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A REVIEW OF FISHERIES INFORMATION RELATED TO PROPOSED HYDROELECTRIC DEVELOPMENTS ON THE MCGREGOR RIVER

Water Use Unit
Habitat Management Division
Field Services Branch
Fisheries and Oceans Canada
1090 West Pender Street
Vancouver, B.C.
V6E 2P1

April, 1986

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EXECUTIVE SUMMARY

Two major floods, the first in 1894 and a second, less severe, in 1948 have been recorded in the Fraser watershed. The latter affected large areas of the lower mainland and low lands in the vicinity of Quesnel and Prince George on the Fraser River and Kamloops on the Thompson River.

The McGregor River is a large northern tributary of the Fraser system. Construction of a dam and storage on the river to provide flood control and hydro-electric energy has been the subject of intermittent studies and reports by government and industry for over 30 years. The most recent studies were terminated by the British Columbia Hydro and Power Authority (BCHPA) in 1981.

In October 1983, the Hon. Stephen Rogers, Minister of Energy, Mines and Petroleum Resources formally requested a review of the McGregor proposals by the Minister of Fisheries. This document presents a review of relevant studies, identifies issues and recommends further study requirements.

Study History

In 1963, the Federal/Provincial Fraser River Board, following extensive analysis, recommended the damming and diversion of the McGregor River into the Peace/Mackenzie system as part of a comprehensive flood control program known as System E. Subsequent biological and engineering studies and reports were followed by a Joint Fraser River Advisory Board report in 1976, which recommended construction of the McGregor project on the basis of power potential and to complement flood control dykes under construction in the lower Fraser. Throughout this period, BCPA conducted engineering feasibility and biological impact investigations, the most recent of which was terminated in 1981. The results of these studies were made available to DFO in 1984.

Throughout this period DFO has also collected information on McGregor River salmon. Currently, DFO is engaged in a salmonid enhancement project using McGregor stock. In addition, DFO annually conducts a visual survey of the number of spawners in the McGregor system.

Project Description

i) McGregor Diversion

This proposal consists of a 140 m high dam situated approximately 32 km upstream from the Fraser. The resulting impoundment would cover approximately 23,500 hectares. The diversion structure would be located between the head waters of James Creek and the Parsnip River. The diversion would provide relatively inexpensive power generation at existing and proposed facilities on the Peace River, downstream flood control in the Fraser and greatly reduced flows in the McGregor River.

ii) Non-Diversion Option

A non-diversion scheme would provide hydro-electric generation potential at the dam site, Fraser flood control, wider reservoir fluctuations and larger residual flows in the McGregor.

Review Of Studies To Date

i) Diversion alternative

Several issues have been identified that must be considered by DFO in judging project acceptability. These issues are:

- a) The impact of the transfer of water and fauna from the Pacific to the Arctic drainages on Arctic fisheries resources in the event of a diversion;

Several parasites have been found only in the Fraser system and if water and associated biota were transferred to the Arctic system they might flourish and put Arctic fish at risk. The susceptibility of Arctic drainage fish to Pacific drainage parasites and pathogenic microorganisms is unknown. Fish/parasite-disease/environment interactions are complex and the scope of biological studies that would be required to quantify the risks involved would be prohibitive. The formulation of a position on this issue will determine whether or not a diversion is acceptable and hence should be among the first decisions made.

- b) The impact of changes in Fraser River water temperature, discharge regime and quality on Fraser River salmon stocks;

The resolution of changes in Fraser River water temperature will largely determine the magnitude and timing of fish maintenance flow releases. Preliminary temperature modelling studies indicated that diversion of cool McGregor River water would have the effect of elevating summer Fraser mainstem temperatures as far downstream as Hope. Salmon have well documented thermal tolerance ranges, and these temperature elevations would make Fraser River salmon more susceptible to temperature related mortality and reduce spawning success. Mitigation of these concerns would require establishment of a McGregor water release schedule.

- c) The impact on chinook utilization of the McGregor River and tributaries;

A McGregor Dam would block upstream migration of an estimated 1000+500 McGregor tributary spawners and an undetermined number of McGregor mainstem spawners. Owing

to the height of the dam and the inundation of upstream spawning areas, it would not be feasible to mitigate damage via fish passage facilities.

Of these diversion related issues the impact of water and fauna transfer between the drainages is considered decision critical. Should any diversion be considered acceptable then the impact of Fraser River water temperature changes is considered to be the issue that will determine the most significant component of the necessary fishery flow regimes.

ii) Non-diversion alternative

There are less fisheries related issues associated with the non-diversion alternative. There would be no direct transfer of water between basins and hence no risk of deleterious fish/parasite-disease/environment interactions in Arctic drainages. Similarly there would be no water quantity related impacts in the Parsnip River, Williston Reservoir or other areas of the Peace/McKenzie system. The maintenance of acceptable mainstem Fraser River water flow, depth, temperature and quality could be more easily achieved under a non-diversion alternative, where more water is available to

mitigate impact since the flow is regulated rather than diverted. However, impacts to McGregor chinooks as a result of blockage would remain and be similar to those associated with the diversion proposal.

Synthesis

Available information relating to fish and fish habitat impacts associated with a proposed dam on the McGregor River suggests that Fraser River flood control can be achieved by either a diversion or non-diversion structure. However, fisheries impacts could vary significantly depending upon whether the structure is operated as a diversion or non-diversion facility.

1 HISTORICAL DEVELOPMENT OF MCGREGOR RIVER HYDRO-ELECTRIC AND FLOOD CONTROL PROPOSALS AND OBJECTIVES OF THIS REPORT REVIEW

The Fraser River and its tributaries drain approximately 90,000 sq. miles (234,000 sq. km.) (Figure 1). The drainage basin is essentially a plateau comprising most of south-central British Columbia, with extensive mountain ranges forming its eastern and western limits. The river is the largest in the province, with a long term annual flow of approximately 96,000 cubic feet per second (cfs) or 2,720 cubic meters per second (m^3/sec) as recorded at Hope. Economically and socially, the Fraser River is the most important river in British Columbia, with the majority of the provincial population residing within its watershed. The Fraser River is also the largest salmon producing system in North America. It supports major populations of all five northeast Pacific species (sockeye, chum, pink, chinook, and coho) and provides benefits to the province through commercial, sport and Indian food fisheries.

Two major Fraser River floods have occurred in recent history. In 1894, a flood with a peak discharge exceeding 600,000 cfs (17,000 m^3/sec) as measured at Mission inundated the sparsely populated Lower Fraser Valley and parts of Prince George, Kamloops and Quesnel. In June 1948, a disastrous flood with a peak discharge of 536,000 cfs (15,200 m^3/sec) as measured at Hope and a 24.98 ft

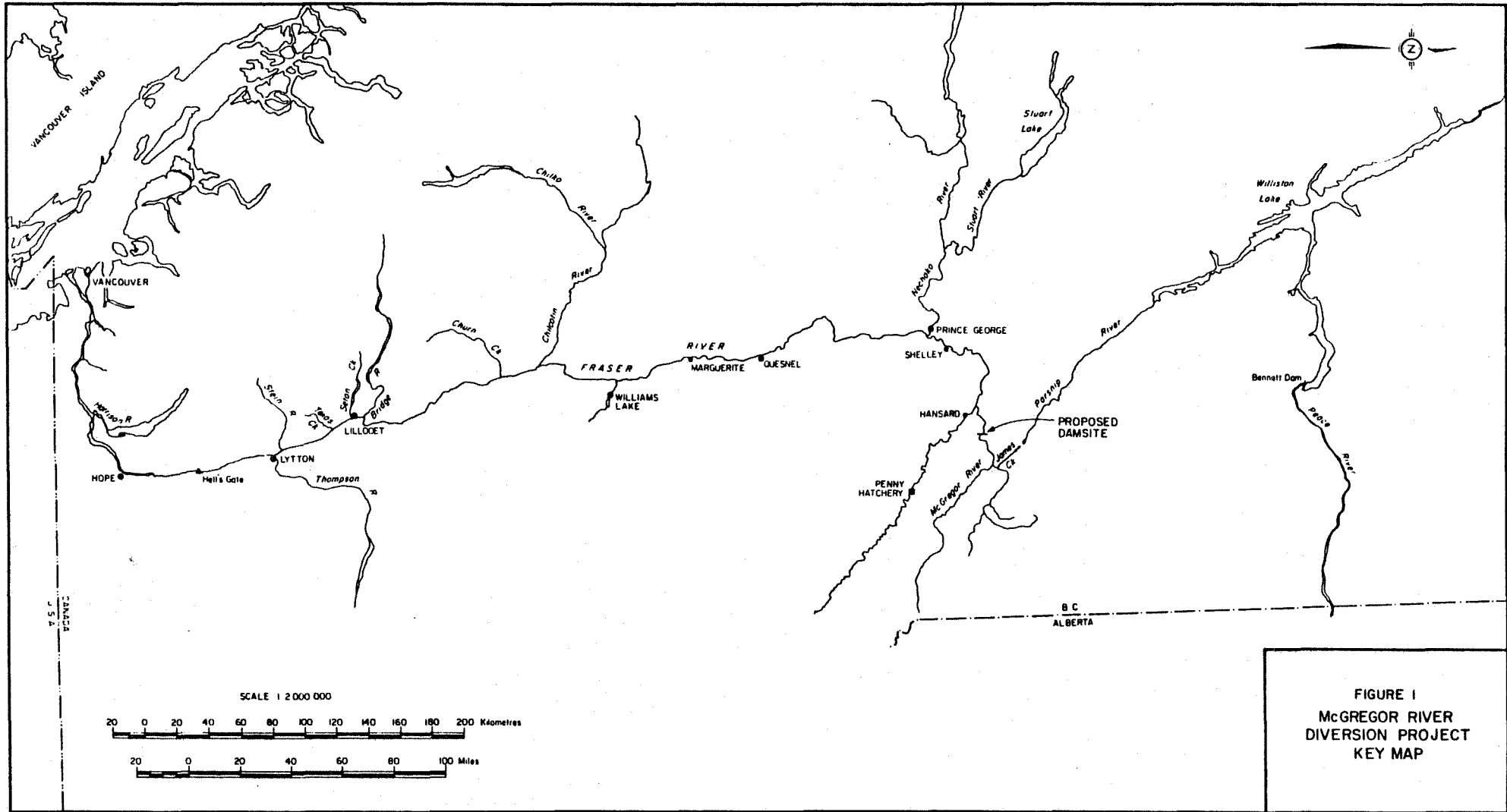


FIGURE 1
 McGREGOR RIVER
 DIVERSION PROJECT
 KEY MAP

(7.62 m) crest at Mission breached the dykes and inundated one third of the Lower Fraser Valley. Only minor damage occurred in Kamloops, Quesnel and Prince George as settlements in the flood plain areas were limited at that time. Relief, rehabilitation and repairs approximated 20 million (1950) dollars and more than 163 mi (261 km) of dykes were repaired or rebuilt.

In the latter half of 1948, the federal and provincial governments formed the joint Dominion-Provincial Board, Fraser River Basin. Its purpose was to study and report on the water resources and requirements of the Fraser River watershed with primary attention to power, fisheries, floods, water supply and recreation. It was the first multidisciplinary examination of the Fraser River system. From 1949 to 1954, this Board collected basic data and compiled information previously recorded by government and other agencies. No comprehensive report was published during this period. In 1955, the Joint Board was replaced with the Fraser River Board, which was to develop a plan for flood prevention for the Fraser River Basin. The plan was to improve dyking in the Lower Mainland, Quesnel, Kamloops and Prince George in addition to examining the feasibility of upstream power producing storage dams which were to be economically self-supporting.

In 1958, the Fraser River Board produced a preliminary report recommending a system of dams on the Fraser River upstream of

Hope. The proposal was re-examined because of major impacts to the salmon resource. A three year federal government study of the Fraser River Basin was undertaken from 1960 to 1962 to obtain data on salmon runs that would be affected by the various development schemes proposed. The final report in 1963 recommended dyking systems for the Lower Mainland and upstream communities and investigation of a system of storage dams called System E. System E proposed dams for the Clearwater, Cariboo, McGregor and upper Fraser watersheds. This proposal was considered the most acceptable combination of economic flood control development while minimizing the impact on the salmon resource.

In 1967 International Power and Engineering Consultants Ltd. (IPEC) was retained by B.C. Hydro to carry out preliminary office examination of the McGregor Diversion proposal from a power point of view. These studies indicated that the diverted flow could increase the energy production at existing and proposed power plants on the Peace River at an attractive cost.

In 1968, the Canada-British Columbia Fraser River Joint Advisory Board replaced the Fraser River Board. The Advisory Board was to proceed with the construction of the dykes recommended by the Fraser River Board, and further investigate the feasibility of System E. The restriction that all System E dams should be economically self-maintaining through power production was removed as

it was considered sufficient that System E be justified by flood control benefits alone. The Joint Advisory Board created a subordinate body, the Fraser River Joint Program Committee, which supervised the construction and studies. One of the required studies was the Upstream Storage Study, and the Ecology Sub-committee was formed to deal with ecological and environmental issues with respect to upstream storage. To aid in this process the Fisheries Service assessed the effect of the proposed flood control development on the Fraser River Basin anadromous stocks. Potential productive capacity of the streams and lakes was determined. Losses to present and potential production of Fraser River salmon from the various combinations of dams with and without mitigation were assessed and an economic evaluation of the losses to the commercial fishery was made. The implications of fish losses to recreationalists and the social and cultural importance of the food fishery to the native people of British Columbia were assessed. This information was presented in an Environment Canada (1974) report, and summarized in the Fraser River Ecology Committee (1976) and the Joint Advisory Board (1976) report.

In 1971, the Provincial Water Resources Service commissioned G.E. Crippen and Associates to undertake additional site exploration to establish project feasibility as part of the 1968 Joint Agreement.

In 1973, International Power and Engineering Corporation Ltd. (IPEC) submitted a report to B.C. Hydro regarding the engineering

feasibility of a McGregor Diversion Project. The proposed project consisted of a 460 foot (140 m) high, 2,720 foot (830 m) long earthfill dam at the head of the McGregor River Lower Canyon, approximately 20 miles (32 km) upstream from the McGregor and Fraser Rivers confluence. The dam would consist of a core zone of silty sand and gravel and two outer sandy gravel shell zones. An auxiliary spillway and low level outlet facilities would be built. The reservoir would have a surface area of approximately 90 sq. miles (23,500 ha) and a volume of approximately 8×10^6 acre ft. ($9,900 \times 10^6$ m³). The reservoir elevation would range from a minimum of 2,455 ft. (748.5 m) to a probable maximum flood height of 2,480 ft. (756 m). A control structure would be located at Arctic Divide between Portage Lake on James Creek and Arctic Lake on the Parsnip River to pass flows into the Parsnip River. The structure would consist of a 640 ft. (195 m) wide overflow concrete weir. It would provide a minimum vertical drop in the water surface of about 10 feet (3 m) to prevent passage of fish from the Parsnip (Arctic) to the McGregor (Pacific) Basin. The construction schedule would be about 66 months (International Power and Engineering Consultants Ltd. 1973).

The diversion of water to the Arctic watershed would increase power generation potential at existing and potential power plants in the Peace River without requiring the construction of new generation or transmission facilities. The amount of flow diverted,

and hence the amount of energy generation increase at the Peace River plants, depends on the quantity of fishwater released at Lower Canyon. For example, the 1973 IPEC report states that if the average annual fishwater release was 1,450 cfs (41 m³/sec) an average annual 6,220 cfs (176 m³/sec) would be diverted to the Peace River resulting in an additional 237 MW at G.M. Shrum and 296 MW at Site 1 (now called Peace Canyon).

In 1975, a preliminary review of environmental impacts of the proposed McGregor Diversion Project on the Parsnip River was completed for B.C. Hydro (Environmental Research Consultants, 1975).

The December 1976 Fraser River Upstream Storage Review Report, which was supported by the Ecology Committee Report, concluded that, with one exception (the Lower McGregor Diversion) the benefits accruing to each project would not exceed the costs. Hence, it recommended construction of the Lower McGregor Diversion in addition to completion of the Fraser Valley dyking program to provide additional protection against Fraser Valley flooding.

Detailed environmental impact studies for the McGregor Diversion Project were initiated by B.C. Hydro in-house staff and consultants in 1976 and coordinated by Reid, Crowther and Partners Ltd. Studies included geology and physiography, river regime and morphology, wildlife, fisheries, social and economic impacts,

resource evaluation, forestry, recreation, land use, Fraser River aquatics and faunal transfer. Renewable Resources Consulting Services Ltd. and later R.L. and L. Environmental Services Ltd. were the major consultants for the aquatic studies.

B.C. Hydro announced suspension of all engineering and environmental work in January 1978. The reason stated was that the presence of several fish parasites in the Pacific drainage and their apparent absence in the Arctic drainage could endanger Arctic fish stocks if the diversion took place (B.C. Hydro and Power Authority, 1978b). The fisheries, recreation, faunal transfer, Fraser River and resource evaluations were incomplete. All findings (complete and incomplete) were reported in Reid Crowther and Partners Ltd. (1978).

The limited input DFO and other government agencies had to the B.C. Hydro studies dealt primarily with studies regarding impacts on the Fraser River mainstem. DFO field studies in the McGregor Basin in 1977 were directed toward chinook life history (Tutty, 1979).

In 1980, B.C. Hydro examined a non-diversion generation alternative to the pre-feasibility/feasibility level. The dam would be similar to the diversion dam but slightly lower at 443 feet (135 m) high. There would be no diversion between the Pacific and

Arctic watersheds hence no need for diversion structures and no risk of (direct) transfer of flora and fauna. Pre-feasibility environmental impact studies for the generation alternative were also prepared (B.C. Hydro and Power Authority, 1980 and Reid Crowther and Partners Ltd., 1980).

Since 1980, information relevant to McGregor River fisheries has been collected by DFO including yearly enumeration of salmon spawners, Salmonid Enhancement Program egg take activities, and further parasitological studies by consultants. B.C. Hydro has also contracted out further parasitological studies, the results of which were published in 1982.

The impetus for this review resulted from the B.C. Minister of Energy Mines and Resources the Hon. Stephen Rogers October 1983 request to the Hon. Pierre de Bane (DFO) that the department "identify the scope of fisheries studies that would be necessary to meet your requirements and also outline the criteria that would be used to judge the (McGregor Diversion) project's acceptability to the Department of Fisheries and Oceans " (Rogers, 1983).

Prior to this report, no comprehensive review of the information available to date had been undertaken. Review of the material indicated that fisheries issues to be addressed could be summarized as follows:

- the impact of the transfer of water and fauna/flora between the Pacific and Arctic drainage on Arctic biota;
- the impact of changes in Fraser River discharge regime water temperature and water quality on Fraser River salmon stocks; and
- the impact on chinook utilization on the McGregor River system.

This report reviews relevant studies to date, identifies the level to which issues have been addressed and recommends further studies considered necessary to fully evaluate the proposed McGregor River diversion and non-diversion alternatives. The potential Fraser River flood peak attenuation that could be achieved with a McGregor River dam is discussed in Appendix I of this report.

An issue by issue format is used in this report. In other words, each issue is discussed in its own section which contains a list of major reports; a discussion of studies to date and/or present conditions; diversion alternative impacts, data deficiencies and issues requiring further study; and a brief discussion of the possible impact of a generation alternative on fishery resources.

2 CHINOOK UTILIZATION OF THE MCGREGOR BASIN

2.1 Major Reports

Environment Canada. 1974. An Assessment of the Effects of the System E Flood Control Proposal on the Salmon Resource of the Fraser River System. Report and appendices. For the Ecology Subcommittee of the Fraser River Upstream Storage Steering Committee. January, 1974.

Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project (4 Volumes) for B.C. Hydro and Power Authority.

Tutty, B.D. 1979. 1977 Chinook Investigations Associated with the McGregor River Diversion. Fisheries and Marine Service Manuscript Report No. 1529. 48 pp.

2.2 Studies to Date

Prior to 1960 little was known about McGregor Basin fish or fish habitat. Data on salmon were restricted to the annual visual assessment of escapements and incidental information collected by fisheries officers. Escapement records are available for 1950 and from 1954 to the present (Marshall and Manzon, 1980; pers. comm., D. Swift, D.F.O., Prince George).

From 1960 to 1962, fisheries investigations were undertaken by the Fraser River Board biological staff under the direction of the Department of Fisheries. Two progress reports (Department of Fisheries 1961 and 1962) and a summary report (Chatwin, B.M. et al. 1963) were compiled on these activities. These studies related primarily to the collection of basic biological data on salmon runs that would be affected by the various proposed development schemes, or Systems. Specific McGregor River studies included spawning ground escapement surveys, habitat characteristics and lower McGregor River water temperatures.

In 1971 and 1972 the Fisheries and Marine Service conducted overview studies of the McGregor Basin for the System E proposal. Activities consisted of aerial, land, and boat observations of the McGregor River drainage basin, anadromous stock, physical habitat of mainstem and tributary streams

emphasizing potential chinook spawning areas, and limited physio-chemical testing. The findings are presented in Appendix A2 of Environment Canada (1974) and discussed throughout the main report. They are summarized in the Fraser River Ecology Committee (1976) and Fraser River Joint Advisory Board (1976) reports.

In 1976 and 1977 Renewable Resources Consulting Services Limited and later R.L. and L. Environmental Services Ltd. conducted aquatic environmental impact studies for B.C. Hydro and Power Authority. One component of these studies dealt with distribution and abundance of fish species, habitat characteristics and seasonal utilization of the McGregor drainage by salmon. Field work for this component comprised repetitive boat electrofishing with tagging studies, set lines, baited minnow traps, gill netting, opportunistic creel census and surveys to assess physical habitat. Study periods were July to November 1976 and late May to November 1977. Curtis MacLeod was the principle investigator. The findings are presented in Reid, Crowther and Partners Ltd. (1978).

In 1977 and 1978, DFO conducted field work in portions of the McGregor Basin accessible to salmon. Efforts were directed toward chinook early life history, overwintering habitat, smolting behaviour and enumeration and timing of spawning stock. Field periods were January 11 to 18, March 25 to 28, mid-April to

June 21 and August 9 to 28 in 1977 and a few days in mid-January 1978. Methods used included weirs across streams, fyke nets, beach seines and backpack electroshockers for juveniles, discharge measurements, drift nets, a broomstick fence trap and aerial helicopter enumeration (with Renewable Resources) for adults. Scales were collected and aged, discharges and winter dissolved oxygen levels and snow cover were measured and spawning substrate was visually assessed. Study results are reported in Tutty, (1979).

In 1982 a SEP egg-take program was initiated on the McGregor system. From August 20 to 25, 1982, 197,960 eggs were collected from James Creek, a tributary of the McGregor River, by SEP Facilities Operations. The eggs were incubated and reared at Penny hatchery. In May, June and July of 1983 a total of 178,126 fry were outplanted back to James Creek. Penny hatchery was not operated over the 1983/1984 winter season due to lack of funding. In the fall of 1984 Enhancement Operations collected 190,000 eggs from James Creek which were placed at the Penny hatchery for incubation and rearing. In addition, Enhancement Operations collected 409,000 eggs from James, Fontoniko and Seebach Creeks for the Quesnel hatchery. (pers. comm. J. McNally and R. Dickson, DFO).

2.3 Present Conditions (primarily to 1978)

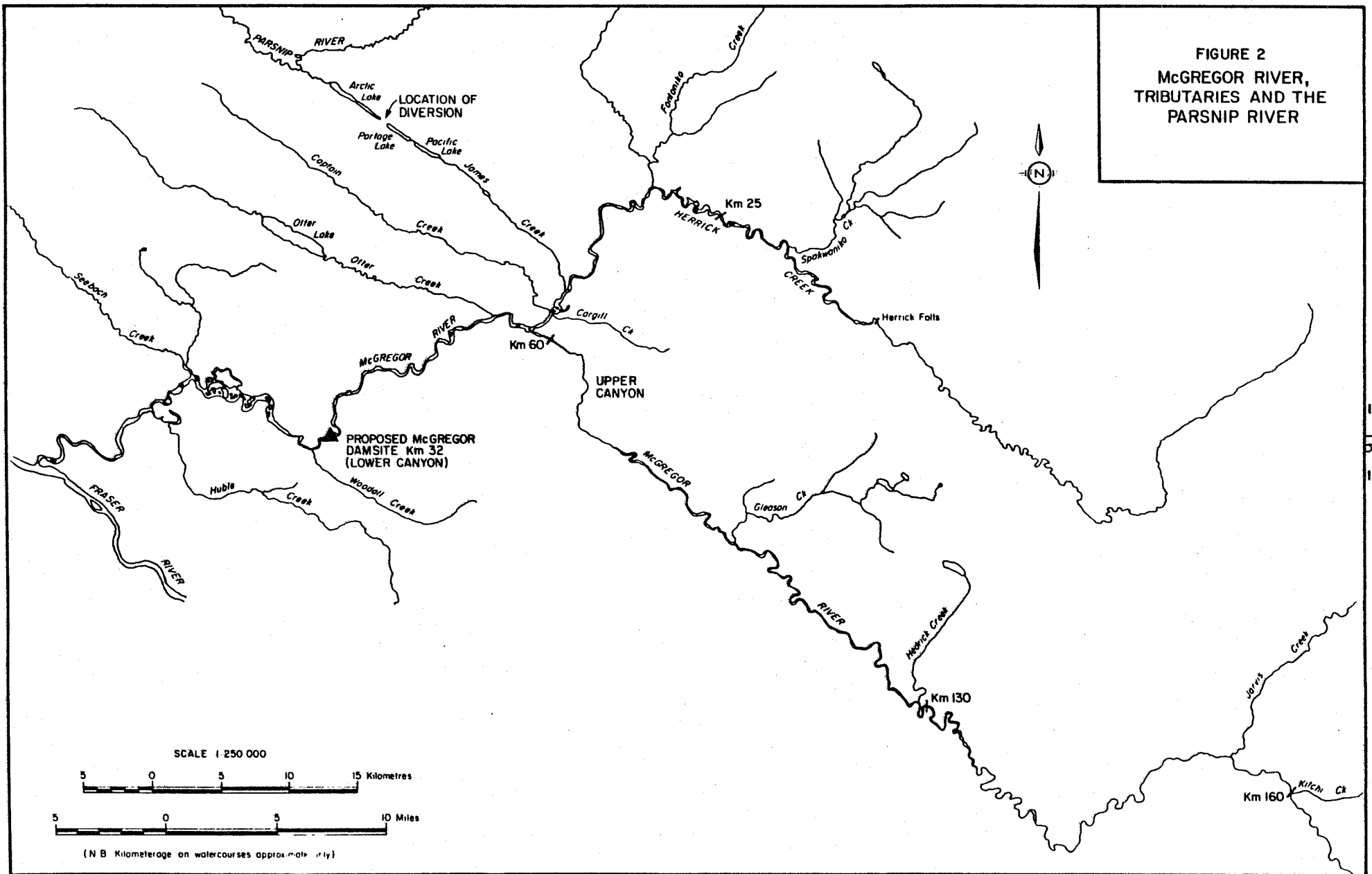
2.3.1 Riverine Habitat

The physical habitat characteristics of the McGregor River and its tributaries (Figure 2) have been assessed to varying degrees. The summary which follows is primarily from Environment Canada (1974) and Reid, Crowther and Partners Ltd. (1978). Habitat presently accessible to chinook is emphasized.

The McGregor River mainstem, approximately 200 km long, is the largest tributary of the upper Fraser. It rises in the icefields of Mount Sir Alexander and flows northwest before turning to the southwest and joining the Fraser 56 km northeast of Prince George. The McGregor Basin is approximately 4760 km². At Lower Canyon, 32 km from the mouth of the McGregor River, the 35 year average flow (1940-1975) is 226 m³/sec. The McGregor contributes on average 35 percent of the Fraser discharge below their confluence. Tributaries encompass a wide variety of habitat types. They can be differentiated on the basis of size, gradient, flow characteristics, substrate composition and thermal regime.

The McGregor River and Herrick Creek mainstems are characteristically turbid hence substrate composition is difficult to assess.

FIGURE 2
McGREGOR RIVER,
TRIBUTARIES AND THE
PARSNIP RIVER



Unseasonably mild temperatures and abnormally low snow and ice accumulation during the 1976/1977 winter enabled DFO staff to view the substrate. Gravels, similar to those of known spawning areas in James Creek, were observed throughout extensive reaches of both watercourses (Tutty 1979).

Of the 17 or so tributaries, Seebach, Otter, Herrick and its tributaries Captain, James, and Fontoniko Creeks are known to support spawning and rearing chinook. The McGregor mainstem supports spawners as well (see Chinook - distribution and abundance of adults).

In the discussion below, distance is measured from the Fraser and McGregor confluence and increases as one proceeds upstream.

(a) The McGregor Mainstem

From the Fraser River confluence to km 31, the McGregor mainstem exhibits meanders and generally low gradients which range from 0.1 m/km to 0.2 m/km. Within this reach there is a gradual progression from near laminar flow conditions and uniform fine textured substrate (D90-2 cm) near the confluence, to moderate gradient between Seebach Creek and the Lower Canyon with associated habitat diversity. (Basically, D90 - 2 cm means that 90 percent of the substrate particles are smaller than a 2 cm

sphere.) Channel braiding, riffle/pool complexes and localized accumulation of vegetative debris characterize this reach which has a higher percentage of gravel and cobble substrate (D90 - 15 cm). There is still evidence of silt accumulation in this reach though it is less extensive than downstream.

The next reach from km 31 to km 32 comprises the Lower Canyon, contiguous habitat and the damsite. There are high bedrock banks and high velocity flows. Substrate varies from large cobble to bedrock.

The reach between the Lower and Upper Canyons (km 32 to km 63) has an average gradient of 1.4 m/km. It lies in a wide, heavily forested valley broken by old river channels, small marshes and meadows and includes the McGregor and Herrick confluence at km 54. The reach provides diverse habitat, including good holding pools.

The Upper Canyon reach (km 63 to 67) has high velocity flows, bedrock chutes, and cascades. This area is believed to be the upstream migrational limit for chinook salmon.

From Upper Canyon to the Hedrick Creek confluence (km 67 to approximately km 130), the stream gradient is low (0.3 m/km) giving low habitat diversity and fine textured substrate (sand and silt).

Between Hedrick and Jarvis creeks (approximately km 130 to km 152) the gradient increases to 2 m/km. The river has high habitat diversity and log jams. The proximity of this reach to glacial headwaters imparts high turbidity and substantial fluctuation in water levels.

The headwaters are characterized by high gradient (7 m/km), a gravel and large cobble substrate, and typically high turbidity.

(b) The Tributaries

Seebach Creek

Seebach Creek is markedly different from other tributaries in the system. The drainage basin is at the eastern end of the Nechako Plateau and the creek has a lower gradient, generally clearer water, and a different discharge regime than other McGregor tributaries. The discharge pattern is similar to that recorded at the Water Survey of Canada gauging station (WSC08KC001) on the Salmon River, a tributary of the Fraser, which also drains the Nechako Plateau. Flows begin to rise from winter low values in April, peak in late April or early May, and recede steadily throughout June and July to annual minimum flows in August, September or October. Rainstorm peaks in both rivers in late summer are uncommon. The Seebach system is braided throughout

except for the lower section of the East Fork, which has large cobble substrate, and upper portions of the tributary, which are swampy with beaver dams (pers. comm., B. Tutty; DFO, Nanaimo).

Otter Creek

Otter Creek is a 42 km long turbid stream which follows a steep walled valley most of its length with some swamps and sedge meadows. Upstream migration is blocked 4 km from the confluence by a 3 m falls. In the first 4 km the substrate is coarse.

Herrick Creek and its tributaries

Herrick Creek is the major tributary of the McGregor and is similar in size to the McGregor at their confluence. It has a moderate gradient (2 m/km) from its mouth to Spakwaniko Creek. This reach has diverse habitat including high quality holding pools.

From Spakwaniko Creek up to and including the 18 m Herrick Falls at km 45.5, the average gradient of Herrick Creek is 12 m/km. There is lower habitat diversity in this reach due to the preponderance of riffles. This reach would be the upstream migrational limit for chinook salmon.

Captain Creek (at approximately km 5 on Herrick Creek) is a clear stream draining a steep sided valley. The gradient is moderate throughout with small falls, less than 1.5 m high, at km 7.6, 11, 15 and 17.2. There are some excellent gravel bars and riffles, particularly up to km 4. Above that, coarse substrate, predominated by large cobble, rubble, boulders and bedrock, restricts suitable spawning habitat.

James Creek (at approximately km 11 on Herrick Creek) has suitable spawning habitat throughout. The best habitat is found below km 1.3. A beaver dam 5 km below Pacific Lake formed a migration block in 1976 and 1977. No beaver dam was observed in a fall 1984 one-day helicopter overflight. The proposed diversion would be through this valley.

Fontoniko Creek has three main branches. The mainstem is accessible to a falls at km 7; the east fork is impassible at its mouth at approximately km 8; and the west fork, while unobstructed to km 14, is glacier fed and subject to high turbidity, cold temperatures and fluctuating flows.

2.3.2 Chinook

(a) Distribution and Abundance of Adults

Chinook salmon (Oncorhynchus tshawytscha) are the only anadromous salmon species found to date in the McGregor River drainage. Other fish present are rainbow trout; Dolly Varden; lake trout; kokanee (land-locked sockeye salmon); mountain whitefish; longnose, largescale, bridgelip and white sucker; northern squawfish; redbreasted shiner; longnose dace; peamouth chub; slimy and prickly sculpin; and burbot (Reid, Crowther and Partners Ltd. 1978). Historically, chinook salmon were known to spawn in accessible portions of Seebach, Otter, Captain, James, and Fontoniko Creeks. In 1977 salmon were found spawning in the mainstems. Tutty (1979) reported capturing by drift net 33 chinook spawning in upper Herrick Creek and the recovery of spawned carcasses along lower Herrick Creek and from the Herrick - McGregor confluence downstream to downstream to the launching site at Mile 22 on Cargyll Road which is 10 to 15 km downstream of the Otter Creek and McGregor River confluence. Similarly, R.L. and L. Environmental Services Ltd. reported sighting 46 mainstem Herrick Creek spawners in 1977 and estimated escapement at twice that (92) in an attempt to correct for early or late arrivals and fish obscured by high turbidity. In 1980, salmon spawning was observed in Herrick Creek immediately downstream of Herrick Falls (pers. comm., B. Shepard, SEP).

Escapement to the spawning grounds began approximately mid-July and lasted to mid-September in 1977 (Tutty 1979). The spawning period extends to the end of September (Environment Canada 1974). Escapement estimates vary widely. Early historic information passed on from trappers and natives suggest 10,000 salmon may have utilized accessible portions of the McGregor system (see Tutty 1979). In 1963 the total escapement was reported to be 3,000 (Fraser River Board 1963). The 1955 to 1972 average escapement of 620 is widely reported. During this period escapement estimates ranged from 125 in 1960 to 1100 in 1964 (Table 1). It is not clear if this estimate applies only to tributaries above the proposed damsite to the exclusion of Seebach Creek as reported in Environment Canada (1974) or includes Seebach Creek, as implied in Tutty (1979). Annual escapement data for chinook in the McGregor Basin is presented as a total (Seebach plus other tributaries) until 1976 after which tributary by tributary data are presented. Chinook escapement estimates from 1973 to 1983 averaged 835 with a range from 400 in 1973 and 1974 to 1500 in 1979. Escapement to Herrick Creek mainstem in 1977, the first year mainstem spawning was reported, is unclear. Table 1 reports 500, Tutty reported 33 (observed) and R.L. and L. estimated 92 from 46 observed.

Tributary by tributary data are available for the period 1978 to 1983. Average escapement for this period was 980. An average

Table 1

ANNUAL ESCAPEMENT OF CHINOOK INTO THE
McGREGOR RIVER SYSTEM

Years	Seebach Creek	Otter Creek	James Creek	Fontoniko Creek	Captain Creek	Herrick Creek	Total
1950							1,000
51							-
52							-
53							-
54							1,500
55							1,255
56							750
57							750
58							900
59							400
1960							125
61							325
62							750
63							850
64							1,100
65							700
66							500
67							700
68							200
69							200
1970							400
71							750
72							400
73							750
74							400
75							400
76							760
77	-	50	300	-	130	500	980
78	100	0	200	280	80	70	730
79	800	10	380	160	80	70	1,500
1980	450	0	205	85	45	4	789
81	400	0	135	85	40	40	700
82	200	0	400	400	60	300	1,360
83	175	0	400	200	40	-	815

36 percent of spawners during this period utilized Seebach Creek and 29, 21, 8, 6 and <1 percent utilized James, Fontoniko, Herrick, Captain and Otter Creeks respectively.

In the 1980 aerial spawning survey, the timing of chinook was observed to be slightly advanced in Seebach and Fontoniko creeks in comparison to Captain and James creeks. Spawning in Seebach Creek was concentrated at the upper and lower portions. In the upper portion, there were approximately equal numbers between the east and west forks. In James Creek, spawning was concentrated in the lower reaches near the mouth, with few spawners between Portage and Pacific Lakes. In Captain Creek, spawners were concentrated in the lower 4 km and in Fontoniko Creek in the left fork (pers. comm. B. Shepard, SEP).

Fraser et al. (1982) discuss the difficulties inherent in collecting escapement data. The discussion is worth repeating as it is especially relevant to this isolated area:

"Although much of our knowledge of the status of Fraser River chinook and coho stocks comes from annual visual assessments of the escapements, the methodology for collecting these data is not consistent from area to area, and is subject to a variable sampling bias. Generally, a Fishery Officer or patrolman periodically

inspects a stream at different stages of the spawning cycle and at major spawning sites. This is usually done on foot, although boats, and more recently aircraft, are often used to augment the area covered. In some cases, the collected data are unreliable due to insufficient manpower to cover adequately the required area; also the turnover among patrolling staff from year to year results in inconsistencies in methodologies and estimates; and annual variations in weather, river turbidity, accessibility to spawning sites, and the shifting of spawning areas to new locations add to the difficulties of accurate enumeration".

Clearly further work is required to determine the escapement into the system. These data deficiencies are discussed below in Diversion Alternative - Data deficiencies and issues requiring further study. However, an "order-of-magnitude" comparison between the total Fraser system escapement and McGregor tributary escapement is helpful in understanding the McGregor's contribution to the chinook resource. Annual escapement of Fraser system chinook for the period 1951 - 1980 averaged 58,000 (Fraser et al. 1982). If the average escapement to the McGregor tributaries is estimated to be 1100 ± 400 for this discussion, McGregor tributary stock is roughly 1 to 3 percent of the Fraser total stock. It is reiterated that this escapement estimate applies to

the tributaries only, does not include possible mainstem escapement and is "order-of-magnitude" only. It is felt that the overall escapement estimates are low due to the relatively high turbidity in the system (especially in the McGregor mainstem) which makes salmon difficult to enumerate.

Total return of chinook to the mouth of the Fraser (escapement plus terminal catch) during the period 1951 - 1980 averaged 200,000. Only terminal exploitation rates are available for chinook since the actual offshore catch of Fraser stocks is largely unknown (Fraser et al. 1982). Assuming the ratio of the total McGregor (tributaries) return to the total Fraser return is the same as the rough escapement return ratio (1 to 3 percent) then the McGregor tributaries contributes an approximate average 2,400 to 5,200 to the total return (after offshore catch).

(b) Incubation and Rearing

Throughout the incubation and pre-emergence phases chinook eggs and alevins remain in the intragravel environment. Tutty (1979) found recently emerged fry in James Creek May 3, 1977 and fry with evaginated yolk sacs in Herrick Creek June 20, 1977. Herrick Creek mainstem is colder than James Creek hence the incubation period is longer (9 - 10 months).

Both "stream-type" and "ocean-type" chinook have been identified in the system. Ninety day ocean-type chinook smolted from James Creek during the third week of August 1977. Juvenile chinook (0+) made extensive use of the mainstem McGregor (km 0-60) during summer and fall with a peak in late July early August. Large smolts (mean F.L. 82.7 mm) with no annulus were captured in Fontoniko, James and Seebach creeks during the April 30 to May 22, 1977 trapping period. Normally, overwintering stream-type chinook scales from adults would be expected to exhibit a freshwater annulus. Examination of scales from McGregor Basin adults indicated that stream type smolts out-migrating in April or May do not necessarily produce a winter annulus before departure or alternatively any scale annulus or check produced is obscured by subsequent estuarine or marine growth. The ensuing lack of discernable freshwater annulus in returning stream-type adults could then result in an underestimation of the stream-type population (Tutty and Yole 1978). The implications for fisheries management of any underestimation are discussed in Data deficiencies and issues requiring further study. Juveniles were most abundant in areas with gravel-cobble bars and high benthic production such as km 46-60 on the McGregor River (Reid, Crowther and Partners Ltd. 1978).

2.4 Diversion Alternative

2.4.1 Impacts of diversion alternative including construction impacts

Impacts which affect anadromous fish will occur during construction of the dam and from activities related to the preparation of the reservoir, whether for the diversion or generation alternative. Upstream movement of chinook and other species will be restricted by increased flow velocities at coffer dams, bridge abutments and diversion works. These impacts could occur at road crossings over tributaries as well as at the damsite. Construction activities increase sediment flow and turbidity which can decrease fish production by reducing intergravel egg survival, by reducing benthic productivity, and by decreasing the efficiency of chinook predation on invertebrates. The long term survival of juvenile chinook, especially stream-type, would be reduced if McGregor Basin food supplies were reduced. Underwater explosions, especially during seasonal congregations (ie. spawning runs) are a hazard to fish. Spillage or seepage of toxic materials such as oil, gas, drilling fluids, sewage and its sterilants, and other chemicals which affect aquatic life could cause fish mortalities. Increased population pressure may increase illegal fishing activities such as poaching.

A McGregor Dam, whether functioning as a diversion or generation structure, would block upstream migration. Fish passage devices would not be feasible owing to the high cost of a high dam fish passage structure and inherent passage design problems, inundation of spawning habitat above the dam, difficulties in getting juveniles out of the reservoir and, for the diversion alternative, flushing juveniles into the Parsnip River. During the period 1978 to 1983 average observed escapement was 980 to the tributaries. An average one-third (355) of the observed escapement was to Seebach Creek and the remaining two-thirds (625) to areas above the proposed damsite. Using the "order-of-magnitude" estimate of 1100 ± 400 tributary spawners, 470 to 1000 will be blocked by the dam. Again, it is stressed that the extent of mainstem spawning is unknown, both above and below the damsite, and these figures are "order-of-magnitude" estimates. Actual escapement may be substantially higher.

Under the proposed diversion scheme, the majority of flow would be redirected into the Peace system with a small amount of water flowing down the McGregor. Table 2 summarizes fishwater release schedules which have been previously suggested by government agencies. None of the various instream flow maintenance methodologies that have been developed over the last twenty years appear to have been used to generate any of these suggested release schedules. Presumably the schedules were developed using

Table 2

MINIMUM FISHWATER RELEASE SCHEDULES PROPOSED BY
VARIOUS GOVERNMENT AGENCIES
1963-1980

Month	A G E N C Y																
	Fraser River Board 1963 ¹		Environment Canada 1974 ³		Fraser River Ecology Committee ⁴ 1976		Fraser River Joint Advisory Board 1976 ⁵		B.C. Hydro Diversion Schemes 1973 ⁶				B.C. Hydro Generation Scheme ^{7, 14} 1980				
	cfs	CMS	cfs	CMS	cfs	CMS	cfs	CMS	^{19, 10} cfs CMS		^{28, 11} cfs CMS		³¹² cfs CMS		cfs	CMS	
January	1000	28.3								250	7.1	250	7.1	130	3.7	6840	194
February	1000	28.3								250	7.1	250	7.1	130	3.7	7190	204
March	1000	28.3			None recommended					250	7.1	250	7.1	130	3.7	6510	184
April	1000	28.3								250	7.1	250	7.1	130	3.7	6720	190
May	as necessary ²									12000	340	250	7.1	130	3.7	12000 ¹³	340
June	1000	28.3	Not Established				Nil Releases			250	7.1	250	7.1	130	3.7	10200	289
July 1-15	1000	28.3 ²								250	7.1	250	7.1	130	3.7	8030	227
July 16-30	3000	85 ²								1000	28.3	1000	28.3				
August	3000	85 ²								1000	28.3	1000	28.3	130	3.7	9380	266
September	3000	85								1500	42.5	1500	42.5	130	3.7	7920	224
October	1000	28.3								250	7.1	250	7.1	130	3.7	7960	225
November	1000	28.3			None recommended					250	7.1	250	7.1	130	3.7	4780	135
December	1000	28.3								250	7.1	250	7.1	130	3.7	8050	228
Average										1450	41.1	470	13.3	130	3.7	7965	226

Table 2 (continued) Legend

1. Source: Fraser River Board. 1963. Final Report of the Fraser River Board on Flood Control and Hydroelectric Power in the Fraser River Basin.
2. As necessary to fulfill [flow] requirements at Hell's Gate during May 1 to 31 and at Shelly during a critical temperature period that could occur in July or August.
3. Source: Environment Canada. 1974. An Assessment of the Effects of the System E Flood Control Proposal on the Salmon Resource of the Fraser River System. January 1974.
4. Source: Fraser River Ecology Committee. 1976. Summary Report of the Fraser River Ecology Committee on the Ecological and other Consequences of the Proposed System E Development in the Fraser River Basin. May 1976.
5. Source: Fraser River Joint Advisory Board. 1976. Fraser River Upstream Storage Review Report. December 1976.
6. Source: International Power and Engineering Consultants Limited. 1973. McGregor River Diversion Project.

Table 2 (continued) Legend (cont)

7. Source: Reid, Crowther and Partners Ltd. 1980. McGregor River Lower Canyon Project Prefeasibility Environmental Review.
8. Flow as required in July and August to limit the Fraser River temperature at Shelly to a maximum 61°F (16°C).
9. Minimum fishwater release of 250 cfs (7.1 CMS) based on assumption that an artificial spawning channel be provided.
10. Column 1 lists those releases suggested in the 1963 Final Report of the Fraser River Board, modified by the subsequent clarifications by the Department of Fisheries, with one exception. The requirements for flow releases in July or August to limit the Fraser River water temperature in addition to the 1000 (28 CMS) to 1500 cfs (42 CMS) flow to aid migration, would occur infrequently and are difficult to estimate. The flows to meet this requirement have therefore been omitted.
11. The flows listed in Column 2 are the same as in Column 1 except for May; the 12,000 cfs (340 CMS) requirement to maintain normal environmental conditions in the lower Fraser

Table 2 (continued) Legend (cont)

River has been omitted and replaced with a continuing 250 cfs (7 CMS) release.

12. The flow listed in Column 3 represents the maximum seepage losses that would be expected from the infilled channel at the damsite. In this case, no water would be discharged through the outlets in the dam.
13. Involves spillage.
14. The generation scheme would not involve any diversion of water to the Arctic drainage.

professional judgement. The schedules vary significantly and require further explanation. The Fraser River Board (1963) report envisioned a diversion project but included an on-site powerhouse to utilize fishwater releases. In 1967 IPEC obtained the following clarifications from the Department of Fisheries on the above mentioned flow releases:

- i. The 3,000 cfs ($85 \text{ m}^3/\text{sec}$) from July 15 to September 30 could be measured at the mouth of the McGregor River. It was estimated that a flow release of 1,000 to 1,500 cfs ($28 \text{ m}^3/\text{sec}$ to $43 \text{ m}^3/\text{sec}$) at the Lower Canyon damsite would be required to maintain 3,000 cfs ($85 \text{ m}^3/\text{sec}$) at the mouth of the river;
- ii. If an artificial spawning channel were provided, a flow of 250 cfs ($7 \text{ m}^3/\text{sec}$) from October 1 to April 30 may be acceptable for incubation,
- iii. A maximum flow release of 12,000 cfs ($340 \text{ m}^3/\text{sec}$) during the month of May would be acceptable even though the average natural flow at the Lower Canyon damsite is about 18,000 cfs ($510 \text{ m}^3/\text{sec}$) (International Power and Engineering Consultants Ltd. 1973).

The Environment Canada (1974) report did not make firm recommendations regarding fishwater releases and cautioned that

"The Lower McGregor Project involves a reduction of the peak freshet discharge from approximately 40,000 cfs to 1,000 cfs. Mitigation of the losses in the Lower McGregor through increased discharge is incompatible with the purpose of this diversion dam". The Fraser River Ecology Committee (1976) report also did not give recommendations but stated that "the provision of adult transportation flows possibly in excess of 3,000 cfs is obligatory if McGregor chinook stocks not affected by inundation are to be maintained in their natural environment". The Fraser River Joint Advisory Board (1976) recommended construction of the McGregor Diversion and nil fishwater releases. Discussions with individuals involved in the development of these fishwater release schedules has not clarified the reasons for the variable release schedules (pers. comm., F. Boyd and W. Schouwenberg, DFO; B. Cox, B.C. Fisheries Branch).

The impacts of decreased flows such as the schedules previously proposed by B.C. Hydro were commented on by R.L. and L. Environmental Services Ltd. and are reproduced verbatim from Reid, Crowther and Partners Ltd. (1978) below:

"After closure of the dam, flows in the Lower McGregor would range from a minimum of approximately 3.7 m³/sec, due to groundwater seepage, through a gradation from 13.3 to 41 m³/sec, due to water releases recommended to

sustain fish flows (International Power and Engineering Corporation Ltd., 1973). Proceeding downstream these flows would be augmented by flows from successive tributaries (Woodall, Seebach and Huble creeks).

Below the dam, water may remain close to 4°C all year round as it would be generated from seepage and/or water releases from the hypolimnion of the reservoir. Thus summer water temperatures would be lower and winter temperature higher than are presently the case. At Seebach Creek water temperature would likely have reached equilibrium with air temperature and, due to reduced flow and increased heating, would warm to much higher maximum temperatures than the present river.

It is expected that dissolved oxygen concentrations below the dam may be low, particularly in the first few years following inundation, due to high oxygen demand in both the hypolimnion and in the substrate near the dam. In the summer, complete reoxygenation would probably occur within a few kilometers. However, in winter, reoxygenation would probably be delayed due to ice cover, low photosynthetic activity, and oxygen uptake by organic material in the river. (Even though water will be released at 4°C in winter, ice cover will result due to cooling).

The nutrient content of both seepage and hypolimnetic waters would be higher than the present McGregor River because of solute dissolution in the substrates and hypolimnetic accumulation of nutrients.

In previous studies, problems due to supersaturation of dissolved gases (especially nitrogen) have been observed in waters below hydroelectric dams (Abelson 1974; Clarke 1973, 1974). This condition, which can cause fish mortalities, occurs when air is forced into solution as water falls into the plunge pool, subsequently rises to the surface of the pool, and reduced pressure induces supersaturation. Nitrogen supersaturation can also occur in the hypolimnion during summer stratification (Geen 1974). This problem is not expected to arise in the McGregor River because the configuration of the basin should permit complete mixing at turnover periods and fishwater releases would promote turnover of hypolimnetic waters. Potential problems may arise if high volume hypolimnetic releases occur prior to spring or fall turnover.

Total benthic productivity downstream of the dam would be reduced because of reduced channel area. However, production per unit substrate may increase below the

dam due to increased nutrients, clearer water and stable flow. Tempering these factors are the lower summer water temperatures which may limit productivity. Below the tributary confluences, it is expected that benthic productivity may be reduced due to increased silt loads during the spring freshet and possible increased biochemical oxygen demand from logging debris which may not be flushed through the system by the lower flows".

"Shallow depth, reduction of holding area, and higher water temperatures in the mainstem may combine to interfere with successful upstream migration to Seebach Creek and mainstem spawning below the dam. Low flows below the dam would result in a reduction of rearing areas. Low turbidity would afford less cover [but better feeding conditions] for juvenile fish. Warmer water temperatures, if they do not exceed lethal limits, could be beneficial by enhancing food production (Reid, Crowther and Partners Ltd. 1978)".

In addition to the impacts mentioned above, the river morphology may be altered such that rearing area is reduced.

If dams are operated to benefit the fisheries resources they can create some positive impacts for fish located downstream. First,

spring and freshet floods can be controlled thereby reducing juvenile loss due to flushing transport into less suitable downstream habitat. Spawning, incubation and rearing habitat damage caused by flooding can be decreased. Stranding of eggs and juveniles due to flow decreases can be reduced. However, flushing flows are still required to clean stream gravel thereby renewing the intergravel environment.

Secondly, low instream flow can be augmented by selective water releases. A common limitation of fish production in a system is the reduction of wetted area in periods of low flow. If these flows are augmented, increased habitat is available. In northern systems overwintering habitat is often a limiting factor and additional overwintering habitat can be created in this way.

Thirdly, if water is selectively released from various elevations in the reservoir, flow regimes can positively alter water temperature, freeze-up and break up times and location of anchor ice thereby improving fish overwintering habitat.

Downstream flow releases will be required to sustain mainstem McGregor spawning, rearing and incubation below the dam and to sustain spawning runs into Seebach Creek. Fishwater release schedules need to be re-examined both in light of the present knowledge of salmon needs for spawning, incubation and rearing

flows as well as the need for releases to meet the requirements of salmon in downstream portions of the Fraser River mainstem.

Regulated flows may also increase opportunities for artificial production and R.L. and L. Environmental Services Ltd. briefly commented on fish production approaches. However, other than mentioning that a stocking program or incubation boxes may be feasible in a regulated downstream environment, the discussion applied specifically to non-anadromous reservoir species (Reid, Crowther and Partners Ltd. 1978),

Provision for onsite fisheries staff to help achieve attempts to mitigate harmful impacts would be useful. These staff could ensure fish salvage operations were carried out and that fish habitat instream construction requirements and the scheduling of activities are adhered to. It may also be beneficial to provide expertise to manage a water budget for fish. Such an individual would work with power project operators and regulators to ensure that river regulation operations were adjusted to meet fish requirements. The person would need to be knowledgeable of the hydroelectric system as well as the water needs of McGregor chinooks and downstream Fraser River salmon stocks.

2.4.2 Data deficiencies and issues requiring further study

If further consideration is given to McGregor hydroelectric/flood control development the following studies specific to chinook utilization of the McGregor Basin should be undertaken.

(a) Assessment Oriented Information

1. In order to assess the impact of the proposal on salmon the productive capacity of the McGregor system should be estimated. Techniques could include estimating spawning area, identifying limiting factors in the system, refining escapement estimates and consulting historical information. A considerable area of apparently unused spawning habitat exists in the system and there is potential for greater chinook production. Based on aerial surveys and ground checks at six points Environmental Canada (1974) estimated a potential spawning capacity of 20,400 chinook in areas of the tributaries accessible to salmon. Confidence limits were not stated in the report. Presently inaccessible areas also have suitable spawning habitat. The extent of mainstem spawning habitat is unknown (Tutty 1979; Reid, Crowther and Partners Ltd. 1978). The theoretical spawning capacity of the McGregor basin can not be accurately quantified without

comprehensive investigations which take into account the variables affecting spawning habitat. Intensive surveys of hydraulic characteristics, stream bed composition, variations in year to year discharge during spawning, food supply, winter incubation flows and water temperature regimes are required.

2. Spawning escapement estimates for the system should be refined, with emphasis on escapements in the turbid McGregor River and Herrick Creek mainstems. Determining spawning escapements is difficult in turbid systems. Radio telemetry is recommended for determining abundance of adult chinook and their movements and spawning locations in these streams.

Another method of estimating salmon escapement which could be considered is the (Bendix) side scan fish counter system. This system counts fish acoustically and has been used extensively in both clear and turbid Alaskan rivers (Cousens et al. 1982). If feasible, one unit or a combination of units could be placed immediately upstream of at the confluence of the McGregor and Fraser and another combination near the damsite. The ratio of escapement above the proposed damsite to the total system escapement could thereby be derived.

Better escapement data are useful factors in determining the present production of stock. However, caution must be used when escapement data are being used as a tool to estimate stream production. Escapement is a function of ocean

survival, fishing pressure, and downstream and natal stream productive potential. As discussed in (1) above, primary emphasis must be placed on assessing the McGregor River Basins' productive capacity.

3. Genetic diversity in the existing McGregor Basin chinook populations should be assessed using electrophoretic or similar techniques. This information would be incorporated into habitat management plans with the objective of conserving the diversity of the chinook gene pool should a dam be built and tributary runs blocked.

(b) Mitigation Oriented Information

1. Flow requirements for mitigating the loss of mainstem habitat and enabling migration in and out of Seebach Creek require further study. As discussed above, positive downstream fishery benefits can accrue from knowledgable regulation of discharge at various freshwater stages of the salmon lifecycle. Optimum overwintering, rearing,

migration and flushing discharges must be determined. A habitat modelling study could provide discharge requirements and provide more reliable fishery flow needs for the range of flow requirements previously proposed. There are over 20 North American methodologies that attempt to assess minimum or optimum instream flow needs (Hatfield and Smith, 1984). All models have weaknesses and must be used with caution as predictive devices. In general, any modelling process attempts to assess useable fish habitat in relation to river flow by comparing the physical parameters (water depth, velocity, substrate, and cover) which exist in the river channel at various flows to the preference ranges of fish for these parameters. The modelling must be augmented with the existing data base and adjusted as necessary when the output is compared with actual instream conditions.

Further, a flow regime should be developed which meets the discharges required for the McGregor Basin as well as those required to maintain optimum conditions for salmon utilizing the mainstem Fraser. These latter requirements are discussed in Salmon Utilization of the Fraser. Under a diversion alternative the two sets of flow requirements may conflict if improperly implemented. For example, large discharges may be required from the McGregor in order to

maintain optimum temperature for Fraser mainstem fish during hot summer periods. Reid, Crowther and Partners Ltd. (1978) have suggested the need for releases in the order of 170 m³/sec at 4°C, whereas it may even be necessary to release 400 m³/sec at 7-8°C in order to lessen thermal shock to fish in the McGregor mainstem. B.C. Hydro's previously reported maximum proposed discharge for mid-July to mid-August is 28 m³/sec (Table 2). An increase from 28 to 400 m³/sec (approximately twice the average instantaneous annual discharge) would likely flush McGregor mainstem stream type rearing chinook downstream, perhaps into poor quality habitat. Likewise, subsequent flow decreases to 28 m³/sec may leave rearing chinook stranded.

(c) Habitat Compensation Oriented Information

1. The potential for habitat development in Seebach Creek should be examined. Escapement records for the period 1978 to 1983 indicate that it presently supports an average 350 spawners, or one third the known (tributary) escapement to the McGregor River. Seebach Creek is accessible to salmon throughout its 32 km length and contains approximately 20,600 sq meters of suitable gravel which would theoretically support 2,000 chinook spawners (Environment Canada, 1974).

Discharge, temperature, food production, substrate characteristics, and cover are factors which affect rearing capacity. These factors as well as limits to overwintering success should be examined to determine the limiting factors under present conditions and to provide a basis for habitat development recommendations (Mundie, 1974). Year round hydrologic conditions with special emphasis on summer temperatures and winter dissolved oxygen will also have to be studied. Available physiochemical data (Table 3) are limited to four summer samples taken by R.L. and L. Environmental Services Ltd. (Reid, Crowther and Partners Ltd. 1978) and three winter D.O. samples taken by Tutty (1979). Seebach Creek temperatures are higher than mainstem temperatures and may exceed desirable limits for rearing chinook in summer; dissolved oxygen may be low (71 percent saturation, Table 3) in winter (pers. comm. R. Dickson and B. Tutty, DFO). Freshwater life history of Seebach stock will have to be studied over several years and the importance of overwintering stream-type juveniles assessed. Annual flow requirements are different for stream-type and ocean-type juveniles. Past scale readings appear to be in error as stream-type chinook were incorrectly identified as ocean-type (pers. comm. B. Tutty, DFO).

Table 3

PHYSIO-CHEMICAL MEASUREMENTS AT SEEBACH CREEK

Date	Location	DO	%O ₂ SAT	BODs	pH	Total Alk	Total Hardness	Ca Hardness	Free CO ₂	TSS	VSS	TDS	Spec Cond	NH ₃ -N	NO ₃ + NO ₂ N	Total P	C
20 08 76		10.3	101		8.0	68	64	54		54		52	122		0.125		
16 06 77		13.0	138	2.2	7.9	86			0.5	115	5	115	148	0.008	0.179	0.016	1.1
19 08 77		10.1	109	0.9	7.8	112			0.7	120	4	120	120	0.002	0.076	0.001	1.3
23 09 77		11.2	103	1.9	7.3	74			0.5	98	11	142	142	0.001	0.116	0.052	13.7
11 01 77	mainstem	9.3	71														
11 01 77	east fork	11.7	89														
11 01 77	west fork	11.8	90														

2. The potential for habitat development in the McGregor mainstem (downstream of the proposed dam) should be assessed using methodology similar to that employed for Seebach Creek.

3. The potential for three types of fish production namely wild, semi-natural (e.g. spawning channels), and artificial (e.g. hatcheries), should be assessed. The findings would be crucial to evaluate the merits of alternate habitat management options.

4. Design and implementation of follow-up studies on the effectiveness of the habitat management decisions should be part of any habitat management efforts.

2.5 Generation Alternative

The non-diversion generation alternative has not been studied as thoroughly as the diversion alternative.

2.5.1 Impacts with generation alternative

As with the diversion alternative, during the construction phase fish populations immediately below the damsite and other construction areas would be detrimentally affected by habitat destruction as a result of increased sediment loads and turbidity. Underwater explosions, spillage or seepage of toxic materials and illegal fishing activities are also potential impacts.

Salmon spawning areas above the dam would also be inundated with this alternative, and provision for fish passage over the dam would not be feasible. On the lower McGregor River mean monthly winter flows would increase by approximately 150 to 450 percent and mean monthly spring and summer flows would be decreased by approximately 5 to 60 percent (Reid Crowther and Partners Ltd. 1980). This is a much greater flow of water than is proposed for the diversion alternative. In addition, the temperature and water quality regime would be different.

2.5.2 Data deficiencies and issues requiring further study

The data deficiencies and issues requiring further study relevant to the generation alternative are similar to those for the diversion alternative. Present and potential productivity of the McGregor system should be refined. Mitigation and habitat compensation opportunities will be similar to those discussed in the diversion alternative. Flow requirements for maintaining mainstem habitat and enabling migration in and out of Seebach Creek require further study but it is felt the non-diversion alternative offers greater scope for remedial flows. The hydrologic study should include the impacts of temperature changes, increased winter and decreased summer flows, supersaturation of dissolved gases and the nature of the residual flow regime on the lower McGregor mainstem. The mainstem and Seebach Creek may have habitat development potential. Information on proposed daily operating regimes is required to delineate the range of expected flow and stage variations on the lower McGregor River. Hourly and daily fluctuations caused by situations such as spilling, emergency operation during sudden load rejection, normal maintenance, weekday vs weekend load demands, rapid change from maximum to minimum turbine output and reservoir filling should be estimated.

Some of the information which will be gathered regarding flow requirements for the diversion alternative will be relevant to defining generation alternative impacts.

3 SALMON UTILIZATION OF THE FRASER RIVER

3.1 Introduction

The Fraser River, the largest river in British Columbia in length, drainage area and total discharge supports at least 38 fish species in its lower reaches and an additional eight species occur in the upper drainage (Northcote, 1974). The Fraser River is the greatest producer of salmon in North America and supports major populations of all five northeast Pacific species - sockeye, chum, pink, chinook, and coho.

Hydroelectric and flood control development on the McGregor would affect the annual discharge patterns, level, volume, temperature and quality of water in the Fraser River. Changes in these hydrologic factors will in turn impact the Fraser River fisheries resource. Impacts on salmon are described below.

The following hydrologically related studies assessed changes which might occur in various areas of the Fraser if the McGregor River flow was markedly decreased or withdrawn:

1. water volume changes in the Fraser River and the impact on salmon fisheries;

2. water level changes in the Fraser River and its impact on chum and pink salmon and their habitat below Hope;
3. water temperature changes in the Fraser River between the mouth of the McGregor River and Hope and the impact on sockeye salmon resources;
4. water quality changes in the Fraser River and the impact on the salmon fisheries resources.

The bulk of the studies were carried out by B.C. Hydro and their consultants in response to concerns expressed by government agencies and were initiated late (1977) in the historical development of the project.

A detailed assessment of the Fraser River issues was pre-empted by the suspension of the project in 1978. Hence the information available and discussed below is based upon preliminary findings.

To date, no definitive estimate has been made of the extent that the McGregor Diversion Project would reduce the salmon stock of the Fraser system. In the early 1970's, Fisheries and Marine Service attempted to estimate the total reduction in Fraser River salmon production given a variety of System E scenarios, including the McGregor Diversion Project alone. The reduction in salmon

survival rates given the McGregor Diversion Project without mitigation are presented as percentages in Table 4. The data and assumptions used to develop these figures are not stated clearly. For example, it is unclear why chinook losses in the Grand Canyon Basin, which is on the Fraser River upstream of the McGregor River, are estimated at 30 percent as a result of the McGregor Diversion Project. In addition, the assumptions used appear to include:

- 1) no fishwater release whatsoever from the McGregor Diversion Project;
- 2) for all salmon species, there is a direct relationship between peak discharge in the Lower Fraser and overall fry-to-adult salmon survival, ie. if the peak discharge decreases 2 percent salmon production drops 2 percent.

The relationship giving rise to the discharge versus production assumption was devised from information on Chilko River smolt survival as a function of Chilcotin River discharges during out-migration. This relationship may be affected by predation pressure and was considered valid only within a certain population range. Hence, the assumption is no longer considered completely valid (pers. comm. M. Fretwell, DFO). Any further studies regarding the McGregor Diversion Project should include estimates

Table 4

REDUCTION IN SURVIVAL RATES OF SALMON STOCKS
AS A RESULT OF REGULATION AT LOWER MCGREGOR WITHOUT MITIGATION

Location of Stock	Chinook (%)	Sockeye (%)	Coho (%)	Pink (%)	Chum (%)
Grand Canyon Basin	30	-	-	-	-
McGregor River Basin	82	-	-	-	-
North Fraser Area	11	16	-	-	-
Central Fraser System	10	12	10	12	-
Thompson River Basin	2	2	2	2	-
Lower Fraser Area	2	2	2	2	2

Source: Environment Canada. 1974. An assessment of the effects of the System E flood control proposal on the salmon resource of the Fraser River system.

of salmon productivity changes with and without various fishwater release schedules.

3.2 Salmon Utilization of the Fraser River -

The Impact of Water Level and Flow Changes Above Hope

3.2.1 Major Reports

International Pacific Salmon Fisheries Commission. 1977. Annual Report 1976. New Westminster, Canada.

Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project (4 Volumes) for B.C. Hydro and Power Authority.

3.2.2 Studies To Date

Diversion of the McGregor River flow into the Peace System would decrease the net discharge of the Fraser River. The biological implications of this were first addressed in the 1976 System E summary report. Fish passage problems at fishways and natural low water obstructions were discussed. Later, B.C. Hydro consultants concentrated on a review of data from hydrology studies and relevant literature. Field work for physical data input to the hydrologic models was undertaken but no fisheries field work was done. Impacts of water discharge decreases are discussed in Reid, Crowther and Partners (1978). The

implications of water level changes in the Fraser River have also been discussed by the IPSFC for both the McGregor Diversion Project and Kemano Completion Project.

3.2.3 Present Knowledge

River discharge influences the upstream spawning migration and downstream juvenile migration of salmon. Most literature describes the influence of discharge on sockeye and pink salmon. In the other salmon species, behavioural patterns such as migration are also influenced by discharge changes. Unfortunately, comparatively little is known about the influence of discharge on these other species.

Upstream migration studies by Gilhousen (1960) demonstrated a significant relationship between Fraser River discharge at Hope and the timing of the Adams River sockeye run. The duration of the upstream sockeye migration from the Fraser River estuary is inversely related to the total volume of flow between June 1 and September 15.

The timing of the upstream migration of Fraser River sockeye and pink salmon appears to be more critical than for other salmon populations. Sockeye do not normally delay in the river as do

some chinook populations (Andrew and Geen, 1960). Thompson (1945) found that a delay of 12 days at Hell's Gate prior to construction of the fishways prevented all sockeye salmon from reaching their spawning grounds and lesser delays reduced the reproductive capacity of the fish. A delay of two to four days may be critical for some up-river races of sockeye (Andrew and Geen, 1960). Two facts appear to be involved in contributing to reduced productivity of sockeye as a result of delay. First, sockeye do not feed on their upstream migration. Therefore, during the period of delay, the fish use energy reserves normally available for migration, gonad development and spawning activities. Secondly, when sockeye arrive on the spawning grounds later than normal, conditions are less favourable for spawning, and egg-to-fry survival.

Several studies of downstream migration have suggested a relationship between Fraser River discharge and marine survival of sockeye and pink salmon. For example, IPSFC data for the Chilko sockeye population indicates a direct relationship between discharge of the Fraser River at the approximate time of smolt downstream migration and the smolt-to-adult survival rate (IPSFC Ann. Rep., 1967). Increased marine survival of Fraser River pink salmon was once thought to be related to increased river discharge at the time of seaward migration in April (Anon., 1971). However, the relationships between Fraser River discharge

and survival of sockeye and pink salmon (as well as other salmonid juveniles) are not clear. For example, more recent data for pink salmon (IPSFC Ann. Rep., 1973, 1976 and 1983) indicate that low volumes of runoff from the Fraser River for the months April through July are more favourable to zooplankton production and hence pink survival in marine environments.

3.2.4 Diversion Alternative

(a) Impacts

The McGregor River flows currently comprise approximately 34 percent of the average annual Fraser River flow below the mouth of the McGregor; 28 percent at Shelley, which is approximately 20 km upstream of Prince George; 16 percent at Marquerite, which is between Quesnel and Williams Lake; 13 percent above Texas Creek, near Lillooet, and 9 percent at Hope. Contribution to the mean monthly flows at Hope range from 4 percent for January to approximately 12 percent for October. The lowest percentage contributions occur in the period January to March inclusive.

The alteration in Fraser River discharge as a result of the McGregor Diversion could have an impact on salmon production in the Fraser River. Discharge regimes of non-diversion dams can be

advantageous to anadromous fish when peak discharges are reduced and minimum flows increased. However, the diversion of McGregor flows would result in the same general discharge pattern for the Fraser River but with reduced flow for both peak and minimum discharge periods. The reduction of discharge could cause passage problems at fishways, difficult natural fish passage areas such as low water obstructions, and at confluences of tributaries with the Fraser.

The main fishways at Hell's Gate operate at full design capacity with a minimum of 6.0 ft (1.83 m) water depth throughout the structures. The equivalent river discharge as measured at Hope for this water depth in the fishways is approximately 67,000 cfs (1,890 m³/sec) and 69,000 cfs (1,955 m³/sec) for the right (west) and left (east) bank main fishways. For river discharges less than those noted above the main fishways operate at reduced capacity. When the water depths at the fish exit (upstream) ends of the fishways are reduced to less than 0.30 m (12 inches) the structures are considered impassable for migrating adult salmon. The fish exit (upstream) ends of the fishways go dry at about 49,000 cfs (1,388 m³/sec) and 50,000 cfs (1,416 m³/sec) for the right and left bank fishways respectively.

Diversion of the McGregor River would reduce the capacity of the fishways throughout much of that operating range.

The Bridge River fishways were designed to operate at full capacity when they have at least 3 ft (1 m) of operating depth which occurs at a flow of 28,000 cfs (795 m³/sec) in the Fraser (at Jesmond or Big Bar). For the last date of sockeye migration (September 30) the lowest recorded flow (1951) was 26,200 cfs (740 m³/sec) which could be tolerated. The McGregor diversion would reduce this flow by about 2,000 cfs (55 m³/sec) to 24,200 cfs (685 m³/sec). For the last date of pink salmon migration (October 16) the lowest recorded flow (1946) was 22,000 cfs (625 m³/sec) which would give a water level at the bottom of the fishway. The McGregor Diversion would reduce this flow by about 2,000 cfs (55 m³/sec) to 20,000 cfs (5567 m³/sec) resulting in a water level 1.5 ft (45 cm) below the bottom of the fishway (IPSFC, 1984).

The impact of the reduction of discharge on fish passage capacity would depend upon the synchrony of passage of large numbers of fish and frequently of occurrence of reduced flows.

Natural low water obstructions that hinder fish migration occur at China Bar Rapids and Scuzzy Rapids 2 miles (3 km) and 3 miles (3 km) respectively upstream of Hell's Gate, Little Hell's rapids (at Whites, or Tsileuh Creek 1.5 miles (2 km) downstream of Hell's Gate) and Saddle Rock about 13 miles (21 km) downstream of Hell's Gate. DFO is contemplating surveying water surface

profiles at Saddle Rock near Yale during low water levels to assess the relative degree of passage difficulty under existing conditions. This information would permit a frequency analysis of conditions created by the proposed McGregor Diversion. (IPSFC, 1984).

Lower Fraser River levels may result in fish passage problems at the entrance to tributaries such as Churn Creek, Texas Creek, Stein River and Bridge River. For example, when the Fraser River was low in early October 1981 passage for pink salmon from the Fraser River into Bridge River was restricted by a short steep rapids just upstream from the confluence. Discharge in the Fraser River above Bridge River was approximately 26,000-27,000 cfs (737-765 m³/sec) at that time. This condition had not been observed previously at this location and is believed to have been caused by flushing out of gravel deposits at the site due to a combination of low Fraser River level and relatively high flow in Bridge River attributed to heavy rains. It is estimated that access to Bridge River becomes difficult when Fraser River discharge drops to 38,000 cfs (1,076 m³/sec) as measured above Bridge River (IPSFC, 1983).

No hydrologic analysis of flows at various Fraser River locations has been done. No estimates of the impact of delay of adult migration on salmon production have been made. The IPSFC esti-

mated that the reduction of Fraser River discharge due to the McGregor Diversion would extend the Adams River sockeye run by about five days but did not state whether this delay would occur regardless of hydrologic conditions on the Fraser or under specific conditions. The effect of this extension on subsequent survival would depend on the timing of the run and water temperatures along the migration route and at the spawning grounds. However, the extension of the run would increase the possibility of lower survival and reduced production of this major sockeye run.

As mentioned above, the impact of reduced flows during juvenile salmon out migration is also a concern. In 1976, the IPSFC suggested that, based on the Fraser discharge: smolt survival relationship, the survival of Chilko sockeye smolts could be reduced by one percent as a result of removal of McGregor flow. (IPSFC Ann. Rep., 1976). Further, the average annual catch of 4 million Fraser sockeye could be reduced by 15 percent and the future potential catch of 9 million or more could be similarly reduced (IPSFC Ann. Rep., 1976). (The average annual catch of sockeye during the period 1979 to 1982 was 5.6 million.)

However, the Fraser discharge: smolt survival relationship does not appear to be as strong as previously believed and should be considered tentative. Until this relationship is more fully

understood, the impact of reduced discharge upon salmon smolt survival is unquantifiable.

In general, a reduction in water volume will increase the density of fish and therefore exacerbate the incidence of disease, especially at areas of fish concentration such as natural fish hindrances and fishways.

Mitigation and enhancement opportunities for decreased water flow regimes were not discussed in the Reid, Crowther and Partners Ltd. (1978) report. Fishwater release schedules suggested in previous reports were inconsistent, discussed in Chinook utilization of the McGregor Basin and summarized in Table One. In summary, the Fraser River Board (1963) recommended flows as necessary to fulfill flow requirements at Hells Gate during May. It is not made clear in the report why the Board felt that flow in May might be a potential problem. Environment Canada (1974) stated that no mitigating measures with respect to discharge, other than an annual 1000 cfs (28 m³/sec), were recommended for the Lower McGregor project unless a Grand Canyon dam was constructed. (The Grand Canyon dam was part of the System E proposal and was to be situated on the Fraser River upstream of the McGregor River). The Fraser River Ecology Committee (1976) report did not recommend any McGregor fishwater releases in relation to Fraser river adult migration requirements.

(b) Data Deficiencies and Issues Requiring Further Study

The premature suspension of the McGregor River studies prevented complete analyses of the Fraser River work. If further consideration is given to the McGregor project completion of the following studies specific to water flows in the Fraser River would allow the fisheries implications of the project to be assessed.

Assessment Oriented Information

1. Further information on flow conditions at known and expected migration hindrances under a variety of fishwater release schedules and historic flow discharges is needed. Information on water velocity should be examined with respect to fish swimming behaviour and limitations. For example, the morphology of the river channel at Scuzzy Rapids is such that at low flows there may not be any flow suitable for fish passage as is the case at present (typical) flows. Hence fish would have more difficulty and use greater energy reserves negotiating Scuzzy Rapids and similar areas.
2. Better information regarding the influence of discharge on chinook, coho and chum salmon is required to predict the impacts discharge fluctuations will have on various life cycle stages of these species.

3. Estimates should be made of salmon production losses due to decreased water volume and the resulting increased incidence of disease as a result of fish crowding. This issue is especially crucial since water temperature may be elevated during the spawning migration, which would further exacerbate the incidence of disease. In addition, estimates should be made of salmon production losses due to delay in upstream salmon migration and low flow related injury.
4. A complete evaluation of the impact of reduced water levels due to the McGregor Diversion would have to include the combined effects of any other potential Fraser River regulation projects such as Kemano Completion.

Mitigation Oriented Information

1. Alternative management plans should be identified and evaluated in order to minimize fisheries losses. Positive impacts should be identified and optimized in the management plan.
2. Mitigation options could include provision for the release of adequate flow from the McGregor Diversion to maintain fish passage in the event of low flow. The re-design of fishways or new construction would have to be examined;

these activities may be impractical because of engineering constraints or excessive cost.

3. There is a general theoretical relationship between tailrace elevation and turbine mortality. This has not been measured at Seton Creek, but lower Fraser River level would be expected to cause increased turbine-related mortality. It is unlikely that any study at Seton G.S. could achieve the precision required to measure the small increase in mortality anticipated as a result of lowered water levels attributable to McGregor Diversion. The McGregor project would not reduce the average water level at the powerhouse much in comparison to present fluctuations. The Fraser River level at Seton powerhouse currently varies as much as 40 ft (12m) (M. Fretwell, IPSFC, pers. comm). There should be an awareness that this and similar impacts may not be quantifiable beforehand but may contribute to the decline of the fisheries resource. There will likely be a need for post project studies to clarify these impacts so that corrective action could be taken.

Habitat Compensation Oriented Information

1. Replacement of fish losses through habitat restoration and improvement and artificial production will have to be investigated.

3.2.5 Overview of Generation Alternative Impacts

A McGregor Lower Canyon generation development would reduce summer mean monthly flows up to 6 percent at Hope and 18 percent at Shelly. Mean monthly winter flows would increase in the order of 14 percent to 18 percent at Hope and 65 percent to 87 percent at Shelly. Water level reductions in spring and fall would be small. The impacts these flows would have on issues raised above have not been examined. Clearly, the impacts at fish hindrances would not be as severe as diversion impacts since the reduction in flows would not be as extreme. Possible beneficial and adverse biological impacts have not been examined. The scope of investigation would be similar to those outlined above. Any positive benefits should be identified and optimized in a habitat management plan.

3.3 Salmon Utilization of the Fraser River - The Impact of Water Level and Flow Changes Below Hope

3.3.1 Major Reports

British Columbia Hydro and Power Authority. 1979. McGregor River Diversion River Regime and Morphology Volume III: Fraser River. Hydroelectric Design Division. Report No. 958. January 1979.

Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project (4 Volumes) for B.C. Hydro and Power Authority.

Renewable Resources Consulting Services Ltd. 1978. Impact of the McGregor River Diversion on Fish in the Fraser River. A Progress Report. Prepared by C. McLeod, R.L. and L. Environmental Services Ltd. and R. Mohn, Renewable Resources Consulting Services Ltd. Edmonton, Alberta. March, 1978.

3.3.2 Studies to Date

The Lower Fraser River below Hope and some of its tributaries are major spawning grounds for pink and chum salmon and incubation

and rearing habitat for juvenile salmon. The proposed diversion of the McGregor River into the Peace River watershed would lower the water levels in the Lower Fraser River due to the reduction of flows. This, in turn, would result in loss of spawning, incubation and rearing habitat. Spawning activity does occur in the mainstem of the Fraser River. However, the side channels, separated from the mainstem by gravel, sand bars, or islands, and the lower reaches of some of the tributaries, are important spawning areas for chum and pink salmon and also the most vulnerable to lower river stages. An estimated 3.3 million pink spawners utilized the mainstem, side channels and mouths of small tributaries in 1983 (IPSFC, 1984).

Concern was expressed to B.C. Hydro by the Fisheries Service of Environment Canada and the International Pacific Salmon Fisheries Commission regarding the potential loss of chum and pink salmon spawning areas. One year of studies were undertaken by B.C. Hydro and their consultants in 1977 directed primarily at chum salmon and consisted first of evaluating water velocity and depth in spawning areas under reduced flows and second of an assessment of the probable resultant impacts on salmon. A representative group of channels and tributaries was selected jointly by B.C. Hydro biologists and Fisheries Service staff. The areas were Johnson Channel, Peters Channel, Wahleach Channel, Greyell Slough Harrison River below Morris Creek, and the Stave River downstream

of Ruskin Powerplant. It was felt that measureable changes in the physical environment of these sites and resultant changes in habitat availability and use would provide an indication of the relative impact on habitat in the remainder of the Lower Fraser River.

Mitigation and habitat compensation opportunities were not examined in the work done for B.C. Hydro due to the suspension of the project. The scope of studies required to address the issues is discussed below in Data deficiencies and issues requiring further study.

3.3.3 Evaluation of decreased flows below Hope

(a) Data Collection

Available data necessary for the analysis were assembled by B.C. Hydro from various sources. Hydrometric data were collected from the Water Survey of Canada (WSC), hydrographic data (river soundings) from Public Works Canada (PWC) and Inland Waters Directorate (IWD), aerial photographs from Pacific Survey Corporation, and bank stabilization information from B.C. Water Resources Services. Additional data required were obtained from field surveys conducted in 1977 for B.C. Hydro by Underhill

Engineering Ltd. of Vancouver. The field activities included topographic surveys of the channel beds, water profile observations, and velocity measurements in selected channels. Details of the available hydrologic data and field activities are discussed in Section 4.2 and 4.3 of B.C. Hydro and Power Authority (1979).

The compilation of fisheries data included field work and literature reviews. Reconnaissance of the four side channel areas and two tributary backwaters was undertaken during low flow conditions (February 23 and April 12-21, 1977). Specific known chum spawning areas were observed. Each side channel area was surveyed twice during the fall spawning period; initially October 25-28 and again December 1-3, 1977. Habitat use in the Harrison River was determined from previous reports and observations made on September 28, October 4-5, and November 5, 1977. Chum salmon use of the Stave River was determined from published and unpublished materials and one survey on November 1, 1977.

Spawning areas were identified either by the presence of fish or newly formed redds. Potential spawning areas were determined on the basis of apparent suitability of substrate and hydraulic conditions. During the fall of 1977 low flow conditions in the main Fraser River reduced or terminated inflow to most side channel areas, creating good visibility in spawning areas and

allowing wading surveys of all sites. Surveys were conducted with two people, one wading on each side of the channel to the maximum depth possible. Measurements and observations on depth, velocity, substrate composition, and probable ground water sources were noted.

Redd locations, concentrations of fish, carcasses, and estimated usable spawning areas (1977 wetted conditions) were plotted on air photo blue prints. Potential spawning areas (based primarily on substrate) near observed spawning areas were also plotted. This information was used by B.C. Hydro to estimate the amount of spawning area with different discharges (Reid, Crowther and Partners Ltd. 1978).

Field collection of small fishes, specifically juvenile salmon and trout, augmented this work. Field periods were July 12 to 14, September 27 to 29, and December 12 to 16, 1977 (B.C. Hydro and Power Authority 1978).

(b) Analysis of Hydrologic Data

The analysis of the historical hydrologic data was made on a probability basis. The daily streamflow data for the McGregor River at Lower Canyon (WSC Station 08KB003) and for the Fraser River at Hope (WSC Station 08MF005) were analyzed for 1960 to

1975, the period for which concurrent records were available. For post diversion analysis, the Fraser River discharges at Hope were computed by subtracting the observed McGregor flows from the observed Fraser flows at Hope assuming a three day travel time for flow from the McGregor River to Hope.

The salmon habitat in the Harrison River is subject to the variation of both the Fraser and Harrison River discharges, hence the flow probability analysis incorporated data from WSC Station 08MG013 near Harrison Hot Springs.

(c) Analysis of Hydraulic Data

For the purpose of hydraulic analysis preferred spawning areas for chum were identified as those areas where the minimum depth was 14 cm, maximum nose velocity was 1.0 m/s and suitable gravel existed (McLeod, 1977 in B.C. Hydro and Power Authority, 1979). The range of water depths and nose velocities preferred by spawning chum salmon have been studied by several investigators (Collings, 1974). The reported preferred depths range from 14 m³/sec to 1.5 m or deeper and preferred nose velocities from 0 to 1.0 m/s. (The nose velocity has been defined as the velocity at a depth of 12 and 18 m³/sec above the streambed by different investigators). In these studies it was assumed velocities at these two depths would not differ significantly. Velocities at

18 m³/sec were measured in field studies and subsequently used as nose velocities in the analysis.

The water levels in the study channels and tributaries, for various flows, were computed using the computer program HEC-2, developed by the Hydrologic Engineering Centre, U.S. Army Corps of Engineers.

The ratio between nose velocity and average velocity at a vertical varies in accordance with the depth of flow, hence the distribution of nose velocities over the width of the channel bed could be computed from the hydraulic data. A relationship between depth of flow and the ratio of nose velocity to average velocity was developed by Fisheries staff for salmon stocks on the Nanika and Morice rivers (Environment Canada, 1976) and was applied to the lower Fraser River data. Finally, the estimated area available for chum spawning in the study channels was computed using various Fraser River discharges.

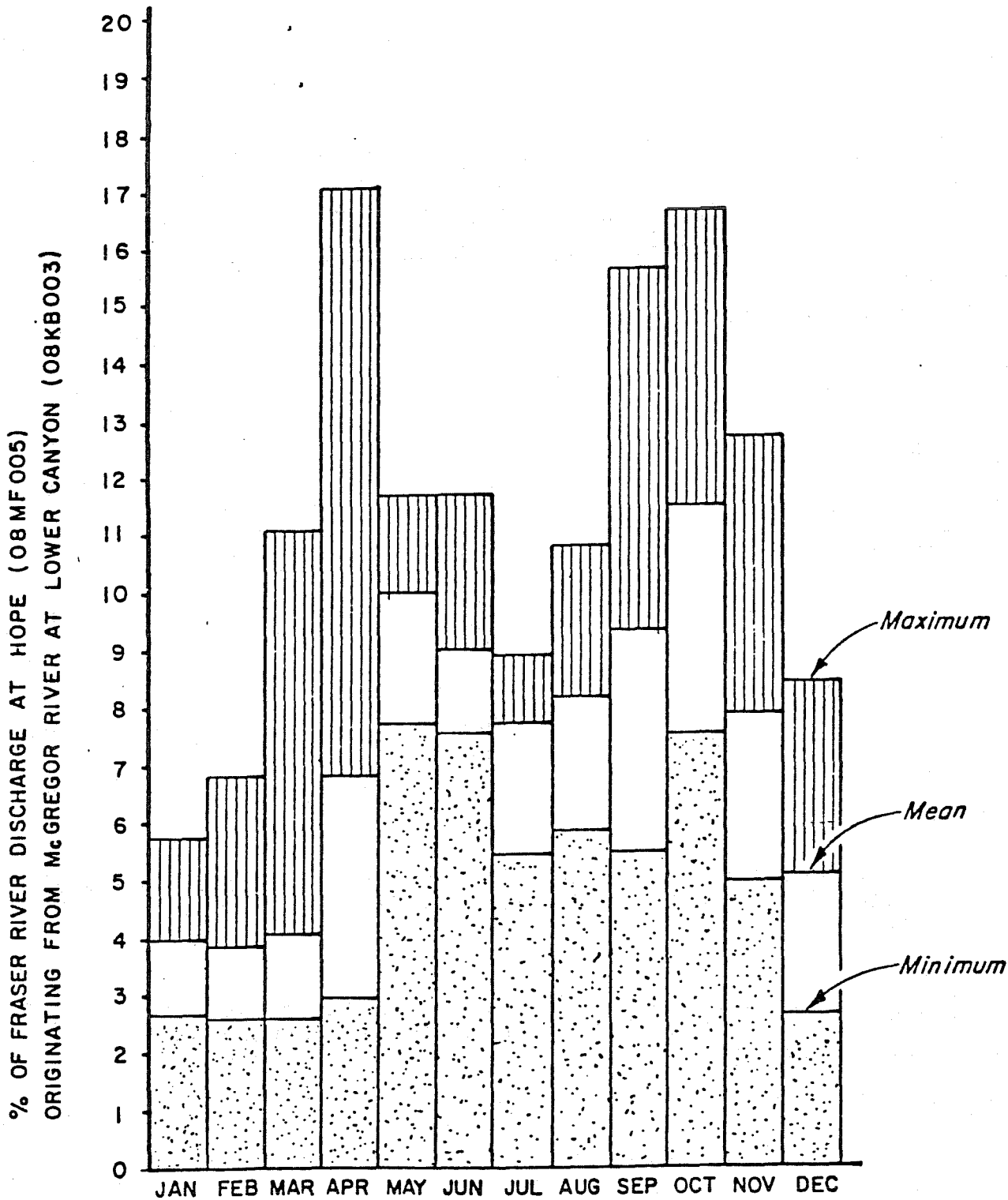
The area available for chum spawning in the Stave River study area (the reach below Ruskin Dam), under various Fraser River discharges, was difficult to determine. The area is completely under tidal influence when Fraser River discharges are less than 1500 m³/sec, which is the upper limit of flows during the spawning season. The analysis was further complicated by the

intermittent operation of the Ruskin power plant. To estimate the impact the hourly water level fluctuations would have to be known for a range of Fraser discharges. These data were not available hence the potential loss of Stave River spawning area could not be calculated.

3.3.4 Diversion Alternative

(a) The Impact of Diversion on Lower Fraser River Hydrologic and Hydraulic Characteristics

The results of the hydrologic analyses showed that the McGregor River contributes 9 percent of the mean annual discharge for the Fraser River at Hope. Based on monthly averages of the 1960 to 1975 data, the seasonal variation was between 2.5 and 17 percent (Figure 3). The monthly averages of estimated daily flow reduction for mean flow, minimum flow and flows with a 75 percent probability of exceedance during the spawning seasons are summarized in Table 5. If there were no flow release from the McGregor Reservoir the post diversion mean daily discharge at Hope would be reduced by 9 percent on average during September. The reduction would be about 11 percent in October and decrease to 9 percent in November and 5 percent in December and January. At minimum Fraser River flows, the reduction in discharge at Hope



- Based on mean monthly discharges between 1960 & 1975

FIGURE 3
DISCHARGE RELATIONSHIP
MCGREGOR RIVER TO FRASER
RIVER AT HOPE

Source: British Columbia Hydro and Power Authority. 1979

Table 5

FLOW REDUCTION DOWNSTREAM OF HOPE DURING
CHUM SALMON SPAWNING SEASON

Flow Probability	Month	Potential Reduction in Flow (%)
Mean Flow	Sep	9.1
	Oct	11.2
	Nov	8.8
	Dec	5.3
	Jan	5.0
75% Exceedance	Sep	8.5
	Oct	11.8
	Nov	7.6
	Dec	6.1
	Jan	4.7
Minimum Flow	Sep	10.4
	Oct	10.6
	Nov	7.0
	Dec	6.3
	Jan	5.2

Based on observed data for Fraser River at Hope (08MF005) and
McGregor River at Lower Canyon (08KB003) for the period 1960 to
1975.

Source: British Columbia Hydro and Power Authority. 1979.
McGregor River Diversion River Regime and Morphology Volume III:
Fraser River

would be 7 percent at the beginning of September and increase to over 20 percent at the end of September and first half of October. The reduction in minimum daily flow at Hope would range from 5 to 9 percent during November and December and 4 to 6 percent in January. The effect of diversion on the minimum daily flow at Hope would be 3 to 4 percent in the remaining winter months.

The above results were based on analysis of 1960 to 1975 data. Records back to 1912 are available for the Fraser River at Hope. A comparison of short and long term records indicated that the period 1960 to 1975 was wetter than average. Flows for this period averaged 6 to 12 percent greater than average in September, 10 to 20 percent greater in October, and about 10 percent greater in November and December. The differences would have been even greater had not a portion of the Nechako River flow been diverted from the Fraser Basin since the middle of the 1950's.

Table 6 presents hydraulic data regarding the reduction of water levels in the Lower Fraser River side channels after diversion. Water levels were estimated to drop 5 to 20 m³/sec in the side channels.

Over time (10 or 20 years) the morphology of all the river channels would change because of the alteration of water flow and

Table 6

REDUCTION OF WATER LEVELS IN LOWER FRASER RIVER
SIDE CHANNELS AFTER DIVERSION

Flow Probability	Month	Approximate Reduction in Water Level (cm)			
		Johnson	Peters	Wahleach ¹	Greyell
Mean Flow	Sep	10	10	20	15
	Oct	30	20	15	20
	Nov	20	10	20	10
	Dec	20	10	10	5
	Jan	10	2	10	5
75% Exceedance	Sep	20	10	10	15
	Oct	20	10	20	15
	Nov	10	10	15	10
	Dec	20	3	10	5
	Jan	10	3	3	5
Minimum Flow	Sep	20	20	10	15
	Oct	20	20	15	10
	Nov	10	3	10	10
	Dec	20	3	3	5
	Jan	10	3	3	5

¹ No outflow from Wahleach powerplant

² Channel completely cut off from Fraser River after diversion

³ Channel completely cut off from Fraser River under natural flow conditions

Source: B.C. Hydro and Power Authority. 1979. McGregor River Diversion River Regime and Morphology Volume III: Fraser River.

sediment deposition. The ultimate changes are difficult to predict. Water surface width and other channel dimensions in plan at different river sites and at corresponding flows vary approximately in proportion to the square root of discharge. However, slope and bed material size complicate any analysis. Over the long term (centuries) reduced Fraser River flows will affect the pattern of gravel deposition downstream of Hope as almost the entire gravel-bed load of the Fraser River is presently being deposited between Hope and Chilliwack. There will be adjustments to slope and bed material size which will affect the size of potential spawning beds.

(b) The impact on Chum Salmon Spawning Areas

The observations regarding depth and velocity preferences made in the 1977 study are summarized in Table 7 and compared with those of previous workers in Table 8. Depth ranges are biased, as only velocities to wading depth could be measured. In areas of the side channels where spawning occurred in 1977, maximum depth (to the extent available in 1977) did not appear to be a limiting factor as long as other conditions were suitable.

The available spawning areas and average reduction of spawning areas under various flow regimes are summarized in Tables 9 and 10. The losses vary from 1 to 37 percent in September, 2 to 45

Table 7

CHUM SALMON SPAWNING DATA, LOWER FRASER RIVER SPAWNING AREAS
(November 4 - December 2, 1977)

	(N)	DEPTH (m)		VELOCITY ² (cm/sec)	
		Mean	Range ¹	Mean	Range
Wahleach Slough					
- in powerhouse influence	(17)	0.56	0.35-0.73	23.6	15.2-39.6
- outside powerhouse influence	(17)	0.34	0.18-0.70	15.0	0.0-45.7
Peters Slough	(6)	0.47	0.40-0.55	0.0	-
Chehalis delta, Area 6	(37)	0.25	0.14-0.52	13.4	0.0-44.2

- ¹ Max. depth measurements limited to redds accessible by wading; redds were also present in deeper water.
² Velocity taken immediately upstream of redd on undisturbed gravel, 0.12 m above streambed.

Source: Reid, Crowther and Partners Ltd. 1979. Report on Environmental Studies for the McGregor Diversion Project. Volume II - Tables and Figures.

Table 8

SUMMARY OF REPORTED DEPTH VELOCITY REQUIREMENTS FOR CHUM SALMON

	DEPTH (m)		VELOCITY (cm/sec) ¹	
	Mean	Range	Mean	Range
1977 study	0.36	0.14-0.73	14.9	0.0-45.7
Smith, 1973	0.30	-	72.7	46.0-101.0
Thompson, 1972	0.18	-	-	45.7-97.5
Burner, 1951	0.25	0.05-0.76	-	-
Collings, 1974	-	0.15-0.53	-	21.3-100.6
Strekalova, 1963	-	-	-	21.0-100.0

¹ Taken at 0.12 m above streambed, except Strekalova (1963) unknown.

Source: Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project. Volume II - Tables and Figures.

Table 9

AVAILABLE SPAWNING AREA FOR CHUM SALMON UNDER NATURAL CONDITIONS

Flow Probability	Month	Available Spawning Area (m ²)			
		Johnson	Peters	Wahleach	Greyell
Mean Flow	Sep	27 200	51 700	163 000	23 000
	Oct	24 300	49 300	161 000	21 750
	Nov	15 400	44 200	152 000	18 600
	Dec	2 800	31 800	106 500	12 600
	Jan	1 350	11 200	73 000	10 000
75% Exceedance	Sep	23 500	49 000	160 500	21 500
	Oct	18 000	45 800	156 500	19 600
	Nov	7 900	38 600	131 500	9 600
	Dec	1 250	1	67 000	9 600
	Jan	750	1	1	7 600
Minimum Flow	Sep	10 000	40 400	139 000	16 500
	Oct	7 600	38 400	131 000	15 450
	Nov	1 200	1	64 000	9 550
	Dec	400	1	1	4 250
	Jan	400	1	1	4 250

1 Channel completely cut off from Fraser River

Source: B.C. Hydro and Power Authority. 1979. McGregor River Diversion River Regime and Morphology. Volume III: Fraser River

Table 10

POTENTIAL LOSS OF SPAWNING AREA AFTER DIVERSION

Flow Probability	Month	Available Spawning Area (m ²)			
		Johnson	Peters	Wahleach	Greyell
Mean Flow	Sep	11.4	4.6	1.2	5.4
	Oct	20.2	5.5	1.9	7.6
	Nov	22.1	5.0	5.3	6.7
	Dec	21.4	9.4	7.5	7.1
	Jan	18.5	100.0 ²	20.5	9.0
75% Exceedance	Sep	15.7	4.5	1.2	6.3
	Oct	27.8	6.8	5.8	9.4
	Nov	31.6	6.2	6.5	7.1
	Dec	20.0	0	47.8	9.4
	Jan	13.3	0	0	11.8
Minimum Flow	Sep	37.0	7.9	8.6	9.1
	Oct	44.7	9.6	10.7	11.3
	Nov	25.0	0	45.3	11.5
	Dec	25.0	0	0	7.1
	Jan	12.5	0	0	11.8

¹ Compared to that available for the same month and flow probability of exceedance under natural conditions.

² Channel completely cut off from Fraser River after diversion.

Source: B.C. Hydro and Power Authority. 1979. McGregor River Diversion River Regime and Morphology. Volume III: Fraser River

percent in October and 0 to 100 percent from November to January. These data must be interpreted with caution. On the basis of the 1977 spawning area observations it was felt that selection of chum salmon spawning areas or estimates of usable areas based on substrate suitability could be extremely misleading, even when conditions fall in the range of reported depth-velocity criteria. The majority of chum were very site specific spawners, with spawning observed to be related to occurrence of groundwater seepage from banks or through alluvial fan deposits or groundwater flow from tributary inflow, which was ephemeral in some cases. The following groundwater sources were felt to be significant for chum in the Lower Fraser River mainstem:

- intergravel seepage from adjacent standing water in the side channels;
- intergravel seepage from the Fraser River mainstem into side channels;
- active streams (permanent or ephemeral) entering the side channel;
- subsurface flow in streambeds or percolation through alluvial fans;

- seepage or springs from banks, hillsides, or even adjacent agricultural land.

Spawning occurred in Wahleach and Greyell Sloughs, but only in areas of hydraulic head or convex bottom above riffles where there was adequate subsurface flow. Wahleach flows from the powerhouse are analogous to clear tributary inflow and were not felt to be representative of active side channel flows which are influenced primarily by Fraser River inflow.

The estimated usable chum spawning area in the study locations based on 1977 field observations is shown in Table 11. As mentioned above the theoretical spawnable areas are not necessarily utilized. In light of the site specificity and selection of spawning habitat exhibited by chum observed in the study area, strict application of general substrate, depth and velocity criteria would substantially overestimate the actual spawning area. The relative percentage loss of each area during the peak spawning season is shown in Table 12. Where applicable, the losses range from approximately 5 to 23 percent of the potential spawning habitat. It was felt that this may be the best indicator of impact, although this estimate still has the same limitations as outlined above.

Table 11

ESTIMATED USABLE CHUM SALMON SPAWNING AREA IN
SELECTED SIDE CHANNELS AND TRIBUTARIES OF THE LOWER FRASER RIVER

Location	Useable Spawning Area (m ²) ¹
Side Channel	
Johnson Slough	10,800
Peters Slough	25,600
Wahleach Slough	34,750
Greyell Slough	9,800
Tributaries	
Harrison River (incl. Chehalis delta & Weaver Cr)	138,500
Harrison bay (incl. Squakum Cr)	18,700
Stave River	88,000

¹ Side channels estimated from 1977 observations, may vary according to discharge. Tributary data from Palmer (1972) and G. Wilson (pers. comm.)

Source: Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project. Volume II - Tables and Figures.

Table 12

APPROXIMATE PERCENTAGE LOSS OF
POTENTIAL SPAWNING HABITAT FOR CHUM SALMON IN
LOWER FRASER RIVER STUDY AREAS AS A RESULT OF
WITHDRAWAL OF MCGREGOR RIVER FLOWS
(AVERAGE FLOWS NOVEMBER 1-30; 1960- 1975 PERIOD)

Study Area	Percentage Loss
Side Channel	
Johnson Slough	22.6
Peters Slough	5.4
Wahleach Slough	5.3
Greyell Slough	N/A
Tributaries	
Harrison Bay ¹	10.2
Stave River	N/A

¹ At Harrison River inflow of 150 m³/sec.

Source: Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project. Volume II - Tables and Figures.

(c) The Impact on Pink Salmon Spawning Areas

Goodlad (1958) indicated that "extensive examination of pink redds during the winter of 1957-1958 revealed that none of the Fraser River pink salmon spawned in depths of less than four feet of water". These observations were made during September and October, 1957, when flows had been about 2,070 m³/sec, similar to the mean flow expected after diversion of the McGregor River. The Department of Fisheries and IPSFC (Anon., 1959) suggested that depths up to at least 7.5 m are used by pink salmon for spawning in the mainstem Fraser River. Harrison River spawners were observed spawning throughout the main channel in areas up to 7.6 m in depth, as well as in shallower side channels. Observations in other areas such as the Thompson River and Seton Creek indicate that pink salmon spawn in shallow water (less than 1.3 m) as well (M. Fretwell, pers comm). Pink salmon were observed digging in depths of water less than 0.45 m in the mainstem Fraser above Wahleach Slough in 1977. These redds (or perhaps false redds) were later exposed in late October by normal decreasing water levels. Substantially increased spawning escapements since 1957 may have resulted in expansion of the area utilized by pinks to include a greater variety of depths, velocities and substrates. Envirocon (1977) found eggs deposited in a redd in 0.46 m depth of water, indicating that some spawning may occur in shallow areas in the mainstem. At three locations

examined during their survey, substrate and velocity data appeared suitable for spawning in depths less than 1.2 m. Suitable substrate conditions were present in deeper offshore areas; however, higher velocities may limit use of these areas.

To obtain a general indication of the effects of flow reduction on water depths over the pink salmon spawning areas water level profiles were examined. With complete withdrawal of McGregor River flows, mean lower Fraser River water levels would be 0.19 m lower between September 15 and October 30. Water levels at the mouth of the Harrison River would be decreased by approximately 0.18 m. The total effect of this reduction of pink salmon spawning areas is uncertain because the minimum or maximum depths used by pink spawners in the mainstem Fraser River is not known. However, indications are that the effect on the total usable area may be slight.

During the winter months, the effect on Fraser River water levels as a result of McGregor withdrawal was considerably less than in fall. Hence, a net benefit may result because the decrease in stage from spawning to incubation with McGregor withdrawal would be less than what normally occurs. Mean flows during the low flow month of February would be reduced by 5.4 percent. This reduction would generally lower mean water levels by only 4 cm. Harrison River levels at the mouth would be reduced by 7 cm.

(d) Log Towing and Dredging

To facilitate navigation and log towing, scuffler (or drag-line) dredging occurs in the Fraser River between Sumas and Hope. Both log towing and scuffler dredging can damage pink and chum habitat in this reach of the river. Lower water levels may necessitate additional dredging.

In contrast to the mainstem Fraser River, depth reductions in the lower Harrison River during late summer to winter flows are almost certain to have an indirect effect on salmon spawning areas (pink salmon, as well as other species). Water levels in and below the Harrison Rapids are affected by the level of the Fraser River and at high water in the Fraser the effect may extend to Harrison Lake (Anon. 1967). Frequent dredging is carried out in portions of the Harrison Rapids and the lower Harrison River to facilitate log towing. It can be anticipated that any reduction in river level would result in additional dredging and damage to salmon habitat. An examination of dredging in the Harrison River in 1967 (Anon. 1967) indicated that the principal area affected was the rapids, which was the section of main river channel heavily used by salmon spawners. From 1936 to 1966, a total of 660,000 m³ of material was dredged from the river. Water levels were reduced and the crest of the bottom profile near the upper end of the rapids was lowered by

0.21 m and shifted 150 m downstream. Reduced water levels shut off water sources and fish access to several side channel spawning areas. Spoil from the dredging had covered (to 1967) 83,900 m² of sockeye spawning area.

(e) Passage Into Spawning Areas

Reid, Crowther and Partners Ltd. (1978) stated that:

"Reduced flow of the magnitude caused by the McGregor Diversion during the spawning period would cause no additional problems to fish movement into the side channels examined. Although reduction of flows below the entrance sill would result in reduced access to some spawning areas (ie. Peters Slough) this condition normally occurs. Probability of flows exceeding those necessary for spillage into the side channel (Peters Slough) would probably be reduced by about 5 percent.

Reduced flows in the Fraser could influence the amount of area in the braided delta of the Lower Chehalis River which meets minimum passage depth criteria (0.18 m) for chum salmon. At lower

Harrison River flows (150 and 75 m³/sec) during November approximately 10-18 percent less would meet the necessary depth criteria. This reduction was not considered serious and falls well within the acceptable passage criteria for salmon (Thompson 1972). Problems could result if spawning occurs in these same areas or if the reduction in flow dries up access flow to discrete spawning channels in the delta. Insufficient survey data were available to predict spawning area loss".

It seems likely that the reduced flows would cut off access to the side channels earlier in the season than presently occurs, which is not made clear in the above quotation. A net benefit could result if reduced flows did prevent access to spawning grounds in sidechannels which dewater as the season advance.

(f) Harrison Bay Rearing Areas

The analysis for Harrison Bay rearing areas indicated changes in wetted area depending on the Fraser River flow. Although varying slightly with different Harrison River flows, losses in wetted area were not expected to exceed 4 percent, and were negligible from spring to fall. As a result no impacts were expected on

species using the area for feeding purposes from spring to fall; data were lacking on the extent of use of this area during the winter months. However, it was felt resident fish should not be affected by the small overall reduction in area.

(g) Data Deficiencies and Issues Requiring Further Study

The premature suspension of the McGregor River studies prevented complete analysis of the lower Fraser River work. However, the findings to date are useful for defining and augmenting future studies. If further consideration is given to the McGregor hydroelectric/flood control development implementation of the following studies should provide the information necessary to fully understand the technical implications of this aspect of the project.

Assessment Oriented Information

1. As was the case with other Fraser River issues studied, hydrologic analysis of the lower Fraser River was hampered because the available data had to be obtained from many diverse sources. B.C Hydro and Power Authority (1979) stated:

"It was acutely apparent that no single agency or organization was aware of more than a small

portion of the available data required for these studies. As the Fraser River system portrays a vitally important role in the salmon life cycle, it is recommended that one agency be assigned the task of preparing and maintaining a file which would list all sources of information pertaining to the Fraser River system as it affects the salmon fishery".

The time frame for future studies must allow for extensive literature search and review to ensure that any new studies are comprehensive and will not needlessly duplicate effort.

2. The analyses to date assume that the hydraulic properties of the lower Fraser River (width, depth, slope, bed material composition, channel pattern, etc.) would not be affected by the McGregor diversion. Since the Fraser River below Hope is alluvial the assumption is not valid. In fact, lateral channel instability, erosion, and to a lesser degree vertical channel changes have been documented for the lower Fraser River (McLean and Mannerstrom, 1985). Over time (10 or 20 years) the hydraulic properties will change because of changes in water flow and sediment deposition. Rough estimates have been made but further work is required to refine the predictions.

3. The short and long term impacts caused by decreased sediment contributions have not been addressed. Specifically, a detailed sediment balance for the Fraser River delta and its distribution is needed. At present the removal of lower Fraser River gravel and sand for industrial purposes substantially exceeds deposition (Kellerhals Engineering Services Ltd. 1984).

During the early operational years the suspended sediment in the McGregor River would settle in the reservoir or flow into the Parsnip River. The impact of any change in the contribution of McGregor sediment to the total Fraser load and resulting deposition or erosion below Hope is not known and needs to be evaluated over a wide range of sediment loads and hydrologic regimes.

4. The extent of additional dredging activities required to enable navigation to continue in the lower Fraser River is not known. Changing channel hydraulics may necessitate additional dredging which would affect salmon production by degrading habitat and entraining juveniles. Possible impacts should be estimated. Increasing the height of existing dykes would not change channel hydraulics except during extremely high water.

5. The relationship between gravel movement and the suitability of gravels for spawning has not been examined to date for this proposal. This relationship is relevant because in order to maintain suitability as salmon spawning and rearing habitat, fluvial gravels need to be moved about occasionally by water flow to flush out accumulations of fines and thereby maintain their permeability. The rate of gravel movement depends directly on velocity but the relation is non-linear. A 10 percent change in the velocity could lead to a much larger change in the rate of gravel transport. To quantify this effect and to determine the impact on spawning areas would require extensive biological and hydraulic studies.

6. Further field studies are required to clarify the significance of ground water inflow to the maintenance of spawning areas. Otherwise, it is likely that estimation of side channel spawning area lost as a result of decreases in main channel flow will be inaccurate and of limited use for measuring impact.

7. Reduced discharge at the mouth of the Fraser River could affect the environment in what appears to be a very critical stage in the life cycle of sockeye and pink salmon. Delay of entry into sea water may decrease the survival of sockeye

smolts. However, there is evidence to suggest that lower discharge during the period of pink fry emigration is favourable to higher survivals (IFSFC 1977). The relationships between estuarial environment and survival of sockeye, pink and other salmon species needs to be better understood in order to fully evaluate the biological effects of a permanent reduction in the Fraser River discharge.

8. No estimates of fish production losses have been prepared. Pink salmon escapement to the mainstem Fraser spawning areas during dominant (odd numbered) years averaged 733 500 in the period 1957 to 1977. In 1985, 5.2 million pink, the largest escapement on record, utilized the area (IPSFC, 1985). Annual chum salmon escapement to the lower Fraser Basin averaged 368,000 in the period 1960 to 1976 with approximately 30 percent (110400) using the lower Fraser River mainstem. (Renewable Resource Consulting Service Ltd. 1978). In addition to utilization for spawning by pink and chum, all salmon species utilize the lower Fraser at some critical part of their life cycle. Estimates of productive losses would have to include losses due to removal of spawning area, estuarine and upriver rearing habitat degradation, dredging and entrainment impacts and losses due to reduced flushing flows.

Mitigation Oriented Information

1. Fishwater release schedules should be developed to mitigate changes in lower Fraser River water levels. The issue of conflicting fishwater releases has been discussed in Chinook Utilization of the McGregor Basin-Diversion Alternative-Data Deficiencies and Issues requiring further studies. Standards for acceptable lower Fraser River water levels will have to be incorporated into minimum McGregor fishwater release schemes, as will release schedules for mainstem Fraser temperature requirements and McGregor River chinook requirements.

Habitat Compensation Oriented Information

1. Replacement of fish losses through habitat restoration and improvement and artificial production will have to be investigated. Habitat development could involve the restoration and improvement of natural habitats such as side channels and sloughs. Artificial production methods such as spawning channels or fish culture facilities could be examined if mitigation and habitat development techniques would not offset losses to fish and fish habitat.

Clearly, an environmental impact assessment of the issue of water level changes and their affect on Fraser River fish would be

extremely complex. Development of study design, mitigation requirements and management plans must involve on-going data sharing and cooperation among international, federal, and provincial agencies as well as hydrology and fisheries specialists.

3.3.5 Overview of Generation Alternative Impacts

To date only brief overview environmental studies have been undertaken for the generation scheme (Reid, Crowther and Partners Ltd. 1980). A McGregor Lower Canyon generation development would increase mean monthly winter flow 14 to 18 percent and decrease mean monthly summer flows from 0 to 6 percent at Hope (Table 13). There would be little change in fall. Hydrologic modelling of the lower Fraser River under McGregor generation flow regimes has not been undertaken. Likewise possible beneficial and adverse biological impacts have not been examined. The nature of investigation would be similar to, but reduced in scope from, that outlined above and would include the identification of positive benefits which may occur with higher winter water levels.

Table 13

CHANGES IN MEAN MONTHLY DISCHARGE AT HOPE UNDER
MCGREGOR RIVER GENERATION DISCHARGE

Month	A	B	C	D
January	32600	4.1	21.0	+16.9
February	30400	4.1	23.7	+19.6
March	28700	4.7	22.7	+18.0
April	58500	7.0	11.5	+4.5
May	174000	10.3	6.9	-3.4
June	252000	8.8	4.0	-4.8
July	200000	7.4	4.0	-3.4
August	128000	7.7	7.3	-0.4
September	86000	9.3	9.2	-0.1
October	70500	11.4	11.3	-0.1
November	56200	8.5	8.5	NIL
December	40400	5.1	19.9	+14.8
YEAR	96900	-	-	-

- A Historic Average Flows at Hope (cfs)
- B % Historic McGregor Contribution at Hope
- C % McGregor Contribution at Hope with Generation
- D Difference in % contribution

Source: Reid, Crowther and Partners Ltd. 1980. McGregor River Lower Canyon Project Prefeasibility Environmental Review.

3.4 Salmon Utilization of the Fraser River - The Impact of Water Quality Changes

3.4.1 Major Reports

Reid, Crowther and Partners Ltd. 1978a. McGregor River Diversion Project, Fraser River Water Quality Study. February 1978. 18 pp and Figures and Appendix.

Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Projects. Volume I - Text and Volume II - Tables and Figures. Prepared for B.C. Hydro and Power Authority.

3.4.2 Studies to Date

The proposed McGregor River Diversion would reduce flows and alter the water quality in the McGregor River downstream of the dam and in the Fraser River downstream of the McGregor and Fraser confluence. These flow reductions would reduce Fraser River effluent dilution, mixing ratios and receiving water assimilative capacity and may create significant water quality impacts in areas of the Fraser River mainstem.

A preliminary assessment of potential Fraser River water quality impacts resulting from the proposed diversion project was conducted by Reid, Crowther and Partners Ltd. in 1977 and 1978 for B.C. Hydro. The study area extended from the confluence of the McGregor and Fraser Rivers to the Fraser delta. The initial evaluation indicated that the most significant areas of waste discharge on the Fraser mainstem were at Prince George and downstream from Mission in the Lower Mainland. The Fraser River from Prince George to the Lower Mainland has much less waste discharge and hence this section of the river was not examined in the water quality assessment. The Prince George area would experience the greatest percentage flow reduction on the Fraser and is the site of major concentrations of waste discharges such as kraft pulp and paper mill effluents. While reduction in flow due to the diversion would be slight in the Lower Mainland, certain pollutants have already reached or exceed the assimilative capacity of the river. Hence, even a small reduction in flow could be significant.

The data examined in the Reid, Crowther and Partners Ltd. reports were restricted to existing information; no field studies were undertaken. The study was confined to an analysis of large volume, point source discharges. In comparison to small volume, point source discharges and large volume, non-point source discharges the former are more readily quantified and considerably more information exists for them.

Water quality data for the Fraser River at Prince George were collected from a variety of sources including; the B.C. Ministry of the Environment Pollution Control Branch, annual reports of pulp mills, consultant reports (Beak 1973, 1974. and 1975) and the IPSFC (Servizi 1975). The Uncertain Future of the Lower Fraser, (Dorcey 1976) was the major source of water quality information for the Lower Fraser River below Hope.

A preliminary study of pulp mill effluent mixing patterns before and after the proposed diversion was undertaken by Dr. S. Beltaos of the Alberta Research Council. The objective was to compute the spreading patterns of pulpmill effluents for a representative range of flow rates pre- and post- McGregor Diversion. The data base for this study was extremely limited, therefore the results must be considered approximations. The report is appended to Reid, Crowther and Partners Ltd. (1978a).

The decision to suspend the project prevented comprehensive data compilation and analysis. There was no input regarding the scope of the study or data analysis from fisheries consultants or regulatory agencies and no estimates of fisheries losses were made. The reports are therefore an accumulation of limited and now dated information and represent a very preliminary assessment.

3.4.3 Present conditions (primarily to 1978)

As mentioned above, the Prince George and Lower Mainland areas receive the largest effluent flow inputs and hence the review of the data concentrated on these areas.

(a) Upper Fraser River near Prince George

The review of available effluent and receiving water quality data for the Upper Fraser River near Prince George to 1977 prompted Reid, Crowther and Partners Ltd. (1978) to report that:

1. Dissolved oxygen concentrations and water temperatures of the Fraser River near Prince George were unaffected by the increased organic load and water temperatures from pulp mill discharges near Prince George. Values for non-filterable residues, organic carbon, tannins and lignins did however, increase downstream of Prince George pulpmill discharges.
2. The increases noted in true color, nitrogen, phosphorus and total residue in receiving water during September and October were attributed to increased river discharges and natural river sediment loads.
3. Coliform levels were elevated above B.C. Pollution Control

Objectives two to four miles downstream of the Prince George Municipal sewage outfall.

Despite the increases in certain parameters downstream of pulpmill and sewage outfalls, Servizi and Burkhalter (1970) concluded that at that time the volume and turbulence of the Fraser River was sufficient to disperse existing waste and minimize potential pollutant effects. These conclusions were based on data collected from 1963 to 1968. Findings by Beak Consultants (1974 and 1975), which included 1973 and 1974 field data, concurred with these conclusions. The Pollution Control Branch data, which were up to date (to 1977) were not commented on in the Reid, Crowther and Partners Ltd. water quality report to any greater extent than were the Servizi and Burkhalter (1970) and Beak (1974 and 1975) reports.

(b) Lower Fraser River

The summary of existing water quality conditions in the Lower Fraser River to 1977 were based extensively on Westwater Research findings (1976) which concluded:

1. The biochemical oxygen demand (BOD) in the Lower Fraser River was low. Furthermore, the lowest dissolved oxygen concentrations reported remained above 85 percent saturation.

2. Nutrient concentrations in the Lower Fraser River were low in comparison to other river systems. The increases in nutrient concentrations noted during spring runoff were attributed to natural erosion processes and sediment transport.
3. Trace metals were elevated in the vicinity of Vancouver. While individual trace metals rarely exceeded the lowest known toxic concentration, a toxicity index based on combined concentrations of heavy metals occasionally exceeded the "threshold of harm" in the Lower Fraser River.
4. Fecal coliforms were elevated above acceptable levels for bathing and boating in the North and Middle Arm of the Lower Fraser River.
5. Toxic substances such as chlorinated hydrocarbons, ammonia, phenols, and other hydrocarbons, had not been detected in the lower Fraser River water samples. These findings are not surprising however, as many of these substances have limited solubility and are therefore not likely to be detected in water samples.

In summary, Reid, Crowther and Partners Ltd. (1978a) concluded that there is "an indication of deterioration of water quality conditions in the river at Vancouver, however the data were not truly quantitative".

3.4.4 Diversion Alternative

- (a) Impacts of flow reduction on effluent dispersion/dilution and assimilative capacity of receiving waters

In the Upper Fraser River near Prince George, the proposed diversion would reduce critical winter low flow by as much as 41 percent at Shelly, 30 percent at Prince George, and 15 percent at Marquerite. Estimates of dilution ratios indicate that 1977 pre-diversion flow levels were insufficient at Prince George (between Prince George Pulp and Paper and the Nechako confluence) to satisfy the recommended dilution ratio criteria of 50:1 established by Environment Canada to prevent sublethal impacts to fishery resources. Following diversion, Beltaos (1977) and Reid, Crowther and Partners Ltd. (1978a) estimated that dilution in this area would be further reduced to approximately one half of the recommended criteria and the area of reduced assimilative capacity would increase by approximately one mile. The reduction in flows resulting from the proposed diversion would therefore substantially increase the likelihood of sublethal impacts to fish in the vicinity of the confluence of the Nechako and Fraser Rivers.

Flows in the Lower Fraser River (below Hope) would be reduced by 3 to 6 percent during low flow months as a result of the proposed

diversion. Reid, Crowther and Partners Ltd. did not calculate post-diversion dilution ratios for the Lower Fraser River, hence empirical predictions of water quality impacts following diversion were not possible. However, in 1977 they concluded that the assimilative capacity of the Lower Fraser was already taxed and that any reduction in flow would only serve to exacerbate water quality concerns.

Several alternatives to mitigate against the impact of the proposed diversion on Fraser River water quality were briefly discussed in Reid, Crowther and Partners Ltd. (1977) and are reproduced verbatim below:

"1. Flow Augmentation

Maintenance of a set minimum flow in the Fraser River in the December to March period.

2. Plant Location Regulations

Require that new wet industries in the Prince George area locate downstream of the confluence with the Nechako river.

3. Waste Treatment Requirements

Require that wet industries include advanced waste treatment

systems in their development design".

Presumably, the three mitigation options discussed above could be expanded on as follows:

1. Minimum discharge requirements for the McGregor River (not Fraser River) during the low flow period (December to March) should be established to ensure that the proposed diversion will not reduce mainstem Fraser River water quality below acceptable criteria for protection of sensitive fish life history stages which may be present during these months.
2. New industrial facilities in the Prince George area which propose to discharge effluent into the Fraser River should be required to discharge below the Fraser and Nechako River confluence.
3. Existing facilities should be required to upgrade waste water treatment. The design of proposed facilities should include advanced waste treatment systems.

The second and third mitigation options identified above need close examination. Environmental agencies would need technically sound data bases and the support of land use zoning authorities in order to require new Prince George area industrial facilities to

locate downstream of the Nechako. In addition, relocation of industrial discharges to improve dilution characteristics is not an acceptable alternative to improved source control. The cost of upgrading water treatment at existing facilities along the length of the Fraser River would be considerable if borne by a single developer (ie. B.C. Hydro). Rather, a phased program of upgrading treatment facilities at the expense of the water user would be required. However, this approach would fail to address immediate water quality concerns. From a cost/benefit perspective it would also be difficult to establish an accurate corresponding economic benefit which is realized as a result of water quality improvements.

These two mitigation measures were not recommended in the final Reid, Crowther and Partners Ltd. reports (1978 and 1978a) perhaps because of the shortcomings outlined above. Feasible mitigatory measures include water releases (one, above) and the following:

The existing effluent outfalls should be examined and where necessary modified or extended to promote improved effluent mixing. Alternately, the feasibility of redirecting effluent discharges to sanitary sewer (with resulting secondary treatment), or recycling waste water, could be assessed.

(b) Data Deficiencies and Issues Requiring Further Study

In recognition of the preliminary nature of this impact assessment, and in light of the changes in permitted effluent discharges to the Fraser River since 1977, the following data deficiencies and issues requiring further study should be addressed in order to assess the impact of water quality changes.

Assessment Oriented Information

The information on water quality impacts resulting from the proposed diversion is limited and dated. Considerably more information presently exists on receiving water quality of the Fraser River and biological resource impacts than was available in 1977. These data would require evaluation.

1. The number of permitted discharges as well as characteristics of effluent discharges to the Fraser River have changed since 1977, and will be reflected by changes in effluent loadings and effluent dilution/dispersion/mixing characteristics in the Fraser River. The most recent effluent discharge data for the Fraser River should be assembled and analyzed. Updated information on effluent discharge locations, effluent characterization and discharge volumes would be available through the Ministry of Environment Water Management Branch.

3. The existing receiving water quality for the Fraser River should be assembled and reviewed.
4. The pre- and post-diversion waste discharge dispersion characteristics and effluent dilution ratios for reaches of the Fraser River most susceptible to water quality degradation should be determined. Minimum river flows in conjunction with maximum reported effluent discharge flows should be examined in order to evaluate worst case scenarios. In certain locations consideration will have to be given to examining the effects of multiple waste discharges and overlapping dilution zones. Consideration should also be given to assessing the synergistic or additive effects reduced Nechako River flows at Prince George may have on effluent dispersion. This assessment should also consider the effects of small volume point source discharges (eg. food processing industries, oil/gas refineries, metal plating industries, etc.) and non-point source large volume discharges (eg. stormwater, agricultural runoff, etc.) on effluent loadings, dilution ratios and mixing.
5. Potential changes in receiving water quality of the Fraser River downstream of the Nechako confluence should be predicted first, with respect to the McGregor Diversion flows and second, with respect to the combined McGregor Diversion

and minimum potential Kemano Completion project flows. The anticipated receiving water quality should be compared to water quality criteria for protection of fisheries resources.

6. The effect water level reductions will have on effluent outfall or diffuser performance must be determined. This may be particularly important in areas such as Prince George, where pulpmill effluents are discharged to the Fraser River via diffusers.
7. The effect of the dam and spillway on total gas pressure (supersaturation) of downstream McGregor and Fraser River waters should be predicted and compared to existing criteria for protection of fishery resources. Supersaturation is not expected to be a problem under normal diversion operating conditions. However supersaturation may result if large volumes of water are released for downstream temperature control or for other reasons. Supersaturation can be mitigated by using proper dam and spillway design and by creating riffle habitat in the receiving watercourse (ie. the McGregor River) if feasible to do so.
8. The potential effects of the proposed diversion on suspended sediment loads and turbidity in the mainstem Fraser River should be assessed. This issue is discussed further in

Salmon utilization of the Fraser River - water flow and level changes below Hope. Changes in the frequency of high suspended sediment concentrations should be evaluated. High concentrations have been suspected of exacerbating the development of temperature- and stress-related diseases in sockeye, especially during freshet (IPSFC 1984).

9. Quantitative biological data for the Fraser River should be collected and reviewed. These data would provide information on present biological communities in the river, their sensitivity to various types of water quality degradation, and background data against which future (post-diversion) biological communities could be compared.
10. The impacts water quality changes will have on fish and fish habitat will have to be assessed. Residual fish losses will have to be determined and incorporated into the economic evaluation of the project.

Mitigation Oriented Information

1. The mitigatory measures proposed to date (flow augmentation, plant location regulations and waste treatment regulations) will have to be assessed.

3.4.5 Overview of Generation Alternative Impacts

To date only brief overview environmental studies have been undertaken for the generation scheme (Reid, Crowther and Partners Ltd. 1980). A McGregor Lower Canyon generation development would increase mean monthly winter flow 14 to 92 percent at Shelly. Mean spring and summer flows would decrease 9 to 12 percent. There would be little change in the fall flows (Reid, Crowther and Partners Ltd. 1980). Similarly, mean monthly winter flows at Hope would increase 14 to 18 percent, decrease up to 6 percent in the summer and change little in the spring or fall (Table 12). No analysis of the flow regimes or impacts has been undertaken. However, some general comments can be made.

The increased winter flows at Prince George would increase effluent dilution ratios during winter months. Effluent dilution in the lower Fraser River below Mission would also increase in winter although the amount of change would be difficult to estimate due to the more complex hydrologic system, the varied waste discharges, and lesser percentage increase in flows.

During the spring and summer months when a McGregor Diversion project would reduce flows, the assimilative capacity of the Fraser River would generally be reduced. Depending on the reduction this could result in sublethal impacts to fish

populations moving upstream and downstream and spawning in the mainstem during these months.

The scope of any further studies regarding water quality impacts of a McGregor Generation project on the Fraser mainstem would be similar to that outlined above for the diversion alternative. However, unlike the diversion proposal the generation alternative could produce benefits during winter months. The existence of both positive and negative impacts (resulting from decreased summer flows) suggests the need for an overall assessment. The possibility of gas supersaturation will be much greater than under the diversion alternative and the potential for mitigatory measures will have to be assessed.

3.5 Salmon Utilization of the Fraser River - The Impact of Water Temperature Changes

3.5.1 Major Reports

British Columbia Hydro and Power Authority. 1979. McGregor River Diversion River Regime and Morphology Volume III: Fraser River. Hydroelectric Design Division. Report No. 958, January 1979.

Renewable Resources Consulting Services Ltd. 1978. Impact of the McGregor River Diversion on Fish in the Fraser River. A Progress Report. Prepared by C. McLeod, R.L. and L. Environmental Services Ltd. and R. Mohr, Renewable Resources Consulting Services Ltd. March 1978. 102 pp.

3.5.2 Studies to date and present conditions

(a) Introduction

Water temperatures in the Fraser River downstream of the McGregor River begin to rise in mid-February from near 0°C to peak temperatures in late July and August. Water temperatures then decline during fall and winter. A general downstream warming tendency in the river has been observed between Hansard, which is

just upstream of the McGregor River confluence, and Hope. Annual maximum water temperatures (prior to 1977) at Hope ranged from 16°C to 22°C and averaged about 19°C. The McGregor River usually contributes water 1°C to 1.5°C colder than the Fraser River at Hansard. Major upstream migrations of salmon occur on the Fraser River during the months of July, August, and September when the Fraser River temperatures reach their highest level. Fisheries agencies expressed concern that the withdrawal of cool McGregor water could elevate summer water temperatures in the mainstem Fraser. Salmonids have well documented thermal tolerance limits, optimum temperatures for growth, and preferred and restricted temperature limits for migration, spawning, and egg incubation. The diminution of upstream cold water sources could increase downstream temperatures which could have a deleterious impact on mainstem adult migration leading to reduced spawning success. Because of the location of the McGregor Diversion project in the headwaters of the Fraser River drainage basin, almost all the anadromous stocks in the Fraser would experience the effects created by the project.

As a result of these concerns, B.C. Hydro and consultants undertook two related studies in 1977. First, B.C. Hydro modelled the changes in summer water temperature in the Fraser River downstream of the McGregor River confluence which would result from the McGregor Diversion. Second, the fisheries consultants R.L. and

L. Environmental Services Ltd. and Renewable Resources Consulting Services Ltd. commented on the impact to fisheries that might result from the temperature changes. As with other Fraser River studies, these were not completed because the project was suspended.

(b) Fraser River water temperature modelling

A stream temperature prediction model developed by W.L. Morse for the Columbia River was used for the study. Water temperature data (spot measurements) from the Water Survey of Canada (WSC); the International Pacific Salmon Fisheries Commission (which extensively recorded and modelled Fraser River water temperatures) B.C. Ministry of Environment, Pollution Control Branch; Environment Canada, Inland Water Directorate, Water Quality Branch; Westwater Research Centre; and the Federal Department of Fisheries were utilized. McGregor River water temperature data collected in 1976 and 1977 by B.C. Hydro and its consultants were also utilized.

Continuous recording thermographs were installed by B.C. Hydro for the period mid-May to mid-September 1977 at six loctions along the Fraser River from Hansard to Hope and in six of the major tributaries. However, these field records were incomplete or invalid for a variety of reasons - installation difficulties, stopage of

chart drive mechanisms, exposure of instruments to the atmosphere during low flow conditions, and positioning in the plume of tributaries rather than in well mixed mainstem waters.

Hydrologic discharge data were compiled from WSC records. Climatological data were compiled from the Atmospheric Environment Service (AES) of Environment Canada and included cloud cover, sea level air pressure, dry bulb temperature, dew point temperature, wind speed and wet bulb temperature. River channel geometry data (cross sections and water surface elevations) were obtained from WSC, British Columbia Department of Highways, and B.C., CN, and CP Railways. Cross section information for Hell's Gate was supplied by the IPSFC.

The stream temperature prediction model was applied to the Fraser mainstem from Hansard to Hope with and without McGregor River flow. Each day of the simulation was divided into four 6-hour time periods. It was felt that these increments provided a reasonable approximation of the diurnal temperature fluctuations consistent with performing a minimum of calculations. Two sequences of flows were analyzed from Hansard to Hope using 1977 recorded weather data to calibrate the model. The first sequence used 1977 discharges and water temperatures recorded during the period July 31 to August 8. This short time period was the only occasion during the summer of 1977 when the weather system was

sufficiently stable or water temperature data sufficiently complete to enable model calibration. The second sequence used discharges recorded during the period July 31 to August 8, 1970. Discharges were selected from 1970 because they were low (43 percent to 97 percent of the 1977 discharge during the same time period) and in a sense represented a "worst case" scenario. The 1977 temperatures and other data were used in the second sequence.

The reliability of the modelling results is questionable for several reasons; incomplete field records as a result of improper installation and mechanical failure of thermographs, a short period of effective modelling data (8 days), and incomplete analysis of "worst-case" scenarios. The concerns regarding reliability of the results are discussed further in Data deficiencies and issues requiring further study, below.

In addition to the modelling work, probability of exceedence curves were developed for water temperatures at Hell's Gate. The curves were based on 27 years of water temperature records for the period July 20 to August 20 and reflected maximum recorded water temperatures and maximum seven day average temperatures. Details of the modelling and probability of exceedence methodology are given in B.C. Hydro and Power Authority (1979).

(c) Analysis of changes in water temperature and the impact on fish

The analysis of changes in water temperature and its impact on mainstem fisheries was restricted to a review of the literature and examination of the modelling results. No field work was undertaken. The analysis and discussion was based primarily on the temperature requirements of sockeye salmon. Sockeye were considered to be the most important species found in the Fraser River basin because of their large biomass and economic significance. In addition, sockeye salmon have been the subject of the most applicable and extensive research on physiology and environmental requirements. The analysis was reported in Reid, Crowther and Partners Ltd. (1978) and Renewable Resources Consulting Services Ltd. (1978).

3.5.3 Diversion Alternative

(a) The Impact of McGregor Diversion on Fraser River Water Temperature

A summary of temperature changes predicted by B.C. Hydro modelling results is presented in Tables 14 and 15. Even though the simulation uses 6-hour time increments it is unclear whether spot

Table 14

SUMMARY OF MODEL RESULTS: 1977 FLOWS, WATER TEMPERATURES AND WEATHER CONDITIONS

Location	Average Temperature with McGregor River Flows (°C)	Average Temperature without McGregor River Flows (°C)	Difference in Predicted Average Temperatures ..T Loc (°C)	Maximum Difference in Predicted Temperatures (°C)	Minimum Difference in Predicted Temperatures (°C)	Average of Difference in Predicted Maximum Daily Temperatures (°C)	Average of Difference in Predicted Minimum Daily Temperatures (°C)
Fraser R. at Hansard (above McGregor R.) 31 Jul - 7 Aug 77	14.1	14.1	0	0	0	0	0
Fraser R. at Hansard (below McGregor R.) 31 Jul - 7 Aug 77	13.4	14.1	0.7	1.0	0.4	0.6	0.7
Fraser R. at Prince George Sawmill (above Nechako R.) 31 Jul - 7 Aug 77	13.8	14.7	0.9	1.4	0.5	0.8	0.8
Fraser R. at Prince George Sawmill (below Nechako R.) 31 Jul - 7 Aug 77	15.2	16.1	0.9	1.6	0.6	0.9	1.0
Fraser R. at Quesnel (above Quesnel R.) 1 Aug - 8 Aug 77	16.2	17.3	1.1	1.8	0.6	0.9	1.1
Fraser R. at Quesnel (below Quesnel R.) 1 Aug - 8 Aug 77	16.1	16.9	0.8	1.3	0.3	0.7	0.6

Table 14 - Continued

Location	Average Temperature with McGregor River Flows (°C)	Average Temperature without McGregor River Flows (°C)	Difference in Predicted Average Temperatures ..T Loc (°C)	Maximum Difference in Predicted Temperatures (°C)	Minimum Difference in Predicted Temperatures (°C)	Average of Difference in Predicted Maximum Daily Temperatures (°C)	Average of Difference in Predicted Minimum Daily Temperatures (°C)
Fraser R. at Hwy. 20 (above Chilcotin R.) 2 Aug - 8 Aug 77	16.1	16.8	0.7	1.2	0.4	0.7	0.7
Fraser R. at Hwy. 20 (below Chilcotin R.) 2 Aug - 8 Aug 77	16.1	16.6	0.6	1.1	0.3	0.6	0.7
Fraser R. at Lytton (above Thompson R.) 3 Aug - 8 Aug	16.7	17.4	0.7	1.2	0.4	0.7	0.7
Fraser R. at Lytton (below Thompson R.) 3 Aug - 8 Aug	16.8	17.4	0.6	0.9	0.2	0.5	0.5
Fraser R. at Hope 3 Aug - 8 Aug	16.9	17.6	0.7	1.0	0.3	0.5	0.6

NOTE: Caution must be exercised when comparing average temperatures at different locations, as the temperatures are averaged over different time periods, and the temperatures are generally rising at a specific location over the time period considered.

Source: Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project Volume Two - Tables and Figures. Prepared for B.C. Hydro and Power Authority.

Table 15

SUMMARY OF MODEL RESULTS: 1970 FLOWS, 1977 INITIAL WATER TEMPERATURES AND WEATHER CONDITIONS

Location	Average Temperature with McGregor River Flows (°C)	Average Temperature without McGregor River Flows (°C)	Difference in Predicted Average Temperatures ..T Loc (°C)	Maximum Difference in Predicted Temperatures (°C)	Minimum Difference in Predicted Temperatures (°C)	Average of Difference in Predicted Maximum Daily Temperatures (°C)	Average of Difference in Predicted Minimum Daily Temperatures (°C)
Fraser R. at Hansard (above McGregor R.) 31 Jul - 7 Aug 77	14.1	14.1	0	0	0	0	0
Fraser R. at Hansard (below McGregor R.) 31 Jul - 7 Aug 77	13.4	14.1	0.7	1.1	0.5	0.6	0.7
Fraser R. at Prince George Sawmill (above Nechako R.) 31 Jul - 7 Aug 77	14.2	15.1	0.9	1.3	0.5	1.2	0.8
Fraser R. at Prince George Sawmill (above Nechako R.) 31 Jul - 7 Aug 77	15.7	16.7	1.0	1.4	0.7	1.3	0.8
Fraser R. at Quesnel (above Quesnel R.) 1 Aug - 8 Aug 77	17.2	18.4	1.3	1.7	0.8	1.1	1.5
Fraser R. at Quesnel (below Quesnel R.) 1 Aug - 8 Aug 77	16.9	17.9	1.0	1.3	0.6	0.8	1.2

Table 15 - Continued

Location	Average Temperature with McGregor River Flows (°C)	Average Temperature without McGregor River Flows (°C)	Difference in Predicted Average Temperatures ..T Loc (°C)	Maximum Difference in Predicted Temperatures (°C)	Minimum Difference in Predicted Temperatures (°C)	Average of Difference in Predicted Maximum Daily Temperatures (°C)	Average of Difference in Predicted Minimum Daily Temperatures (°C)
Fraser R. at Hwy. 20 (above Chilcotin R.) 2 Aug - 8 Aug 77	16.9	17.7	0.8	1.2	0.7	0.9	0.8
Fraser R. at Hwy. 20 (below Chilcotin R.) 2 Aug - 8 Aug 77	16.8	17.4	0.6	1.0	0.3	0.7	0.7
Fraser R. at Lytton (above Thompson R.) 3 Aug - 8 Aug	17.8	18.4	0.6	1.1	0.4	0.7	0.5
Fraser R. at Lytton (below Thompson R.) 3 Aug - 8 Aug	17.7	18.1	0.4	0.6	0.2	0.4	0.3
Fraser R. at Hope 3 Aug - 8 Aug	17.9	18.3	0.4	0.6	0.2	0.3	0.4

NOTE: Caution must be exercised when comparing average temperatures at different locations, as the temperatures are averaged over different time periods, and the temperatures are generally rising at a specific location over the time period considered.

Source: Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project Volume Two - Tables and Figures. Prepared for B.C. Hydro and Power Authority.

measurements, daily maximum, or daily mean temperatures are utilized in the simulation. At the very least, the calculation were (presumably) based on spot measurements taken during the daylight and hence fairly representative of the warmest temperatures of the 24 hour period. Average temperature increases under 1977 discharge conditions are predicted to range from 0.5°C at Hope to 1.1°C above Quesnel (Table 14). Maximum predicted temperature increases are highest (1.8°C) at Quesnel.

According to the modelling data the temperature differences are not increased under low flow conditions. Average temperature increases under 1970 discharge conditions are predicted to range from 0.3°C at Hope to 1.5°C at Quesnel (Table 15). Maximum predicted temperature increases are highest (1.7°C) at Quesnel. However, as noted above, for this analysis tributary temperatures were assumed to be identical to those in 1977. These two data sets are summarized in Table 16.

The probability of exceedence curves for Hell's Gate water temperatures are shown in Figures 4 and 5. The probability of temperatures reaching 20°C at Hell's Gate would increase from about 10 percent to 22 percent with diversion. The probability of this temperature existing for seven days increases from 2.5 percent to 7 percent.

Table 16

PREDICTED FRASER RIVER TEMPERATURE CHANGES WITH MCGREGOR DIVERSION PROJECT

(A) for 1977 Observed Conditions and (B) 1970 Low Flows with 1977 Initial Water Temperature and Weather Conditions. After B.C. Hydro and Power Authority, Accuracy $\pm 0.6^{\circ}\text{C}$ for Average and $\pm 0.3^{\circ}\text{C}$ for Difference Values.

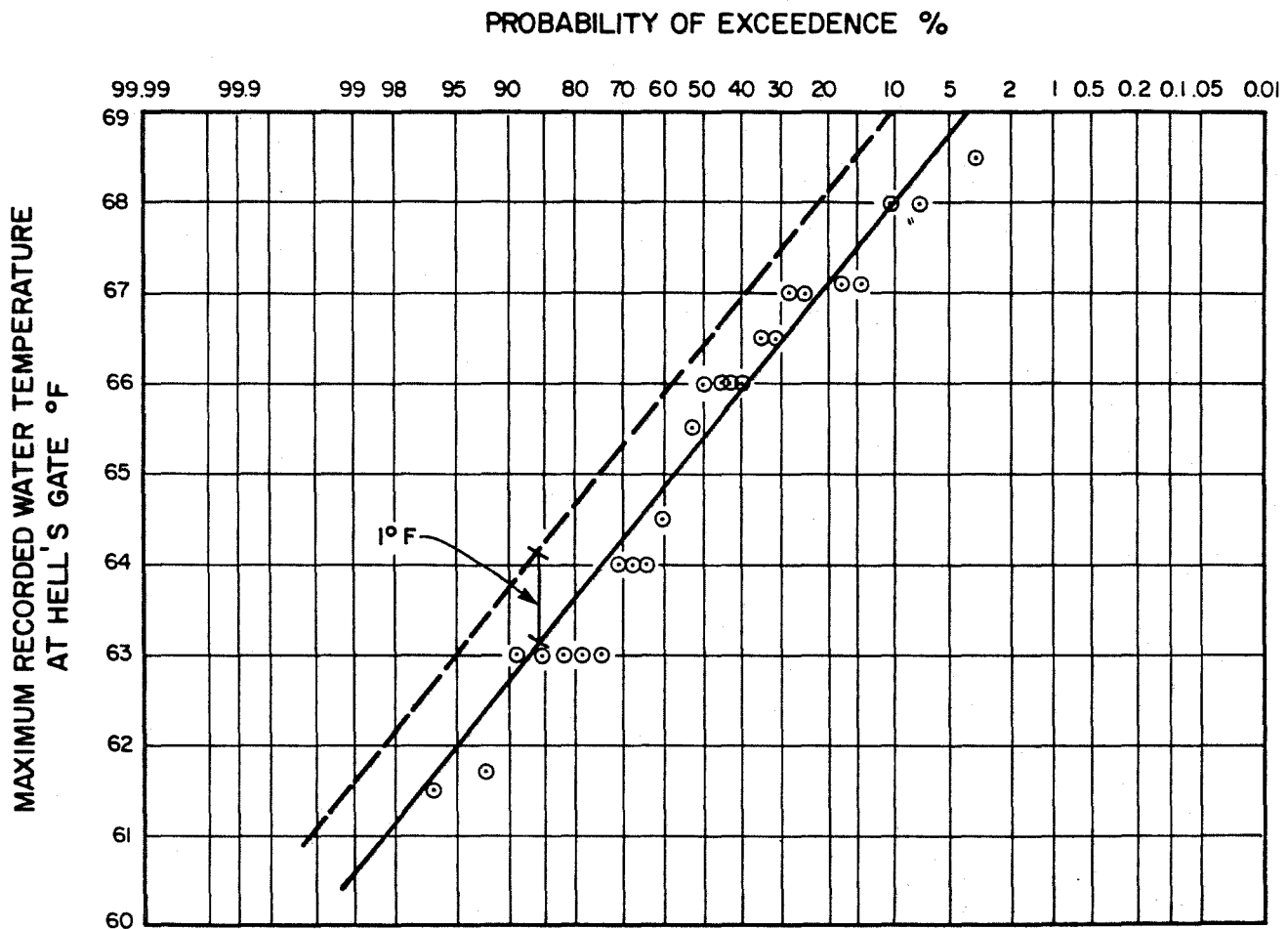
Fraser River Location	Distance of Reach (km)	Average Daily Pre-Diversion Temperature ($^{\circ}\text{C}$)	Average Daily Post-Diversion Temperature ($^{\circ}\text{C}$)	Average Temperature Difference ($^{\circ}\text{C}$)	Average Daily Maximum Temperatures ($^{\circ}\text{C}$)	Time Period
(A) 1977						
Mouth of McGregor R. (below Hansard)	0	14.1	14.1	-	-	31/7-07/8
Prince George (above Nechako R.)	100	13.9	14.8	0.9	15.0	31/7-07/8
Quesnel	167	16.1	17.2	1.1	17.4	31/7-07/8
Highway 20 (above Chilcotin R.)	122	16.1	16.8	0.7	17.3	01/8-08/8
Lytton (above Thompson R.)	236	16.8	17.4	0.6	17.6	02/8-08/8
Hope	267	17.1	17.6	0.5	17.7	03/8-08/8

Table 16 - Continued

Fraser River Location	Distance of Reach (km)	Average Daily Pre-Diversion Temperature (°C)	Average Daily Post-Diversion Temperature (°C)	Average Temperature Difference (°C)	Average Daily Maximum Temperatures (°C)	Time Period
(B) 1970						
Mouth of McGregor R. (below Hansard)	0	14.1	14.1	-	-	31/7-07/8
Prince George (above Nechako R.)	100	14.3	15.2	0.9	15.7	31/7-07/8
Quesnel	167	17.2	18.4	1.2	18.7	31/7-07/8
Highway 20 (above Chilcotin R.)	122	16.9	17.7	0.8	17.9	01/8-04/8
Lytton (above Thompson R.)	236	17.8	18.4	0.6	18.9	02/8-08/8
Hope	267	17.9	18.3	0.4	18.5	03/8-08/8

Source: Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project Volume Two - Tables and Figures. Prepared for B.C. Hydro and Power Authority.

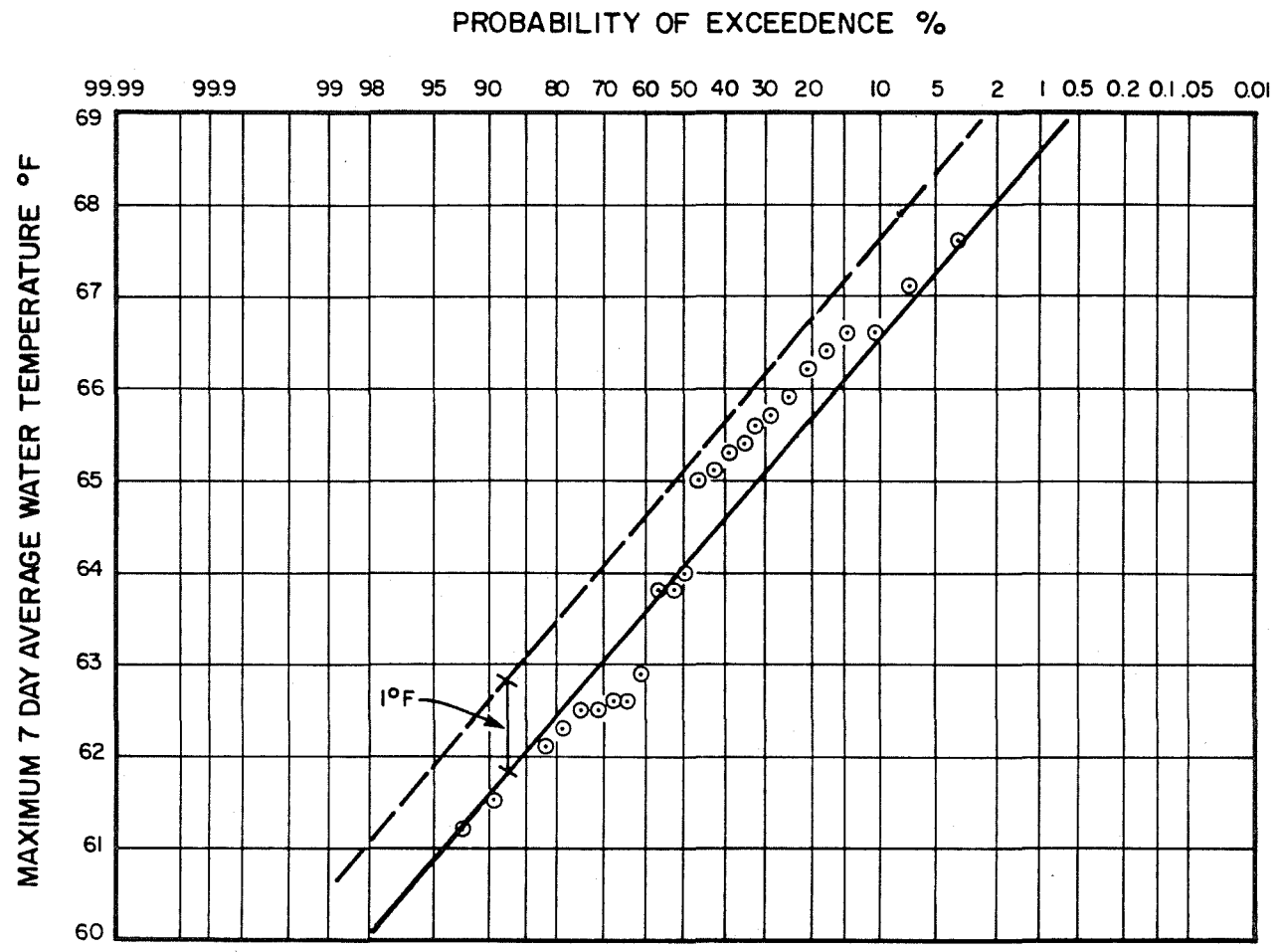
Figure 4 Probabilities of Exceeding Maximum Water Temperature at Hell's Gate During Period 20 July to 20 August
Source: British Columbia Hydro and Power Authority



LEGEND

- Estimated probability based on maximum recorded temperatures for 27 years between 1942 and 1977. (Note: Regulated by Kenney Dam since 1952)
- - - Estimated probability assuming total withdrawal of McGregor River flows based on an estimated increase of 1°F at Hell's Gate

Figure 5 Probabilities of Exceeding Maximum Seven Day Average Water Temperature at Hell's Gate for Seven Day Period Beginning from 20 July to 20 August
Source: British Columbia Hydro and Power Authority



LEGEND

- Estimated probability based on maximum recorded temperatures for 27 years between 1942 and 1977. (Note: Regulated by Kenney Dam since 1952)
- - - Estimated probability assuming total withdrawal of McGregor River flows based on an estimated increase of 1°F at Hell's Gate

- (b) The impact of water temperature increases on Fraser River salmon

Salmonids have optimal thermal tolerance levels for growth, reproduction and migration. Servizi and Jensen (1977) have identified three temperature related factors which affect Fraser River fish. They are acute thermal shock, infections and energetics.

Acute thermal shock

Acute thermal shock occurs when water temperatures are elevated to the degree that they cause rapid fish death in seconds or minutes because of extremely high temperatures or slower death in hours and days at lower but still elevated temperatures. Effects vary with species, season, stage of life cycle, size, age condition and acclimatization temperature. Rapid mortalities to salmon and trout can be expected at temperatures exceeding 25°C. Snyder and Blahm (1971) report that all juvenile chinook and chum salmon died within seconds at temperatures of 32°C., and within 37-66 minutes at 26.7°C. Slow death temperature zones for salmon range from 13°C. to 25°C., depending upon acclimatization temperatures and the degree of temperature increase. Brett (1970) reported that no species of juvenile salmon would survive a week at 25°C. Servizi and Jensen (1977) found adult sockeye salmon to be less resistant

to higher temperatures than juveniles, dying from acute thermal shock at about 24°C.

The only record to 1977 of apparently lethal water temperatures in the Fraser River is from 1942 (Simmons 1942). Spot temperatures up to 22.5°C. were recorded, and dead and dying sockeye salmon were observed between Prince George and Quesnel. B.C. Hydro's modelling results indicated that water temperatures in this reach can be expected to increase 1°C to 1.5°C (Tables 14 and 15) if the McGregor River were diverted. Therefore, the occurrence of rare conditions such as those in 1942 may be more frequent and result in spot temperatures exceeding 23.5°C in the Fraser River, with a greater probability of salmon mortality.

The temperature of 20°C was the highest mean daily water temperature considered safe for adult sockeye migrating in the Nechako River (Anon. 1976). This limit would not be exceeded in the Fraser River in most years after diversion. However, in some low flow years migration temperatures may approach or exceed this limit. In addition, even though 20°C has been cited by many authorities as a critical temperature, adverse temperature-related effects occur at temperatures below 20°C, particularly among fish that have been stressed or exposed to disease (IPSFC, 1984).

Detailed information is not available on the susceptibility of other species of salmon to acute thermal shock. However, it is

likely that there are similarities in thermal tolerance ranges among the salmonid species (pers. comm, R. Brett).

Infectious disease

Various environmental stressors lower the resistance of fish to infectious disease. Stressors such as high water temperature, crowding and sublethal concentration of pollutants cause increased susceptibility to infection.

Salmonids in fresh water exhibit diseases such as columnaris (caused by Flexibacter columnaris), infectious hematopoietic necrosis (IHN) (caused by a virus) and saprolegniaceous fungi. Columnaris, IHN and, to a lesser degree the fungi have been associated with Fraser River sockeye deaths. The Reid, Crowther and Partners Ltd. (1978) impact assessment was restricted to a discussion of columnaris because temperature was thought to be the major stressor causing columnaris in fish. Columnaris has been associated with large losses of sockeye in the Fraser system, is usually observed in warm weather, and occurs only in fresh water. Depending on the virulence of the bacterial strain, infection thresholds can occur at water temperatures as low as 10°C. Incidence of infection increases and varies inversely with time to death as temperature increases from 12.2°C to 23.3°C (Holt et al. 1975). In salmonids the infection rate approaches zero at temperatures less than or equal to 9.4°C.

A relationship exists between prespawning mortality of many sockeye salmon races and water temperatures in the Fraser River; the most obvious is in the Horsefly sockeye run (Quesnel River system). The prespawning mortality of this population and other races has been correlated with the water temperature of the lower Fraser River recorded at Hell's Gate (IPSFC Ann. Rep. 1974; Williams 1976; Cooper, 1982). Statistically significant correlations exist between prespawning mortality for dominant cycle runs versus average daily water temperatures.

The temperature increases which might result from diversion are small on a site specific basis but large in the context of the affected area. Reid, Crowther and Partners Ltd. (1978) states that:

"Prespawning mortalities of the dominant cycle Horsefly run could be increased by as much as 7.8 percent (1970 flows) to 10.4 percent (1977 flows). Percentage increases over prediversion conditions appear lower in years of higher temperatures; however, this trend may be misleading because the total percentages of fatal infections are higher at increased temperature and less virulent strains of columnaris would be more likely to infect fish at the higher temperatures. When related to the mean escapement of 294,600 fish in the dominant

cycle runs from 1961-1973, expected increases in prespawning mortality could represent additional losses of about 23,000 - 31,000 spawners for the Horsefly run alone."

It is not stated how the consultants arrived at the above figures. Reid, Crowther and Partners Ltd. (1978) go on to state that other early runs such as the early Stuart, Nadina, and Chilko would experience significant mortalities as well.

Energetics

Most of the energy requirements of salmon during the spawning migration must be provided by the metabolism of stored fats and protein. Sockeye adults do not feed during migration, for example and chinook feed only intermittently. Migrating spawners use chemical stores for three principal functions; physiological maintenance, gonadal development and maturation, and locomotion. Metabolic energy demands increase with temperature hence Fraser River temperature increases above ambient levels would be expected to increase the energy expenditure of migrating salmon. In addition, there is reduced availability of oxygen in warmer waters thus migrating fish expend more respiratory effort obtaining oxygen.

R.L. and L. Environmental Services Ltd. and Renewable Resources Consulting Services Ltd. (1978) developed a crude prediction of increased energy expenditure by sockeye migrants as a result of higher Fraser River water temperatures. Their discussion is reproduced verbatim here:

"From current predictions the average Fraser River temperatures after diversion will increase from approximately 17°C to 18°C during July and August in low flow years. Using this increase, estimates of metabolic rate increase can be obtained with the aid of predictive isopleths provided in Brett and Glass (1973). Under these conditions the oxygen consumption of a 3 kg fish would be expected to increase approximately 7.5% (265 mg O₂/kg/hr-285 mg O₂/kg/hr) at a swimming speed of 118 cm/sec. This was the estimate computed for Stuart Lake sockeye salmon spawners in 1959 (Brett 1965).

The active metabolic rate of sockeye salmon is one of the highest on record, exceeding those determined for other salmonids by 30%-40% (Brett and Glass 1973). Stuart River sockeye spawners were reported by Idler and Clemens (1959) to have a metabolic rate of approximately 47.9 cal/kg/day or 1.1 cal/kg/km when

extrapolated to their migration speed. Brett (1965) indicated that the energy expenditure of Stuart River sockeye was nearly 80 percent of the maximum rate (est. 60 cal/kg/day) of which fish of this size are capable. At previously calculated metabolic rates and conditions, the energy expenditure of these Stuart River sockeye within the Fraser River may increase by about 2.7 percent as a result of postdiversion water temperature increases.

The impact on this race and others migrating up the Fraser River cannot be quantified; however, the increased temperatures will further deplete energy stores before the fish reach the spawning grounds and thus may affect spawning success, and will increase the probability of mortality in case of emergency demands on fish, such as delays or blockages, during their migration. Cooper and Henry (1962) found that as a result of a delay of 3-4 days, the majority of one segment of the 1960 Early Stuart run died before reaching the spawning grounds."

Summary

It would be extremely difficult to quantify the impact of water temperature increases on the Fraser River salmon resource. The

impact of water temperature increases on adult migration and spawning success and juvenile outmigration and food sources need to be quantitatively assessed. This latter issue was not addressed in the McGregor Diversion studies. However, enough evidence exists for sockeye salmon to confirm the risk of serious losses to this species and possibly other species in the event of increased water temperature as a result of the withdrawal of McGregor River flows.

The physiological effects of water temperature increases on other salmon species are not as well known as for sockeye. In the absence of conflicting data, the general approach is to assume the effects would be similar because the species are in the same genus (pers. comm. R. Brett).

Mitigation of the adverse temperature increases and resultant impacts from the diversion would require cold water releases from the McGregor reservoir. B.C. Hydro and Power Authority (1979) predicted that a discharge of approximately 3,990 cfs (113 m³/sec) at 4°C would be required to produce an average daily temperature of 13.9°C at Prince George under 1977 flow conditions. During lower flow years (such as 1970) larger releases in the order of 6,000 cfs (170 m³/sec) would be required.

Further, large summer releases of 4°C water would expose salmon migrants in the Upper Fraser and McGregor River to thermal shock.

Larger releases at 7°C to 8°C would be a more realistic method of ensuring proper downstream temperatures. Renewable Resource Consulting Services Ltd. (1978) further state that:

"... to avoid disruption to migration patterns of sockeye and to allow some control of water temperatures in the lower Fraser to perhaps limit columnaris, discharges would probably be required by about July 10. Gradual flow increases to a maximum may be required prior to this, in order to avoid "shock" to resident fish or salmon already in the river system. To be effective, flows would be required throughout August (the month of maximum water temperatures in the lower Fraser) and possibly until the end of the first week in September."

Obviously, in a scheme diverting an average 226 m³/sec to generating facilities on the Peace system, fishwater releases in the 100's of m³/sec would have the possibility of significantly depleting water available for generation.

In addition, as discussed in the section Chinook Utilization of the McGregor Basin there may be conflict between flow requirements for McGregor mainstem chinook rearing and mainstem Fraser temperature maintenance. The larger discharges required to

maintain Fraser River temperatures may flush McGregor River rearing chinook into poor quality habitat. Subsequent flow decreases may leave them stranded.

(c) Data deficiencies and issues requiring further study

If further consideration is given to the McGregor Diversion project the following studies specific to Fraser River water temperatures should be undertaken:

Assessment Oriented Information

1. The results of the stream temperature modelling should be confirmed. Modelling capability has probably improved since the mid 1970's. The available methodologies for river temperature modelling should be reviewed and the most suitable model for the characteristics of the Fraser River and the requirements of the study should be used. The available data base of Fraser River hydrological, meteorological, and water temperature should be incorporated into the model. Several new post- 1977 data bases are available. For example, at time of writing, the IPSFC has accumulated about three years of data on Fraser River temperatures which were collected to assess the potential impacts of Alcan's Kemano Completion project.

2. In the 1977 B.C. Hydro study, the model simulated only eight days - July 31 to August 8. Only one 'worst case' scenario was evaluated when the simulation used 1970 low flows and 1977 temperatures. A thorough review of historic summer flow and temperature extremes of the Fraser mainstem and large tributaries should be undertaken. 'Worst case' scenarios that would result from the withdrawal of the McGregor flow, and possible combined McGregor and Kemano Completion flows, should be simulated.

3. Using the new simulation results, an assessment of the impact of water temperature increases on adult salmon, juvenile salmon, and food web organisms in the Fraser mainstem should be undertaken. B.C. Hydro's assessment was restricted to the impact on adult sockeye salmon; the other anadromous species and their various life stages are of concern as well. This assessment would be a precursor to the estimation of fisheries losses that would result from temperature increases.

Mitigation Oriented Information

1. Mitigatory fish water release regimes should be fully explored before any form of habitat compensation or artificial fish production is investigated. Without adequate

mitigation any wild or artificial stock of fish utilizing the Fraser mainstem will experience elevated temperatures and associated negative impacts.

Habitat Compensation Oriented Information

1. Once preliminary estimates of fisheries losses have been established, habitat restoration and improvement and artificial production opportunities should be thoroughly assessed.

3.5.4 Overview of Generation Alternative Impacts

To date only brief overview environmental studies have been undertaken for the generation scheme (Reid, Crowther and Partners Ltd., 1980). No analysis of the resulting Fraser River temperature regime has been undertaken. However, some general comments can be made.

Operating a McGregor generation facility with multilevel penstock intakes would enable regulation of water temperature both in the McGregor and mainstem Fraser Rivers. As discussed above, water temperatures of at least 7 or 8°C would be desirable to prevent thermal shock to fish near or in the plume of the McGregor flow. Low level intakes would receive water at 4°C, upper level intakes

would receive higher temperature water; downstream water temperatures could be regulated by mixing these waters.

Reservoir temperature modelling would be required to ensure there would be sufficient warm upper layer water to mix with the 4°C water to sustain acceptable (greater than 7-8°C) water temperatures downstream for the required periods of time.

4 FAUNAL AND FLORAL TRANSFER BETWEEN PACIFIC AND ARCTIC DRAINAGES

4.1 Major Reports

Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project. Volume 4 - Faunal Transfer. Prepared for B.C. Hydro and Power Authority.

Envirocon Ltd. 1982. Sentinel testing for Ceratomyxa shasta in the McGregor and Fraser Rivers. Prepared for British Columbia Hydro and Power Authority. Vancouver. January, 1982.

E.V.S. Consultants Ltd. 1982. Sentinel testing for the infectious stage of Ceratomyxa shasta in the Fraser and McGregor Rivers. 1981. A report on Field Exposure and Laboratory Incubation phases. Prepared for British Columbia Hydro and Power Authority by D.R. Munday and G.A. Vigers, E.V.S. Consultants Ltd., North Vancouver. March 1982.

Arai, H.P. and D.R. Munday. 1983. Protozoan and metazoan parasites of fishes from the headwaters of the Parsnip and McGregor Rivers, British Columbia: a study of possible parasite transfaunations. Can. J. Fish. Aquat. Sci. 40(10): 1676-1684.

Ching, H.L. and D.R. Munday. 1984. Geographic and seasonal distribution of the infectious stage of Ceratomyxa shasta Nobel, 1950, a myxozoan salmonid pathogen in the Fraser River system. Can. J. Zool., 62(6): 1075-1080.

4.2 Studies to Date

In 1976 and 1977 three studies related to the possibility of faunal and disease transfer between the Pacific and Arctic drainages were undertaken by consultants for B.C. Hydro. The three studies pertained to the fish fauna, the fish parasite fauna, and bacterial and viral diseases. The reports on these studies are included in Reid, Crowther and Partners (1978) Volume 4. A later study was conducted in 1981 to determine the presence or absence of the infective stage of the pathogenic protozoan Ceratomyxa shasta in the McGregor River and at three sites in the Fraser River. The findings are reported in Envirocon Ltd. (1982) and E.V.S. Consultants Ltd. (1982). The results of the investigations on the fish parasite fauna and on the distribution of Ceratomyxa shasta were formally published in Arai and Munday (1983) and Ching and Munday (1984).

4.3 Principal Results Relevant to Potential Faunal and Disease Transfer

4.3.1 Fish fauna

Four species present in the upper Fraser River were identified as being absent from the upper Peace River. These are: chinook salmon, bridgelip sucker, white sturgeon, and leopard dace. The first two were collected from the McGregor River upstream from the proposed damsite and the other two may occur there. Of 20 species known to occur in the British Columbia portion of the Peace River, 10 are absent from the Fraser River. Only one of these, the Arctic grayling, was collected from the Parsnip River system. The northern pike, absent from the Fraser River but present in the Peace River, was not found in the Parsnip River system and is considered to be absent from the upper Peace River beyond the W.A.C. Bennet Dam. The consultants considered it unlikely that northern pike would have access to the proposed McGregor reservoir and, hence, the Fraser River. The northern pike is a fish of particular concern because it is a voracious predator and host of the tapeworm Triaenophorus crassus, which, in its juvenile plerocercoid stage, resides in the flesh of salmonid fishes rendering the infected fish aesthetically unacceptable to the consumer.

4.3.2 Viruses and bacteria known to be fish pathogens

Several bacterial species or species groups that are potential or known pathogens of fish were reported to occur in the Parsnip and McGregor river drainages. Of these, the organism (now known as Renibacterium salmoninarum), which causes bacterial kidney disease (BKD), was found only in the McGregor River in one rainbow trout. No viruses were isolated, but because of previous reports of the occurrence of IHN in chinook salmon in the upper Fraser River this virus was recognized as a potential hazard if it gains entrance to the Peace River watershed.

4.3.3 Parasites

Of the 78 species or species groups of parasites reported from fishes from the Parsnip and McGregor rivers, 26 were found in only one of the watersheds (12 from the Parsnip River and 14 from the McGregor River). Three of these 26 species were regarded as posing the greatest threat to fisheries resources through transfaunation. All three are protozoans detected only in the McGregor River: Ceratomyxa shasta, Cryptobia salmositica, and Haemogregarina irkalukpiki. Ceratomyxa shasta was found in chinook in the McGregor River mainstem and James Creek, the Herrick Creek tributary through which diverted waters would

flow. The latter two species were considered to be of lesser importance because they require intermediate hosts in their life cycles and are said to be less pathogenic. Because Ceratomyxa shasta was identified as the parasite of potentially greatest danger, specific investigations were conducted to provide information on the distribution of the infective stage of this parasite in the McGregor and mainstem Fraser rivers. These investigations demonstrated the presence of the infective stage in the Fraser River at a site near Prince George and at two lower river sites. The infective stage was not detected in the McGregor River.

4.4 Comments on B.C. Hydro's Consultants' Findings and Conclusions

4.4.1 Fish fauna

The fact that some differences exist in the fish fauna between the McGregor and Parsnip rivers, and more generally between the Peace and Fraser Rivers, is reason enough to be concerned about possible transfer of species from one system to the other. The ecological consequences of such transfer could be serious. Further, the possible adverse genetic and ecological effects on fish stocks due to interwatershed transfer of previously segregated stocks of species common to both watersheds cannot be dismissed lightly. Assuming there will be barriers to "upstream" movement of fish, the greatest potential problems will be associated with fish transfer from the McGregor River to the Parsnip River and further downstream to the Peace-Mackenzie River system. However, upstream transfer from the Parsnip River to the McGregor River and Fraser River could take place during construction, before barriers to fish passage are functioning.

4.4.2 Viruses and pathogenic bacteria

Of the most serious bacterial and viral pathogens known to occur widely in the upper Fraser River, only the cause of BKD was

detected. The failure to detect other serious pathogens which are widespread in salmonid rivers of British Columbia, such as Aeromonas salmonicida (the cause of furunculosis) and the virus causing infectious hematopoietic necrosis (IHN), is likely due to an inadequate sampling regime. These organisms are most readily detected in salmonids in spawning condition or just after spawning, when the defense mechanisms of the fish have deteriorated. Further, the most sensitive method for detecting IHN involves using ovarian fluid for the test. This was not done. In general, the report downplays the potential significance of viral or bacterial disease transfer between watersheds. As with the potential transfer of fishes, the problem of transfer of viruses and bacteria would be most serious for the McGregor to Parsnip direction, with subsequent downstream effects in the Peace-Mackenzie system. However, transfer in the reverse direction could occur during construction or if barriers to upstream migration of fish are not foolproof.

4.4.3 Parasites

The report recognizes that interwatershed transfer of parasites and possible changes in parasite abundance and ecology due to environmental alterations could be detrimental to fisheries resources. However the emphasis on Ceratomyxa shasta alone is

misleading. Potential problems resulting from possible transfer of other parasites, or even different "strains" of the same species, cannot be ignored. Further, due to limitations in sampling and the manner in which samples were handled and shipped, some parasite species present either in the McGregor River or Parsnip River may have been missed. As noted in the comments on "Fish fauna" and "Viruses and pathogenic bacteria," the most likely transfers will occur from the McGregor River to Parsnip River (and thence possibly through the Peace-MacKenzie system) but transfer in the reverse direction may also be possible.

The specific studies directed at determining the presence of the infective stage of C. shasta in the McGregor River cannot be considered definitive and it is not acceptable to conclude with certainty that the infective stage is absent from this river. Additional studies covering other sites in the McGregor River and repeated in other years are necessary.

4.5 General Summary and Conclusions

1. Although many statements within B.C. Hydro's consultants' reports could be challenged, this review has concerned itself with more general aspects of the study.
2. In general, although the report recognizes the potential adverse effects of interwatershed biota transfer and identifies certain fishes and organisms living within them as candidates for interwatershed transfer, it tends to minimize the possibilities, and likely detrimental effects, of such transfers.
3. The possible existence of differences between the two watersheds in their free-living invertebrate fauna and the potential consequences of interwatershed transfer of elements of these faunae was not addressed. Interwatershed transfer of free-living invertebrates could result in disturbances of existing ecological balances and could serve as vectors for the introduction of non-native species or strains of parasites of fish or invertebrates that could be detrimental to the native aquatic fauna.
4. There is also a conspicuous absence of any concern about interwatershed transfer of flora (e.g., algae) and the potential consequences thereof.

5. There is ample documentation in the scientific literature showing that there can be detrimental consequences of introducing non-indigenous species in aquatic environments so that possible undesirable impacts from the McGregor Diversion proposal from biota transfer cannot be denied. The difficulty lies in predicting the actual specific effects that will occur.
6. Because studies to date have shown that there are differences in certain elements of the biota between the two watersheds under consideration, there is clearly a risk associated with linking these watersheds. The risk involves possible introduction of non-indigenous free-living (fishes, invertebrates and flora), parasitic, and microbial organisms. The introduction of free-living organisms could have serious impacts on the native fauna and flora through competition, predation, and genetic interactions. Introduced parasites, bacteria, and viruses could flourish to the detriment of indigenous fishes.
7. There seems to be little to be gained from further field studies addressing the question of biota transfer because the existence of many differences between the two watersheds is already well-established. Additional field studies would probably only serve to increase the number of

species known to occur in only one of the watersheds and heighten concerns about the consequences of interwatershed transfers.

8. An experimental approach to assessing the consequences of interwatershed transfer of specific organisms seems unrealistic. The laboratory and field investigations required to assess the impact of all new host-parasite/disease-environment associations that could result would be prohibitive.
9. The Canadian Government has identified the interwatershed transfer of biota as being of concern with other large water use projects. For instance, in the Garrison Diversion Project the United States had proposed to transfer water from the Missouri River Basin into the Hudson Bay system for irrigation purposes and the Canadian government successfully opposed the proposal on the grounds that the technology presently available is not sufficient to protect Canadian waters from undesirable impacts associated with water flowing into Canada.
10. If construction and operation of the McGregor Diversion were to proceed, then the actual consequences could be assessed through a monitoring program. However, it would

then be too late for remedial action if damage occurred, because the damage would be irreversible.

11. If a generation project were to proceed there would be no interbasin transfer of water and hence no direct faunal (or floral) transfer. There would be a small possibility of indirect transfer via human activity as the utilization of the area would generally increase.

**5 IMPLICATIONS OF WATER TRANSFER
BETWEEN PACIFIC AND ARCTIC DRAINAGES**

5.1 Major Reports

Environment Research Consultants. 1975. A Preliminary Environment Impact Assessment of the Effects of the McGregor River Diversion on the Parsnip River Valley. Volume I - The Report and Volume II - Illustrations. Prepared for B.C. Hydro and Power Authority.

Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies for the McGregor Diversion Project Volume I - Text and Volume II - Tables and Figures. Prepared for B.C. Hydro and Power Authority.

British Columbia Hydro and Power Authority. 1978a. McGregor River Diversion River Regime and Morphology Volume 2 - Parsnip River. Hydroelectric Design Division. Report No. 830 March 1978.

5.2 Studies to Date

The studies to date for the McGregor Diversion project discuss the implications of water transfer to the Arctic drainage only as far as the Williston Reservoir. In 1975 Environment Research Consultants (1975) prepared a preliminary environmental impact assessment for B.C. Hydro. Similarly the detailed environmental studies undertaken by Renewable Resources Consultants Ltd. in 1976 and 1977 were restricted to the Parsnip River and the Parsnip Arm of Williston Lake. The findings were reported in Reid, Crowther and Partners Ltd. (1978). The river regime and morphology studies were also restricted to the Parsnip River (B.C. Hydro and Power Authority, 1978a).

5.3 Diversion Alternative

5.3.1 Impacts

A synopsis of the predicted impact on Parsnip fisheries if the diversion were to proceed is reproduced verbatim from Reid, Crowther and Partners Ltd. (1978) below:

As a result of diversion the Parsnip River would undergo marked physical changes, especially in its upper reaches.

The thermal regime would be altered such that warming in summer would be delayed by input of cold reservoir flow and in summer reservoir water would warm ambient Parsnip River waters to 12-14°C.

Reservoir flows entering the Parsnip would be well oxygenated but would undergo subsequent depletion due to the input of oxygen demanding organic materials to the river. Reoxygenation would be slower due to reduced photosynthetic activity in the deep and turbid waters; a condition most critical in winter when ice cover further inhibits reoxygenation.

Water leaving the reservoir would be low in nutrient concentrations and turbidity, but these increased flows would

rapidly accumulate suspended materials and dissolved solutes in the Parsnip Basin, resulting in nutrient loading to the Parsnip Arm of Williston Lake being greater than at present.

Benthic productivity would decrease in the Parsnip with increased water depth, turbidity and instability of substrate. This loss would be most significant below the Table River where substrate favours benthic productivity. Decline in benthic productivity would be greatest immediately following diversion and would moderate as the river bed stabilizes.

Changes to the mouths of tributaries entering the Parsnip River as a result of diversion would occur slowly enough for benthic communities to have time to adapt. Resultant coarser substrates would be at least as favourable to benthic production as present substrates.

The diversion would cause higher flushing rates, and increased inputs of allochthonous material (suspended solids, dissolved solids, nutrients) to the Parsnip Arm of Williston Lake. A gradient would develop during the summer from low production at the mouth of the Parsnip due to low photosynthetic activity in the turbid waters, to maximum production where dissolved nutrients are still available and

particulate matter has settled out. As the water entering Williston Lake from the Parsnip would be oxygen deficient the biota would be adversely affected in the Parsnip Arm particularly in winter.

5.3.2 Data deficiencies and issues requiring further study

1. The studies to date are seriously deficient as the analysis of the impact of water transfer to the Arctic drainage was restricted to the Parsnip River and Williston Reservoir. To adequately assess the fisheries implications of the project, impacts to the aquatic resources of the Lower Peace River, and the Peace-Athabasca Delta in particular, must be fully evaluated. Fish resources in the Peace-Athabasca delta have been extensively studied; hence it should not be necessary to conduct further field investigation.

A hydrologic model for the Peace Athabasca delta area already exists. To determine the change in delta water levels, the proponents should use the existing model to route the diversion flow through the Williston Reservoir, the Peace River and the Peace-Athabasca Delta. The modified operation of the Bennett Dam should be taken into consideration and the existing hydrologic model could be used. These studies

should take place early in the development of the project so as to enable the timely identification of any problems as well as evaluation of mitigative measures.

2. If the operating scenarios for the dams below Williston Reservoir are to be altered in any significant way as a result of McGregor River Diversion, losses of critical Peace-Athabasca delta habitat may increase. The delta is a very large and important nursery and summer feeding area for some 24 species of fish, and provides crucial spawning habitat for a number of these. Following the filling of the Williston Reservoir on the Peace River, and the placing of rock weirs on two of the Delta outflow channels, Lake Athabasca and the Peace-Athabasca Delta have exhibited substantially reduced annual fluctuations, with higher winter levels, and lower spring levels. Riparian vegetation communities have been altered and now tend to be more limited in extent and indicative of stable environments. The effects resulting from habitat alteration as well as those related to fish passage considerations at the weirs have been extensively studied. Federal/Provincial studies are now underway to provide fish passage facilities around the rock weirs at the Peace-Athabasca delta. Significant flow alterations could reduce the effectiveness of these facilities and hinder or prevent migrating fish from

negotiating the delta channels thereby further reducing already depressed fish stocks.

5.4 Generation Alternative

With the McGregor Generation alternative there would be no diversion of waters into the Arctic drainage. Hence, there would be no concern regarding the fish resources of the Parsnip River Peace River or Peace-Athabasca delta with respect to a generation alternative.

6 ECONOMIC EVALUATION

6.1 Major Reports

Reid, Crowther and Partners Ltd. 1978. Report on Environmental Studies For the McGregor Diversion Project Volumes I - Text and Volume II - Tables and Figures. Prepared for B.C. Hydro and Power Authority.

6.2 Studies to Date

Canadian Resourcecon Ltd. undertook an economic evaluation of the McGregor diversion which was to be used by B.C. Hydro in their overall project benefit cost analysis. The evaluation is presented in Reid, Crowther and Partners Ltd. (1978). The study was intended to provide economic evaluations of changes in all resource uses that might take place in British Columbia as a result of the project. The evaluation included forestry losses, recreation effects, commercial wildlife losses, fishery losses and flood control benefits. An economic evaluation of power production was not included in the environmental reports. The overall benefits and costs of the project were to be assessed in dollar terms where possible from both a provincial and regional perspective. The study area largely encompassed the Fraser-Fort George Regional District.

6.3 Diversion Alternative

6.3.1 Evaluation of Fish losses

Because of the suspension of studies in early 1978, the consultants had no estimates of overall Fraser system fish losses that might occur as a result of the McGregor Diversion. However, a methodology for measuring the economic value of a loss was developed and applied to some preliminary estimates from the system E studies. The findings are presented in Reid, Crowther and Partners Ltd. (1978) and the summary "Present Value of Total Net Fraser Salmonid Fishery Costs of the Project" is presented verbatim here:

"The project would reduce the net value of commercial fisheries by \$11.9 million, using the most likely price scenario discounted to 1977 at a 10 percent interest rate. Using willingness-to-pay measures, the total reduction in recreation value amounts to \$7.3 million using the most likely price scenario, discounted to 1977 at a 10 percent interest rate. Using the required compensation approach, the loss of recreation values (which in this case are broadly defined to encompass all intangible social values) amounts to \$94.8 million discounted to 1977 at a 10 percent interest rate.

Given the scenarios outlined in the text these net value figures accurately measure the commercial fishery costs of the project. However, the caveats attached to this calculation cannot be over emphasized. These net value figures are the end result of a whole set of assumptions, and changes in one or more of the assumptions could produce radically different value estimates.

Key assumptions intrinsic to this analysis include:

- Fraser salmonids taken by U.S. fishermen are as valuable to British Columbia as those taken by Canadian fishermen;
- foregone efficiency benefits due to the current management structure are appropriately tallied as regional economic and cultural benefits;
- the Salmonid Enhancement Program will go forward, following the scenario in Table 9.5;
- fishery managers will maintain future escapement at the same levels regardless of the project, so that the native food fishery and fresh water sport fishery would be unaffected;

- the opportunity cost of labour in the processing sector is 85 percent of the wage rate;
- the allocation of future output between the commercial and recreational fishery is reasonably accurate;
- future investment in the harvesting sector will be controlled, so that efficiency benefits are expanded due to utilization of excess capacity;
- the loss scenario produced in the Department of Environment's System E study is appropriate.

If future research proves any of the above assumptions incorrect, then the analysis should be reviewed".

With respect to the third key assumption, SEP did not go ahead with all the Fraser activities as was planned at the time this report was written. The report states that fish would be more abundant after the McGregor River Diversion Project than before because of increases in fish production from salmon enhancement efforts. Losses attributed to the project would therefore be losses from potential and not current stocks. The value of these losses from potential are calculated using net wholesale values based on the assumption that SEP would proceed for Fraser River

stocks. The report stated that if SEP did not proceed as planned, the analysis should be revised.

6.3.2 Data deficiencies and Issues requiring further study

1. In order to measure the economic value of fishery losses, the losses would have to be estimated and updated figures used. SEP production figures should be updated.
2. In describing the general benefit-cost approach, Canadian Resourcecon Ltd. recognized that option and existence value may be important in the McGregor issue. However, they stated that there was no way of measuring these values, even though several surveys have been carried out in the last two decades which attempt to estimate non-use preservation benefits. A study of non-use preservation values associated with the Fraser River should be carried out. This is particularly important as some fish stocks and other environmental assets may be eliminated as a result of the project.
3. Alternative ways of measuring recreational fishing values were discussed. These were, willingness of anglers to pay to maintain the opportunity and the compensation required to

leave the anglers indifferent if they had to give the opportunity up. The authors conclude that the correct measure depends on property rights, the implication being that the compensation measure applies if one can assume that recreationists have vested rights in the existing and future allocation. However, the willingness to pay measure is used when one is evaluating an increase in recreational opportunities. When recreational opportunities are being reduced, compensation required is the appropriate measure. Regardless of actual or assumed property rights, recreationists are currently enjoying a certain level of recreational activity. If recreational activity were reduced, the welfare loss to society would be measured by the amount that those current consumers would have to be compensated to induce them to willingly forego the reduction.

4. Economic losses are based on an implicit assumption that existing stock productivity and harvest rates will remain the same with the project. If stock productivity (or recruitment) rates were to decline significantly as a result of project impacts then either the rate at which the stock would be harvested in the mixed stock fishery would drive the stock to extinction, or harvest rates would have to be reduced to preserve the stock. In either case economic losses would be greater than forecast. Therefore, the

biological assessment should include determination of whether or not productivity of the impacted (natural) stocks would decline.

5. One issue that is not dealt with in the Reid, Crowther and Partners Ltd. (1978) report but is important to all power project decisions is the method of measuring power benefits. B.C. Hydro's standard approach to project selection is based on the alternative cost methodology. This methodology involves three steps, the first of which is to estimate future electrical demand. Second, projects which can feasibly be implemented in time to meet the perceived demand are identified. Thirdly, the unit costs (eg. capacity costs \$/kw) of the various feasible alternatives are compared and the lowest cost alternative selected. The methodology assumes the power benefits exceed the true costs. This is a serious weakness of this methodology as it considers and selects projects relative to one another rather than relative to other uses of the resource. Ideally, social benefits should be estimated in absolute terms, so that the net benefits of electrical generation projects can be compared with the net benefits of economic contributions from existing and potential environmental (eg. fish production) systems.

6.4 Generation Alternative

To date no comprehensive economic evaluation has been done for the generation alternative. Methodologies would generally be similar to those used in the diversion studies, hence the data deficiencies outlined above should be resolved in any economic evaluation of a generation alternative.

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APPENDIX I

The significance of the proposed McGregor River Lower Canyon Dam
in terms of Fraser River flood control

At the present time, several settled areas on the Fraser River floodplain are prone to inundation during high water conditions. The areas are in Prince George, Quesnel, Kamloops and the lower Fraser Valley from Agassiz-Rosedale to Steveston. Based on the historical water level data at Mission, the five largest floods in the period of record occurred in 1882, 1894, 1948, 1950 and 1972 (McLean and Mannerstrom, 1985). The largest maximum daily flow of 600,000 cfs (17,000 m³/sec) as measured at Hope with a 26 ft (7.9 m) stage at Mission occurred in 1894 and has a return period of approximately 1 in 140 years; in 1948 the maximum daily flow was 536,000 cfs (15,200 m³/sec) at Hope with a 24.98 ft (7.6 m) stage at Mission.

On any river system, dykes and storage dams decrease the likelihood of flooding. The McGregor River, a large northern tributary of the Fraser River above Prince George, has been seriously studied as a potential storage site since the 1950's. The drainage basin of the McGregor River is 1840 sq. miles (4,770 sq. km.) as measured at Lower Canyon. This is 2.2 percent of the total Fraser River drainage area above Hope. However, the McGregor River contributes a disproportionately large discharge to the total Fraser River discharge. Table A1 presents the ratio of McGregor River discharge to Fraser River discharge at Hope for various (recorded) conditions. On average, 8 percent, or 8,260 cfs (234 m³/sec) of the mean annual discharge of the Fraser River at Hope for the period 1960-1982 originated from the McGregor River; the maximum instantaneous discharge recorded for the McGregor is 16 percent of that recorded for the Fraser River

at Hope. A peak McGregor River discharge of 65,000 cfs (1,840 m³/sec) is estimated to have an average return period of about 40 years. The contribution of the McGregor River to the upper reaches of the Fraser River is, of course, even more significant. For example the ratios of mean McGregor River June flows to mean Fraser River June flows is 29 percent at Shelly (near Prince George) and 18 percent near Marguerite (between Quesnel and Williams Lake). Clearly, the installation of a dam and resulting storage capability on the McGregor River would improve flood control for the Fraser mainstem.

The existing storage reservoirs can help to attenuate flood peaks. The Aluminum Company of Canada's (Alcan's) Nechako River reservoir and B.C. Hydro's Bridge River reservoir have been estimated to be capable of reducing a peak flood level of 1894 proportions by 0.7 ft (0.2 m) at Mission. Operations of these reservoirs during the April-May period in 1972 in anticipation of a major flood event achieved a reduction of approximately 40,000 cfs (1,133 m³/sec) in the peak flow of the Fraser River at Hope which corresponded to a reduction of about 1.3 ft (0.4 m) in the peak elevation at Hope. This freshet reached a maximum daily discharge at Mission of 508,500 cfs (14,405 m³/sec) and stage of 23.28 ft (7.1 m) on June 17, 1972. On that occasion, Alcan provided 400,000 acreft (493 x 10⁶ m³) in the Nechako system and B.C. Hydro provided 1,370,000 acreft (1690 x 10⁶ m³) of storage capacity in the Bridge River system. B.C. Hydro provided an additional 100,000 acreft (123 x 10⁶ m³) of emergency flood control storage at Stave Lake. Under natural conditions, there would have been an estimated one-in-three probability that the 1894 flood be equalled or exceeded at Mission during the 60 year period from 1973 to 2032. This estimated probability is reduced to 1 in 5 given the present emergency flood control capability at Nechako and Bridge River, and would be further reduced to 1 in 11

with a McGregor River Project (Fraser River Joint Advisory Board, 1976).

At present, the dykes would prevent all damage when the water level is below 24.00 ft (7.3 m) at Mission and 50 percent of the potential damage when the water level is between 24.00 ft and 26.00 ft (7.3 m and 7.9 m) at Mission. However, there are problems common to any system of river dykes no matter how well (or how high) constructed. The flood hazard in a dyked area is aggravated by the duration of high water levels; dykes tend to deteriorate when subjected to high water levels for extended periods, and so become less reliable means of flood control (Fraser River Joint Advisory Board, 1976). Higher flood levels and resultant higher pressures accentuate problems related to seepage, shear failure on the landward face of the dyke, and piping through the foundation. In addition, foundation preparation on poor soils imposes restrictions on dyke height. In some cases, the net effect of higher dykes is a false sense of security and further development in areas still susceptible to flooding.

Additional and more reliable protection against flood plain inundation can be achieved by a McGregor River dam at Lower Canyon. A McGregor dam would reduce the flood peak at Mission by 0.7 ft (0.2 m) given a flood equivalent to that of 1894. The duration of the flood crest would also be reduced. A McGregor dam, being upstream of Prince George, would also provide protection for Prince George, Quesnel and Kamloops.

From the flood control point of view, leaving aside benefit/cost analysis, it makes little difference to the lower Fraser whether the McGregor River inflow is diverted to the Parsnip River (the diversion alternative) or simply stored during freshet behind the

dam (the non-diversion alternative). Analysis of the non-diversion proposal confirms that the project has a total live storage capacity of "about 155 percent of the average May through July runoff volume" and the storage capacity "is greater than the project flood control storage required" (Fraser River Joint Advisory Board, 1976). The non-diversion alternative could be a dual purpose project built to generate electrical energy as well as to provide flood control. The latter requirement implies that, in flood years, the reservoir will be drawn down to a pre-specified level by about May 1 and the turbine discharge will be reduced to zero or curtailed drastically during May and June. The schedule of reservoir regulation would be dictated by the on-going studies undertaken by the B.C. Ministry of Environment (snow survey, climatological observations, run-off prediction) in conjunction with the Fraser River Flood Control programme now in place. As discussed above, the operation of the existing reservoirs on the Fraser River tributaries are now geared to generate flood control benefits in areas such as Prince George, Quesnel, Kamloops and the Lower Fraser Valley. The negotiations are done by the Ministry of Environment directly with the owners of those reservoirs, ie. Alcan (Nechako River) and B.C. Hydro (Bridge River). As mentioned above, the regulation of the reservoir for flood control may not be required under normal circumstances. The degree of regulation will be dependant on snow pack and the climatological conditions prevailing at the time.

Table A1 The ratio of McGregor River discharge to Fraser River discharge at Hope for various recorded conditions.

$$\begin{aligned} & \text{Ratio of } \frac{\text{Mean Annual Discharge of McGregor at Lower Canyon}}{\text{Mean Annual Discharge of Fraser River at Hope under present condition}} \\ & = \frac{8,260 \text{ cfs (1960-1982)}}{102,120 \text{ cfs (1960-1982)}} = 0.08 \end{aligned}$$

$$\begin{aligned} & \text{Ratio of } \frac{\text{Mean Monthly (June) Discharge of McGregor (1960-1982) at Lower Canyon}}{\text{Mean Monthly (June) Discharge of Fraser (1960-1982) at Hope}} \\ & = \frac{23,160 \text{ cfs}}{258,930 \text{ cfs}} = 0.09 \end{aligned}$$

$$\begin{aligned} & \text{Ratio of } \frac{\text{Maximum Daily Flow of McGregor (occurred on June 12, 1972)}}{\text{Maximum Daily Flow of Fraser (occurred on May 31, 1948)}} \\ & = \frac{68,500 \text{ cfs}}{536,700 \text{ cfs}} = 0.13 \end{aligned}$$

(For the above calculations, the time base for McGregor record was from 1960-1982 at Lower Canyon; for the Fraser River at Hope, a 1912-1982 time base was used)

$$\begin{aligned} & \text{Ratio of } \frac{\text{Maximum Instantaneous Discharge of McGregor}}{\text{Maximum Instantaneous Discharge of Fraser}} \\ & = \frac{73,800 \text{ cfs (occurred on July 12, 1972)}}{459,000 \text{ cfs (occurred on June 16, 1972)}} = 0.16 \end{aligned}$$

(For the above calculations, the time base for McGregor record was from 1960-1982 at Lower Canyon; for the Fraser River at Hope, a 1950-1982 time base was used)