on physical and chemical characteristics. Water temperatures are normally cold, the reservoir is ice covered throughout the winter, and suspended sediment levels are often elevated by clearcut logging within the Elk watershed (B.C. Hydro, pers. com.).

Downstream System

The live storage of the reservoir is estimated at less than 0.1 percent of the mean annual volume of the river. WSC gauging data for the Elk River near its confluence with the Kootenay are not available for the post-1950 period, but is unlikely that the effects of the dam would be detectable. There are no chemical water data for the lower Elk River.

The Elk River below the Elko Dam flows through a small steep-walled, high-gradient canyon with numerous rapids, chutes and small pools, and boulders, rubble and gravel substrates of limited value as spawning habitat.

SPORT FISH POPULATIONS

Reservoir

No quantitative biological studies have been undertaken in the vicinity of the Elko reservoir. Angling catches indicate that the principle sport fish species above the dam are bull trout, cutthroat trout, brook trout and mountain whitefish, the latter species supporting most angling effort during the winter.

Downstream System

Angling catches indicate that the principle sport fish species below the dam are rainbow, cutthroat and bull trout, in addition to the ubiquitous mountain whitefish. The Wigwam River serves as a major spawning habitat for bull trout which move up from Lake Koocanusa, and small numbers of these fish may also use the lower Elk River for rearing. Kokanee have been observed in the lower Elk River, but the extent of use is not documented (Fisheries Branch, pers. com.).

RECREATIONAL FISHERY

Reservoir

Local anglers seldom fish the reservoir because of the lack of easy access relative to other parts of the Elk River (Fisheries Branch, pers. com.) and ease of access to the nearby shoreline of Lake Koocanusa. The Elk River upstream of the reservoir is an important angling river in the East Kootenays and supports upwards of 14,000 angler days per annum, mainly for mountain whitefish, with smaller numbers of bull, cutthroat and rainbow trout taken (Fisheries Branch, pers. com.).

Downstream System

The Elk River below the dam is accessible by road. Catches are small and dominated by mountain whitefish (B.C. Fish and Game Branch 1966), with smaller numbers of cutthroat, rainbow and bull trout (Fisheries Branch, pers. com.). Angling success is probably lower than the 1.3 - 2.0 fish/hr rate measured for the more upstream portions of the Elk River (Martin 1983).

DUNCAN
(Duncan Lake)

PROJECT

Description

The Duncan dam is a major flood control structure located on the Duncan River at the outflow of Duncan Lake, above its confluence with the Lardeau River (Map A). No electricity is generated at Duncan. The dam was developed for water storage and flood control as part of the 1961 Columbia River Treaty. The project was completed in 1967 and is operated by B.C. Hydro. Duncan is an earth fill dam 40 m high and 792 m long. The concrete spillway has 2 chutes equipped with flip buckets, and two sluices are provided to draw water at a depth of 35 m below full pool. There are no fishways, but flows through the sluices are regulated at times to permit bull trout to move in and out of the reservoir from the lower Duncan River (B.C. Hydro, pers. com.).

Water Licences and Operational Constraints

The conditional water licence, issued in 1962, permits storage of up to 1727 million m^3 of water. Conditions attached to the licence included:

- clearing of timber from the reservoir area (in consultation with the Ministry of Forests)
- provision of public access to the reservoir
- provision of up to $5000 per year for two years for fish and wildlife studies on remedial measures
- undertaking of remedial fisheries and wildlife measures based on reports from the Department of Recreation and Conservation
- release of water at times and in quantities as directed (by the Water Comptroller) for the public benefit.

Enhancement Facilities

A 3.2 km long, 11 m wide, spawning channel was constructed adjacent to Meadow Creek, a tributary of the lower Duncan River, by B.C. Hydro in 1967 to compensate for the loss of kokanee spawning habitats in the Duncan River system. The number of kokanee spawners using the channel and adjacent portions of Meadow Creek from 1967 through 1985 averaged 487,000 annually (range 238,000 - 1.4 million) (Hutchinson 1987). B.C. Hydro cleared the debris from the flooded reservoir in preference to pre-impoundment clearing and completed the task in 1978. A boat launching ramp for use by anglers was constructed in the mid-70's at Lardeau on Kootenay Lake in preference to Duncan Lake.

OPERATIONAL REGIME

Duncan Lake is utilized for flood control and for water storage for hydroelectric facilities on the Columbia River in the U.S.A. Withdrawals are made in response to complex water requirements in the lower Columbia system in the U.S.A., and are accordingly very erratic (Figure 17). Available storage is utilized to the maximum possible extent (Figure 18). Reservoir volume in February-March of each year is reduced to 3-4 percent of maximum to receive the spring freshet. The associated drawdown is 25 - 27 m below full pool. The reservoir is typically at or near full pool from July through October each year (Figure 18). Releases are often at their highest in December and January, i.e. the opposite of the unregulated pre-project hydrograph. This reversal is of considerable significance to the limnology of Kootenay Lake (see Corra Linn).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Duncan Lake has not been studied nor sampled following construction of Duncan Dam. The present reservoir has a maximum volume of 1.73×10^9 m^3, a surface area of 7140 ha and a mean depth of 24 m. Prior to project development, Duncan Lake was observed to be turbid during early summer due to high loadings of glacially derived silt carried in during the freshet (Peterson and Withler 1965c). Erosion due to logging along the upper Duncan River contributed to high sediment inputs. The Duncan watershed contains substantial areas under glaciers and a high input of glacial silt into the reservoir and siltation of the littoral zone is probably a continuing phenomenon. Water temperatures in the lake are also likely strongly influenced by cold inflows from the heavily glaciated watershed. Summer water temperatures in the Duncan River inflow to Kootenay Lake are approximately 10° C (Daley et al. 1981); these flows are drawn from the bottom of Duncan Lake (Figure 18) indicating that the lake is well stratified when full in summer. The marked drawdowns at other times probably lead to complex patterns of stratification development and breakdown. Winter and pre-freshet water temperatures are probably in the 4-5° C range throughout the reservoir. Mean water residence time is 5.2 months.

No chemical sampling has been undertaken in Duncan Lake. The pre-impoundment lake was judged to be unproductive (Maher 1961, Peterson and Withler 1965c). Daley et al. (1981) sampled Duncan River inflows to Kootenay Lake and noted very low dissolved phosphorous levels (0.002 - 0.003 mg/l and high turbidity. Duncan Lake probably does not retain a significant nutrient loading due to the relatively short residence time of 5.2 months), the extensive drawdown depletion, and the low nutrient content of the inflows, and is likely oligotrophic or even ultra-oligotrophic.

Downstream System

Operation of the Duncan Dam has produced no detectable effect on the annual mean discharges in the lower Duncan River (Figure 19). Peak flows, normally in the freshet, have been attenuated by approximately 20 percent. Flows through the summer are now approximately 60 percent of the pre-project summer flows, while mid-winter flows have been increased by 100 to 200 percent (Figure 20).

Prior to construction of the dam, the lower Duncan River below Duncan Lake was characterized by high concentrations of glacial silt and high turbidity in spring and summer. This material is now retained within the reservoir. Extensive sloughs connected to the lower Duncan River were probably used as spawning and rearing areas - no detailed inventories were made (Peterson and Withler 1965c). Lower Duncan River tributaries have moderate to steep gradients, some have barriers to fish passage, and most provide spawning habitat for bull trout and rainbow trout in the lower reaches only (Peterson and Withler 1965c). The lower Lardeau River provides little suitable rearing habitat for rainbow trout due to steep gradients and small substrate size (Irvine 1977).

Meadow Creek is exceptional and is a low gradient stream with an extensive meander pattern and extensive gravel areas. The creek was a prime spawning area for kokanee, rainbow trout and bull trout prior to Duncan Dam development, and the creek and associated spawning channel is presently heavily used by kokanee. A hatchery for the Gerrard stock of rainbow trout, which are highly valued sport angling fish in the north arm of Kootenay Lake, is presently operated at Meadow Creek; fingerlings are stocked to local waters including Duncan Lake (Fisheries Branch, pers. com.).

SPORT FISH POPULATIONS

Reservoir

No population inventories or creel censuses are available for the pre-impoundment lake or post-impoundment reservoir. Based on anglers' reports, pre-impoundment Duncan Lake contained relatively small numbers of rainbow trout, bull trout and white sturgeon (Maher 1961, Peterson and Withler 1965c). Trout and char probably used the upper Duncan River and tributaries for spawning. Kokanee are not reported as having used the lake or upper tributaries. In 1979 the Fish and Wildlife Branch reported kokanee to be the dominant sport fish in the reservoir, followed by bull trout, burbot and mountain whitefish; rainbow trout were thought to make up a small proportion of sport fish numbers (Sigma 1979). Bull trout spawners enter the tailrace from time to time and enter the reservoir through the low level outlet (B.C. Hydro 1988b). Rainbow trout were stocked into Duncan lake in 1987 with unknown results (Fisheries Branch, pers. com.).

Downstream System

The large kokanee spawning escapements to the lower Duncan River were terminated in 1968 by development of the Duncan Dam. Four escapement counts were made prior to dam construction and annual enumerations of 2.8 million, 456,000, 13,000 and under 7000 were made from 1964 through 1967 respectively (Figure 21). Other species were not monitored but numbers would have been far lower than for kokanee. Kokanee escapements to the Lardeau River have declined to approximately 15 percent of the peak escapement measured in 1974 (Figure 21). Total Meadow Creek kokanee escapements (natural creek + spawning channel) have also declined since the mid 1970's (Figures 21 and 22). These declines followed the construction of the Libby Dam in 1973 and could be causally related to a decline in productivity of the Kootenay Lake system (see Corra Linn). Meadow Creek spawning channel escapements have fluctuated around a mean of about 175,000 since construction of the channel (Figure 22) and have not shown the overall decline evident in escapements to the natural Meadow Creek or Lardeau systems. Escapements to the natural creek areas have always exceeded the spawning channel escapements. Based on the relatively short record length available, it appears that post-project kokanee spawning escapements in Meadow Creek have not yet replaced even 50 percent of the natural pre-project escapement levels.

A rainbow trout stocking program for the Duncan River was attempted from 1971 through 1973 (2000, 37,000 and 3200 fingerlings stocked respectively) and recently revived in 1986 (15,000 fingerlings stocked).

RECREATIONAL FISHERY

Reservoir

No creel data are as yet available to quantify sport fishing in Duncan Lake. Anglers are known to use the lake in relatively small numbers, fishing for rainbow trout, bull trout and mountain whitefish (Fisheries Branch, pers. com.). The generally superior angling in Kootenay Lake probably entices most anglers away from potential use of Duncan Lake.

Downstream System

Both rainbow trout and mountain whitefish are taken by anglers in the lower Duncan River (B.C. Hydro 1988b) with fairly substantial numbers (2000 - 3000) of whitefish being caught annually. No detailed creel data are available.

CORRA LINN
(Kootenay Lake)

PROJECT

Description

The Corra Linn dam is the primary hydroelectric outlet of the west arm of Kootenay Lake (Map A). The dam is a 21 m high, 518 m long concrete gravity structure located 8 km below Grohmann Narrows, a natural constriction at the confluence of the west arm and the lower Kootenay River. Grohmann Narrows is the primary hydraulic control on the flows and water levels in Kootenay Lake, while Corra Linn provides up to 2.5 m of additional storage and the necessary hydraulic control for its own power plant plus a sequence of four run-of-river reservoirs (Upper Bonnington, Lower Bonnington, South Slocan and Brilliant.

Corra Linn is provided with a gated spillway of 7700 m^3/s capacity. The generating plant has a nameplate capacity of approximately 42 MW. The plant was built by the Consolidated Mining and Smelting Company (Cominco) from 1930 to 1932 and was operated initially as a run-of-river plant. Storage control commenced in 1939. The plant is presently operated by West Kootenay Power. The Corra Linn forebay is used by B.C. Hydro as the take-off point for the Kootenay Canal project (see Kootenay Canal).

Water Licences and Operational Constraints

The initial water licence issued in 1939 permitted a maximum diversion of 294 m^3/s (10,400 cfs). This was increased to 357 m^3/s (12,600 cfs) in 1950. There were no constraints on diversion due to fisheries or other environmental concerns. The water levels of Kootenay Lake are subject to an order issued in 1938 by the International Joint Commission which sets maximum permissible levels according to a rule curve (Daley et al. 1981).

Electrical Generation

The Corra Linn power plant operates at 40 to 95 percent of its capacity throughout the year, with higher outputs during the months of July and August when Kootenay Lake levels approach their allowable maximum. Corra Linn contributes about 5 percent (range 3-9 percent) of West Kootenay Power's total monthly electrical generation.

Enhancement Facilities

No fisheries mitigation or compensation measures were requested nor provided for the development.

OPERATIONAL REGIME

Kootenay Lake is a natural lake occupying the central portion of the Purcell Trench and receives the flow from three major rivers - Kootenay, Duncan and Lardeau. The west arm of the lake is the outflow and becomes the lower Kootenay River which is presently regulated by Corra Linn and the other West Kootenay Power dams (see Upper Bonnington, Lower Bonnington, South Slocan, Kootenay Canal and Brilliant).

The lake has come under increasing regulation for hydroelectric and flood control purposes, commencing with Corra Linn in 1932 (hydroelectric generation), Duncan Dam in 1967 (flood control and Columbia River treaty storage) and Libby Dam in Montana in 1973 (Columbia River treaty storage and power generation). About 57 percent of Kootenay Lake inflow is presently regulated (Environment Canada 1988). Hydrological regulation by the upstream dams (Duncan and Libby) has eliminated the June freshet peak in Kootenay Lake outflows and lake levels (Daley et al. 1981). Lake levels in June are now about 2 m lower than they were prior to such regulation, but levels at other times of the year have been altered only slightly. Winter inflows and outflows to and from the lake were approximately doubled following completion of Duncan Dam and were increased about 2-4 times following regulation by Libby Dam (Figure 23).

Corra Linn's turbine capacity is less than one-quarter that of the Kootenay Canal plants (see Lower Bonnington) which also draws water from the Corra Linn forebay. Corra Linn's turbine discharges (Figure 24) have little correlation to Kootenay Lake volumes (Figure 25) and are most influenced by user demands within the West Kootenay Power supply system. Despite the presence of upstream storage dams, the capacities of the plants at the lake outlet (Corra Linn and Kootenay Canal) are not in complete hydraulic balance with available water supplies. Water is normally passed over the Corra Linn spillway each year in the May-July period, and occasionally in other periods (Figure 24).

Most hydroelectric and flood control storage is provided by Duncan and Libby dams (about 22 and 44 percent of total streamflow through Corra Linn, respectively). Kootenay Lake's storage is limited to about 3-4 percent of its total volume; however, because of its large volume such annual storage amounts to over 1500 million m^3.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Lake water levels presently fluctuate over a 2.5 m range (Figure 25) and reach the minimum levels in April or May each year as the lake is drafted for freshet inflows. Kootenay Lake levels are primarily a function of three factors - water releases from Duncan reservoir (Figure 17), which are held very low from March through June, releases from Libby reservoir, which are similarly low in late winter and early spring, and unregulated run-off from numerous smaller tributaries in spring and summer. Lake level fluctuations are suspected of being a cause of declines in west arm kokanee populations (see Sport Fish Populations: *Reservoir*). The mean water retention time of the entire lake is estimated at 15.9 months, although the west arm has a mean retention time of only 5 days due to its narrow configuration and its direct connection to the lake outflow (Daley et al. 1981).

Temperatures of lake inflows range from 5 to 20° C for the Kootenay River inflows (south) and 2 to 10° C for the Duncan-Lardeau inflows (north) (Daley et al. 1981). The lake is thermally stratified from mid-June through the end of October (Daley et al. 1981, Crozier and Duncan 1984). Summer water temperatures at the surface reach 16-18° C and the 10°C isotherm typically extends down to the 20-30 m depth.

Prior to 1950 Kootenay Lake was oligotrophic (Larkin 1951), typical of most large natural lakes in British Columbia. In the early 1950's a Cominco fertilizer plant commenced discharging large quantities of phosphorus and nitrogen rich effluent to the St. Mary River, a tributary of the Kootenay River above Kootenay Lake. Phytoplankton and zooplankton concentrations increased markedly in response to the increased nutrient loadings, to the point where algal blooms were a common occurrence in the 1960's (Daley et al. 1981). Pollution abatement measures in 1969 and 1975 at the upstream fertilizer plants initiated a period of nutrient decline in the lake. This was exacerbated by nutrient retention behind Libby Dam, commencing in 1973 and, to a lesser extent by retention behind Duncan Dam, commencing in 1967. Besides acting as nutrient traps these reservoirs have led to the enhancement of nutrient stripping from the river systems below the dams, and shifting the nutrient loading times from spring and summer to winter (Daley et al. 1981).

By 1984 phosphorous concentrations in the lake appeared to have moved close to equilibrium with phosphorous inputs (Crozier and Duncan 1984). Concentrations of total phosphorous and orthophosphorous dropped by factors of almost 40 from 1968 to 1978, and have declined only slightly since 1978. Present phosphorus loadings in the lake are probably now lower than during the 1950's, i.e. before the high loadings from upstream effluents (Fisheries Branch, pers. com.). Total phosphorous concentrations presently range from 0.009 to 0.012 mg/l, while orthophosphorous concentrations are at or below the minimum detection level (0.003 mg/l). By contrast, nitrogen concentrations have remained relatively constant since development of Duncan and Libby dams, although ammonia decreased by a factor of about 5 between 1969 and 1975 due to reduction of ammonium phosphate in upstream fertilizer plant effluent (Crozier and Duncan 1984).

Chlorophyll-*a* levels have declined in response to the declining phosphorus loadings. Mean levels in the south arm declined by 50 percent between 1966 and 1978, while peak levels at various sampling locations throughout the lake decreased by a factor of 3 from 1966 through 1978. High variability in zooplankton biomass (excluding *Mysis*) has obscured the long- term trends, but there has apparently been no significant decline. *Mysis* was introduced in 1949 to supplement the lake food chain (Northcote 1972) and, although well established by the 1960's, has declined over the past decade for reasons not yet apparent.

In an attempt to improve the productivity of some sections within the lake, phosphate enrichment of the west arm was commenced on a pilot basis in 1986. A revised fertilization program for the entire lake is currently being considered (Fisheries Branch, pers. com.).

Downstream System

See Duncan, Corra Linn, Upper Bonnington, Lower Bonnington and South Slocan.

SPORT FISH POPULATIONS

Reservoir

Kootenay Lake supports populations of rainbow trout, kokanee, bull trout, burbot and mountain whitefish. One race of rainbow trout - the Gerrard stock - matures later than other races and attains weights of 8 to 20 kg, making them the main trophy angling species in the lake.

Kokanee are the most abundant sport fish within Kootenay Lake (Andrusak 1986), and consist of three racially distinct populations - north arm, south arm and west arm stocks (Vernon 1957). Eutrophication during the 1950's and 1960's caused increases in fish stocks throughout the lake, and especially in west and north arm kokanee and west arm whitefish populations (Andrusak 1986). West arm kokanee increased in size during this period. The introduction of *Mysis* in 1949 to supplement the lake food chain (Northcote 1972) was additionally responsible for increased growth rates in west arm kokanee. The size of north arm kokanee has not changed significantly within the past 20 years, although fecundity has declined (Andrusak 1986).

Kokanee populations in the west arm have undergone a marked rise and fall within the past two decades. Population rises, accompanied by high angling catches and success rates (see Recreational Fishery), followed the rise in nutrient enrichment of the lake. This was followed by a crash caused by overfishing and poor stream production (Andrusak 1986), and possibly a reduction in the survival of kokanee fry due to benthic shortages caused by drawdowns in the west arm in April and May each year when kokanee fry migrate into the west arm. Stocks have not responded to production at two west arm spawning channels (Kokanee and Redfish creeks). There has been no apparent trend in north arm kokanee numbers which are supported mainly by Meadow Creek spawning habitats, while south arm populations are thought to be depressed in comparison to 1970's levels (Andrusak 1986).

Rainbow trout populations in Kootenay Lake consist of distinct stocks (Andrusak 1986). The main lake population consists of Gerrard stocks, while the south and west arms support smaller sized trout which seldom exceed 5 kg in size. Gerrard trout spawning escapements have been monitored for the past 30 years (Figure 26). Increased escapements through the late 1970's are believed to be partly due to enhancement from the Meadow Creek hatchery. Declines in escapements through the 1980's may be related to declines in kokanee stocks in the lake, but this has yet to be determined. Rainbow trout growth rates have not been documented to have declined over the years, as has been the case with kokanee.

Downstream System

Corra Linn discharges directly into the Upper Bonnington reservoir (see Upper Bonnington).

RECREATIONAL FISHERY

Reservoir

Sport fishing has been a major recreational pursuit on Kootenay lake since at least the 1930's. The main attractions have been trophy rainbow trout and bull trout. Sport angling in the Kootenay region was estimated to have a total value of about $18 million in 1981 (Reid 1986), of which the Kootenay Lake fishery provided a large proportion. In 1984 at least 14 resorts were located on the west arm and were dependent on the lake's sport fishery.

Prior to the 1960's, most sport fishing was concentrated on the main lake and was directed at larger rainbow trout. Some fish populations responded to nutrient enrichment of the lake, in particular west arm kokanee, portions of the north arm kokanee populations and west arm whitefish. The increased size in west arm kokanee numbers attracted anglers, so that by the mid 1970's more than 50 percent of the angling activity on the lake was directed towards these stocks, compared to an estimated 10 percent prior to this period (Andrusak 1986). Angling catches and success rates dropped sharply after the mid 1970's and the fishery has been closed since 1980 in an attempt to restore kokanee populations (see above). Angling effort and catches on kokanee in the south and west arms increased following the west arm declines (Figure 27) due partly to liberal daily limits (15), but have also shown significant declines since the mid-1980's.

Non-Gerrard strain rainbow trout in Kootenay Lake are fished from July through September. Anglers fish the stream deltas along the shoreline for small rainbows, while fly fishing in late summer takes place along the south arm shorelines. Most fishermen troll the lake with heavy tackle for rainbow and bull trout. Catch rates for such fishing is relatively low - 40-50 hours per fish (Andrusak 1986). Angling for Gerrard rainbow trout is done mainly in fall in the north arm, and from fall through spring in the south arm. North and south arm trout fisheries have declined through the 1980's, while the west arm fishery declined sharply (Figure 28) due to the declines in kokanee numbers (prey species as well as target species for angling). Prior to this period a west arm rainbow trout fly fishery was popular with sport anglers.

Unlike other sport fisheries in B.C., bull trout are actively sought by anglers on Kootenay lake, and can grow to 15 kg in size. Management effort on bull trout has been relatively limited to date, and has consisted of some stocking of major tributaries such as the Kaslo River (Andrusak 1986). Unlike many other stocks in the lake, bull trout effort and catches have increased in the south arm in recent years, although they have declined slightly in the north arm (Figure 29). Trends in bull trout catches and effort are not well defined due to high inter-annual variability.

Mountain whitefish are abundant in Kootenay Lake and were taken in large numbers in the 1950's and 1960's (Figure 30). Angling effort and catches declined very markedly in the early 1970's due to an overall decline in angling interest due to economic conditions in the region and province. These parameters have remained at relatively low levels due to the declines in the general sport fishery in the lake. Whitefish are mainly incidental species in angling catches.

Burbot were actively fished in west arm by a small number of anglers. Catches are thought to have declined since the inception of the Libby dam and a reduction in peak flows though the west arm (Andrusak 1986).

Downstream

See Upper Bonnington.

UPPER BONNINGTON

PROJECT

Description

Upper Bonnington Dam is situated in the Kootenay River approximately 2 km below Corra Linn (Map A) and is a concrete gravity dam, 330 m wide and 6 m high. The dam is equipped with a gated concrete spillway of 6400 m^3/s capacity. There is no provision for storage behind the dam. The main generating plant on the left bank has a total nameplate capacity of about 63 MW, while the city of Nelson maintains a small power plant on the right bank. Upper Bonnington was built by Cominco in 1908, was rebuilt in 1940, and is presently operated as part of the West Kootenay Power System.

Water Licences and Operational Constraints

The initial water licence for a maximum diversion of 40 m^3/s (1400 cfs) was issued in 1897, and subsequent licences granted in 1905 and 1937 to total 383 m^3/s (13,514 cfs). The City of Nelson is licensed to divert a maximum of 40 m^3/s (1428 cfs). No constraints or conditions of fisheries relevance apply to the licences.

Electrical Generation

Upper Bonnington operates as a run-of-river plant at 35 to 60 percent of capacity throughout the year. Turbine discharges parallel those from Corra Linn and are highest in June and July. Upper Bonnington contributes approximately 5 percent (range 4-7 percent) of West Kootenay Power's total monthly generation.

Enhancement Facilities

No fisheries mitigation or compensation measures were requested nor provided for the development.

OPERATIONAL REGIME

Upper Bonnington has minimal storage capacity and a small volume, hence small changes in daily or periodic storage translate into relatively large changes in vertical water elevation. It is operated as a run-of-river reservoir. All flows released through Corra Linn are passed directly through the Bonnington and South Slocan plants.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Water levels in the Upper Bonnington reservoir below Corra Linn fluctuate over a 5 m range during the year (West Kootenay Power, operations data). Lowest levels occur in March and April, and highest levels in May and June. The present volumes and depths of the reservoirs are not recorded but water residence times are probably less than a day due to the limited storage.

No limnological data are available for Upper Bonnington reservoir. Routinely collected samples in Kootenay Lake, above Corra Linn from 1985 to 1988 indicated that water entering the Bonnington reservoir had a pH of 8.0 (range 7.7 - 8.4), filterable residue of 88.7 mg/l (68-100), specific conductivity 152 μmhos/cm (124 - 180), total nitrogen 0.08 mg/l (0.01 - 0.18) and total phosphorus 0.006 mg/l (0.003 - 0.01) (R. Crozier, Waste Management Branch, pers. com.). Dissolved oxygen content of west arm lake water presently ranges from 8.5 to 15.0 mg/l (Crozier and Duncan 1984). Routine sampling from 1972 through 1977 (Water Investigations Branch 1979) found 44 percent of samples in the lower Kootenay River below Corra Linn reservoir (i.e. including all reservoirs in the lower Kootenay system) to be supersaturated with dissolved gases at concentrations of 110 to 120 percent, and another 44 percent to be saturated at 120 to 140 percent. Minor symptoms of gas bubble disease have been found in squawfish in Brilliant reservoir (Clark 1977), and the condition is probably prevalent throughout all the lower Kootenay reservoirs.

Downstream System

See Corra Linn, Upper Bonnington, Lower Bonnington and South Slocan.

SPORT FISH POPULATIONS

No inventory data are available. The reservoir was stocked with 10,000 rainbow trout fingerlings in 1972.

RECREATIONAL FISHERY

No data are available. Recreational use of the Bonnington reservoir is very limited due to the availability of high class sport fisheries in nearby Kootenay Lake and elsewhere in the West Kootenay region.

LOWER BONNINGTON

PROJECT

Description

Lower Bonnington Dam is located less than 1 km below Upper Bonnington (Map A) and is a similarly constructed concrete gravity dam 180 m wide and 11 m high. The dam is equipped with an ungated spillway of 5700 m^3/s capacity. There is no provision for storage behind the dam. The generating plant has a nameplate capacity of 47 MW. The project was built by West Kootenay Power and Light in 1924-25 and refurbished in 1963.

Water Licences and Operational Constraints

The initial water licence for a maximum diversion of 40 m^3/s (1400 cfs) was issued in 1897. The main licence covering the hydroelectric development was issued in 1927 for an additional 255 m^3/s (9000 cfs). No constraints or constraints related to fisheries were appended to the licences.

Electrical Generation

Lower Bonnington operates in the same mode as Upper Bonnington and provides approximately 5 percent (range 4-9 percent) of West Kootenay Power's total monthly output.

Enhancement Facilities

As for Upper Bonnington.

OPERATIONAL REGIME

As for Upper Bonnington.

PHYSICAL AND CHEMICAL ENVIRONMENT

As for Upper Bonnington.

Reservoir

As for Upper Bonnington.

Downstream System

As for Upper Bonnington.

SPORT FISH POPULATIONS

As for Upper Bonnington.

RECREATIONAL FISHERY

As for Upper Bonnington.

SOUTH SLOCAN

PROJECT

Description

South Slocan project is located 1.5 km below Lower Bonnington Dam (Map A) and consists of a total concrete gravity dam 21 m high and 552 m total width (multiple sections). The dam is provided with an ungated spillway on a separate channel of 6100 m^3/s capacity. The generating plant has a nameplate capacity of 47 MW. The project was completed by Cominco in 1928 and is now part of the West Kootenay Power system.

Water Licences and Operational Constraints

The water licence, first issued in 1939 and amended several times thereafter, permits a maximum diversion of 306 m^3/s (10,000 cfs). No provision was made for water storage. No constraints related to fisheries were appended to the licence.

unknown. The very low proportions of sport fish present (see above) and the availability of better angling in nearby Kootenay and Arrow lakes results in very low angling interest in the lower Kootenay reservoirs.

Downstream System

As for the lower Columbia below Keenleyside Dam (see Keenlyside).

C. PEACE RIVER SYSTEM

PORTAGE MOUNTAIN
(W.A.C. Bennett Dam)
(G.M. Shrum Generating Station)
(Williston Lake)

PROJECT

Description

The W.A.C. Bennett Dam, a 183 m high 2134 m long concrete and earth fill dam on the Peace River at Portage Mountain (Map B), is the second highest dam in B.C., (after Mica) and impounds the largest body of fresh water in B.C. (and one of the largest in North America). The dam has one ungated 850 m long concrete spillway terminating in a flip bucket. There are no sluices or fishways. The G.M. Shrum powerhouse is located at the base of the dam and has a nameplate capacity of 2146 MW, the largest in B.C. The project was completed in 1967 and the impoundment (Williston Lake) reached the maximum permissible operating level for the first time in 1972. The project is owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

Two conditional water licences issued in 1962 permit storage of a maximum of 39 billion m^3 water and a maximum diversion of 1650 m^3/s. The maximum permissible operating level was initially set at 670.6 m and was changed in 1972 to 672 m. In 1987 B.C. Hydro proposed an increase in the maximum allowable operating level - this is under consideration by the Water Rights Comptroller.

A series of conditions pertain to the amounts of water released from the reservoir. These cannot be less than 28 m^3/s (1000 cfs) at any time. Releases from December through March have to be equal to the natural inflows, and for the rest of the year the lesser of 283 m^3/s (10,000 cfs) or the natural flow. For the purposes of licence compliance, downstream discharges are gauged at Hudson Hope from 16 July through 15 September, and at Taylor for the remainder of the year. A number of clauses in the water licence relate to fisheries and environmental concerns:

- the reservoir was to be cleared (pre-impoundment); clearing was limited to a navigational channel only; nearly 5 percent of the reservoir was covered with floating debris and snags following filling (Barrett and Halsey 1985); B.C. Hydro elected to clear the debris following reservoir formation and this process has taken place over a period of some 15 years);
- public access to the reservoir was to be provided;
- \$10,000 was to be made available to the Department of Recreation and Conservation to conduct a study and report on protection measures for fisheries and wildlife (the use of these funds is not documented but may have contributed in part to reports by Barrett and Halsey (1985) and Bruce and Starr (1985));
- B.C. Hydro was to undertake and complete remedial measures for fisheries and wildlife protection (sic) as directed by the Comptroller of Water Rights (a 5-year \$10 million compensation program was initiated in 1989 in fulfilment of this requirement).

Electrical Generation

Over the sample period 1984 through 1987, the G.M. Shrum plant produced from 256 million to 1.8 billion kWH of electricity monthly, at capacities ranging from 15 to 100 percent. Monthly electrical production constituted from 23 to 41 percent of B.C. Hydro's total output.

Enhancement Facilities

No specific compensation or enhancement measures were undertaken until the mid 1980's when boat launches and shoreline recreational sites were developed in Dunlevy Provincial Park and near Mackenzie. A comprehensive program which includes fisheries studies and potential enhancement measures was initiated in 1988. As part of this program 22,000 rainbow trout fingerlings were stocked into two small regional lakes in 1989 (B.C. Hydro, pers. com.)

OPERATIONAL REGIME

G.M. Shrum generating plant provides a large proportion of B.C. Hydro's daily production. Output varies in response to demand, which varies according to diurnal, seasonal and annual load requirements, and system efficiency requirements which are affected by water (snow pack) availability. Attempts are made to limit spillage to the absolute minimum, but this is not always possible under uncertain seasonal inflows and outputs (Figure 34). Drawdown over the period 1984-1987 averaged about 11 m per year, with maximum drawdown being timed for the commencement of the freshet (Figure 35). Under the present operating regime, live storage is about 20 percent of total reservoir volume (Figure 35). The reservoir reached maximum permissible operating limit only once in the 1984-1987 period, spilling a total of 7 percent of total volume.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

No habitat inventories or surveys were made of the watershed prior to project development. Tributary streams on the east side of the reservoir have low gradients (2 percent) near the mouths (B.C. Hydro 1988a) and sections of these were lost by inundation, while some sections with steeper gradients (4 - 7 percent) at high elevations remained above the maximum flood line. West side streams are not as steep (1-2 percent, B.C. Hydro 1988a). Streams on the east side of the Parsnip reach lost productive spawning, rearing and overwintering habitats (Bruce and Starr 1985). The Mesilinka and Ingenika rivers on the west side have low gradients and have retained high spawning and rearing potential for Arctic grayling, mountain whitefish, bull trout and lake whitefish (B.C. Hydro 1988a). The Finlay River appears to be providing habitat for bull trout, Arctic grayling, rainbow trout and mountain whitefish (Bruce and Starr 1985); low gradient reaches in the Finlay were flooded (B.C. Hydro 1988a). The Parsnip, Ingenika and Ominika rivers are presently the only systems known to provide lake whitefish spawning habitat (Bruce and Starr 1985). The Parsnip tributaries (507 km) and Finlay tributaries (261 km) provide relatively abundant spawning potential, while the Peace reach tributaries have much less potential (67 km). Many of the smaller streams have poor substrates for spawning (B.C. Hydro 1988a).

Williston Lake has a surface area of 117,870 ha (B.C. Hydro 1988a), a shoreline perimeter of about 1770 km (B.C. Research 1977) and a mean depth of 44 m. The three main arms correspond to the inundated river systems - Peace, Finlay and Parsnip (Map B). More detailed descriptions of the watershed characteristics and reservoir morphometry are given by Barrett and Halsey (1985).

The reservoir is dimictic and totally ice covered in winter. The water column is isothermal in winter with all sub-surface temperatures less than 1.3° C (B.C. Research 1977). Summer surface water temperatures rarely exceed 15° C, and the reservoir forebay becomes thermally stratified by July-September with the bottom temperature near 4° C. Oxygen levels throughout the water column are usually close to saturation, and there were no signs of decomposition in 1975-76 (despite the abundance of flooded debris). The reservoir is alkaline, has low to moderate total dissolved solids content, and can be classified as oligotrophic or even ultra-oligotrophic because of low nitrogen and phosphorus in all seasons (B.C. Research 1977). There is little or no variation in nutrient concentrations either seasonally or in each of the three main arms, and nutrient overturn is low within the water column. Primary production is dominated by diatoms. Zooplankton populations were dominated by lacustrine copepods in earlier samples (B.C. Research 1977) but by cladocerans (*Daphnia* spp.) in later studies (B.C. Hydro 1988a). All levels of biological activity are low, particularly at depth. The drawdown region was found to be particularly non-productive (B.C. Research 1975). The flushing rate has been cited as 2.2 years (B.C. Research 1977), however, based on 1984-1987 data (B.C. Hydro operations data) the turnover rate is calculated to be about 19 months.

Downstream System

The W.A.C. Bennett Dam presently discharges directly into Dinosaur Lake above Peace Canyon Dam (see Peace Canyon).

SPORT FISH POPULATIONS

Reservoir

Pre-impoundment surveys of the Peace River and tributaries prior to impoundment were cursory (Withler 1959) and did not quantify the amounts and quality of tributary habitat either existing or lost by inundation, or the numbers and distribution of the important fish species. Sport fish species collected during sampling included rainbow trout, mountain whitefish, lake whitefish, lake trout, Arctic grayling and ling (burbot) (Withler 1959). Arctic grayling, mountain whitefish, rainbow trout and bull trout probably preferred the steeper gradient reaches of tributaries even prior to reservoir formation (B.C. Hydro 1988a). Most juveniles probably rear in the lake due to the extensive littoral zones, but the extensive drawdowns and siltation limit lake rearing potential (Bruce and Starr 1985).

The present fish stocks of the reservoir and tributaries have not been studied in detail - this is the main intent of the first phase of the Williston fishery compensation program (B.C. Hydro, pers. com.). Surveys in 1974 and 1975 (Bruce and Starr 1985, Barrett and Halsey 1985) captured the same 14 species present in pre-impoundment surveys and found large numbers of lake whitefish in the Peace arm. Sport fish now comprise 14 percent of total fish populations whereas in 1974/75 the proportion was 24 percent (B.C. Hydro, pers. com.). Lake whitefish are still the most numerous sport fish in Williston lake, but are small in size (< 300 gm). Kokanee have colonized Williston Lake extensively since impoundment, most likely from the Parsnip River system (B.C. Hydro, pers. com.). They have since moved though the lake to the downstream reaches (see Peace Canyon). Bull trout are relatively abundant, but Arctic grayling and mountain whitefish have virtually disappeared from the lake, while rainbow trout have been reduced to 40 percent of 1974/75 levels. There is probably competition between lake and stream stocks for available stream spawning habitat (Barrett and Halsey 1985).

Downstream System

See Peace Canyon.

RECREATIONAL FISHERY

Reservoir

No creel data are available for Williston Lake and its tributaries. Angler reports are the best available source of current information on the recreational fishery (Fisheries Branch, pers. com.). Williston lake is important regionally for the recreational fishery because of the scarcity of suitable lakes in the Peace River region. Most sport fishing takes place on the east side of the lake. Bull trout are sought by anglers but the take of large fish has declined. Overall angling success rates have declined in the 1980's compared to the previous decades. The rainbow trout fishery now is mainly restricted to the lower Peace Reach and a few tributary streams, but localized fisheries are available at a few sites on the reservoir (e.g. near Mackenzie). Catches of kokanee are increasing. Indian sustenance fishing takes place in some reaches but the extent and catches have not been quantified.

Downstream System

See Peace Canyon.

PEACE CANYON
(Dinosaur Lake)

PROJECT

Description

Peace Canyon (previously known as Site One) is a 46 m high concrete dam located 21 km below W.A.C. Bennett Dam (Map B). The dam is provided with six gated spillways. There are no fish passage facilities. The powerplant located at the base of the dam has a nameplate capacity of 700 MW. The dam was constructed by B.C. Hydro from 1975 through 1979 and the reservoir reached full pool in mid-1979.

Water Licences and Operational Constraints

The conditional water licence issued in 1974 allows for diversion up to 1980 m^3/s; no storage is specified. Three clauses in the licence relate to fisheries and environmental issues:

- the flooded area was to be cleared;
- public recreational facilities were to be provided;
- B.C. Hydro was to implement programs for the protection and enhancement of fish (and wildlife) habitat in consultation with the Department of Recreation and Conservation.

Electrical Generation

Peace Canyon produced from 60 to 442 million kWH monthly from 1984 through 1987, at capacities ranging from 12 to 88 percent. The plant produced from 1.5 to 11.5 percent of B.C. Hydro's total monthly output.

Enhancement Facilities

An access road and boat launching ramps were built in compliance with an order attached to the water licence. Further development of campgrounds and public recreational sites could be provided if public use eventually justifies them.

A 1980 order to the water licence plus subsequent agreements between B.C. Hydro and the Ministry of Environment led to the construction and operation of a 50,000 capacity rainbow trout pilot hatchery for stocking of Dinosaur Lake. The performance of the hatchery and stocking program was evaluated over a 3-year period (see Sport Fish Populations: *Reservoir*) and found to provide negative net present values. Despite disagreement on the magnitude of the negative values (Ministry of Environment 1987), B.C. Hydro and the Ministry agreed to terminate hatchery operations in 1989, pending further compensation associated with Peace Canyon hydroelectric development. Rainbow trout fingerlings are now stocked to Dinosaur Lake from southern hatchery sources.

OPERATIONAL REGIME

Peace Canyon operates purely as a run of river project, using the extensive storage of the upstream Williston Lake. Turbine and spill discharges (Figure 36) closely match those of W.A.C. Bennett Dam (but at a much lower head). Reservoir volume fluctuates over a very small range, and the average drawdown recorded from 1984 through 1987 was 0.5 m (Figure 37).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Dinosaur Lake is a long and narrow reservoir with a maximum surface area of 805 ha, and confined for much of its length to steep-sided valley walls. Low-gradient areas are restricted to the vicinities of the large tributaries such as Johnson and Gething creeks. Discharges of the inflowing tributaries average less than 1 percent of total annual reservoir inflows (B.C. Hydro, operations control data). The mean water retention time is 3.8 days.

Johnson Creek was considered the major pre-impoundment spawning and rearing area for rainbow trout, although it was subjected to siltation by logging activities (Ash 1976a,b). About 35 percent of Johnson and Gething creeks was lost to fish use by inundation (Wightman and Taylor 1978). Johnson Creek is the only tributary providing natural spawning habitat to Dinosaur Lake. No fish were found in Johnson Creek immediately following break-up (Hammond 1986) which casts doubt on its overwintering value. The only other noteworthy pre-impoundment spawning area was the terminal 1 km of Gething Creek which provided the only identified spawning area for bull trout (Ash 1976b). Tributary streams have widely fluctuating flows, heavy sedimentation of spawning substrates and short accessible lengths relative to their watershed areas (Wightman and Taylor 1978). The mainstem Peace River constituted poor fish spawning habitat due to siltation and severe water fluctuations from the Bennett Dam (Ash 1976b).

No detailed limnological studies have been made of the reservoir. Because of its morphometry and very short retention time, the reservoir is very likely well-mixed and the chemical and physical characteristics probably closely approximate those of Williston Lake above it, i.e. oligotrophic, slightly alkaline, oxygen saturated throughout the water column, temperatures ranging from 1-4° C in winter to about 15° C in summer, and with low total dissolved solids content. Dissolved gas concentrations have not been monitored; signs of gas embolism have been noticed in netted fish in Dinosaur Lake (Hammond 1986).

Copepods were observed to be passed from Williston lake prior to impoundment (Ash 1976b) and were intensively utilized as a food source by rainbow trout and other fish species congregating in the Bennett Dam tailrace. Sampling in Dinosaur lake in 1983 and 1984 (Hammond 1984, 1986) confirmed the passage of copepod zooplankton though the Bennett Dam; numbers increased sharply following spills. The larger zooplankton are heavily cropped by fish, especially rainbow trout (Hammond 1986).

Downstream System

Below Peace Canyon Dam the Peace River is confined to a deeply incised valley to 6 km wide and 180 to 250 m deep (Farstad et al. 1965). The stream banks are unstable and actively eroding, with frequent slumping and sliding. The river gradually changes from a single channel to a braided system with numerous islands. The water quality of the system is characterized by adequate dissolved oxygen and high turbidity which increases with increasing distance from the Peace Canyon Dam because of increased proportion of tributary inflows (Renewable Resources Ltd 1979). The mainstem river has higher water temperatures in the winter and lower temperatures in the summer than the tributaries because of the hypolimnetic withdrawals from Williston Lake which are routed through Dinosaur Lake. Maximum daily and monthly mean flows below Peace Canyon were strongly curtailed by W.A.C. Bennett Dam in 1968, while minimum daily and monthly flows were increased 2- to 4-fold (Figure 38). The mean annual flow was depressed for a period of 4 years following the closing of W.A.C. Bennett Dam in 1968 and for 1 year following the closing of Peace Canyon Dam in 1979 (Figure 38).

Many potential habitats in the mainstem and in the tributaries are affected by sedimentation resulting from natural erosion along the tributary stream banks. Filamentous algae occur sporadically in the lower Peace river. Chironomids are the dominant zoobenthic forms, followed by mayflies and stoneflies.

SPORT FISH POPULATIONS

Reservoir

The Peace River and associated tributaries below W.A.C. Bennett Dam were studied from 1973 through 1975 prior to Peace Canyon impoundment (Ash 1976a, 1976b). Rainbow trout was the most abundant sport fish species (36 percent occurrence, based on gill netting and angling), followed by lake whitefish (29 percent), mountain whitefish (14 percent), bull trout (5 percent), Arctic grayling (4 percent) and northern pike (2 percent). Longnose suckers were the most common coarse fish. Rainbow trout and Arctic grayling were noted to move up the Peace River reach for spawning and/or feeding and to congregate in the Bennett dam tailrace (Ash 1976a, 1976b).

A pilot hatchery, established at the reservoir as part of the water licence commitment, produced 350,000 rainbow trout for Dinosaur lake stocking from 1981 through 1986 (B.C. Hydro, pers. com.). Gill netting, undertaken as part of the program evaluation (Hammond 1984, 1986), indicated that rainbow trout (44 percent), lake whitefish (32 percent), mountain whitefish (14 percent) bull trout (8 percent), and kokanee (2 percent) to be the most common species (5 years after reservoir filling). About 30 percent of the rainbow trout were of hatchery origin. Also present in small numbers were Arctic grayling, burbot, suckers and other coarse fish. Hatchery bred rainbow trout matured at age 3 and were found not to repeat spawn (Hammond 1986). The oldest rainbow trout in the lake were 6+. Similar growth rates were measured for hatchery and wild stocks. Fish entrained out of Dinosaur Lake may entail a loss in Dinosaur Lake stocks (Hammond 1986), but there may also be significant recruitment from Williston Lake.

Downstream System

The fishery resources of the Peace River below Peace Canyon Dam were studied (Thurber Ltd 1976, Renewable Resources Ltd. 1979) as part of an impact assessment for the proposed Site C dam, 81 km below Peace Canyon Dam. Based on seining, gill-netting and electroshocking, 9 sport fish and 17 coarse fish species were found to occur in the lower Peace system. Mountain whitefish were the most abundant sport fish species, followed by arctic grayling, rainbow trout, bull trout, northern pike and walleye. Longnose- and large-scale suckers were the most common non-sport fish species. The lower sections of Maurice and Lynx creeks were the only sites located within the 80 km reach below Peace Canyon which were used by spawning rainbow trout, although resident populations of rainbow trout were found to occur in Brenot and Farrell creeks and the upper Halfway River. Arctic grayling spawned in Maurice, Lynx and Farrell creeks as well as in the Moberly and Halfway rivers, and possibly in the mainstem Peace River. Mountain whitefish spawned in the Moberly and Halfway rivers as well as on the mainstem Peace River. The location of bull trout spawning habitats was not determined, but was suspected to be the Halfway River. A more detailed study of the fish populations in these tributaries is currently under way (B.C. Hydro, pers. com.).

RECREATIONAL FISHERY

Reservoir

The Peace River below Williston was relatively heavily used by anglers prior to Peace Canyon development, although creel data were not routinely collected. The mainstem river appears to have been used in preference to tributary mouths (Fisheries Branch, pers. com.). A major attraction for anglers was the Bennett dam tailrace where most rainbow trout were caught (e.g. 264 of 274 trout caught in 1974 (Ash 1976a); this area is now closed to angling. The extent of sport fishing in the reach prior to Bennett dam construction is not documented.

Recreational angling in Dinosaur lake following project completion was relatively intense. Two reasons for this were the absence of better angling in the lake-poor Peace River region, and the presence of the pilot hatchery at the dam site. In 1984 4702 anglers fished for 13,470 hours on Dinosaur Lake, but success was relatively poor at 0.3 to 1.66 fish/angler per day (Hammond 1986). About 60 percent of harvested rainbow trout were of hatchery origin. Anglers removed an estimated 20-28 percent of the total rainbow trout (wild + hatchery) population in the reservoir in 1984.

Downstream System

Sport fishing in the Peace River below Peace Canyon Dam was last studied in 1979 as part of the impact assessment for the proposed Site C dam (Renewable Resources Ltd. 1979). In 1978 anglers were predominantly local residents of the area, and rated the quality of angling as good, although they concentrated heavily on the tailwater areas below Peace Canyon Dam. Mountain whitefish were the species most commonly taken. Walleye and arctic grayling were frequently caught but in much smaller numbers, and rainbow and bull trout were relatively scarce in creels. In 1978 angling use of the 80 km reach below Peace Canyon Dam and the larger tributaries such as the Halfway, Pine and Beatton rivers was estimated to be 10,500 angling-days per year (excluding the use made by construction workers at Peace Canyon at that time).

D. FRASER RIVER SYSTEM

SHUSWAP RIVER
(Peers Dam)
(Sugar Lake)
(Wilsey Dam)
(Shuswap Falls Power Plant)

PROJECT

Description

The project was constructed by the West Canadian Hydroelectric Corporation in 1929, and consists of a 13 m high, 98 m long, concrete dam (Peers Dam) at Brenda Falls which is the outlet of Sugar Lake, and the Wilsey Dam located 31 km further downstream which supplies Shuswap Falls generating station (Map A). Peers Dam has an ungated spillway provided with stop logs, plus four gated sluices to control discharge. There is no powerhouse at Peers Dam.

Wilsey Dam is a concrete arch structure 30 m high and 40 m long, and was designed as a run of river project for the minimum historical discharge of about 15 m^3/s. Retention behind the dam is limited to a small headpond with storage of 154 million m^3 and a drawdown of more than 8 m. Wooden stave penstocks supply the powerhouse which had a nameplate capacity of 1.7 MW when built and was enlarged to 5.2 MW in 1942. The dams and powerplant are presently owned and operated by B.C. Hydro

Water Licences and Operational Constraints

The water licence for the initial development permitted maximum storage in Sugar Lake of 24.7 million m^3, and diversion at the Wilsey Dam of 10 m^3/s (350 cfs) for power generation. Following plant refurbishment in 1942 the allowable storage was increased to 123.4 million m^3 and the allowable diversion to 14 m^3/s (500 cfs). There are no provisions in the licences for releases or control for fishery purposes.

Electrical Generation

The amount of power generated at Shuswap Falls varies considerably. Between January 1984 and June 1987 monthly generation ranged from about 1.1 million kWH (28 percent capacity) to 4.7 million kWH (120 percent of nameplate capacity), with a monthly contribution of 0.1 percent or less to the B.C. Hydro integrated hydroelectric grid system.

Enhancement Facilities

No fisheries enhancement facilities were developed by the utilities who have owned and operated the Shuswap plant. A pilot hatchery was built by DFO in 1984 and an experimental facility was completed in 1986 (Rosberg and MacKinlay 1987). The 1987 and 1988 stocking programs for the middle and lower Shuswap tributaries were based on provision of chinook, coho and rainbow trout from the hatchery. B.C. Hydro has indicated concerns for potential conflicts between the developing program and the power plant, i.e. passage of juveniles through the powerhouse and adults returning to the tail-race (DFO 1982).

A fish ladder was proposed for the Sugar Lake dam when the Shuswap Falls plant was built (1929) but was apparently not carried through because of lack of funds and general disinterest at the time (Starr 1978). Sugar Lake was not cleared prior to impoundment in 1929, and large amounts of debris still remain in the lake. B.C. Hydro has a program of debris removal.

OPERATIONAL REGIME

Sugar Lake is utilized as storage for the Shuswap Falls power plant. However, Peers Dam does not provide full flow control (B.C. Hydro, Operations Control Department, pers. com.) and a large proportion of the annual freshet flows are discharged (Figure 39). Drawdowns are extensive and the lake is normally fully drafted by March of each year (Figure 40). Wilsey Dam provides little storage, and drawdowns and water level increases are rapid and extensive when the power plant operates. Shuswap Falls plant operates automatically, and shutdowns occur frequently due to overloads and occasional mechanical and electrical problems.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Sugar Lake has a surface area of 2080 ha, a total littoral area of 480 ha, a mean depth of 35 m and maximum depth of 83 m (Aquatic Studies Branch 1982). Mean water residence time is 6 months. The major tributaries are the upper Shuswap River (60 km) and Sitkum and Sugar creeks. Aquatic vegetation is abundant in the lake and includes *Ranunculus aquatilis*, *Potamogeton aquatilis*, *P. richardsonii* and *P. gramineus*; milfoil *Myriophyllum* spp. is absent (Aquatic Studies Branch 1982). The lake is oligotrophic with low total dissolved solids (45 mg/l), low conductance, low turbidity (Secchi disk readings to 10 m), high dissolved oxygen (10-11 mg/l) at all levels, and water temperatures ranging from 2 to 18° C (Ministry of Environment, lake survey data).

Downstream System

Monthly and daily releases from Sugar Lake (Figure 39) show considerable variation, typical of a plant used for short-term or peaking power production. The high variability in water releases through Peers Dam leads to high variability in wetted areas, flow velocities and other habitat parameters along the 32 km reach between Peers and Wilsey dams.

Pre- and post-impoundment data for the WSC gauging station below Shuswap Falls (Figures 41 and 42) show that mean maximum monthly discharges from January through March have been increased by about 50 percent through releases of water from Sugar lake. Monthly mean and minimum discharges have been unaffected, typical of a small run of river plant with limited headpond storage.

Short-term flows in the Shuswap River are significantly affected by sudden plant shutdowns.

The 15.2 km reach from Sugar Lake to the Cherry Creek confluence has a moderately high gradient (0.6 percent) and a confined channel. Habitats are composed mainly of fast riffles and runs. Mean surface velocities exceed 1.0 m/s, and 23 percent of the area is usable by salmonid juveniles during low flows. Only the stream margins appear usable at higher flows. The 13.1 km reach below the Cherry Creek confluence has transitional gradients and the channel is moderately confined with a small number of side channels which provide the most important rearing habitat. Stream side cover is good. The reaches are used extensively by rainbow trout (Fee and Jong 1984). The 3.7 km reach above Wilsey dam is a low canyon and is subject to back flooding from the headpond. About 50 percent of the reach is deep pools and glides, and most of it is silted due to the low current velocities.

The 19.1 km reach below Wilsey Dam is wide and unconfined. Habitats are complex because of stream instability, and there are extensive side-channel habitats. About 73 percent of the side channel areas have velocities <0.4 m/s suitable for juvenile salmonid rearing. The extensive gravels are rated as good spawning habitat for kokanee, chinook, coho and sockeye (Fee and Jong 1984). The 4 km reach above the Mabel Lake inflow has very low gradients (0.07 percent), extensive uniform meandering glides, very fine substrates and no pools, and is generally unsuitable for spawning, adult holding or rearing.

Shuswap River water pH ranges from 7.5-7.9, has low specific conductivity, hardness, nitrite/nitrates and dissolved nitrogen, and moderate levels of total phosphate (Fee and Jong 1984). Mean water temperatures in July are about 15.5° C, and 10.5° C in September.

SPORT FISH POPULATIONS

Reservoir

Detailed studies of Sugar lake fish populations have not been made, and only general information is available from lake surveys (Ministry of Environment, lake survey data; Aquatic Studies Branch 1982) and from angler reports (Ministry of Environment 1983). Suckers and redside shiners are the dominant species. Sport fish species include rainbow trout, bull trout, mountain whitefish, kokanee and burbot. The upper Shuswap River contains resident rainbow, cutthroat and bull trout and mountain whitefish, while bull trout are know to spawn in Sitkum Creek (Ministry of Environment 1983).

Downstream System

The dominant sport fish in the middle Shuswap system is mountain whitefish (Fee and Jong 1984); densities have been estimated (swimming surveys) at 13 - 152 fish/km (Griffith 1979). Rainbow trout are comparatively scarce (0 - 12 fish per km). Estimated total fish biomass in the Shuswap is relatively low (3.7 gm/m^2,) and suspected causes are a lack of high quality spawning habitats and a low to moderate benthic production in the high velocity sections (Griffith 1979).

Present salmon spawning areas in the middle Shuswap are limited to a 10 km section below Shuswap Falls (Brown et al. 1979a). Kokanee are reported as spawning throughout the 9 km reach below the dam, and much use is made of secondary channels (Bowman and Stewart 1984).

The middle Shuswap River below the falls supports 75,000 juvenile chinooks in July and 10,000 in September (Fee and Jong 1984). Chinook juveniles occur in low to moderate densities during moderate flows in July. Few chinook smolts are found in the middle Shuswap River (Bowman and Stewart 1984).

Chinook were introduced into the middle Shuswap above the Wilsey Dam in 1977 (Fee and Jong 1984). A pilot hatchery was built at Shuswap Falls in 1984 and an experimental facility completed in 1986 (Rosberg and MacKinlay 1987). The objective is to enhance chinook, coho and rainbow trout stocks throughout the Shuswap River system.

RECREATIONAL FISHERY

Reservoir

Angler use of Sugar Lake has been estimated at 10,000 days (in 1982, Ministry of Environment 1983). An earlier (1974) creel census indicated that kokanee comprised more than 90 percent of the catch, with rainbow trout (7 percent), bull trout (1 percent) and mountain whitefish (1 percent) making up the rest. Angler success rates are judged to be low (about 0.25 fish per rod-hour, Ministry of Environment 1983), and kokanee and rainbow trout caught are small (20 cm, 100 gm average). The west shore of Sugar Lake has road access for sport fishermen, and there are two resorts situated on the shoreline.

Downstream System

Angling pressure between the two dams has not been measured (Ministry of Environment 1983), but mountain whitefish is the principle species taken, along with smaller numbers of rainbow trout and bull trout.

LA JOIE
(Downton Lake)

PROJECT

Description

La Joie is the uppermost of two hydroelectric projects on the Bridge River (Map C). The La Joie Dam is an 87 m high, 1000 m long, earth fill dam located at La Joie Falls above the Hurley River confluence, and about 90 km above the Bridge River confluence with the Fraser River. The dam has an ungated spillway and two separate low level outlets equipped with Howell-Bunger valves. A generating plant below the dam has a nameplate capacity of 22 MW. The project was constructed in 1948, and redeveloped in 1957. Increasing the capacity of Downton Lake through diversion of Gun Creek and/or the Hurley River is currently being studied (B.C. Hydro, pers. com.).

Water Licences and Operational Constraints

The conditional water licences for the La Joie project, issued in 1927 and revised in 1949, permit storage of a maximum of 705 million m^3 and diversion of up to 42.5 m^3/s. There are no provisions for release of water for fisheries or other purposes.

Electrical Generation

La Joie generating plant is much smaller than the main Bridge River plants below Carpenter Lake (see Terzaghi Dam) and contributes from 10 to 15 million kWH monthly, about 0.3 to 0.5 percent of the total B.C. Hydro hydroelectric supply, and operates at a high capacity of 80 to 90 percent in most months.

Enhancement Facilities

No fisheries mitigation or compensation measures were offered nor sought for La Joie development. The reservoir area was not cleared of standing timber prior to filling.

OPERATIONAL REGIME

Downton Lake's available storage is used to the maximum extent possible for hydroelectric storage and release. Lake volume fluctuates regularly between 20 and 100 percent capacity (Figure 43) with a corresponding drawdown fluctuation. B.C. Hydro does not record spill frequency at La Joie Dam, but the regularity of the lake reaching 100 percent volume capacity (Figure 43) suggests that it occurs almost annually.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Downton Lake has a surface area of about 2400 ha, a maximum depth of 80 m and a mean depth of 30 m. Mean water residence time is 6.3 months. Drawdowns are very extensive, reaching 30 to 40 m in most years. No information is available on the physical and chemical characteristics, although they are probably similar to Carpenter Lake (see Terzaghi Dam).

Downstream System

A 5 km reach of the Bridge River separates La Joie Dam from the headwaters of Carpenter Lake (see Terzaghi Dam).

SPORT FISH POPULATIONS

Reservoir

No specific information available. Downton Lake is probably similar to Carpenter lake (see Terzaghi Dam).

Downstream System

See Terzaghi Dam.

RECREATIONAL FISHERY

Reservoir

As for Carpenter Lake (see Terzaghi Dam).

Downstream System

See Terzaghi Dam.

TERZAGHI DAM
(Bridge River Generating Plant)
(Carpenter Lake)

PROJECT

Description

Terzaghi Dam is located about 60 km downstream of La Joie Dam and 30 km above the Bridge river - Fraser river confluence (Map C). Terzaghi Dam is a 54 m high, 360 m long, earthfill structure with a gated concrete spillway and a small low-level outlet. There is no powerhouse at the dam site. Two separate 5 km tunnels lead water from the impoundment (Carpenter Lake) into Seton Lake through two powerhouses which together have a capacity of 428 MW. From Seton Lake the diverted water continues through the Seton Creek Generating Station. Terzaghi Dam was built in 1948 by the B.C. Electric Commission and raised in 1960 following reconstruction of the La Joie Dam. The project is presently owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The conditional water licences for the Terzaghi Dam and Bridge River plants permit a total diversion of 153 m^3/s and storage of up to 909 million m^3. There are no provisions for release of water for fisheries or other purposes. Requests from DFO and the Fisheries Branch for water releases through Terzaghi Dam over the years have been rejected by B.C. Hydro because of the perceived high costs of the foregone power generation and the lack of a suitable outlet for continuous flow releases in Terzaghi Dam (B.C. Hydro 1982c).

Electrical Generation

The Bridge River plants (Bridge 1 and 2) normally operate at 60 to 80 percent of their capacity from September through April, during which time they generate up to 260 million kWH per month. From May through August generation is cut back to much lower outputs. Monthly contributions to the B.C. Hydro hydroelectric grid range from 4 to 10 percent.

Enhancement Facilities

No fisheries mitigation or compensation measures were offered nor sought for the Bridge River developments. The reservoir areas were not cleared of standing timber prior to filling. Several community-based enhancement projects for coho (incubation boxes) are based in Lytton, and the Salmonid Enhancement Program (SEP) has examined the possibilities of enhancement for anadromous salmon stocks in the system on several occasions.

OPERATIONAL REGIME

The Bridge River plants supplied the bulk of the electrical power to the B.C. lower mainland prior to development of the Peace River projects, and still supply substantial proportions in the winter months (Figure 44). Carpenter Lake, along with the upstream Downton Lake, is used as a storage reservoir, which is somewhat unusual for a reservoir in tandem with another. Recorded spills are infrequent and of short duration and low magnitude at Terzaghi Dam (Figure 45). Reservoir operations are characterized by wide fluctuations in volume and annual drawdowns (Figure 46).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Carpenter Lake has a surface area of approximately 4900 ha, a maximum depth of 47 m, a mean depth of 23 m and a mean retention time of 3.8 months. The lake has a fairly extensive system of inflowing tributaries, the most important being Hurley, Gunn and La Joie creeks.

There do not appear to be any systematic water quality data for the Bridge reservoirs. A small number of samples, taken in 1988 as part of an assessment for a proposed mining operation in La Joie Creek, a tributary of Bridge River (Congress Operating Corporation 1988), indicate that the surface waters of Carpenter Lake are neutral to moderately alkaline (pH 6.8 - 7.9) with low dissolved (1 - 80 mg/l) and suspended (10-33 mg/l) solids content. Carpenter Lake is turbid during the high run-off periods in June when tributary inflows contain large amounts of suspended silts of glacial origin. Carpenter Lake waters have moderately low conductivity (76 - 89 μmhos/cm) and alkalinity (25 - 29 mg/l $CaCO_3$), while nitrate content appears to be low (nitrate as nitrogen content measured at high of 0.33 mg/l, most samples below detection limits), suggesting that the reservoirs are oligotrophic or even ultra- oligotrophic. Winter kill due to anaerobic conditions may occur in the reservoirs (Fisheries Branch, pers. com.).

Downstream System

Below Terzaghi Dam the Bridge River continues for about 10 km, fed only by small tributary streams, to the confluence with the Yalakom River, and then continues for another 20 km to join the Fraser River above Lillooet.

The WSC gauge at the Terzaghi Dam site was dismantled following completion of the dam in 1948, and only pre-impoundment flows are available (Figures 47 and 48). These indicate that the Bridge River had a very wide range in seasonal flows with a mean annual maximum discharge from 250 to 350 m^3/s and a mean annual minimum about 15 m^3/s. The year to year mean discharge was around 100 m^3/s and fairly consistent from year to year due to the wide elevational ranges within the Bridge River watershed (from glaciers to relatively low relief interior plains). Flows from July through October generally approximated the mean annual discharges of about 100 m^3/s, and minimum monthly discharges in this period were in the 30 to 150 m^3/s range. Mean minimum monthly winter flows in the lower reaches were of the order of 10 to 15 m^3/s.

La Joie and Terzaghi dams effectively retain inflows in most years, and spills from Terzaghi Dam to the lower Bridge River occur for short durations (1-5 days) in years of very high run-off only; this has occurred in 6 of the past 22 years (B.C. Hydro, Operations Control Department). Seepage water maintains a slight flow in the river below the dam, but this is considered inadequate for sport fish habitat maintenance (Fisheries Branch, pers. com.).

SPORT FISH POPULATIONS

Reservoir

Carpenter Lake contains populations of rainbow trout, Dolly Varden, kokanee and mountain whitefish (Fisheries Branch, Kamloops, data files), but these have neither been studied nor quantified. These populations probably make use of tributary streams for spawning and rearing. Observations have been made of Dolly Varden and kokanee spawning in lake tributaries in the area (Fisheries Branch, Kamloops, data files). Rainbow trout redds have been observed in La Joie and Gun creeks (Beniston 1988) which are tributary to Carpenter Lake. Good rearing and spawning habitat has been documented in low gradient portions of these and other creeks (Beniston 1988), although most tributary creeks appear to have high-gradient constrictions which might make upstream passage for spawners difficult. It is likely therefore that physical limitations constrain the amounts and quality of tributary stream habitat available to reservoir resident fish.

Downstream System

Juvenile salmonid sampling in Bridge River below Terzaghi Dam (Stewart and Matthew 1984) has recorded rainbow trout, Dolly Varden, mountain whitefish, sculpins and lampreys. Suggested spawning periods for sport fish in the system are March-June for rainbow trout, September through November for Dolly Varden, and late fall for mountain whitefish.

Detailed habitat inventories of the lower Bridge River have not been undertaken. Access to the mainstem river by anadromous salmon is restricted at low flows by the rapids in the river about 1 km and 4.5 km up from the mouth and the numerous debris blocks, e.g. 1 km below the Yalakom-Bridge confluence (DFO 1983). These same blockages could at times restrict resident sport fish movements. Both the Bridge and Yalakom rivers carry high silt loads derived from slides, outwashes, run-off from deforested areas, highway construction, placer mining operations and some glacial flour from higher elevations. Large areas within the channels of the Bridge and Yalakom rivers were impacted by placer mining (gold) operations dating from the previous century (DFO 1962), but present-day restrictions have considerably reduced these types of impacts to instream fish habitat (Fisheries Branch, pers. com.).

RECREATIONAL FISHERY

Reservoir

No angling data have been collected for Carpenter and Downton lakes, but recreational fishing is known to be very light (Fisheries Branch, pers. com.). Key reasons for this are the very poor angling conditions on the reservoirs due to the stumps and snags, the extensive drawdowns of the reservoirs, possible poor angling returns, and the availability of much superior recreational fishing opportunities on natural lakes in the area. Carpenter Lake was stocked with kokanee fingerlings in the past (555,000 in 1970, 326,000 in 1971 and 96,000 in 1973; Fisheries Branch, Kamloops, data files). There is no recorded information on the success of these measures. Present-day fishery management interest in the reservoirs is tempered by the poor angling conditions and the certainty of better management returns from regional lake enhancement and management (Fisheries Branch, pers. com.).

Downstream System

There is no recorded information on recreational fishing interest in the lower Bridge River, but it is probably minimal due to the very low flow conditions prevailing for most of the year. Tributary creeks probably offer more scenic opportunities. Of much greater concern within the Bridge River system is the impact of project development and operations on steelhead and other anadromous salmonids below the Terzaghi Dam (Hirst 1991).

SETON
(Seton Lake)

PROJECT

Description

The Seton Creek project consists of a 7.6 m high, 130 m long, concrete gravity dam located 0.6 km below the outlet of Seton Lake and approximately 4 km above the confluence of Seton Creek and the Fraser River (Map C). The dam is provided with a radial gate spillway, a siphon spillway, a power canal inlet, a fish water sluice of 12.5 m^3/s flow capacity, and a fishway with vertical baffles and an estimated capacity of about 1 m^3/s. Cayoosh Creek flows into Seton Creek about 1.4 km below Seton Dam and is itself impounded by a rock fill timber crib dam 5.8 m high and 250 m long. A 450 m concrete-lined diversion tunnel links the forebay of Cayoosh Creek dam to Seton Lake. A 4 km long concrete-lined power canal leads flows over Cayoosh Creek to a generating station, located on the right bank of the Fraser River about 1 km downstream from the Seton Creek - Fraser River confluence The generating station has a nameplate capacity of 42 MW. About 80 percent of the total discharges through the powerhouse originate from the Bridge River system (La Joie and Terzaghi Dam) via diversions into Seton Lake, the remainder being derived from local run-off into Seton Lake and seasonal diversions of water from Cayoosh Creek (since 1980). The project was commenced in late 1953 and was in service by 1956.

Water Licences and Operational Constraints

The conditional water licence in 1953 authorized the B.C. Electric Company to divert a maximum of 3.2 billion m^3 per annum. The water licence stipulates that the spill discharge at Seton Dam shall be maintained at 11.3 m^3/s (400 cfs) during adult sockeye migrations and at 5.7 m^3/s (200 cfs) at other times (or lesser amounts if so determined by the Minister of Fisheries). There are no provisions relating to non-anadromous fisheries.

Frequent and ongoing negotiations between B.C. Hydro, International Pacific Salmon Fisheries Commission (IPSFC) and DFO over the years have resulted in a set of operating recommendations to safeguard spawning and incubating pink salmon in Seton Creek, to permit efficient passage of adult sockeye into Seton Lake, and to facilitate passage of out-migrating sockeye smolts. Minimum permissible discharges over the spillway now vary from 5.7 to 11.3 m^3/s, depending on the presence of migrating salmon in the system, and maximum allowable discharges during spawning migrations are now limited to about 55 m^3/s (2000 cfs), except in emergencies. Constraints on minimum and maximum discharges were initially set on the basis of an approximation to natural flows, and have been fine-tuned over the years, based on observations of successful fish passage and spawning.

Electrical Generation

From 1984 through 1987 Seton produced from 4 to 30 million kWH of electricity per month, at capacities from 15 to 100 percent, and contributed from 0.1 to 1.2 percent of B.C. Hydro's total monthly output.

Enhancement Facilities

A 5000 m^2 spawning channel was constructed by the IPSFC below Seton Dam to compensate for pink salmon spawning habitat destroyed by inundation at the outlet of Seton Lake. The channel was used for the first time in

1961 and has since supported pink salmon spawning runs of 2500-22,000 on an odd-yearly cycle. A second 17,500 m^2 channel with a capacity of about 20,000 spawners was added in 1967 and has since been used to full capacity (40,000 in 1989) by pink salmon on an odd-yearly cycle. There are no enhancement facilities for non-anadromous fish.

OPERATIONAL REGIME

The operation of Seton relies mainly on storage in Carpenter and Downton lakes (see La Joie and Terzaghi Dam) since live storage in Seton Lake is restricted by the water licence. There is insufficient storage in the Bridge River - Seton/Anderson lakes system to permit continuous full operation of Seton, and the plant usually operates on a restricted daily schedule according to short-term load demands (Figure 49). During the winter months the plant operates at or near full capacity, but generation is cut back to 50 percent or less of capacity in other months.

Operation of the powerhouse in recent years has been modified in an attempt to meet the flow requirements of migrating sockeye salmon. To reduce the likelihood of spawners congregating at the tailrace and gaining entry to the draft tubes, the plant has been run at full load or else shut down completely during salmon migration periods (July to November depending on the run). Running at full load during juvenile downstream migrations is also permitted since there appears to be a high survival rate of fish passing through the turbines (B.C. Hydro, pers. com.).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Seton Lake is a natural glacial lake and is presently 2430 ha in extent, has an estimated mean depth of 97 m and a maximum depth of 151 m (Ministry of Environment, lake survey data). The change in lake elevation following construction of Seton Dam is not documented. Operation of the Bridge River and Seton plants produces minimal changes in lake levels (Figure 50).

The lake is oligotrophic with a total dissolved solids content of about 80 mg/l (Ministry of Environment, lake survey data). Temperature and total dissolved solids content of the lake decreased following diversion of Bridge River water into Seton Lake in 1948, while turbidity increased (Green and Andrew 1961). A dramatic reduction in zooplankton standing crops was attributed to a high flushing rate from the lake but may also indicate a high cropping rate by sockeye smolts which have a high productivity in Seton lake (M. Fretwell, DFO, pers. com.). A positive impact of damming Seton lake has been the colder water temperatures passing to the pink salmon spawning areas in Seton Creek (Geen and Andrew 1961).

Downstream System

Seton Creek below the dam is a low-gradient stream 4.5 km in length containing high quality spawning gravels and cobble and large amounts of glacially-derived silt. Two large spawning channels are located adjacent to the creek (see Project: *Enhancement Facilities*).

Present (post-impoundment) flows are made up of water released through the fishway, the fish water sluice (Figure 51) and through the spillway. Pre-impoundment flow data for Seton Creek were of very short duration; comparisons of pre- and post-impoundment flows (Figures 52 and 53) indicate that the long-term mean annual regulated flow may be similar to that which existed under pre-impoundment conditions, but variability has increased. Peak flows have increased by up to 40 percent due to sudden discharges over the spillways and through the radial gates. The maximum permissible diversion down the power canal is about 110 m^3/s (4000 cfs), and live storage within Seton lake is limited by provisions in the water licence. Mean minimum monthly flows appear relatively unchanged due to the minimum flow restrictions contained in the water licences and required in annual operating constraints recommended by DFO.

Cayoosh Creek drains Duffey Lake and is more precipitous than Seton Creek. A major barrier restricts fish movements between the upper reaches and lower 3 km section. Flows in Cayoosh Creek typically range from 4 to 83 m^3/s and are significantly higher in conductivity, turbidity, alkalinity, hardness, calcium, sulphate and fluoride than Seton Lake water (Fretwell 1980). Cayoosh Creek inflows dilute Seton Creek discharges and make them less attractive to migrating sockeye than the tailrace discharges which draw on pure Seton lake water and which are encountered first by Gates and Portage creek's salmon moving up the Fraser River. This was identified as a major cause for sockeye delays at the tailrace in the years following project completion (International Pacific Salmon Fisheries Commission 1976). In 1979 a temporary gravel and cobble diversion tunnel was built across Cayoosh Creek and all flows less than 7 m^3/s were diverted into Seton Lake via the reopened diversion tunnel (Fretwell 1980). This procedure has been repeated on an experimental basis until the present and has become an important management strategy to avert sockeye delays at the powerhouse tailrace, although the annual construction and removal of the dam causes sedimentation of habitats in lower Cayoosh and Seton creeks. Cayoosh Creek is much colder than Seton Creek (Fretwell 1980) and temperatures of the Seton creek outflow depend on the relative mix of the two sources.

SPORT FISH POPULATIONS

Reservoir

Seton Lake has received little attention from anglers or fisheries management because of more important resources in smaller, more productive lakes in the region. Rainbow trout are the most important sport fish present, but distribution and population characteristics are unknown. A few samples taken in the lake have revealed the dominance of non-sport fish species such as redside shiners, squawfish and bridgelip suckers (Ministry of Environment, lake survey data).

Downstream System

Rainbow trout, mountain whitefish and Dolly Varden are resident in both Seton and Cayoosh creeks (Hebden 1981, Bengeyfield 1982), but densities and population characteristics have not been studied.

RECREATIONAL FISHERY

Reservoir

No information available.

Downstream System

Small numbers of steelhead are taken annually in Cayoosh Creek (Hebden 1981) but the fishery for non-anadromous species in Seton and Cayoosh creeks has not been documented.

WAHLEACH
(Jones Lake)

PROJECT

Description

The project consists of an 18 m high, 418 m long, earth fill dam constructed across the outlet of Wahleach (Jones) Lake in the upper Fraser Valley (Map C). A 3 m high dam across nearby Boulder Creek diverts water into Wahleach Lake. Wahleach Dam has a 122 m^3/s capacity spillway and the Boulder Creek diversion dam is equipped with an 0.6 m diameter fish water sluice with a manual sliding gate. There are no fishways. A 4.5 km conduit leads water from Wahleach Lake to a power house on the left bank of the Fraser River, located above Cheam View. The power plant has a name plate generating capacity of 60 MW. The development was completed in 1952.

Water Licences and Operational Constraints

The water licence permits the storage of 180 million m^3 of water per year and the maximum diversion of 13 m^3/s (470 cfs) for power purposes. No stipulations exist for the release of water for other purposes. The releases to the pink salmon spawning channel (see Project: *Enhancement Facilities*) are based on an agreement between DFO and B.C. Hydro (Fraser and Fedorenko 1983).

Electrical Generation

Between January 1984 and December 1987 the Wahleach power plant generated from zero to 51 million kWH per month (114 percent of nameplate capacity) and supplied up to 1.5 percent of B.C. Hydro's total monthly output.

Enhancement Facilities

The Jones Creek spawning channel was built by DFO in 1954 (alleged to be the first spawning channel in North America) and paid for by the B.C. Electric Company (Hourston and MacKinnon 1956). The objective was to maintain the existing pink salmon runs in Wahleach (Jones) Creek following reduction in creek flows by impoundment and diversion. The channel is 600 m long, 3 m wide and supports 6300 spawning pink salmon. A diversion structure at the lower end prevents pink and other salmon from entering the creek channel (MacKinnon et al. 1961). The mean flow required for channel operation is about 0.6 m^3/s (20 cfs) with some 1.4 m^3/s (50 cfs) preferred during adult in-migrations. No enhancement facilities were developed for non-anadromous fisheries.

OPERATIONAL REGIME

Generation at Wahleach varies considerably from month to month, with no fixed pattern of generation at any time of the year. For 3 out of the 48 months in the 1984-1987 period there was no power generated, and for about half of the period the plant's generation was less than a third of capacity. The storage volume in the lake is normally used to the maximum extent possible with maximum drawdowns of up to 16 m occurring by March - April each year prior to the freshet inflows (Figure 54).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Jones Lake has a surface area of 460 ha, a maximum depth of 29 m, and a mean depth of 13.4 m. Large sections of the shoreline consist of sand and gravel beaches. Extensive logging has taken place within the watershed, and the resulting siltation has caused problems in the pink salmon spawning channel over the years (Fraser and Fedorenko 1983). Possible siltation problems in the reservoir itself have not been documented.

Jones Lake is oligotrophic. In 1981 total dissolved solids were measured at 29 - 38 mg/l, total nitrogen at 0.05 - 0.13 mg/l, total phosphorus at 0.007 mg/l and conductance was found to be low (Ministry of Environment, lake survey data). Dissolved oxygen ranged from 8 mg/l at the surface to about 6 mg/l near the bottom, suggesting some decomposition at depth. Jones Lake contains large amounts of floating logs and sunken material, including stumps and deadheads (Ministry of Environment file notes, Surrey). Secchi disk readings in 1981 (September) were 6+ m, and water temperatures ranged from 13.5 at the surface to 9 at the bottom (Ministry of Environment, lake survey data). Some *Ranunculus* occurs along the shorelines.

Downstream System

Habitat characteristics of Wahleach (Jones) Creek have not been documented, and there are no stream gauging data. The pink salmon spawning channel operates independently of the hydroelectric development for much of the time, but requests are sometimes made to B.C. Hydro to release up to 1.4 m^3/s between 15 September and the end of October to provide sufficient water for in-migrating pink salmon.

SPORT FISH POPULATIONS

Reservoir

Gill netting in 1981 and 1987 revealed an abundance of small kokanee and rainbow trout in Jones Lake (Fisheries Branch, Surrey, data files). In 1987 the CPUE was 41 fish/100 m^2 per 24 hrs, and there was a wide range in sizes (mostly below 20 cm). An April 1981 survey of lake tributaries revealed that many are not accessible to spawning rainbow trout at maximum reservoir drawdown because of obstructions in the terminal reaches. *Mysis* shrimp were introduced to Jones Lake in 1969 with unknown results (Fisheries Branch, Surrey, data files). Angling pressure is judged to be an important constraint on rainbow trout and kokanee numbers in Jones Lake (Fisheries Branch, pers. com.).

Kokanee and rainbow trout spawn in a number of smaller tributaries to Jones Lake. A 1981 survey (Fisheries Branch, Surrey, data files) results in counts of 550 spawning kokanee in Flat Creek, 20 in Boulder Creek and 160 in Glacier Creek. Rainbow trout spawn in much smaller numbers (12 in Glacier Creek, none seen elsewhere above the dam).

Jones Lake was stocked in the 1930's (15000 rainbow trout in 1930, 50,000 kokanee eggs in 1934, 1935 and 1936 respectively), but has not subsequently been stocked (Fisheries Branch, Surrey, data files).

Downstream System

Fish use of much of the natural creek below the impoundment is precluded by the presence of a diversion structure at the entrance to the spawning channel. Kokanee make use of the lower 500 m (estimates of 1700 (1969), 7000 (1970), 4000 (1971), 6400 (1973) and 2050 (1981) are documented (Fisheries Branch, Surrey, data files). Pink, chum and a few coho also use these habitats, but no data are available on the extent or quality of these habitats or the use by non-anadromous species. Cutthroat trout stocked in the Fraser River tend to congregate in the mouths of tributaries such as Wahleach Creek and are the basis for an important recreational fishery (Fisheries Branch, pers. com.).

RECREATIONAL FISHERY

Reservoir

Access to Jones Lake is very good, and several resorts and cabins are located on the shoreline. The tributaries are closed to angling. There are no creel data available to indicate angling pressure or success rates. Angling pressure is judged to be moderate in most years , but is an important constraint on rainbow trout and kokanee numbers (Fisheries Branch, pers. com.).

Downstream System

Recreational fishing is normally not permitted in the lower tributaries.

STAVE FALLS
(Stave Lake)

PROJECT

Description

Two hydroelectric projects impound the Stave River in the lower Fraser Valley, i.e. Stave Falls and Ruskin (see Ruskin). Stave Falls Dam is a concrete gravity structure 26 m high and 67 m long, equipped with a 6 m gated outlet through the penstocks. There is no spillway on the structure. A separate saddle dam (Blind Slough Dam) of 18 m height and 195 m length is provided with sluiceways and four radial gates. Stave Falls was built in 1911 by the Stave Lake Power Company and the dam wall raised in 1922-23. The generating plant has a nameplate capacity of 52.5 MW and is presently owned and operated by B.C. Hydro.

Both Stave Falls and Ruskin generating stations make use of water diverted into Stave and Hayward lakes from Alouette Lake (see Alouette).

Water Licences and Operational Constraints

The final water licence, issued after the dam was raised in 1923, entitles the holder to store 274 million m^3 of water and to use a maximum quantity of 60 m^3/s (6300 cfs). There are no provisions for releases for fisheries or any other purposes.

Electrical Generation

Stave Falls generating plant produced 3 to 31 million kWH monthly from 1984 through 1987 at 8 to 82 percent capacity, and produced 0.1 to 1.3 percent of B.C. Hydro's total monthly output. Stave and Ruskin were once base load plants and provided the bulk of power used in the B.C. lower mainland prior to the development of the Bridge and Peace rivers. The Stave plant is now more than 75 years old and a redevelopment scheme is currently being studied (B.C. Hydro, pers. com.).

Enhancement Facilities

No fish enhancement facilities were established in conjunction with the hydroelectric development. DFO established chum and coho incubation boxes and rearing ponds in 1981. A hatchery on Inch Creek (near Nicomen Slough on the Fraser River) was completed by DFO in 1984 (MacKinlay 1985a) and utilizes Stave River as a satellite stream for chum salmon production. The Alouette Correction Facility and local societies have maintained rearing ponds for chum, coho and rainbow trout near the lake.

OPERATIONAL REGIME

Stave Lake is utilized as a storage reservoir and, in addition, draws on storage in Alouette Lake (see Alouette) via a connecting adit. Inflows are made up of snow melt freshet plus heavy winter rainfall. Reservoir operations are consequently complex and lead to erratic changes in reservoir volumes and drawdowns, the latter reaching from 6 to 8 m below full pool in most years (Figures 55 and 56). Drawdowns to 5 m and more can occur more than once in a year.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Stave Lake has a surface area of 5858 ha, a maximum depth of 101 m, a mean depth of 35 m and an average water residence time of 5 months. In 1987 total dissolved solids content averaged 10 mg/l (Ministry of Environment, lake survey data), pH was 6.7, total conductance 10 umhos/cm, and turbidity from 2 - 2.5 m (Secchi disk). Turbidity in the upper reservoir area and in the inflowing tributaries increase during the freshet period. Water quality data (EQUIS data cited by B.C. Hydro n.d.) indicate that total nitrogen and total phosphorus contents are low.

Downstream System

Stave Falls discharges directly into Hayward Lake (see Ruskin).

SPORT FISH POPULATIONS

Reservoir

Detailed fish population studies of Stave Lake have not been undertaken. Gill netting undertaken as part of a general lake survey in 1987 (Ministry of Environment, lake survey data) indicated kokanee to be the dominant sport fish species (12 percent of total catches); other sport fish present included cutthroat trout (6 percent), Dolly Varden (4 percent) and rainbow trout (less than 1 percent). Non-sport species dominated the catches (78 percent), northern squawfish and redside shiner being the most common. Immature fish are predominant in cutthroat and rainbow trout populations, while the kokanee population comprises a wide variety of age classes (Ministry of Environment, lake survey files). Sloughs along the upper Stave River have been observed to hold significant numbers of cutthroat trout, while the upper tributaries have the characteristics of good Dolly Varden spawning habitat (Ministry of Environment, lake survey data).

Downstream System

See Ruskin.

RECREATIONAL FISHERY

Reservoir

Creel data are not available for Stave Lake. Access to the lake is good and the area provides scenic recreational fishing opportunities. Cutthroat trout up to 60 cm length are reported caught by anglers (Fisheries Branch, Surrey, data files), while large Dolly Varden are also present. Angling success rates are probably low (0.2 fish/hr, Fisheries Branch, Surrey, data files).

Downstream System

See Ruskin.

RUSKIN
(Hayward Lake)

PROJECT

Description

Ruskin Dam lies below Stave Falls and is a 59 m high, 125 long, concrete gravity dam equipped with a 3700 m^3/s capacity spillway and seven radial gates. Ruskin was completed in 1930 by the B.C. Electric Company, and is presently owned and operated by B.C. Hydro. The generating plant has a nameplate capacity of 105.6 MW.

Both Stave Falls and Ruskin generating stations make use of water diverted into Stave and Hayward lakes from Alouette Lake (see Alouette).

Water Licences and Operational Constraints

No specific water licence for Ruskin Dam could be located. Ruskin is operated solely as a run-of-river reservoir and may be covered by the licence issued for Stave Falls (see Stave Falls). There are no operational constraints or fisheries provisions attached to the Stave Falls licence.

Electrical Generation

Ruskin power plant produced from 4.6 to 36 million kWH monthly over the 1984 - 1987 period. Maximum output did not exceed 50 percent of the plant's maximum capacity in this period. The plant produced from 0.2 to 1.2 percent of B.C. Hydro's total monthly output.

Enhancement Facilities

No compensation or enhancement facilities for fisheries were provided by the operating utilities. In 1978 DFO constructed a high water channel downstream of Ruskin Dam to alleviate flow fluctuation impacts on spawning salmon (Hirst 1991). Commencing in 1989 plant operations were modified to reduce impacts to chum salmon redds and rearing fry (Hirst 1991).

OPERATIONAL REGIME

Ruskin is operated purely as a run of river reservoir based on storage in Stave and Alouette lakes (Figure 57). Reservoir volume and drawdown fluctuate frequently, but over a relatively restricted range. Maximum water levels were held 1 - 2 m below maximum for the 1984-1987 period, and mean fluctuations were of a similar range (Figure 58).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Hayward Lake is 276 ha in extent, has a maximum depth of 38 m and a mean depth of 16 m. Average water retention time is less than 3 days. The shorelines are steep and rocky. The lake was not cleared prior to development and standing snags and stumps and floating debris present a hazard to boaters and anglers. A debris reduction program was initiated by B.C. Hydro in 1989. Shoreline access is generally difficult except for one small B.C. Hydro recreational area. The reservoir has no major tributary inflows.

The reservoir is relatively turbulent because of the small volume relative to the Stave Falls inflows and the water column is consequently well-mixed. In 1985 the lake was surveyed (Ministry of Environment, lake survey data) and found to be oligotrophic. Dissolved oxygen was 9.5 mg/l and September water temperatures 15 - 16° C throughout the water column. Mean pH was measured at 6.8, specific conductance 12 umhos/cm, total dissolved solids 14 - 16 mg/l, total nitrogen 0.14 mg/l and total phosphorus 0.006 mg/l.

Downstream System

The Stave River from Ruskin Dam to the Fraser River confluence is a 3.5 km reach subject to tidal influence. Shorelines are mainly sands and fine gravels and are subject to fluctuating water levels due to tides and the changing discharges through the Ruskin plant turbines (Brown and Musgrave 1979). Urban and industrial encroachment has impacted on numerous areas along the shorelines.

SPORT FISH POPULATIONS

Reservoir

Hayward Lake was stocked with rainbow and cutthroat fry (and sometimes eggs) from 1933 (following reservoir impoundment) to 1945 (Figure 59). No documentation of the results has been located. Most recent stocking has included rainbow and cutthroat fry and steelhead smolts (Fisheries Branch, Surrey, data files). A post- stocking evaluation in 1987 (Ministry of Environment, lake survey data) resulted in a gill netting CPUE of 9.2 fish per $100/m^2/24$ hr but no sport fish were caught; suckers and chub dominated the fish fauna of the reservoir. No detailed fish population studies of the reservoir have been undertaken.

Downstream System

The Stave River below Ruskin Dam continues to be used by spawning chum, coho and chinook salmon. Losses to fry and possibly eggs occur from stranding and other impacts from flow fluctuations and are being addressed through constraints on powerhouse operation (Hirst 1991). Similar impacts probably accrue to steelhead smolts stocked in Hayward Lake and passed through the turbines. Use of the downstream river or the extent of flow impacts have not been quantified.

RECREATIONAL FISHERY

Reservoir

Hayward Lake is utilized by anglers but the extent and success rates have not been monitored. Hazardous boating conditions, poor access and low numbers of sport fish are present limitations to recreational fishing. The feasibility of enhancement through a put-and-take fishery based on net pens is presently under consideration (B.C. Hydro, pers. com.).

Downstream System

The anadromous sports fishery is important in the Stave River below Ruskin: a survey in 1985 revealed that 19 percent of all anadromous cutthroat trout angling in the lower Fraser River system took place at the Stave mouth and 21 percent of all cutthroat taken came from these sites (Scott 1985). The non-anadromous fishery is probably negligible.

COQUITLAM RIVER
(Coquitlam Lake)

PROJECT

Description

The project consists of a 30 m high, 300 m long, earthfill dam across the Coquitlam River, approximately 16 km above its confluence with the Fraser River (Map C). The dam is equipped with an overflow weir of 500 m^3/s capacity, a large gated sluice tunnel, and a separate outlet for the Greater Vancouver Regional Water District (GVRD) supply. A 4 km power tunnel leads water to Buntzen Lake (see Buntzen) from where power flows are directed to the Buntzen generating stations on Indian Arm. There is no generating station at Coquitlam Dam and no fish passage facilities. Coquitlam Dam was constructed in 1914 (Vancouver Power Company) and rehabilitated in 1980 (B.C. Hydro).

Water Licences and Operational Constraints

The water licence permits total storage of about 3.2 billion m^3, and maximum diversion of 82 m^3/s. A separate water licence is held by the GVRD Water District for drinking water removal from the reservoir. There are no provisions in the licence(s) for any releases for fishery needs. Total licensed withdrawals are about 3 m^3/s more than the mean annual inflows to Coquitlam Lake (Water Investigations Branch 1978).

Electrical Generation

See Buntzen Lake.

Enhancement Facilities

No facilities are associated with the hydroelectric project. Local conservation groups maintain coho and steelhead incubation boxes along the upper tributaries below the dam.

OPERATIONAL REGIME

Coquitlam Lake is used as supplementary storage for power generation from Buntzen Lake. The extent of seasonal and annual drawdowns and the periodicity of water transfers are not recorded by B.C. Hydro. Spills were a common occurrence prior to raising of the dam (1980) but are now uncommon due to the high demands made by the GVRD water supply system. The GVRD now utilizes all the water available in terms of its water licence.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Total storage of Coquitlam Lake is 222 million m^3. Coquitlam Lake is inaccessible to anadromous fish and is off-limits to public access because of the GVRD water storage restrictions.

Downstream System

Pre-impoundment discharges of the Coquitlam River were not gauged. The mean annual inflow to Coquitlam Lake is estimated at about 35 m^3/s, while the mean annual flow in the lower Coquitlam River (derived mainly from tributaries such as Scott and Hoy creeks) from 1968 through 1987 was 4.8 m^3/s (Environment Canada 1988). The discharge regime of the Coquitlam River below the impoundment is highly variable (Figure 60) with most variation coming from flood flows from the upper tributaries. Mean and minimum flows are more constant. Flows in August and September are typically very low (Figure 60).

From 1949 to 1965 extensive gravel removal took place in the lower and mid-sections of the river, much of it accompanied by channelling (Marshall et al. 1980). Additional bed and shoreline impacts were caused by diking and flood protection works. The overall results were channel confinement, an increase in gradient, unstable river bottom, and a tremendous increase in silting. An estimated 87 percent of mainstream habitats are coated with fines from gravel mining operations (De Leeuw 1982). Bank slides due to instability are common. There is a considerable inconsistency in the existing gravel substrates due to flooding, gravel extraction and bed instability, and a severe depletion of biological productivity. Gravel removal has continued to date, although at a lesser intensity (Ross et al. 1985).

Tributaries to the Coquitlam still contain useful habitats for coho, steelhead and cutthroat trout, but are being increasingly impacted by urbanization. Of the usable wetted width within the total system, 18 percent is in the tributaries. Hoy Creek is not affected by gravel mining and offers the best habitats for spawning and rearing (De Leeuw 1982).

SPORT FISH POPULATIONS

Reservoir

Coquitlam Lake is closed to public access and is consequently not stocked nor managed for recreational fishing.

Downstream System

The mainstem Coquitlam River was once intensively used by spawning coho, chum and pink (and possibly sockeye) salmon (Hirst 1991). Sharp declines were associated with gravel mining, channelling, urbanization and (possibly) dam construction. Present anadromous fish populations using the river include small numbers of coho, chum, steelhead, cutthroat and Dolly Varden. There appears to be no significant non-anadromous sport fish populations within the system.

RECREATIONAL FISHERY

Reservoir

Coquitlam Lake is closed to public access.

Downstream System

The Coquitlam River is presently managed for a steelhead and anadromous cutthroat fishery (Fisheries Branch, pers. com.). The non-anadromous fishery has not been measured but is probably negligible.

BUNTZEN
(Buntzen Lake)

PROJECT

Description

A 16 m high, 110 m long, concrete dam at the northern end of Buntzen Lake impounds the lake and directs discharges along several 0.5 km long penstocks to a power plant located on the shore of Indian Arm (Map C). The plant has a nameplate capacity of 76.7 MW. The dam is provided with an ungated spillway of uncertain discharge capacity. A diversion tunnel linking Coquitlam lake to Buntzen Lake discharges immediately above the Buntzen Dam. The Buntzen development was built in 1903 (Vancouver Power Company) and modified in 1912. It is presently owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The final water licence, issued in 1933, permits the diversion of a maximum of 26 m^3/s of water from Coquitlam Lake to Buntzen Lake and the same amount to the powerhouse. No storage in Buntzen lake is specified. There are no clauses related to fisheries or other environmental concerns.

Electrical Generation

The two Buntzen power plants (#1 and #2) together generated from near zero to 28.5 million kWH of electricity per month over the 1984 - 1987 period. Plant outputs were from zero to slightly over 50 percent of full capacity. Maximum Buntzen production over this period accounted for just under 1 percent of B.C. Hydro's total monthly output.

Enhancement Facilities

No fisheries compensation or enhancement facilities were required nor offered.

OPERATIONAL REGIME

Buntzen Lake is used essentially as a headpond for the Buntzen powerplant and relies on storage in Coquitlam Lake. Volume and drawdown fluctuations are relatively small (Figure 61). Inflows to Buntzen other than the Coquitlam Lake diversion are small, and Coquitlam Lake storage is the major constraint on operations at the Buntzen power plant.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Buntzen Lake has a surface area of 151 ha, a maximum depth of 65 m and a mean depth of 30 m. Mean water retention time, based on the ratio between volumes passed through from Coquitlam lake and the volume of Buntzen Lake is about 49 days. However, a temperature profile of the lake in June 1979 (Ministry of Environment, lake survey) showed that some degree of stratification was present (range from 19.5° C at the surface to 6° C at 29 m depth). Since the Coquitlam Lake diversion outlet is close to the penstock intakes it appears that mixing through the water column is limited, with a consequent higher water retention time for the bulk of the lake volume.

The lake shoreline is generally steep and rocky, with a steep drop-off in most areas. Anmore Creek is the only tributary offering useful sport fish habitat, but appears to be under-utilized by cutthroat trout and kokanee, the two salmonids native to the lake (Ministry of Environment, lake survey data). Spawning platforms were installed in the creek in 1981 to supplement natural habitats (Fisheries Branch, Surrey, data files).

Secchi disk readings in summer 1979 were 10.5 m, and dissolved oxygen concentrations were found to be 9 mg/l at all depths to 25 m. The pH was measured at 5.9 - 6.5, specific conductance at 13 - 15 umhos/cm, and total dissolved solids 13 - 14 mg/l (Ministry of Environment, lake survey data). Other water chemistry data are not available but the lake appears to be typically oligotrophic.

Downstream System

Buntzen Lake flows are discharged to the marine environment in Indian Arm.

SPORT FISH POPULATIONS

Reservoir

Gill netting samples in 1979 (Ministry of Environment, lake survey data) contained only 5 percent sport fish, these being mainly immature cutthroat trout; samples were dominated by longnose suckers and redside shiners. The CPUE was not calculated. A similar sample taken in 1987 following cutthroat trout stocking gave a relatively high CPUE of 126 fish/100 m^2/24 hr, although only 9 percent were cutthroat and 20 percent kokanee, the remainder being dominated by squawfish and chub. Cutthroat trout caught averaged approximately 30 cm in length and kokanee 20 cm.

Downstream System

No inland fish populations exist below Buntzen.

RECREATIONAL FISHERY

Reservoir

Because of its proximity to, and easy access from, the lower mainland population centres, Buntzen Lake is heavily utilized by anglers. Over a 9-month period (January-September) in 1980 the angling pressure was measured at 2374 hours total, and from 250 to 500 hours per month for the April-August period. The average angling time per angler per day was measured at 2.9 hours (Fisheries Branch, Surrey, data files).

Sport-fishing success rates in Buntzen Lake have been measured at 0.01 to 0.25 fish/hr for cutthroat, rainbow and kokanee, with total catches (sportfish only) ranging from 0.14 to 0.97 fish/hr (Figure 62). The variations are likely due to a number of factors including variations in angling pressure, angler interest and seasonal shifts in populations of species such as kokanee. The lake was stocked with rainbow trout in 1979, and pre- and post-stocking angling success rates measured at 0.15 fish/hr and 0.63-0.77 fish/hr respectively.

Downstream System

No inland fishery exists below Buntzen lake.

ALOUETTE
(Alouette Lake)

PROJECT

Description

Alouette Dam was constructed at the outflow of the South Alouette River in 1926 (Burrard Power Company) and rehabilitated by B.C. Hydro in 1983 to provide 209 million m^3 of storage (Map C). The dam is a 20 m high, 315 m long, earthfill structure with a concrete overflow weir, three vertical lift gates and a low level outlet port. A power tunnel less than 1 km in length leads from the northern end of the lake to Stave Lake and discharges through two outlets - an adit and a small generating plant of 8 MW capacity. Discharges into Stave Lake are then passed through Stave Falls (52.5 MW) and Ruskin (105.5 MW) generating plants. The impounded Alouette Lake is a major recreational feature of Golden Ears Provincial Park.

Water Licences and Operational Constraints

The initial water licence (dated 1923) permitted the B.C. Electric Company to divert 20 m^3/s from Alouette Lake to Stave Lake. In 1929 diversion of an additional 8.5 m^3/s (300 cfs) was licensed together with storage of a maximum of 186 million m^3. There are no provisions for water releases for fisheries or any other purposes.

In 1971, following representations by DFO, B.C. Hydro undertook to maintain a minimum flow of 0.7 m^3/s in the S. Alouette River which in turn entailed a minimum release of about 0.06 m^3/s continuously through the low level outlet. This agreement is still in effect, although the actual amounts released since August 1986 have ranged from 0.17 m^3/s to 1.2 m^3/s (B.C. Hydro, Operations Control Department data).

Electrical Generation

The generating plant at the outlet of the power tunnel on Stave Lake generates power when flows are released to Stave Lake. In the period from January 1984 through December 1987 the plant operated in only 7 months out of 48, with generation ranging from near zero to 5.2 million kWH per month (about 90 percent of capacity). Stave Falls and Ruskin plants use Alouette flows to contribute from 1 to 3 percent of B.C. Hydro's total monthly output.

Enhancement Facilities

No enhancement facilities were constructed by the project proponents. The Haney Correctional Institute, located on the S. Alouette River maintains coho salmon and steelhead incubation and rearing boxes as well as rearing ponds for chum salmon fry. A fishway over the dam has been suggested from time to time but is not considered economically feasible (B.C. Ministry of Environment 1979) because of the limited habitat potential above the dam. Access into the lake for Pacific salmon would lead to salmon being flushed through the power tunnel into the Stave lake system and consequent problems with returning adult spawners (DFO, pers. com.)

OPERATIONAL REGIME

Alouette Lake's main function is to provide active storage for use by the Stave River plants. Inflows are derived from freshet flows from Coastal Mountain watersheds plus run-off from high winter rainfall. Less than 20 percent of diverted flows to Stave Lake generate power at the Alouette plant, the remainder are discharged directly via the adit (Figure 63). The adit, diversion tunnel and trash racks require frequent cleaning because of the large amounts of debris within the lake basin. Drawdowns are erratic and unpredictable (Figure 64) but affect only some 10 percent of lake volume because of the depth of the lake (see below).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Alouette Lake has a surface area of 1650 ha, a maximum depth of 140 m and a mean depth of 64 m. Mean water retention time is 4.7 months. The size of the littoral area is estimated at less than 90 ha (Aquatic Studies Branch 1982), a result of the quick drop-off along most of the lake shoreline. In 1981 the pH was measured at 5.6-6.5 and Secchi disk readings were 6.1-16.6 m. Summer surface water temperatures were

15° C, and the water column appears to be at or near dissolved oxygen saturation throughout the upper 30 m at least. Total phosphates and total nitrogen are low (EQUIS data, cited by B.C. Hydro n.d.), and total dissolved solids seldom exceed 20 mg/l (Fisheries Branch, Surrey, data files). Aquatic macrophytes are absent (Aquatic Studies Branch 1982). The original lake shore was not cleared prior to lake impoundment and submerged stumps and floating debris are still common. Fluctuating reservoir levels are probably detrimental to spawning of kokanee and lake trout, which are almost totally dependent on littoral areas for spawning (Knight 1987).

Gold Creek, the upper Alouette River and Moyer Creek are the only significant tributaries with any sustained discharge into the lake. The latter two are characterized by boulders, steep gradients and erratic discharges which distracts from their potential as fish habitat. The lower 3.8 km of Gold Creek are accessible to salmonids although only about 0.7 km is good rainbow habitat (Knight 1987). Gold Creek's productivity is estimated at a relatively low 3 gm/m^2 but even this is regarded as being close to capacity level (Griffith, cited by Knight 1987).

Downstream System

The pre-impoundment annual mean discharge of the S. Alouette River was about 23 m^3/s while the post-impoundment mean flow in the early 1960's was 2.4 m^3/s (Environment Canada 1988). This dropped to 1.9 m^3/s following the 1971 agreement between DFO and B.C. Hydro to release 0.06 m^3/s constantly from the reservoir (Walker 1983). Impoundment has completely altered the flow regime of the S. Alouette River (Figure 65), but has not eliminated the occurrence of flash floods which are detrimental to rearing habitats and downstream spawning gravel beds (Hartman 1968, Slaney 1973). Timber removal has occurred throughout the watershed over large areas and together with the associated urbanization has increased the surface run-off to the river and increased the incidence of flooding (Walker 1983).

The present S. Alouette River flows in a channel which was developed under much larger flows. Consequently there are no side channels and very little bank overflow (Walker 1983). Changes in flows over a wide range consequently do not drastically affect the wetted width of many reaches. A 1982 survey (Andrew et al. 1982) recommended discharges of 2.3 m^3/s from the reservoir to obtain 100 percent coverage of wetted areas within pink salmon spawning habitats. A 1984 detailed survey (Sookachoff 1984) led to a revised recommendation of a 1.5 m^3/s (53 cfs) release from the reservoir during spawning and incubation (mid-October through April) and a release of 0.6 m^3/s (22 cfs) during rearing periods. Present releases to the lower river (Figure 66) come within range of the recommended flows, but accurate flow releases through the outlet are technically difficult to obtain (B.C. Hydro, pers. com.).

About 25 km of the South Alouette River below the dam are subject to regulated flows. The upper 13 km are highly diverse (Walker 1983) and include chutes, cascades, riffles and pools. Substrates range from gravels to rubble, boulders and sand. There is much variety in habitat conditions for rearing juvenile salmonids. The continual encroachment of deciduous and coniferous stream bank vegetation into the stream bed following the withholding of the larger annual floods has increased the incidence of bank shading and has improved rearing conditions. The lower 12 km have low habitat potential due to silting, channelling, diking, urbanization, waste disposal and road maintenance (DFO escapement files, B.C. Hydro, pers. com.).

SPORT FISH POPULATIONS

Reservoir

Alouette Lake contains five important sport fish species - rainbow trout, cutthroat trout, lake trout, kokanee and Dolly Varden, but numbers are low in accordance with the oligotrophic nature of the reservoir and the limited amounts of spawning habitat available.

Lake trout were stocked in 1968 (166,000 fry and yearlings, Fisheries Branch, Surrey, data files); sampling in 1985 and 1986 produced only old fish of good condition and mean length of 66 cm resulting from the stocking - no other year classes were found (Knight 1987). Present kokanee numbers are low, although variety of year classes exist; mean lengths of sampled fish has been 22 cm. Cutthroat trout (average length 32 cm), rainbow trout (average length 25 cm) and Dolly Varden (mean length 50 cm) all have low densities. An estimated 46 percent of total fish biomass in Alouette Lake is made up by non-sport species, chiefly suckers, squawfish, chum and redside shiners (Knight 1987).

Alouette Lake has been stocked periodically from 1938 (Figure 67). More intensive stocking has taken place within the past 7 years but has not yet led to an increase in the low angler success rate (mean of 0.14 fish/day, Knight 1987). The present plan involves stocking of 25,000 cutthroat fingerlings per year into net pens where they will be maintained and eventually released by the Corrections Branch (Fisheries Branch, Surrey, data files).

Downstream System

All five salmon species occurred historically in the Alouette River system (McMynn 1953). Large runs of sockeye, chinook, coho, chum, steelhead and cutthroat took place to Alouette Lake prior to 1926. Gold Creek was reported as being an important spawning stream. Chinook were not reported after construction of the Alouette Dam in 1926, and sockeye disappeared in 1930. Declines in coho and chum salmon followed the gravel removal operations in the 1950's. Chum salmon have increased in abundance due to enhancement, and now have runs of 8000 to 15000 each year. The 1982 chum escapement of 18,500 was the largest on record.

RECREATIONAL FISHERY

Reservoir

Alouette Lake is a major recreational feature of the scenic Golden Ears Provincial park and has good access from lower mainland population centres. Recreational fishing is probably increasing due to growing human populations in the lower mainland, despite the present poor angling success rates. A creel census from July though October 1986 (Paish 1987a) estimated 1013 angling days expended for a total catch of 142 sport fish (approximately 0.04 fish/hr). About 60 percent of the sport catch was rainbow trout, 32 percent were kokanee, and the remainder cutthroat, Dolly Varden and lake trout. A winter creel census (Paish 1987b) in the same year (November through May) revealed far fewer anglers (87) but significantly higher success rates of 0.12 - 0.6 fish/hr due to the presence of more expert anglers on the lake in the winter season (Paish 1987b).

Downstream System

There appears to be no significant non-anadromous recreational fishery in the S.Alouette River below the Alouette Dam.

E. SOUTHERN COASTAL SYSTEMS

CHEAKAMUS
(Daisy Lake)

PROJECT

Description

The project consists of a 28 m high, 680 m long earth fill dam across the outlet of Daisy Lake on the Cheakamus River, approximately 20 km above the confluence with the Squamish River (Map C). The gated concrete spillway has a total capacity of 1400 m^3/s, and the dam has two radial gates, a low level sluice gate and a 0.7 m diameter hollow cone valve. A small turbine generator (150 kW) discharges to the Cheakamus River (about 0.6 m^3/s) and supplies local power to operate the sluice gates. A 11 km tunnel diverts water from Daisy Lake to a powerhouse on the upper Squamish River with a nameplate capacity of 140 MW. The Cheakamus project was completed in 1957 and is owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The water licences permit B.C. Hydro to store a maximum of 55.5 million m^3 of water, and to divert a maximum of 863.5 million m^3 per annum. The licence contains provisions that flows must be maintained for "fish propagation" in the Cheakamus River. Downstream flows for fish are released through the hollow cone valve, the setting of which depends on the reservoir elevation and is determined by B.C. Hydro in consultation with DFO. Fish water releases to the downstream river from 1984 through 1987 ranged from 0.5 to 1.9 m^3/s (19 to 66 cfs). The water licence required the proponent to clear the reservoir site in consultation with the B.C. Parks Branch.

Electrical Generation

The plant's monthly output from 1984 through 1987 ranged from near 9 million kWH (about 10 percent of capacity) to over 107.5 million kWH (>100 percent of capacity). Total contributions to the B.C. Hydro hydro-electric grid ranged from 0.2 to 3.2 percent.

Enhancement Facilities

No enhancement facilities were developed by the proponent as mitigation or compensation for fisheries impacts. There are no fishway facilities for salmon at the dam. A spawning channel near Paradise Channel, a subsidiary channel to the Cheakamus River, was built by DFO in 1982 for pink, coho, chinook and chum salmon. DFO constructed a hatchery on Tenderfoot Creek in 1982 and the capacity was doubled in 1984 (MacKinlay 1985b). The hatchery is the present basis for chinook, coho and steelhead enhancement of the Squamish and Cheakamus river systems.

OPERATIONAL REGIME

Cheakamus is operated mainly as a peaking plant for loads generated in the lower mainland. Daisy Lake receives inflows from snow melt on the heavily glaciated Coastal mountain ranges in addition to winter rainfall. The lake has insufficient storage to retain all inflows, even in average precipitation years, and spills to the lower Cheakamus River are an annual feature of the operation (Figures 68 and 69). Severe flooding in the lower Cheakamus and Squamish rivers occurs periodically despite storage provided in Daisy Lake.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Daisy Lake has a maximum surface area of some 520 ha, a mean depth of 10 m, and is oligotrophic with total dissolved solids content averaging near 30 mg/l (Ministry of Environment, lake survey data). Shorelines are generally steep and rocky; old alluvial fans are exposed at maximum drawdown and contain significant amounts of gravels, probably used by littoral spawning species such as kokanee. The surrounding terrain is heavily glaciated and inflowing tributaries contain substantial sediment loads. Considerable amounts of debris occur along the lake shore and on the bottom (despite a clause in the water licence requiring reservoir clearing). Aquatic macrophytes (*Equisetum* spp.) occur along some littoral areas.

Daisy Lake tributaries, including the upper Cheakamus River, are characterized by steep gradients, falls, boulders and numerous blockages (Ministry of Environment, lake survey data). The upper Cheakamus River is separated by blockages from the lake and has small patches of spawning gravels and pools used by rainbow trout. The other tributaries are similar in the prevalence of obstructions and steep gradients. A typical tributary - Brew Creek - was surveyed (Wightman n.d.) and found to provide little useful habitat for Dolly Varden at present and probably not even under pre-impoundment conditions, but did offer limited amounts of habitat for rainbow trout. Despite the limitations observed, there must be substantial amounts of rainbow trout and kokanee spawning habitat available to sustain the relatively high populations in the lake (see Sport Fish Populations below).

A 1981 survey (Ministry of Environment lake survey data) measured lake turbidity at 0.5 - 2.0 m (Secchi disk), specific conductance at 33 umhos/cm and dissolved oxygen at 9 mg/l at all depths to 14 m. Water temperatures in summer ranged from 12° C at the surface to 10° C near the bottom (14 m). Average water retention time in the lake is 6 days, hence the water column is likely well-mixed throughout. Total phosphorus was measured at 0.008 mg/l (but total dissolved phosphorus only 0.003 mg/l), total nitrogen 0.04 - 0.07 mg/l and total ammonia nitrogen 0.007 - 0.009 mg/l. Water quality considerations in Daisy Lake are currently the subject of an ongoing study program by the Environmental Protection Service and other agencies (Environment Canada 1982) and eutrophication of the lake is a strong possibility.

Downstream System

Daisy Lake's licensed storage capacity is less than its diversion capacity and consequently pre- and post-impoundment flows in the Cheakamus River below the Dam show little difference in maximum daily and maximum monthly flows (Figures 70 and 71). Mean flows, however, were reduced by more than 50 percent by project development, as were minimum monthly and daily flows. The latter tend to be more stable due to the low-level releases, but are considered too low for optimal salmon rearing in the mainstem river (DFO, personal communications). Apart from the overall reductions in flows, the diversion dam has shaped the monthly flow pattern by markedly reducing spring and fall flows.

Because of storage limitations in Daisy Lake, water is spilled every year (Figure 68). Spills normally coincide with the high run-off associated with melting snow pack in the mountainous watershed, but may also occur in winter due to very high precipitation. The flooding risks to mainstem fish habitats in the Cheakamus and lower Squamish river valleys thus remain high, despite the presence of flow regulation. The most valuable fish habitats within the lower Cheakamus River are restricted to a 12 km reach above the Cheakamus-Squamish confluence. Above this reach a canyon with chutes and falls restricts access. There do not appear to be any detailed habitat survey data for the lower river and most studies to date have been related to salmon escapement checks (e.g. Demontier 1978).

Water quality in the Cheakamus River may have some effects on fish habitat quality. Glacial silts enter the river via the tributaries and siltation of the Daisy Lake forebay is a continuing problem (B.C. Hydro, pers. comm.), hence siltation of spawning gravels may be occurring. Decreasing water quality due to Whistler village sewage outfalls is now the subject of an ongoing monitoring program by EPS and other agencies (Environment Canada 1982). Late summer water temperatures in the Cheakamus River are generally 9.5° C or less (Demontier 1978) and no temperature related effects on salmonids have been documented.

SPORT FISH POPULATIONS

Reservoir

Daisy Lake supports populations of rainbow trout, kokanee and Dolly Varden which are the basis for an important recreational fishery. Detailed population data are not available. Gill netting catches in 1981 (Ministry of Environment lake survey data) were 90 percent rainbow trout, 6 percent kokanee, 1 percent Dolly Varden and the remainder sculpins. The rainbow trout were all immature (20 - 25 cm lengths), while kokanee were mixed age classes (20 cm mean length). Gill netting in 1987 (Ministry of Environment lake survey data) gave a CPUE of 93 rainbow trout/100 m^2/24 hr of 16 - 35 cm lengths. No other fish were captured.

The Cheakamus River was stocked with rainbow trout and steelhead eggs and fry from 1940 through 1952 (Fisheries Branch, Surrey, data files); the river and Daisy Lake have not been stocked since development of the Cheakamus project.

Downstream System

The lower Cheakamus River sustains a significant population of rainbow trout (Fisheries Branch, pers. comm.) but no quantitative data are available.

RECREATIONAL FISHERY

Reservoir

A July - August 1980 creel census of Daisy Lake (Fisheries Branch, Surrey, data files) indicated an angling CPUE of 2.2 fish/day and about 0.66 fish/hr. An estimated 46 percent of the creel was rainbow trout, 54 percent were kokanee, and most fish caught were under 25 cm length. Spin casting and trolling were the most successful methods, and boat anglers were 2-3 times more successful than shore anglers. No estimates of total angling pressure on the lake have been made.

Downstream System

Angler reports indicate that rainbow trout in the lower Cheakamus River support an important recreational fishery (Fisheries Branch, pers. comm.), but quantitative data have yet to be collected. Cutthroat trout and Dolly Varden are reported as either absent or very low in numbers.

CLOWHOLM
(Clowholm Lakes)

PROJECT

Description

The Clowholm hydroelectric project is located at the head of the Salmon Arm of Jervis Inlet on the Sechelt peninsula (Map C). The project consists of a concrete gravity dam of 22 m height and 402 m length. The dam impounded a small lake (Lower Clowholm Lake) joined to a larger upper lake (Upper Clowholm Lake) by a short channel. The concrete spillway has a maximum discharge capacity of 850 m^3/s, and the dam is equipped with two 10 x 8 m radial gates. There are no fishways. The powerplant is located at tidewater level below the dam and has a name plate capacity of 30 MW. Clowholm was completed by the B.C. Electric Company in 1957 and is presently owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The conditional water licenses were issued in 1957 and permitted maximum storage of 105 million m^3 and a maximum diversion of 75 m^3/s (2650 cfs). There are no specific provisions for fisheries in the licenses, but they did require the B.C. Electric Company to remove all merchantable timber from the reservoir (presumably the lower impoundment) after flooding, to remove and burn all floating debris, and to cut all large cedar stumps at the head of Upper Clowholm Lake during drawdowns.

Electrical Generation

Clowholm generating plant produced from 2890 to 18900 kWH of electricity per month over the 1984-87 period, at capacities ranging from 25 to over 100 percent on a daily basis. Clowholm's contribution to B.C. Hydro's total electrical production for the same period ranged from less than 0.1 to about 0.9 percent.

Enhancement Facilities

No fisheries enhancement facilities were provided during or following project development.

OPERATIONAL REGIME

Clowholm's operational regime reflects the availability of water which varies considerably on a month-to-month basis as a result of supply from winter rainfall as well as snow melt. No cyclic patterns in reservoir drawdown or in plant operation are discernible, although higher generation during the peak run-off months, usually June and July, is evident. Reservoir depletion (for both lakes combined) is frequently at the 10 to 20 percent level, and drawdowns are erratic, typically ranging from 1 to 5 m below full pool (as gauged in lower Clowholm Lake, Figure 72).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Clowholm Lakes' surface area is about 490 ha. No limnological data are available. A pre-impoundment survey (Smith and Larkin 1950) indicated that the upper lake had steep banks, no shoal areas and was at least 100 m deep. The lower lake was estimated to be about 15 m deep prior to project development. The Clowholm River had extensive spawning gravels (Smith and Larkin 1950, B.C. Game Commission 1956, J. Stephen, Conservation Officer, filed notes). Some tributaries, e.g. Red Tusk Creek have been observed to be used as spawning habitat (species not stated) while others, e.g. Copper Creek, are limited in habitat quality because of coarse substrates, obstructions and low flows (B.C. Game Commission 1956).

Downstream System

The power plant discharges directly into Jervis inlet and there is no known freshwater aquatic habitat below the project.

SPORT FISH POPULATIONS

Reservoir

No inventories of the lakes have been undertaken. Angler reports suggest the presence of cutthroat trout and Dolly Varden char (J. Stephen, Conservation Officer, filed notes). The pre-impoundment lakes were judged to be unproductive (Smith and Larkin 1950) due to their depth and the lack of benthic organisms and observable plankton.

Downstream System

No information available.

RECREATIONAL FISHERY

Reservoir

Small numbers of anglers use the lakes each year with an estimated success rate of about 1 fish/day for Dolly Varden and cutthroat trout (Fisheries Branch, Surrey, data files).

Downstream System

No freshwater angling available.

F. VANCOUVER ISLAND SYSTEMS

STRATHCONA
(Upper Campbell Lake)

PROJECT

Description

The Campbell River hydroelectric development (Map C) consists of three impoundments (Strathcona, Ladore, John Hart) plus two diversions (Heber River, Salmon River) which supply water to the storage reservoirs. Strathcona Dam is a 53 m high, 511 m long, concrete and earthfill structure supplied with a 3-bayed gated spillway of unstated capacity. Strathcona Dam was completed by the B.C. Power Commission in 1958 to impound Upper Campbell Lake, which in turn backs up Buttle Lake. The storage capacity of Upper Campbell Lake is 870 million m^3. The powerplant at the dam has a nameplate capacity of 67.5 MW and is now owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The conditional water licence issued in 1956 permits the diversion of a maximum quantity of 88 m^3/s. No storage limitations are specified. There are no conditions pertaining to fisheries or other environmental considerations.

Electrical Generation

Strathcona produced from 8 to 32 million kWH of electricity per month over the 1984-1987 period. Monthly outputs were from 6 to 66 percent of maximum capacity. The plant supplied from 0.2 to 0.9 percent of B.C. Hydro's total monthly output.

Enhancement Facilities

No compensation or enhancement facilities were provided for the Strathcona development.

OPERATIONAL REGIME

The Campbell River development plants are operated as baseload plants for electricity supply to Vancouver Island. Much of the live storage used for Strathcona production comes from Buttle Lake and the remainder from Upper Campbell Lake. Total storage in Buttle and Upper Campbell lakes is insufficient to retain all inflows, and spillage occurs in about 50 percent of all years (Figure 73). Upper Campbell Lake is drawn down as far as possible each year to accommodate freshet inflows, but high winter run-off often occupies part of this storage and drawdowns and volume fluctuations tend to be variable from one year to the next (Figure 74). Drawdowns in Buttle Lake are not monitored by B.C. Hydro's Operations Control centre.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Prior to Strathcona development, Upper Campbell Lake was 625 ha in extent and had a maximum depth of 40 m and a mean water retention time of 14 days (McMynn and Larkin 1953). Total dissolved solids content was approximately 56 mg/l. There was no distinguishable thermocline in summer, and dissolved oxygen was at or near saturation throughout the water column. Plankton was diverse, although overall productivity was estimated to be low because of nutrient limitations (McMynn and Larkin 1953). A large number of small tributaries enter the lake; the largest tributaries are Thelwood, Myra and Phillips creeks, each of which has small lakes within their basins.

Impoundment by Strathcona Dam extended the surface area to 2526 ha and removed an estimated 65 percent of sport fish spawning habitat in the tributaries (McMynn and Larkin 1953). The mean water retention time of present Upper Campbell Lake is 3.9 months.

A limnological survey in 1976 i.e. about 20 years after its formation, found Upper Campbell reservoir to be ultra-oligotrophic (B.C. Research 1977). The thermal and dissolved oxygen profiles were approximately the same as the pre-project conditions. Inorganic nitrogen concentrations at that time were very low and less than the total phosphorous concentrations (the opposite ratios to most B.C. reservoirs and lakes) which lead to the conclusion that Upper Campbell Lake's productivity was limited by nitrogen (more recent studies in Buttle Lake found phosphorous to be the main constraint - see below). Species diversity amongst the phytoplankton was low, and chlorophyll-*a* values were correspondingly low. The benthos was dominated by chironomids, although abundance was severely curtailed in the drawdown littoral zones. Similar conditions prevail in adjacent Buttle Lake, which has a surface area of 4203 ha, a mean depth of 70 m and a maximum depth of 130 m.

In 1965 Western Mines Ltd were granted surface mining rights for a copper-lead-zinc mine and mill in the Myra Creek valley, tributary to Buttle Lake. Mining operations commenced in 1967 with discharges being directed into Buttle Lake via a submerged outfall at the southern end. By 1980 water quality in Buttle Lake had been significantly affected, particularly with respect to copper, zinc and reactive silica (Clark 1980) and was regarded as borderline with respect to the protection of aquatic biota. The severest biotic changes were recorded for phytoplankton (Munteanu and Austin 1981) where dominant communities were replaced by sparse communities of high tolerance to heavy metals. Dominance by *Rhizosolenia eriensis* has been documented (Deniseger et al. n.d.) which bioaccumulates zinc 56,000 times and copper 34,000 times over background dissolved levels. Stricter effluent and tailings discharge control measures were instituted by the operating company following representations by the Ministry of Environment and other agencies.

Sampling in September 1983 (Fisheries Branch, Nanaimo, data files) recorded total dissolved solids content as 31 mg/l, pH 7.4 and evidence of gradients in both water temperature (15° C at surface, 8° C at 18 m) and dissolved oxygen (10 mg/l at surface, 6 mg/l at 18 m). By 1985 the *Rhizosolenia eriensis* bloom was observed to have abated; the pH of lake water was greater than 8 at all sampling stations (but considerably higher at 9-10 in Myra Creek below the mine tailings disposal) and increases in zooplankton such as Cladocera were observable (Fisheries Branch, Nanaimo, data files). Buttle Lake is still oligotrophic or even ultra-oligotrophic (Hatfield 1982a). Nutrient concentrations are very low - total phosphorus is about 0.004 mg/l and total inorganic nitrogen 0.028 mg/l. On the basis of the N:P ratio, phosphorus is regarded as limiting. Chlorophyll-*a* is low (about 1 mg/l), with phytoplankton dominated by diatoms and zooplankton dominated by copepods (*Cyclops* and *Diaptomus*) and cladocerans (*Bosmina* and *Daphnia*). Macrobenthos density is very low.

Both Buttle and Upper Campbell lakes have a severe lack of suitable spawning and rearing habitat for sport fish species such as rainbow trout (Tredger and Taylor 1980). The lack is evident even in larger lake tributaries such as the Elk River (see Heber River) and Thelwood Creek where fry may be flushed out by heavy freshet flows (Tredger and Taylor 1980).

Downstream System

Strathcona plant discharges directly into Lower Campbell Lake (see Ladore).

SPORT FISH POPULATIONS

Reservoir

Pre-impoundment netting in Upper Campbell Lake (Fisheries Branch, Nanaimo, data files) recorded rainbow trout and Dolly Varden of several age classes and sizes; mature spawners were recorded in the lake; no quantitative estimates of population sizes were recorded. No detailed population studies were made of sport fish populations in Buttle and Upper Campbell lakes. The Elk River is known to be a major contributor of rainbow trout populations in Upper Campbell Lake, and some 450-550 were observed during snorkel surveys in spring 1989 (Fisheries Branch, Nanaimo, data files).

Declines in numbers in Buttle Lake were documented on the basis of declining angling harvests (see Recreational Fishery: *Reservoir* below). Rainbow trout were noted as being very sensitive to zinc and cadmium toxicity (Fisheries Branch, Nanaimo, data files), and this fact coupled to the lack of a similar decline in adjacent but limnologically similar Upper Campbell Lake inferred that the declines in fish were due to the high heavy metal concentrations from tailings disposal in the Myra Creek watershed.

Field studies (Hatfield 1982b) of Upper Campbell and Buttle lake sport fish populations in 1982 (following improved tailings disposal and mine waste management) provided total population estimates of 22,400 in Buttle Lake and 31,000 in Upper Campbell Lake. Rainbow trout comprised 46 percent of fish in Buttle Lake and 48 percent in Upper Campbell Lake. Cutthroat trout made up 24 percent and Dolly Varden 28 percent of Buttle Lake populations. Only one fish marked in Buttle Lake (Dolly Varden) was subsequently found in Upper Campbell Lake, suggesting limited movements of fish down through the lake system. However, fish appear to range widely through Buttle Lake (Hatfield 1982b) and inter-lake movement may be significant. Fish have been observed to be passed through the Strathcona power turbines (Fisheries Branch, Nanaimo, data files).

The most recent gill netting (1988) in Buttle Lake produced very high catches - 265 fish/100 m^2/24 hr, of which 45 percent were rainbow trout (25-30 cm lengths) and 55 percent Dolly Varden (26 - 34 cm lengths); females of both species showed signs of having spawned (Fisheries Branch, Nanaimo, data files). Fish distribution in Buttle and Upper Campbell lakes is highly variable (Hatfield 1982b), hence these high catches, which were made near the inflows of Myra and Thelwood creeks at the southern tip of the lake, may not be representative of the whole lake area.

Downstream System

See Ladore.

RECREATIONAL FISHERY

Reservoir

The extent of recreational angling in Upper Campbell and Buttle lakes prior to the impoundment at Strathcona is not documented but was probably very light. The first documented creel census for either lake was in 1960 when a success rate of 0.8 fish/rod-hour was estimated (Fisheries Branch, Nanaimo, data files); the total number of anglers and the total harvests were apparently not estimated. Angling success in Buttle lake showed a significant decline in the 16-year period after 1964 (Figure 75). By contrast, success rates in Upper Campbell Lake have increased since 1978 and most recently (1986) were estimated at about 0.8 fish/rod-hour, i.e. the same rate as in Buttle Lake shortly after Strathcona Dam completion and prior to mining activities and tailings disposal in the Myra lake drainage. The species composition of the catches is not documented, except for the 1964 creel in which 62 percent of the catch was rainbow trout, 37 percent cutthroat trout and 1 percent Dolly Varden (Fisheries Branch, Nanaimo, data files). Hatfield (1982b) estimated total angling harvests in May 1982 to be 600 - 700 fish in Buttle Lake and 1500 in Upper Campbell Lake.

Downstream System

See Ladore.

LADORE
(Lower Campbell Lake)

PROJECT

Description

Ladore (sometimes known as Ladore Falls) Dam is a concrete gravity structure 37 m high and 94 m long, located 14 km above the mouth of the Campbell River (Map C) and 13 km below Strathcona Dam (see Strathcona). The concrete spillway has three gates, and the dam is provided with a 2.5 m diameter Howell-Bunger valve able to discharge 85 m^3/s. The powerplant is located at the foot of the dam and has a nameplate capacity of 54 MW. There is no fishway. Ladore was completed in 1949 by the B.C. Power Commission and modified in 1955-57 to accommodate the extra discharges from the Quinsam, Heber and Salmon river diversions (see Quinsam, Heber and Salmon). The plant is presently owned and operated by B.C. Hydro.

Water Licences and Operational Constraints

The conditional water licence, issued 1955, permits a diversion of no more than 81 m^3/s. There are no provisions for fisheries or other environmental concerns.

Electrical Generation

Ladore generates from 8 to 24 million kWH of electricity monthly, at capacities ranging from 20 to 60 percent. Monthly outputs comprise from 0.2 to 1.2 percent of B.C. Hydro's total monthly production.

Enhancement Facilities

No compensation or other enhancement facilities were provided for the development.

OPERATIONAL REGIME

Ladore power plant is operated in tandem with Strathcona above it and has the same turbine discharge and spill characteristics (Figure 76). Ladore reservoir (Lower Campbell Lake, sometimes known as Campbell Lake) is utilized as a run-of-river reservoir with a small amount of live storage (Figure 77). Drawdowns are erratic and seldom exceed 2 m below full pool.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Campbell Lake was surveyed some 12 years prior to impoundment at Ladore Falls (Carl 1937, cited by McMynn and Larkin 1953). The lake had a surface area of 1075 ha, a mean depth of 17 m and a maximum depth of 60 m. The lake temperature was warm, even at depth (10° C at 30 m depth) and there were signs of moderate oxygen depletion at depth. Benthic fauna were sparse.

Three years after reservoir formation a well-defined thermal gradient was present (McMynn and Larkin 1953), ranging from 18° C at the surface to less than 4° C at 60 m depth. Dissolved oxygen was 83 percent of saturation at 55 m depth, Secchi disk readings were 8 m, and total dissolved solids content was approximately 40 mg/l. No further limnological studies appear to have been made of Lower Campbell Lake since McMynn and Larkin's (1953) survey. The present reservoir has a surface area of 2250 ha (Fisheries Branch, Nanaimo, data files); depth dimensions have not been documented. Mean water retention time is 32 days (computed from B.C. Hydro, Operations Control Department data).

The quality and quantity of tributary habitat supplying Lower Campbell lake is not documented. The lake receives discharges from three major diversions (see Project: *Description* above), but appears to have few other major tributary systems. Significant amounts of spawning habitat for salmonids have been created at the Strathcona dam tailrace.

Downstream System

Ladore discharges directly into John Hart Lake (see John Hart).

SPORT FISH POPULATIONS

Reservoir

Pre-impoundment Lower Campbell Lake was populated by rainbow trout, cutthroat trout and Dolly Varden (Carl 1937, cited by McMynn and Larkin 1953), with sticklebacks and sculpins being the only non-sport fish species recorded. Rainbow trout were abundant but seldom exceeded 25 cm in length; cutthroat trout were larger but seldom caught. Both rainbow and cutthroat trout were recorded as abundant in the 3-year old reservoir formed from Lower Campbell Lake (McMynn and Larkin 1953), and again 8 years after impoundment when Dolly Varden were also recorded as being numerous (Fisheries Branch, Nanaimo, data files). A recent snorkel survey (1988) documented up to 375 fish immediately below the Strathcona tailrace, another 50 - 100 fish 50 m below the Strathcona Dam, and up to 275 spawning rainbow trout below the dam pilings (Fisheries Branch, Nanaimo, data files). Lower Campbell Lake has never been stocked.

Downstream System

See John Hart.

RECREATIONAL FISHERY

Reservoir

A 1980 survey of 89 anglers on Lower Campbell Lake resulted in a catch estimate of 0.74 fish/rod-hour (Fisheries Branch, Nanaimo, data files); totals angling pressure or catch composition were not estimated. A 1986 survey (Fisheries Branch, Nanaimo, data files) estimated use of the lake by 315 anglers, catching 3105 fish of unstated species (but keeping only 2025), with an angling success rate of 2.3 fish/day (approximately equivalent to 0.76 fish/rod-hour, assuming 3 hours angling per day for the average angler). Catch composition of the 1986 survey is not known.

Downstream System

See John Hart.

JOHN HART
(John Hart Lake)

PROJECT

Description

John Hart is the lowermost development of the three (Strathcona, Ladore, John Hart) which regulate the Campbell River (Map C). The dam was built in 1947 and impounds John Hart Lake. The concrete gravity dam is 20 m high and 200 m long, with a concrete spillway and three sluice gates. A 1 km long flume leads water to the powerhouse sited on the bank of the Campbell River about 3 km further downstream. The John Hart generating station has a nameplate capacity of 120 MW. From 1970 through 1973 a proposed expansion to John Hart was studied, with alternative possibilities of either increasing the powerhouse size or constructing new (some underground) facilities. These schemes have been held in abeyance since 1977. The dam was extensively repaired from 1986 through 1988.

Water Licences and Operational Constraints

The water licence for the John Hart scheme permits a maximum diversion of 88 m^3/s (3100 cfs). DFO records (e.g. DFO 1966) suggest an informal agreement by B.C. Hydro to limit discharges to a maximum of 120 m^3/s (4300 cfs) and a minimum of 28 m^3/s (1000 cfs), but no such stipulations appear in the water licenses and present spills exceed these limits (see below).

Electrical Generation

John Hart generates from 34 to 84 million kWH of electricity monthly, and supplies from 0.9 to 3.5 percent of B.C. Hydro's total monthly output. The three Campbell River plants together generate from 60 million to 140 million kWH per month, and contribute up to 5 percent of the provincial hydroelectric energy. The schemes are operated as combined base load and peaking plants, and outputs vary from near zero to more than 100 percent of plant capacity. There is a hydraulic imbalance between the three developments, the John Hart plant having the lowest capacity, and a consequent need to frequently spill water from John Hart Lake.

Enhancement Facilities

No enhancement facilities were undertaken by the proponent during development of any of the Campbell River schemes. Side-channels for chinook, chum and steelhead, located below the powerhouse, were designed in 1984 by DFO (DFO 1984) and had been partially implemented by 1988 (DFO, pers. com.).

OPERATIONAL REGIME

The flow regime within the 5 km river reach between John Hart Dam and the river mouth is totally controlled by releases through the dam and powerhouse. Daily discharges through the turbines from January 1984 through December 1987 (Figure 78) ranged from about 50 to 110 m^3/s (1700 to 3900 cfs). Spill releases in 1986 and 1987 were sudden, and ranged from zero to as high as 340 m^3/s (12,000 cfs) within the space of a few days. The reservoir provides a minimal amount of storage and drawdowns have seldom exceeded more than 0.5 m within any one month (Figure 79).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

John Hart Lake is a relatively small reservoir of uncertain surface area size (B.C. Hydro data = 530 ha, McMynn and Larkin (1953) = 363 ha, Fisheries Branch, Nanaimo = 296 ha). The mean water retention time is slightly under 2 days (based on data from B.C. Hydro, Operations Control Department). Maximum depth is 23 m, mean depth 12 m, and about 30 percent of the lake area consists of shallows less than 10 m deep (McMynn and Larkin 1953).

There has been little interest in the limnology of the lake. Some 6 years after formation McMynn and Larkin (1953) found dissolved oxygen to be at or near saturation throughout the water column, and to be isothermal (near 15° C in October). The reservoir was -‑ported to have a fine silt bottom with few benthic organisms following formation (McMynn and Larkin 1953), this is probably still the case. Fish habitat along the shorelines appears to be limited to some localized areas within small tributary streams.

Downstream System

The lower Campbell River is about 5 km in length from the John Hart Dam to the river mouth, ranges in width from 40 to 100 m, and is generally swift flowing. Prior to construction of the John Hart Dam, the Elk Falls were a natural blockage to anadromous salmon (Hamilton and Buell 1976). The present limit to upstream migrations is the pool below the John Hart tailrace. The Campbell River is generally deficient in spawning gravels for two reasons - a lack of supply from the upper watershed due to impoundment, and fluctuations in discharge which have washed out existing gravel substrates (Hamilton and Buell 1976).

Salmonid rearing habitats are limited in the lower Campbell River, which leads most anadromous species, including steelhead, to depend on the Campbell River estuary for rearing habitat. The river is considered to have a sub-optimal food supply, and a lack of adequate protective cover vegetation (Hamilton and Buell 1976).

SPORT FISH POPULATIONS

Reservoir

A gill net sample in March 1980 (Fisheries Branch, Nanaimo, data files) resulted in catches of small numbers of rainbow trout (mean length 24 cm, range 15 - 28 cm), cutthroat trout (mean length 35 cm, range 326 - 44 cm) and Dolly Varden (mean length 30 cm, range 24 - 41 cm), and very few sculpins. The lake has not been stocked and local tributary habitats apparently maintain the locally important sport fish populations, although passage of fish through the Ladore powerplant from Lower Campbell Lake is a likely occurrence.

Downstream System

Non-anadromous fish stocks are of relatively little significance in the short reach of the Campbell River below John Hart Dam, and no specific data are available.

RECREATIONAL FISHERY

Reservoir

An extensive angling survey of Vancouver Island in 1986 (Fisheries Branch, Nanaimo, data files) included John Hart Lake, where an estimated total of 30 anglers reported a mean catch rate of 0.8 fish/day, although the angling effort was relatively low (about 1.5 days expended per individual angler). Rainbow trout made up 54 percent of the catch, cutthroat trout 45 percent and Dolly Varden only 1 percent.

Downstream System

No data available.

QUINSAM

PROJECT

Description

The Quinsam project consists of a 9 m high, 31 m long, concrete dam at the outlet of Wokas Lake (Map C). A 5.5 m diversion dam 1 km further downstream diverts water through Gooseneck and Snakehead lakes and Miller Creek to Campbell Lake for electrical generation thorough the Ladore and John Hart generating stations (see Ladore and John Hart). The diversion dam is equipped with a spillway and spill gates. The total Quinsam River drainage is 209 km^2 in extent, and the Quinsam is the major tributary to the Campbell. Major tributaries of the Quinsam River are Iron River, Cold Creek and Flintoff Creek. The project was placed into operation by the B.C. Power Commission in 1956.

Water Licences and Operational Constraints

The initial water licence in 1956 authorized the B.C. Power Commission to store up to 1.2 million m^3 of water in Wokas Lake. The initial request from the B.C. Power Commission (prior to design completion) for an 8.5 m^3/s (300 cfs) diversion (the maximum capacity of the diversion canal) was rejected by DFO. Following extensive reviews and discussion the project was redesigned and licensed to divert a maximum of 4.7 m^3/s (165 cfs) in 1958, with provision for release of 1.7 m^3/s (60 cfs) through the sluice gate for fishery purposes between 1 September and 15 November (Comptroller of Water Rights files). DFO found these releases to be insufficient to safeguard the salmon resources, and by 1957 had agreed with the B.C. Power Commission on a continuous 0.6 m^3/s (20 cfs) release plus guaranteed storage for fishery purposes in Wokas and Upper Quinsam Lakes (the lowermost 0.6 m). This was again amended in 1963 to permit releases of 1.7 m^3/s for 9 months of the year (September through May) and 0.3 m^3/s (10 cfs) for June, July and August. No further changes have occurred to date.

Electrical Generation

The Quinsam diversion generates no power directly, but supplies the Campbell lake system which generates power at Ladore and John Hart generating stations (see Ladore and John Hart).

Enhancement Facilities

DFO established a hatchery on the lower Quinsam River some 3 km above Campbell River which commenced operations in 1974. From 1978 a program of planting of pre-migrant coho and steelhead fingerlings to otherwise inaccessible reaches in the upper Quinsam watershed has been followed. Smolts then migrate seaward through Middle and Lower Quinsam lakes. Recent surveys of the area found most upper watershed lakes and streams heavily utilized by planted fish (Blackmun et al. 1985). Rearing ponds were added to the Quinsam hatchery in 1984. Pink salmon enhancement levels for the lower Quinsam River by 1987 had reached 4.5 million fry released. There are presently no facilities for non-anadromous fish stocks.

OPERATIONAL REGIME

B.C. Hydro's Operations Control Department does not maintain data on storage changes within Upper Quinsam or Wokas lakes. Diversion flows from the Quinsam watershed are combined with releases through Strathcona and recorded as "regulated inflow" into Upper Campbell Lake.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Upper Quinsam Lake has not been surveyed nor sampled for water quality. Wokas Lake has a surface area of 60 ha and a maximum depth of 34 m; the mean depth has not been documented. Dissolved oxygen concentrations have been measured to range from 8.5 mg/l at the surface to 7 mg/l at 28 m depth (Campbell River Junior Secondary School 1978). Lake pH ranges from 6.7 - 7.0 and total dissolved solids content is about 30 mg/l (Ministry of Environment, lake survey data). Shoreline habitats for spawning and rearing are not abundant, and the general abundance of cutthroat trout in the lake (see Sport Fish Populations below) is likely due to small tributary habitats. The general lack of good salmon spawning habitat in the upper Quinsam River area was a key factor in decisions not to invest in fishways during the development of the Quinsam diversion project (DFO, data files).

Downstream System

Fish habitats within the Quinsam River have been surveyed by the Ministry of Environment (Hawthorn 1984). Additional survey data are available from studies done for the Quinsam coal project (Norecol 1983) which is planned for the region surrounding Middle Quinsam Lake.

The Quinsam River below Wokas Lake is a 10 m wide stream flowing within a confined channel and over a 2 percent gradient. The substrate comprises cobbles and large gravels. Below the small diversion headpond the valley and channel are wider (15 m) but the gradient steeper (2.6 percent). Large numbers of cutthroat trout redds occur in the reach immediately above Middle Quinsam Lake (Norecol 1983). Below Middle Quinsam Lake the channel enters a canyon in which substrates are cobbles and large gravels. This reach has numerous cascades, each 50 to 60 m long and 4-5 m high, and a few side channels, important to rearing salmonids. The most significant feature is a 15 m waterfall which is impassable by anadromous salmonids and marks the upper end of the 38 km stretch of the river accessible to spawners. Below the cascades the channel broadens to 20 m and flows through a wide valley with a gradient of only 0.7 percent. Above the Iron Creek confluence the channel enters a marshy area of low gradient and silty substrates. The river below Quinsam Lake has a 1.4 percent gradient with gravel substrates and exposed bedrock. Numerous cascades in this reach are passable by salmonids only during periods of high discharge. The terminal 8 km portion of the river is a low gradient stream with a large proportion of fines in the substrate.

Middle Quinsam Lake has an area of 70 ha, a mean depth of 4 m, and a maximum depth of 15 m (Fisheries Branch, Nanaimo, data files). Most of the lake is less than 6 m deep and the western half less than 4 m deep (Hawthorn 1984). The lake has rocky shorelines and submerged logs from previous logging activities, and has only low to moderate fishery habitat values. The eastern and western portions of the lake support extensive stands of aquatic macrophytes and are more productive habitats for fish. Quinsam Lake has a surface area of 1187 ha (Ministry of Environment, lake survey data) and similar physical features to Middle Quinsam Lake; much of the lake is occupied by snags and debris.

Quinsam River water has a pH ranging between 6.8 to 7.6 and is very low in suspended material (Blackmun et al. 1985, Redenbach et al. 1985), but can become very turbid following storm events (Lukyn et al. 1985). Water temperatures in Middle Quinsam Lake reach 22° C in mid-summer (Blackmun et al. 1985) which may be deleterious to rearing salmonids and which are nearly 4° C higher than temperatures in the lower Quinsam River. Dissolved oxygen concentrations below Middle Quinsam Lake drop to near 77 percent saturation in summer and remain in the high 90's for the rest of the year (Blackmun et al. 1985).

Lake and river waters below the diversion dams are described as oligotrophic (Blackmun et al. 1985, Redenbach et al. 1985, MacIsaac and Stockner 1985) with total dissolved solids ranging from 30 to 50 mg/l, total dissolved phosphorus from <2 to 4.5 μg/l, and total dissolved nitrogen seldom reaching as high as 150 μg/l. Productivity in Long and Middle Quinsam lakes is believed to be essentially limited by nitrogen at the present time (MacIsaac and Stockner 1985). Quinsam River water below the Quinsam hatchery (3 km above the Campbell River confluence) has a significantly higher content of dissolved phosphorus (up to 13 μg/l) and nitrates (up to 57 μg/l) than elsewhere in the system (Redenbach et al. 1985).

No habitat inventory data are available for the reaches through which the diverted water flows to the Campbell lake system. Chemical and physical water quality in Gooseneck Lake, which is the first lake to receive the diverted flows to the Campbell system, is similar to that in the lower Quinsam system (Redenbach et al. 1985).

SPORT FISH POPULATIONS

Reservoir

The fish fauna of Wokas Lake appears to be almost totally dominated by cutthroat trout (Ministry of Environment, lake survey data) with small numbers of sculpins also present. Gill net sampling in 1978 resulted in a 90 percent catch of cutthroat trout, rainbow trout making up the remainder (Campbell River Junior Secondary School 1978). Cutthroat trout sampled reached a maximum size of 35 cm.

Downstream System

Cutthroat trout were the dominant species in Quinsam lake in 1958, 1976 and 1983, based on gill netting samples (Ministry of Environment, lake survey data; Norecol 1983), with small numbers of rainbow trout, Dolly Varden and kokanee also present. All sport fish sampled were dominated by immature age classes. Detailed population studies or analyses of age and sex composition have not been undertaken.

RECREATIONAL FISHERY

Reservoir

Wokas Lake was included in a Vancouver Island-wide creel survey in 1986 (Fisheries Branch, Nanaimo, data files) and 120 anglers were estimated to use the lake. Catches consisted of cutthroat trout only, with a catch per unit effort of 1.7 fish/angler/day, and total estimated catch of 795 for the season.

Downstream System

Quinsam Lake was included in a Vancouver Island-wide creel survey in 1986 (Fisheries Branch, Nanaimo, data files) and 145 anglers were estimated to use the lake. Catches were not analyzed as to species composition, but were probably dominated by cutthroat trout. Catch per unit effort was relatively high at an estimated 2.2 fish/angler/day, and the total estimated catch was 995 for the season.

HEBER RIVER

PROJECT

Description

The project consists of a low diversion dam across the upper Heber River to the west of Strathcona Park in central Vancouver Island (Map C). The flows are diverted into the Drum lakes and from there into the Elk River and then to the Upper Campbell Lake reservoir. No documentation is available on the dimensions of the rock-filled timber crib diversion dam. The diversion was brought into operation by the B.C. Power Commission in 1956.

Water Licences and Operational Constraints

The water licence entitles the holder to divert 111 million m^3 water per annum. A clause requires the licensee to release enough water for "fish propagation" in the Heber River. This was established in 1971 (order attached to Water Licence), following earlier metering and surveys by DFO (DFO 1958) to be not less than 0.6 m^3/s (20 cfs) as measured at the falls in the Heber River near the highway bridge crossing.

Electrical Generation

There is no generation plant on the Heber River and all diverted water is routed through the Campbell lakes system to generate power at the Strathcona, Ladore and John Hart power plants.

Enhancement Facilities

No fisheries protection or enhancement facilities were incorporated in the construction of the diversion.

OPERATIONAL REGIME

A fixed release valve permits the licensed minimum release of 0.6 m^3/s to the lower Heber River, and no gauging or monitoring is carried out (B.C. Hydro, Operations Control Department). The only major tributary of the Heber below the diversion is Saunders Creek, with an estimated maximum discharge of about 3 m^3/s, hence summer flows in the Heber River are likely low and very close to the 0.6 m^3/s minimum discharge through the diversion. Similarly, summer flows in the Elk River have likely been enhanced by the diversion of the Heber River.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The headpond above the diversion is limited in size and does not constitute a significant retention reservoir.

Downstream System

Useful anadromous fish habitat in the Heber River is restricted to a reach of some 10 km length above the Gold River confluence (DFO 1957). Substrates in the lower section consist of gravel pockets and many boulders, and the stream channel is largely confined. Two canyons (300 m and 1.5 km above the Heber-Gold confluence) contain falls from 1 to 3 m in height and are likely barriers to anadromous species such as chum and pink salmon and winter steelhead. Approximately 11 km above the Gold River confluence is a fall of about 4 m height which probably constitutes a total barrier for upstream fish migration. No habitat inventories appear to have been made for the Heber River. The Heber diversion into the Elk River has an influence on fish populations in Upper Campbell Lake (see Strathcona).

SPORT FISH POPULATIONS

Reservoir

There is no information available on the fishery resources above the diversion dam.

Downstream System

All five species of Pacific salmon utilize the Gold River of which the Heber River is a tributary, but no enumerations have been made specifically for the Heber. Steelhead probably make use of the Heber River, but no information is available for any anadromous or non-anadromous sport fish species.

RECREATIONAL FISHERY

Reservoir

No information available.

Downstream System

No information available.

SALMON RIVER

PROJECT

Description

The project consists of a dam on the upper Salmon River which diverts flows from the Salmon River and Paterson Creek via a flume into the outlet of Brewster Lake and then on to Campbell Lake below Strathcona

Dam (Map C). The scheme was constructed from 1956 to 1958. There is no power plant on the Salmon River, and diverted flows are used to generate power at Ladore and John Hart generating stations. The impoundment dam has minimal storage capacity.

Water Licences and Operational Constraints

The conditional water licence entitles the holder to divert 493 million m^3 water per annum. A clause stipulates that a flow of at least 2.8 m^3/s (100 cfs) be maintained at the WSC gauging station 08HD007 (Salmon River above the Memekay River confluence) from 20 August to 15 November and that at least 2.4 m^3/s (83 cfs) be maintained at the same location for the remainder of the year. In addition, a minimum flow of 0.14 m^3/s (5 cfs) is to be maintained at all time below the point of diversion. All flow releases are subject to the water being available in the natural flow of the river. The fish release specifications were developed by DFO in collaboration with the B.C. Power Commission and based on mean seasonal minimum monthly flows.

Electrical Generation

The diversion contributes to power generation through the Ladore and John Hart power stations on the Campbell River.

Enhancement Facilities

No facilities were provided by the utility as mitigation or compensation at the time of construction of the diversion dam. In 1986 a movable fish screen was installed by the Ministry of Environment, with funding provided through SEP, to direct steelhead smolts past the diversion into the Salmon River. SEP has also planted coho in many areas throughout the upper and middle Salmon watershed, using the Quinsam hatchery (see Quinsam) as a fry source. Steelhead fry have been stocked annually into the upper Salmon River and Grilse Creek since 1986. Nutrient enrichment is currently being studied as a means of increasing salmonid productivity of the mainstem Salmon River.

OPERATIONAL REGIME

Operational data on the discharges through the diversion are not kept by B.C. Hydro's Operations Control Department.

PHYSICAL AND CHEMICAL ENVIRONMENT

Upstream System

There is no reservoir above the diversion. Stream habitats above the B.C. Hydro diversion are morphologically similar to those immediately below the structure (Ptolemy et al. 1977) see below. Grilse Creek is regarded as especially valuable steelhead rearing habitat and plans to enhance the reach through nutrient enrichment are currently being prepared (Fisheries Branch, pers, com.). About 20 percent of potentially useful steelhead habitat within the Salmon River system lies above the diversion.

Downstream System

Only post-diversion flows have been monitored at the WSC gauging station above the Memekay River (Figures 80, 81 and 82). Pre-diversionary discharges, including those on which the water licence requirements were based, were computed from correlations and extrapolation from Campbell River records. Salmon River discharges are highly erratic because of the elevational gradients within the watershed, heavy winter rainfall and relatively low summer precipitation. Post-diversionary flows have probably added an element of stability to downstream discharges, but have not overcome any low flow problems in summer nor diminished the incidence of flood freshets, many of which originate below the Salmon diversion.

Until 1980 the Salmon River was accessible to anadromous salmon for a length of 38.5 km (Ptolemy et al. 1977). Boulders, bedload debris and log obstructions were major obstacles to salmonid migrations until removed over a period of 5 years, thereby adding some 12 km to the usable habitat within the system.

The Salmon River is wide (up to 50 m), deep (>2 m), and is slow moving in lower reaches (Ptolemy et al. 1977). The upper reaches have high gradients, confined widths, shallower depths and faster current velocities. Substrates are gravels/cobbles throughout, with some boulders and bedrock segments. Very large amounts of organic debris have accumulated in the river. Gravel movements are common due to the frequent freshets. The lower river channel is unstable, with relatively large channel shifts and braiding.

Riverine habitats are pool-riffle and riffle-glide (Ptolemy et al. 1977). Stream cover is limited in the lower reaches. Limitations to salmon rearing include bedload movements, lack of cover and bank erosion. Salmon

River water is low in conductivity, total alkalinity and total hardness, and pH varies from 6.7 to 7.4

SPORT FISH POPULATIONS

Upstream System

Rainbow trout have been noted throughout the 8 km reach above the diversion dam (Fisheries Branch, Nanaimo, data files) although the condition of the trout was noted to be poor. Kokanee were reported as occurring in smaller headwater lakes in the Salmon drainage (Ptolemy et al. 1977), their present status is unknown. Steelhead trout have been stocked to the upper Salmon River since 1986 and now dominate the fish fauna in the upper system .

Downstream System

No information is available on nonanadromous stocks in the lower Salmon River. Anadromous salmon, including all five Pacific salmon species, plus sea-run cutthroat trout, Dolly Varden and steelhead make use of the lower Salmon system. Sockeye are now seldom recorded in escapement counts, and coho and chinook have shown marked declines which are not correlated directly with development of the diversion in the upper Salmon (Hirst 1991).

RECREATIONAL FISHERY

Upstream

No specific information is available, but recreational fishing is probably minimal in the upper Salmon system because of difficult access and the high incidence of boulders and turbulent reaches.

Downstream System

No information on non-anadromous recreational fishing is available. Because of the dominance of anadromous stocks, particularly steelhead, interest in non- anadromous fishing is probably minimal.

PUNTLEDGE
(Comox Lake)

PROJECT

Description

The Puntledge River diversion project was first developed in 1913 by Wellington Collieries Ltd to supply electricity to coal mines in central and eastern Vancouver Island. An impoundment dam was constructed at the outlet of Comox Lake (Map C), which has a drainage basin of some 450 km^2. About 4 km further downstream was a diversion structure which led water for 5 km via wood-lined flumes and stave pipes to powerhouse on the bank of the lower Puntledge River. The initial plant capacity was 7 MW although this much power was never generated. A fishway into Comox Lake was installed as part of the original project.

The B.C. Power Commission redeveloped the dams and powerhouse from 1953 to 1956 and increased Comox Lake storage from 54 million to 85 million m^3/s. They planned initially to use all 28 m^3/s (1000 cfs) in the existing water licence. DFO strongly opposed any such uses because of the high salmon values of the system, and the reconstructed project was accordingly scaled down to use lesser flows (see below). The present project consists of a 10 m high, 100 m wide concrete and earthfill dam at the outlet of Comox Lake equipped with gated sluiceways and an overflow spillway. The diversion dam is a 3.5 m high, 30 m long, concrete structure with a 2.5 m by-pass channel and a maximum spill capacity of 340 m^3/s. Both dams were furnished with rebuilt fish-ladders in 1955-56, and the main dam was raised by 5 m in 1981 to accommodate the Maximum Probable Flood.

Water Licences and Operational Constraints

The original Wellington Collieries licence was for 28 m^3/s (1000 cfs) maximum diversion, but the maximum actually used did not exceed about 8.5 m^3/s (300 cfs). The licence was transferred to the B.C. Power Commission and then to B.C. Hydro. Considerable discussion and some experimentation with flow releases down the Puntledge River from 1956 to 1964 has led to agreements between DFO and B.C. Hydro regarding flow releases. The present agreements, dating back to 1965, deal separately with the upper river, between the diversion dam and the powerhouse, and the lower river below the powerhouse.

The required minimum flow in the Puntledge River channel below the diversion dam from June to August is 5.7 m^3/s (200 cfs) for the benefit of the summer-run chinook, and 2.8 m^3/s (100 cfs) for the rest of the year (DFO 1974). The minimum flow below the powerhouse must be 21 m^3/s (725 cfs) at all times; this includes the inflows from the Browns River. If DFO considers it necessary to minimize injuries in the tailrace, a shutdown of the power plant can be ordered. From 1963 through 1965 a total shutdown was effected during June and July and the plant operated on a 12-hourly basis only (0600-1800 hrs) during August.

The above formal agreement between DFO and B.C. Hydro has been informally modified in attempts to benefit both fisheries and power generation (DFO 1974). From November through February the 2.8 m^3/s minimum flow below the diversion dam is in effect and provides barely adequate coverage for summer run chinook spawning, but is insufficient for steelhead to ascend Stotan Falls. From March to mid-June, B.C. Hydro provides flows of 5.7 m^3/s below the diversion and draws down Comox Lake (if refill forecasts are favourable) to reduce the incidence of freshet flows in the lower river and to benefit rearing conditions for chinook and other fry. From mid-June to mid-August, the plant is operated at reduced loads to minimize adult injuries at the tailrace, and flows below the diversion are increased to 8.5 to 14 m^3/s (300 to 500 cfs) to minimize pre-spawning adult injuries at Stotan and Nib Falls. After mid-August when summer-run chinook have completed their in-migration, DFO normally agrees to B.C. Hydro reducing flows to 7 m^3/s (250 cfs) to reduce draws on Comox Lake. B.C. Hydro usually requests that flows in the lower Puntledge River be reduced below the agreed minimum of 21 m^3/s (725 cfs) to conserve water in Comox Lake. By 1990 DFO were requesting flows of 17 m^3/s from July through mid-September and 20.5 m^3/s from mid-September through the end of June (DFO 1989). Mid-September to mid-October minimum flows of about 4 m^3/s (150 cfs) are required to operate the spawning channel effectively, and to provide for summer-run chinooks holding in the channel or in the diversion pool below it.

Electrical Generation

The Puntledge generating plant presently has a nameplate capacity of 27 MW. Actual power generation at the plant varies considerably from month to month and within any one period according to peak power demands and the highly variable nature of the storage available in Comox Lake. Some degree of variability in power generation is caused by the flow constraints due to fisheries needs. Between January 1984 and June 1987 monthly power generation ranged from zero to 19 million kWH (100 percent capacity), with contributions to the B.C. Hydro hydroelectric grid ranging from zero to 0.7 percent.

Enhancement Facilities

A fishway into Comox Lake was installed as part of the original project; extensive use by fish has not been documented although the sporadic occurrence of chinook and chum salmon in Comox Lake tributaries testifies to its occasional use. Following redevelopment of the Puntledge project in 1955, DFO requested salmon enhancement facilities to compensate for the various impacts. Following lengthy negotiations involving hearings before the B.C. Energy Commission (B.C. Hydro 1962), B.C. Hydro contributed to building and maintaining a chinook spawning channel adjacent to the diversion dam in 1965. In 1971, following poor results from the enhancement, B.C. Hydro contributed to building rearing ponds adjacent to the spawning channel.

In 1977 DFO established a hatchery on the Puntledge River near Courtenay to build up fall-run chinook, coho and steelhead stocks through restocking throughout the watershed. A spawning channel adjacent to the powerhouse was under design by DFO in 1990 (Sigma Engineering Ltd 1990). There are currently no enhancement facilities specifically for the non-anadromous fishery.

OPERATIONAL REGIME

The Water Licences and Operational Constraints section above outlines the present operational mode of the project as influenced by fisheries constraints. The live storage in Comox Lake is only about 10 percent of its total volume (Figure 83), and the dam does not have full flow control capacity. Under conditions of high inflow (winter rains from October through December, freshet inflows in April and May), B.C. Hydro is obliged to spill to the Puntledge River to avoid flooding damage around the lake. The resultant high flash flows are considered to severely impact redds, rearing smolts and incubating eggs in the lower river (Steelhead Society 1985). Flood flows in excess of 28 m^3/s (1000 cfs) are known to cause migration problems for chinook at Stotan Falls, and the optimal flow is in the 10-20 m^3/s range (Marshall 1974).

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Comox Lake has a surface area of about 1620 ha and a maximum volume of 78 million m^3; mean depth is 61 m and maximum depth exceeds 100 m (Fisheries Branch, Nanaimo, data files). The pH has been measured at 7.3 - 7.4, and total dissolved solids content is recorded as ranging close to 25 mg/l (Fisheries Branch, Nanaimo, data files). The lake has not been studied nor monitored to any extent, and appears to be a typical oligotrophic lake. Samples in June 1975 contained about 30 percent Cladocera and cyclopoid copepods, 23 percent rotifers and 15 percent calanoid copepods, while phytoplankton were dominated by *Rhizosolenia* (Fisheries Branch, Nanaimo, data files). The lake is provided with an extensive system of tributaries, including the upper Puntledge River, Cruickshank River, and Comox, Beech, Pearce, Boston, Harding and Perseverance creeks. None of these have been surveyed for habitat characteristics.

Downstream System

The mean annual post-project discharge in the Puntledge River (gauged in the lower river near Courtenay) is 43 m^3/s (1500 cfs). The pre-project discharge record is relatively short but appears to indicate little difference in terms of maximum and mean flows. Minimum flows, both monthly and daily, are more stable. The Puntledge River has a small watershed and low storage capacity (Comox Lake) in relation to total run-off and monthly and seasonal flow are highly variable. Minimum flows have been stabilized by the impoundment of Comox Lake.

The 1.5 km reach above Nib falls commences at the diversion dam and contains extensive gravel beds still used by chinook. Nib Falls is impassable to salmon at high and low flows. The 2 km reach between Nib and Stotan falls contains patches of spawning gravels used intensively by chinook and coho. The 3 km reach above the powerhouse has a gradually declining gradient and is bounded at the upper reach limit by Stotan Falls which is impassable under low or very high flow (flood) conditions. Migration baffles were installed at Lower Stotan falls in 1969 and Upper Stotan Falls in 1971, and a minimum summer flow established to allow chinook to negotiate the falls. A fishway through Middle Stotan Falls was completed in 1986 (DFO 1985). The lowermost 4 km of river from the powerhouse to the mouth is a low gradient, moderate velocity reach, with some islands and small back channels and is the main spawning area for pink and chum salmon.

Despite the high salmon resource values in the Puntledge River, there appear to be no detailed habitat survey data. Based on the seasonal distribution of spawners, the entire Puntledge River from the mouth to the diversion dam, with the exception of cascades and falls, appeared to contain high quality gravels at the time the hydroelectric project was refurbished (1953 to 1956). The amount of spawning gravels in the river has steadily declined since that time, allegedly due to seasonal freshets which have eroded the stream bed, with no replenishment from higher reaches (DFO 1974).

SPORT FISH POPULATIONS

Reservoir

Gill netting samples in 1948 revealed a predominance of kokanee and Dolly Varden in Comox Lake (Fisheries Branch, Nanaimo, data files), with small numbers of cutthroat trout and smaller numbers of rainbow trout. The lake has not been sampled nor studied in detail, but the present fish populations appear to be dominated by cutthroat trout, with smaller numbers of rainbow trout and very few, if any, kokanee (Fisheries Branch, Nanaimo, data files).

Early (1923 to 1930) attempts to stock the lake and the upper tributaries with sockeye salmon were unsuccessful (Burridge 1954) although the reasons for this were not clear. Due to the long-standing existence of the impoundment dam at the Comox Lake outlet, little interest was expressed in the use of Comox lake and the upper tributaries for salmon production until 1980 when coho fry were released into Comox Lake, the Cruickshank and the Upper Puntledge systems. This program has continued to the present (DFO, pers. com.).

Downstream System

Both cutthroat trout and rainbow trout occur throughout the lower Puntledge, but numbers and densities have not been assessed. The status of Dolly Varden in the lower system is unknown.

RECREATIONAL FISHERY

Reservoir

Comox Lake is easily accessible to lower and central Vancouver Island communities, and supports a relatively large number of lake shore cottages. A Vancouver Island-wide creel census in 1986 estimated a total of 4450 angling days expended on the lake, with a relatively high rate of 5.2 days per angler (Fisheries Branch, Nanaimo, data files). A total catch of 5265 was estimated, giving a catch per unit effort of 1.2 fish/angler/day. Catch composition was not estimated, but most likely consists predominantly of cutthroat trout.

Downstream System

No specific information available on the non-anadromous fishery.

ASH RIVER
(Elsie Lake)

PROJECT

Description

The development consists of a 30 m, 185 m long, rock- and earth-filled dam located on the Ash River at the outlet of Elsie Lake, central Vancouver Island (Map C). The main dam has a concrete weir spillway with a capacity of 1100 m^3/s but no outlets. Four separate saddle dams range in height from 3 to 18 m and width from 50 to 450 m. One saddle dam is equipped with a 2.5 m diameter reinforced concrete culvert which discharges into a channel leading into the main river channel. A 6.5 km power tunnel carries water to a power station of 25.2 MW capacity located on the northern shore of Great Central Lake. The project was completed in 1958.

Water Licences and Operational Constraints

The conditional water licence provides for maximum storage of 76.5 million m^3 and a maximum diversion of 339 million m^3 per annum. A mean minimum monthly flow of 3.5 m^3/s (125 cfs) is required in the Ash River near its confluence with the Stamp River for fisheries protection purposes (referring to anadromous salmon, since the conditions were negotiated by DFO). In addition the discharges from Elsie Lake may not be less than 0.7 m^3/s (25 cfs) from June through August, and not less than 0.3 m^3/s (10 cfs) at other times.

The conditional water licence (issued in 1956) also made provision for "fish collection works" at the power house on Great Central Lake; this provision has apparently not been required to date.

Electrical Generation

The Ash River generation plant is run as a base load plant for most of the year, during which time generated capacity ranges from 18 to over 21 million kWH per month, the latter generation being over 100 percent of the plant's nameplate capacity. During the winter months generation is maintained at a high level, generally in excess of 90 percent capacity, and cut back to about 40 percent capacity during the drier summer months.

Enhancement Facilities

None associated with the hydroelectric project. Elsie Lake and the lower Ash River are frequently stocked with steelhead (see Sport Fish Populations: *Reservoir* below).

OPERATIONAL REGIME

Elsie Lake has a relatively large active storage volume (over 80 percent of total volume) which is fully utilized for power generation (Figure 84). The reservoir is normally fully drawn down by September each year (Figure 85), drawdown ranging from 6 to 14 m below full pool level. Reservoir filling occurs rapidly, usually within a month, following the onset of heavy winter rainfall in the central Vancouver Island region.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Elsie Lake is 1106 ha in extent, has a mean depth of 8 m and a maximum depth of 21 m (Fisheries Branch, Nanaimo, data files). Total dissolved solids have been measured at 32 mg/l, pH at 6.9, and dissolved oxygen is 8 mg/l throughout the water column to a depth of at least 14 m (Ministry of Environment, lake survey data). The lake shoreline was apparently cleared prior to impoundment, and there is a general absence of aquatic macrophytes.

Downstream System

There were no long-term gauging data available at the time the project was designed and constructed, and the discharges were computed largely on the basis of correlations. These estimates suggested that the annual mean minimum flows for the period 1914 to 1921 at the Ash River mouth were near 3 m^3/s. However, DFO estimated the minimum flows from August through October to be about 9.5 m^3/s. Gauged flows from 1956 to 1958 below the dam site gave estimates of mean minimum flows of over 7 m^3/s, which were at the time considered the minimum required for optimal coho rearing in the mainstem Ash River.

Post-impoundment discharges (Figures 86 and 87) are characterized by variable maximum daily and monthly flows, but fairly constant minimum monthly and daily discharges in the Ash River near the confluence with the Stamp River. Flows in August and September decline sharply and consist entirely of the minimum fisheries flows released through the saddle dam outlet.

There are no habitat inventory data available for the Ash River or any of its main tributaries. At least one falls (Dickson Falls, 13 km above the mouth) occurs in the 20 km reach between the mouth and the Elsie Lake dam, and is probably a significant fish blockage.

SPORT FISH POPULATIONS

Reservoir

Gill net sampling during a field reconnaissance in 1969 (Ministry of Environment, lake survey data) indicated a lake fish population composition of 85 percent rainbow trout (including steelhead) and 15 percent cutthroat trout. A program of steelhead releases into the lake was commenced in 1982 with 170,000 smolts released, followed by 215,500 in 1983, 67,060 in 1986 and 104,533 in 88 (Fisheries Branch, Nanaimo, data files).

Downstream System

Earlier (pre-1958) DFO records judged the annual coho escapement to the Ash River to be about 1500. Steelhead were estimated to be about as numerous as coho. No information is available on other species within the Ash River. Sockeye, chinook, chum and pink salmon occur in significant numbers in the Stamp River - Great Central Lake system. A 1976 swimming survey of sections of the lower Ash River (Fisheries Branch, Nanaimo, data files) indicated large (but localized) numbers of cutthroat and rainbow trout up to 1 kg in size; juvenile trout were noted as being numerous.

RECREATIONAL FISHERY

Reservoir

The 1986 Vancouver Island creel census estimated a total of 2795 fish caught annually, with 1450 kept (52 percent) by 420 anglers over a total period of 1310 days. Mean time expended per angler was 3.1 days, and the estimated catch per unit effort was 2.1 fish/ angler/day. The composition of the catch was not estimated.

Downstream System

No information is available on the recreational fishery in the lower Ash River system.

JORDAN RIVER
(Elliott Dam)
(Diversion Dam)
(Bear Creek Dam)

PROJECT

Description

The project consists of a hollow concrete dam 38 m high and 270 m long (Elliott Dam) across the Jordan River on the south-west tip of Vancouver Island (Map C). The dam is equipped with a 650 m^3/s capacity concrete spillway without any spill control facilities. There is a low level outlet with a maximum capacity of about 10 m^3/s. A diversion tunnel runs for about 9 km from the dam to a powerhouse situated at the mouth of the river. The nameplate capacity of the present generating plant, rebuilt in 1971, is 150 MW. The Elliott Dam was constructed from 1969 to 1971.

A short distance upstream are two diversion dams, the Jordan River Diversion Dam (also known as Diversion Dam) and the Bear Creek Dam, both constructed from 1911 to 1913 and upgraded from 1969 to 1971. These are 18 m high earthfill saddle dams with rock spillways and low-level outlets. None of the Jordan River dams have fish passage facilities.

Water Licences and Operational Constraints

The water licence entitles the holder (originally the B.C. Electric Company, now B.C. Hydro) to store a total of some 30 million m^3 water per annum, and to divert a maximum of 10 m^3/s (367 cfs). There are no provisions for water releases for fisheries or any other purposes.

Representations by DFO at various times in the past (e.g. 1964, 1966) have led to B.C. Hydro agreeing to minimum flow releases of about 1 m^3/s for fisheries purposes, but these have been short-term arrangements only. The 1984 - 1987 flow release data for the Jordan plant show no such releases being made, presumably because there is no longer a viable salmon resource in the system below the dams.

Electrical Generation

From 1971 onwards the plant was used as a peaking plant, operating to a maximum of about 300 hours per month. From 1984 through May 1987 electrical production from the Jordan River plant ranged from near zero to about 52 million kWH per month (about 46 percent capacity). Total monthly contribution to the provincial hydroelectric grid ranged from near zero to about 1.4 percent.

Enhancement Facilities

No fish enhancement facilities were incorporated in the construction or redevelopment of the project. Following redevelopment of a new powerhouse in 1971, DFO requested construction of pink salmon spawning channels (at B.C. Hydro's expense) but these were refused on the grounds that the species was not present prior to dam construction. Spawning channels have been considered as part of SEP, but have yet to be investigated in detail (Salmonid Enhancement Program 1983).

OPERATIONAL REGIME

There is no WSC gauging station on the Jordan River. Discharges through the turbines were very erratic for the period 1984 through 1987 (Figure 88), caused by peak load generation demands on Vancouver Island. Discharges through the turbines ranged from zero to almost 60 m^3/s (about 2000 cfs) within the same month. There were no fish water releases for the same period, hence flows below the dam were extremely low during these periods.

Drawdown in the Elliott reservoir is extensive (refer to Jordan Reservoir Drawdown Figure 89 as a guide) reaching a maximum of 4-5 m below full pool. Reservoir levels are not recorded for Bear Creek and Diversion reservoirs at the B.C. Hydro Operations Control Department, but drawdowns in the former reservoir are minimized as far as possible to maintain recreational fishery values along the shoreline (B.C. Hydro, pers. com.). The three dams apparently do not provide full flow control over the Jordan and Bear Creek discharges since spills over Elliott dam are frequent (Figure 88) although usually of short duration and relatively low volume.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

Bear Creek reservoir has a surface area of 58 ha, a maximum depth of 15 m and a mean depth of 6 m. The impoundment is ultra-oligotrophic, with total dissolved solids content of only 18 mg/l and a pH of 6.9; total dissolved phosphorus content is about 3 $\mu g/l$, total nitrogen 23 mg/l, ammonia nitrogen 7 $\mu g/l$ and nitrate/-nitrites 2 $\mu g/l$ (measurements made in 1983, Ministry of Environment, lake survey data). The reservoir contains considerable amounts of debris, although the area was apparently logged prior to initial impoundment. The surrounding terrain has been extensively logged within the past decade. Dissolved oxygen content ranges from 8 to 8.5 mg/l throughout the water column, except near the bottom where the content is only 2.5 mg/l (Ministry of Environment, lake survey data), suggesting the likelihood of stagnation and decomposition in the hypolimnion. Bear Creek reservoir has minor tributaries only, most of which dry up in late summer and provide minimal trout rearing habitat (Ministry of Environment, lake survey data).

Diversion reservoir has a surface area of 200 ha. Major tributaries to Diversion include the upper Jordan River, Wye Creek and a few smaller tributaries. None of these have been surveyed. Elliott reservoir is the smallest of the three impoundments with a surface area of 21 ha, and is supplied by Alligator and Rough creeks as well as the outflows from Diversion reservoir. No surveys of Elliott reservoir have been made, although water quality would likely be very similar to that in the upstream impoundments.

Downstream System

No river habitat inventories appear to have been made for the Jordan River. It is unlikely that anadromous fish occurred to any great extent above the sites of the existing diversions because of the relatively limited stream area available and the steep gradients in the area.

SPORT FISH POPULATIONS

Reservoir

Bear Creek reservoir has been stocked with rainbow trout fry (2038 in 1983, 10,000 in 1986, 10,000 in 1988). Gill net sampling in Bear Creek reservoir in 1983 produced a relatively high catch per unit effort of 18 fish/100 m^2/24 hours (Ministry of Environment, lake survey data). Mean length was 23 cm (range 16 - 34 cm).

Trout apparently are not flushed though into Diversion (and possibly Elliott) reservoirs in appreciable numbers, or else do not survive in those reservoirs. Diversion reservoir was totally drained in 1986 to repair leaking valve seals and very few rainbow trout were observed (Fisheries Branch, Nanaimo, data files).

Downstream System

No information available.

RECREATIONAL FISHERY

Reservoir

Access to the reservoirs is restricted because of logging closures, but is available along poor roads on week-ends. Bear Creek reservoir is known to be used by local anglers, but the level of angling effort and harvest rates have not been determined.

Downstream System

No information available.

G. NORTHERN COASTAL SYSTEMS

FALLS RIVER

PROJECT

Description

The project was built by the Northern British Columbia Power Company in 1929-30 and consists of a 12 m high, 156 m long, concrete gravity dam located at the confluence of Falls River (Big Falls Creek) and the Ecstall River, located 25 km above the Ecstall-Skeena River confluence (Map D). The powerplant, located near the base of Big Falls, had a nameplate capacity of 3.2 MW, and the spillway had a maximum discharge capacity of 850 m^3/s. In 1960 an additional 3.7 MW unit was added. B.C. Hydro purchased the plant in 1964. The dam and spillway were recapped in 1981-83 and the operating level of the reservoir was increased slightly. The capacity of the plant was brought up to 9.6 MW.

Water Licences and Operational Constraints

The conditional water licence, issued in 1929, authorized the utility to divert a maximum of 17 m^3/s (600 cfs) and to store a maximum of 37 million m^3. No provisions were made for fisheries or other purposes.

Electrical Generation

The Falls River plant is operated at a fairly constant monthly load, ranging from 45 to 70 percent of its capacity. Its contribution to the integrated B.C. Hydro grid averages about 0.03 percent.

Enhancement Facilities

None associated with the facility.

OPERATIONAL REGIME

Operational data for the plant are maintained locally at the project site and are not retained by B.C. Hydro's Operations Control Centre.

PHYSICAL AND CHEMICAL ENVIRONMENT

Reservoir

The Falls River headpond is of limited extent. No information is available on the physical, chemical or biological characteris-tics.

Downstream System

The Falls River dam is located adjacent to the 50 m high Big Falls. The powerhouse discharges directly into a 180 m long tailpond which connects to the Ecstall River over a bedrock cascade. The tailpond is subject to strong tidal influence and at high tide the cascade is about 1.5 m under water (Lister 1981). At ebb tide the cascade is 4-5 m high and probably impassable to salmonids. Recorded discharges out of the tailrace range from zero to 566 m^3/s (Lister 1981).

SPORT FISH POPULATIONS

Reservoir

No filed information is available. Cutthroat trout and Dolly Varden occur in the reservoir (B.C. Hydro, pers. com.).

Downstream System

Salmon redds have been observed by divers within the tailpond (Lister 1981, Redenbach 1981) including the areas within the tailrace discharge and near the tidal rapids. The reservoir impounded by the Falls River dam is some 310 ha in extent and not accessible to anadromous salmonids.

RECREATIONAL FISHERY

Reservoir

No information available. Access to the reservoir is limited.

Downstream System

No information available.

CLAYTON FALLS

Clayton Falls power plant is a 702 KW generating station located on the North Bentinck Arm, 3 km west of Bella Coola, north-eastern B.C. The plant is supplied by a 2 km pipeline which draws water from small headpond behind a 16 m high concrete dam located on the ungauged Clayton Falls Creek. The plant was built in 1962 by the B.C. Power Commission and is licensed to divert a maximum of 1.3 m^3/s. Operational data are not maintained by B.C. Hydro's main Operations Control Department and the plant is not integrated into the provincial supply system. The non-anadromous fishery values of the system have not been documented.

INLAND FISHERIES RESOURCES IN HYDROELECTRICALLY REGULATED SYSTEMS

HYDROELECTRIC PROJECTS

A total of 46 hydroelectric dams and diversions (40 owned and operated by B.C. Hydro, 6 owned and/or operated by West Kootenay Power and Cominco) have been reviewed in the preceding sections (Table 1). These range considerably in size and hydrological characteristics (Table 2). Because of the large river discharges and the mountainous terrain, the Peace and Columbia river basins contain the largest reservoirs in B.C., created by mega-projects such as the W.A.C. Bennett, Mica and Revelstoke dams. The Fraser River basin and Vancouver Island contain a larger number of smaller and older reservoirs.

B.C. contains many more small reservoirs than detailed in this report, some of them utilized as water supplies and/or local power generation for mining and forest industrial operations (B.C. Hydro, n.d.). Hydroelectric reservoirs comprise the largest and most numerous of the artificially created water bodies and these are of primary importance to inland fishery resources in the province. In the following sections "reservoir" refers only to the 42 hydroelectric reservoirs detailed in this report.

Large reservoirs such as Williston and Kinbasket lakes retain water for relatively long periods, the average retention time ranging from 15 to 19 months. The large Arrow Lakes, however, have a relatively short average water retention time of slightly over 2 months since they are relatively shallow, the controlling dam (Keenleyside) was specifically designed for short-term flood control and hydrological regulation, and water storage capacity is provided by the upstream Kinbasket Lake behind Mica Dam. Many medium-sized reservoirs have surface areas from 2000 to 7000 ha in extent and mean water retention times from 4 to 6 months. Run-of-river reservoirs which generate power using water stored in reservoirs above them typically have short retention times, sometimes less than 1 day (e.g. Brilliant and Waneta).

In general, hydroelectric reservoirs in B.C. vary considerably in size, morphology, hydrological conditions and operating modes, with no significant correlation between these factors (Spearman rank correlation coefficients > 0.1). Size, depth and drawdown are all determined by the geographic setting of the projects, the period in which they were constructed and the purposes for which they were designed. Some large storage reservoirs such as Kinbasket Lake have extensive annual drawdowns (Table 2) but other large systems such as Kootenay Lake undergo relatively limited seasonal water level changes and provide storage by virtue of their great depth and volume. Most small and medium reservoirs have drawdowns which seldom exceed 10 m below full supply level (FSL) and typically range from 2 to 5 m below FSL. Contrary to this pattern, Downton and Carpenter Lakes are medium size reservoirs (2400 and 4900 ha surface areas) with extensive maximum drawdowns (35 and 28 m respectively).

The earliest hydroelectric dam in B.C. still in use is West Kootenay Power's Upper Bonnington on the lower Kootenay River, constructed in 1908. For 50 years following this project, hydroelectric development in B.C. was characterized by construction of small projects (< 100 MW capacity) in the Kootenays, lower mainland and on Vancouver Island (Figures 90 and 91). Two medium-sized projects were developed in 1948 (La Joie = 428 MW) and 1954 (Waneta = 373 MW) to supply electrical demands in the B.C. lower mainland. Development then returned to more small and medium projects. The megaproject era commenced in 1967 with development of the W.A.C. Bennett Dam on the Peace River (2146 MW), followed within 15 years by five more large projects (Kootenay Canal = 529 MW, Mica = 1736 MW, Seven Mile = 608 MW, Peace Canyon = 700 MW), and Revelstoke (1843 MW). The present situation is thus characterized by many reservoirs of various ages, sizes and operating modes.

SPORT FISH RESOURCES IN RESERVOIRS

Quantitative Index of Sport Fish Abundance

Two types of data from the existing records can be used as indices of sport fish abundance in reservoirs, i.e. gill netting catch rates and angling catch rates.

Gill-netting data for 12 hydroelectric reservoirs were obtained by the Ministry of Environment during periodic lake surveys or specifically to evaluate the success of stocking programs. Additional gill netting sample data were collected by B.C. Hydro during the ongoing monitoring of the recently impounded Revelstoke reservoir. This latter program has provided comparative gill netting sample data for four impoundments - Revelstoke reservoir and Kinbasket, Upper Arrow and Whatshan lakes.

Angling data are available for 16 reservoirs and from these angling catch rates have been derived, expressed as a catch per hour or catch per day. Highly significant correlations exist between gill net catches per unit effort (CPUE) expressed as numbers of sport fish per 100 m^2 of net per 24 hours and sport angling catches, expressed as either hourly or daily catch rates (Figure 92). Based on these regressions, a probable gill net catch was predicted for 16 reservoirs, 11 of which had not actually been sampled by gill netting. Measured and/or predicted CPUE's are thus available for a total of 23 reservoirs and provide a quantitative measure of sport fish population densities (Table 3). Although useful as a quantitative measure, CPUE's must be used with caution. Gill net samples in lakes and reservoirs are often taken as single samples at one time and frequently at one location only in the reservoir. There is thus a strong possibility of spatial or temporal bias, and there is no measure available to determine sampling error.

The CPUE for the Arrow Lakes, predicted from the angling catch rate (246.3 fish/100 m^2/hr = 1.7 fish/hour) is a significant outlier in the regression analysis. Based on comparisons with other large reservoirs in B.C. and with reservoirs in the west Kootenay region (Table 3), the calculated angling catch appears to be an unrealistic representation of sport fish availability throughout the Arrow Lakes. The most likely reason for the bias is a high local success rate recorded by anglers in the Upper Arrow Lakes catching kokanee in large numbers originating from the Hill Creek spawning channel. The mean CPUE actually recorded by Smith (1986) and Fleming and Smith (in prep.) has been used for Arrow Lakes in the following sections.

Status of Sport Fish Habitats and Populations in Hydroelectric Reservoirs

Table 4 summarizes the present status of sport fish populations and habitats in the documented hydroelectric reservoirs. Ten sport fish species are of recreational significance, with rainbow trout the most ubiquitous species, followed by Dolly Varden and kokanee. Non-anadromous cutthroat trout are significant sport fish species in reservoirs within coastal areas, on Vancouver Island and in the Fraser River valley. Mountain whitefish are major population components in reservoirs in the Kootenay and Columbia watersheds and in the Upper Fraser watershed. Other species such as burbot and sturgeon occur in a few reservoirs in small numbers but are significant to recreational anglers.

Assessment of the existing sport fish habitats and populations within hydroelectric reservoirs is necessarily subjective, given the reconnaissance and other judgmental nature of the available data. Categorical 3-point ratings (good-moderate-poor or high-moderate-low) have been used to characterize key elements such as availability of spawning and other habitats, stock densities and the quality of recreational angling.

A rating of "good" for spawning habitats refers to a situation where tributary habitats are available, especially in the lower elevations of such tributaries, and where the descriptions of the tributaries suggest the likely presence of key requirements for spawning and rearing, i.e. low or moderate water velocities, stable flows in the reproductive seasons, gravel availability, no major sediment inflows, and no major impacts from other factors. A "moderate" rating reflects the presence of some negative factor(s) such as access blockage by falls or rapids, or poor quality substrates. Most often it reflects a reduced proportion of reproductive habitats due to flooding by the reservoir. A "poor" rating indicates a general lack of suitable tributary or shoreline habitats, a common occurrence in run-of-river reservoirs and those in steep canyon environments.

Sport fish stock densities have been categorized on the basis of the calculated CPUE's described above. The frequency distribution of the CPUE's was found to be approximately log-normal, and was divided into three groups. A "high" stock density implies a CPUE of more than 21.5 fish/100 m^2/24 hours. A "low" density is less than 4-6 fish/100 m^2/24 hours, and a "moderate" density is intermediate.

Angling success rates, based on creel censuses, were also found to be roughly log-normal in distribution and were split into three categories. A "high" success rate is higher than 1 fish per angler per hour (1 rod) which is approximately the same as 2.67 fish per angler -day for the creel data available for all reservoirs. A catch rate of 2.67 fish per day is about one-third higher than the average provincial angling success rate of 1.98 per day (Stone 1988) and roughly equivalent to the average rate for those regions having the highest mean angling success rates (e.g. Okanagan = 2.61 fish per day (Stone 1988)).

As described under the Columbia, Kootenay, Peace and Fraser River systems and Southern Coastal and Vancouver Island systems, enhancement has been attempted in several reservoirs over the years. In many it has been discontinued because of lack of success or other reasons. Only ongoing or recent enhancement has been included in the summary (Table 4) since it relates directly in some cases to stock density and angling success rates (e.g. Peace Canyon).

Of the 40 reservoirs reviewed (Table 4), 11 (28 percent) support sport fish stock densities rated as high, 7 (18 percent) are moderate and 22 (55 percent) are considered to support low densities or have not been surveyed so as to permit any rating. Of those with high stock densities, 6 (55 percent) are located on Vancouver Island, and 3 (27 percent) are lakes which have been converted into hydroelectric storage reservoirs. Only 6 of the 40 reservoirs (15 percent) are rated as having relatively good spawning habitats available to sport fish populations, and of these, 5 are lakes utilized for storage and the remaining one (Williston Lake) is a very large reservoir with an extensive system of upstream tributaries. These comparisons suggest that lack of habitat in the feeder tributaries and interspecific competition from non-sport fish species are significant determinants of sport fish stock densities in reservoirs (see below).

Habitat Quality in Hydroelectric Reservoirs

There are no definite sets of features which characterize reservoirs with high or low sport fish populations (Table 5). Reservoirs with high sport fish CPUE's include those with good to poor spawning habitat availability (tributaries and shorelines), and include both enhanced and non-enhanced reservoirs. Such reservoirs vary in sizes from small (e.g. Wokas Lake, 60 ha in size and shallow, to the 390 km^2 large Kootenay Lake. Some reservoirs on Vancouver Island (Upper and Lower Campbell and Wokas Lakes) as well as Dinosaur lake on the Peace River have high CPUE's but are described as having poor spawning habitat availability. This seemingly anomalous situation is explained for Dinosaur Lake in that this reservoir was enhanced from a hatchery, and a high proportion of hatchery-bred rainbow trout were included in angling creels (Hammond 1986). For the Vancouver Island reservoirs the rating of "poor" was based on conclusions expressed in reports on the lakes (Tredger and Taylor 1980, Hawthorn 1984). Subjective ratings are usually based on comparisons (either explicitly or implicitly) and it appears likely that the report authors were judging Campbell and Wokas Lakes in comparison to lake systems in general, many of which on Vancouver Island have excellent tributary habitats. These lakes may have inferior habitats by this comparison, but the available habitats are at least sufficient to provide fairly high sport fish stock densities.

None of the habitats or hydrological characteristics considered (Table 5) differ significantly between the three groups of reservoirs (high, moderate or low CPUE's) as measured by Kruskal-Wallis non-parametric analyses of variance ($p > 0.05$ for all comparisons). Comparisons of the various projects (Table 5) suggests the following generalizations:

(i) Size has no relationship to the sport fishery value of a reservoir (Figure 93).

(ii) Drawdowns within the 0-10 m range have no relationship to the sport fishery value of reservoirs (Figure 94). Reservoirs with mean maximum drawdowns greater than 15 m are of relatively low value as sport fish habitats, mainly due to the periodic and extensive inundation of low elevation tributary habitats and the excessive fluctuations in shoreline conditions.

(iii) Retention times have no direct relationship to sport fishery values (Table 5).

Run-of-river reservoirs with low retention times (several days only) generally have low or moderate fishery values (Table 5). Stock densities in such reservoirs can be improved through sustained enhancement (e.g. by an on-site hatchery as at Dinosaur Lake) but probably not by occasional stockings (as at Hayward Lake). Sustained stocking programs supported by hatcheries are expensive to maintain (B.C. Hydro pers. com.). Based on its conformation and lack of tributary habitats Dinosaur Lake would likely support only low densities of sport fish and offer minimal recreational angling if populations were not boosted by frequent stocking. The relatively high stock densities and moderate angling catches in Daisy Lake (mean retention time 6 days) suggests that rapid water and nutrient turnover rates are not the only factors responsible for poor fish productivity of run-of-river reservoirs - lack of tributary habitats may well be a more important factor. The numbers of run-of-river reservoirs in this study are too small to draw definite conclusions. Run-of-river reservoirs in other regions in the Pacific North West have given poor responses to long-term enhancement programs (e.g. Huston 1985).

The ages of hydroelectric reservoirs in B.C. ranges from more than 80 years to less than 10 years. Maturation is an important ecological process in impounded water bodies and is linked to the development of food and to increasing productivity of lentic systems (Petts 1984). A common phenomenon in newly impounded reservoirs is a sharp increase in fish densities due to an influx of nutrients from inundated substrates and organic matter, followed by a gradual levelling off or even a reduction in densities as stability is attained. Maturation may not take place in hydroelectric reservoirs because of relatively rapid water replacement by annual filling and emptying which flushes nutrients out of the system and maintains the reservoirs in an early successional state. Since most sport fish are predators and occupy higher level niches in aquatic ecosystems, their long-term population levels are dependent on maintenance of diverse food webs. All hydroelectric reservoirs for which nutrient or water quality data are available have been found to be oligotrophic (with the possible exception of Daisy Lake - see Cheakmus).

For five of the reservoirs included in this review, (Revelstoke and Brilliant reservoirs and Kinbasket, Whatshan and Upper Arrow Lakes), Smith (1986) found a significant positive linear correlation between reservoir age and total gill net catches (r=0.7) and also a highly significant linear correlation (r=0.99) between reservoir age and the proportion of coarse fish in the total population. An insignificant negative linear correlation (r= 0.24) was demonstrated for the relationship between sport fish and gill net CPUE and reservoir age. Smith (1986) concluded that the data for these five reservoirs (ages 1 to 40 years) indicated a better adaptation by coarse fish species such as peamouth and northern squawfish to lentic environments. A similar comparison for all reservoirs on the B.C. mainland (Figure 95) indicates only a weak correlation (R^2= 0.39, 2nd degree polynomial regression) between reservoir age and sport fish CPUE. The data from enhanced reservoirs are as variable as those from non-enhanced reservoirs. A highly significant correlation (r=0.88, equivalent to R^2=0.77) exists between age and sport fish CPUE's for the reservoirs on Vancouver Island. The latter differ from those on the B.C. mainland in having only very small populations of coarse fish due to the absence of many coarse fish species on Vancouver Island. Although not firmly conclusive because of the variable nature of the various reservoirs (drawdowns, size, available habitats, operating modes etc.), the correlation appears to confirm the significance of coarse fish competition in depressing sport fish number in reservoirs, and they suggest that maturation is of some significance in determining sport fish densities in reservoirs.

Sport Fishing Quality of Hydroelectric Reservoirs

"Quality" of sport fishing is a complex criterion and depends on a number of components. High to moderate sport fish populations are a primary requisite plus an associated high or moderate angling catch success rate at least of the order of provincial success rates. Other factors which play a role are good access (road access) to the reservoir or lake and an aesthetically attractive environment. The latter is a subjectively judged criterion, based on factors such as drawdown, presence of debris and snags, and an attractive environment surrounding the reservoir.

Based on these criteria, about half the number of hydroelectric reservoirs in B.C. are not of a high or even moderate value as angling resources (Table 6). The most significant reason for this would appear to be low population due either to lack of supportive habitats for sport-fish population maintenance and/or competitive depression of sport fish numbers by coarse species. For most hydroelectric reservoirs a lack of habitats means essentially a lack of tributary habitats. Population enhancement is a major contributory factor to maintenance of sport fishing quality in seven of eight reservoirs in which it is regularly applied. Only Alouette Lake, a deep unproductive natural lake, provides low angling success despite recent enhancement measures (Table 6).

Other deterrents to sport fishing quality are debris and/or snags resulting from a lack of pre-impoundment clearing (Williston, Carpenter and Downton lakes), extensive drawdowns (several reservoirs), poor access (Kinbasket Lake), and dangerous boating under some water conditions (Williston Lake).

SPORT FISH RESOURCES IN REGULATED RIVERS BELOW RESERVOIRS

Development of a river for hydroelectric power generation through the construction of a dam or diversion provides both water storage and flow control. Further development of the same system then becomes more attractive from engineering and economic perspectives. Of the 46 dams and diversions reviewed in this report, 23 discharge directly into the headpond of another reservoir. A further two discharge directly into tidal waters. Twenty three dams and diversions described in the above report influence the hydrological and biological characteristics of river systems (Table 7).

The Columbia and Peace rivers, both extensively developed for hydroelectric power generation, retain undeveloped reaches which are strongly influenced by upstream flow regulation. The Lower Columbia River below Keenleyside Dam provides relatively poor mainstem habitat for sport fish species and is subjected to high dissolved gas concentrations. Most sport fish habitats of value lie within the smaller tributaries to the mainstem river (see Keenleyside). The lower Peace River also has relatively low habitat values within the mainstem river (see Peace Canyon) and existing natural sport fish populations rely on tributary habitats. Within rivers of the size of the Columbia and Peace, it is seldom economically feasible to attempt to improve mainstem conditions for fisheries because of the low quality of mainstem habitats and the high costs of changing the operating regimes of large hydroelectric reservoirs.

Medium and small rivers and creeks regulated by hydroelectric dams or diversions in B.C. have poor quality habitats (Table 7) with correspondingly low populations of sport fish, and a low probability of beneficial returns to stream enhancement. Notable exceptions are the Shuswap, Cheakamus, Quinsam and Puntledge rivers. While the Quinsam River has been inventoried by a number of studies, (most related to potential coal development), the information base for the Shuswap, Cheakamus and Puntledge systems is very poor. The general information available for these systems suggests that they have good to moderate capability which could be enhanced by modification to flows (e.g. prevention of sudden flow alterations) and/or to other instream conditions (especially sediment concentrations). For 11 of the 23 systems noted, some type of required water release schedule is either stipulated in the water licence or has been negotiated between DFO and B.C. Hydro (Table 8). In all cases the main intent of the releases has been to improve downstream flow conditions for Pacific salmon. Operational modifications to hydroelectric projects to improve down-stream lotic conditions specifically for inland fish populations have not yet been attempted in B.C.

COMPENSATION FOR IMPACTS TO INLAND FISHERY RESOURCES

The principle of providing compensation for losses to fishery (or other environmental) resources is a comparatively recent development in B.C. and parallels the evolution of impact assessment as an environmental planning and management device. The Jones Creek spawning channel for pink salmon, built in 1954, was the first major fisheries compensation project financed by an electrical utility in B.C., and was followed in 1965 by development of a chinook spawning channel adjacent to the Puntledge River on Vancouver Island. Construction of the Meadow Creek spawning channel in 1968 was the first major compensation project for a non-anadromous species. Revelstoke (hatchery and spawning channel), Keenleyside (additions to a hatchery) and Peace Canyon (hatchery) are the only other project for which non-anadromous fisheries compensation has been provided to date.

The intent of compensation is to redress the losses caused by a development. The wording of agreements is seldom explicit, but in normal use the term "compensation" is accepted to indicate replacement of the lost amounts (of habitats, populations, angling catches or recreational values). The only project for which comparative pre- and post-development data are available is Duncan Dam, which led to the destruction of kokanee spawning habitats. Only three pre-project kokanee spawning enumerations were made for this project (see Duncan, Figures 21 and 22). These suggest that the spawning channel developed as compensation for lost fish habitats may be providing as little as one-tenth of the kokanee spawning numbers removed by the project.

A major difficulty with the evaluation of compensation measures is that replacements are unavoidably different to the resources removed by the impacts. For most river systems developed for their hydroelectric potential, the situation is one where a river with relatively little existing use of its sport fish populations, with limited access for sport anglers, and with unmeasured potential for future use, is replaced by a reservoir with different biological systems and dominant fish species, with improved access, and also with unknown potential for further development and use. Use of a crude and simplistic measure of sport fishing use (e.g. total sport fishing catch) could give an approximate idea of the effectiveness of compensation, but even for such a measure the pre-project data are not available for virtually all the projects reviewed.

For the 46 reviewed dams and diversions, compensation has to date been provided for only four (Keenleyside, Revelstoke, Duncan, Peace Canyon). Compensation is being studied for one (W.A.C. Bennett) and debated for another one (Mica). Of the remaining 40, (Table 9) a few are judged to have potential in the reservoirs or downstream river systems for providing increased sport fishing harvests and recreation if enhancement measures were applied. These include Kootenay Lake (enhancing aquatic productivity), Whatshan Lake, (enhancing sport fish populations), Stave Lake (enhancing populations, improving fishing facilities), Buntzen Lake (enhancing populations), Shuswap River (improving flow conditions in river downstream of dams), Jones Lake (enhancing populations), and Cheakamus River (improving flow conditions in lower river, enhancing populations in Daisy Lake).

CONCLUSIONS AND RECOMMENDATIONS

The major intent of the above review has been to document available information on hydroelectric projects operated by B.C. Hydro, West Kootenay Power and Cominco, and on the sport fish resources within and below the reservoirs and diversions. The review is primarily intended to provide background information to assist in improved fisheries management in regulated systems. Management actions applied to such regulated systems will depend on provincial and regional priorities, on the technical and biological feasibility of overcoming specific limitations, and on the economic feasibility of managing fisheries in and below reservoirs used for electrical power production. Detailed assessments of these specific issues have not been attempted within the terms of reference for this review. However, for certain river systems there are obvious fisheries limitations or needs which can be identified. In addition, a number of issues relevant to improved fishery management in regulated systems have been identified because of repetitive occurrence in different watersheds or in projects of different sizes, ages or designs. The following summarizes the identified factors and provides some recommendations on dealing with them.

PRE- AND POST-DEVELOPMENT STUDIES

The salient points on impact studies in regulated systems are that:

- detailed habitat and population studies prior to project construction are a relatively recent innovation, and most operating hydroelectric developments in B.C. were poorly studied, if at all, from the fisheries perspective prior to construction;

- post-development monitoring has been very limited and generally restricted to occasional brief surveys;

- even the relatively limited post-development monitoring undertaken at Revelstoke by B.C. Hydro has yielded valuable ecological insights into the dynamics of sport fisheries in reservoirs;

- the basic dimensions of hydroelectric reservoirs are of little relevance in predicting their sport fishery values;

- information from existing developments is of value in assessing likely impacts from proposed developments provided it yields insights into habitat use and requirements and interspecific relationships.

It is therefore recommended that impact assessment studies for proposed new hydroelectric developments should:

- *include thorough pre-development habitat surveys of all tributaries to the proposed reservoir plus population studies which cover a sufficient number of biological cycles to establish a reliable baseline for estimation of compensatory replacement and to develop realistic future management objectives for the reservoir and tributary system.*

- *determine the full range of relationships between instream flows below the impoundment or diversion and the habitats affected by flow changes.*

COMPENSATION FOR IMPACTED FISHERIES RESOURCES

The reviewed information indicates that:

- many hydroelectric reservoirs constitute relatively poor sport fish habitat and, in most cases, provide habitats of poorer quality than the river systems which they displace;

- a major cause of fishery impacts in regulated systems is the loss of tributary spawning and rearing habitats;

- restoration of fishery resources lost through hydroelectric development in most cases depends on artificial enhancement through provision of spawning channels and hatcheries;

- the extent to which facilities such as spawning channels and hatcheries can replace populations and recreational angling capacities is difficult to predetermine due to the many hydrological, physical and biological variables involved;

- compensation measures provided for projects now in operation may not be adequately replacing the fishery production capacity of the previous natural systems;

- experience actually gained with enhancement in existing developments is one of the most useful tools for planning compensation for proposed developments;

It is therefore recommended that the performance of the facilities already provided as compensation for the Duncan, Arrow Lakes and Revelstoke developments be critically assessed to determine

- *the extent to which they have been successful in replacing fish stocks and recreational angling capacity removed by the projects;*

- *their main limitations to long-term production capacity.*

ENHANCEMENT OF FISHERIES RESOURCES

The review indicates that:

- compensation for lost or reduced fishery production was not provided for many existing hydroelectric developments;

- a number of these developments retain a good potential for providing increased recreational fishing if suitable enhancement and/or modifications to hydro plant operation are provided;

- some of these systems such as the Shuswap River retain high fishery values, both anadromous and inland, while contributing very small proportions of the provincial electrical energy requirements.

It is therefore recommended that:

- *an assessment of the Shuswap River system from Sugar Lake to Mabel Lake should be undertaken with the objective of determining how to maximize anadromous and non-anadromous fishery values of the system through flow modifications, including*

- *revising the operations of the Shuswap Falls power plant;*

- *modifying or redeveloping Peers Dam*

- *enhancement programs should be developed for regulated systems with the best potential for providing increased recreational angling capacity, in particular*

  - *Whatshan Lake*
  - *Stave Lake*
  - *Buntzen Lake*
  - *Jones Lake*
  - *Shuswap River*
  - *Cheakamus River*

RESTORATION OF KOOTENAY LAKE

Kootenay Lake is a unique hydroelectrically regulated and influenced system in that

- it was a natural and productive lake prior to hydroelectric development within the Kootenay River watershed;

- it remains one of the most productive and recreationally significant large lakes in B.C.;

- the lake provides valuable hydroelectric storage used by all three major power utilities in the province and of prime value to the storage requirements of the Columbia River Treaty between Canada and the U.S.A.;

- nutrient depletion has been identified as a primary factor responsible for declining sport fish populations and angling catches;

It is suggested that consideration be given to retrieving a sufficient share of the economic benefits of the Columbia River Treaty developments to finance the nutrient replenishment of Kootenay Lake to levels sustained prior to development of Treaty projects.

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