MORAN DAM
AND THE
FRASER RIVER FISHERY

A partial reprint of the report

"FISHERIES PROBLEMS RELATED TO
MORAN DAM ON THE FRASER RIVER"

Prepared by Technical Staffs of
Canada Department of the Environment, Fisheries Service
and
International Pacific Salmon Fisheries Commission

Vancouver, B. C.
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PREFACE

The report entitled "Fisheries Problems Related to Moran Dam on the Fraser River" was released by the Minister of the Environment, Jack Davis, on October 7, 1971. The body of this report contains a technical discussion of the fisheries and hydrological implications of constructing a dam at Moran.

Since its publication, a large number of requests have been received from the general public for copies of the report or for the general information it contains. In response to this demand, this extract summary has been prepared and includes the Introduction, Discussion, Summary and Conclusions of the original document. It thus provides a statement of the proposed development and its fisheries implications, a discussion of costs, benefits, and alternatives, and a general summary and conclusions. The pagination of the original report has been retained to permit ready reference.

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FISHERIES PROBLEMS RELATED TO MORAN DAM ON THE FRASER RIVER

INTRODUCTION

The Fraser River system supports many valuable species of fish that would be affected by the construction of Moran Dam. These include five species of Pacific salmon, cutthroat, rainbow and steelhead trout, dolly varden char, sturgeon, eulachon and other less valuable species. The effects of this dam on salmon and steelhead, the most valuable species, form the basis of this report.

Salmon support a large, world-famous commercial fishery in the coastal waters of British Columbia and the State of Washington. They also provide a significant source of food for native Indians throughout much of the Fraser River watershed.

Pink, coho and chinook salmon from the Fraser River contribute substantially to the catches by sports fishermen in the coastal and estuarial waters. Adult chinook and coho salmon and steelhead trout provide outstanding sports fishing in freshwater areas. The lakes and streams of the Fraser River system provide spawning and rearing areas for the freshwater phase of the life cycle of salmon and steelhead. The presence of young and adults in these waters is an important factor supporting resident trout populations, which provide excellent sports fishing throughout the Fraser watershed. These various sports fisheries support ever-expanding recreational and resort industries.

The protection of salmon and steelhead trout is accomplished under provisions of the Fisheries Act administered by the Department of the Environment, Fisheries Service. The International Pacific Salmon Fisheries Commission, appointed in 1937 under a Convention between the United States and Canada, is responsible to the governments of both countries for the protection, preservation and extension of the sockeye and pink salmon fisheries of the Fraser River system. The Department of Recreation and Conservation of the Province of British Columbia is responsible for the protection of steelhead and resident freshwater fish. In view of the common interests of the Commission and the Department of the Environment in the salmon resources of the Fraser River system, this joint report has been prepared to present the fullest possible evaluation of salmon conservation problems that would be created by a high dam on the Fraser River at Moran.

At various times in the past three decades, public attention has been directed toward the possibility of constructing a large hydroelectric dam at Moran on the Fraser River 23 miles upstream from Lillooet (Figure 1). A dam at this location would intercept the drainage from approximately 56,000 sq miles, or about 60 percent of the total Fraser River drainage area of 90,000 sq miles.

The dam would also obstruct the migrations of major populations of salmon to and from spawning grounds located on tributaries of the Fraser River.

The first development proposal was made in 1955 by a private company, Moran Power Development Limited. This company

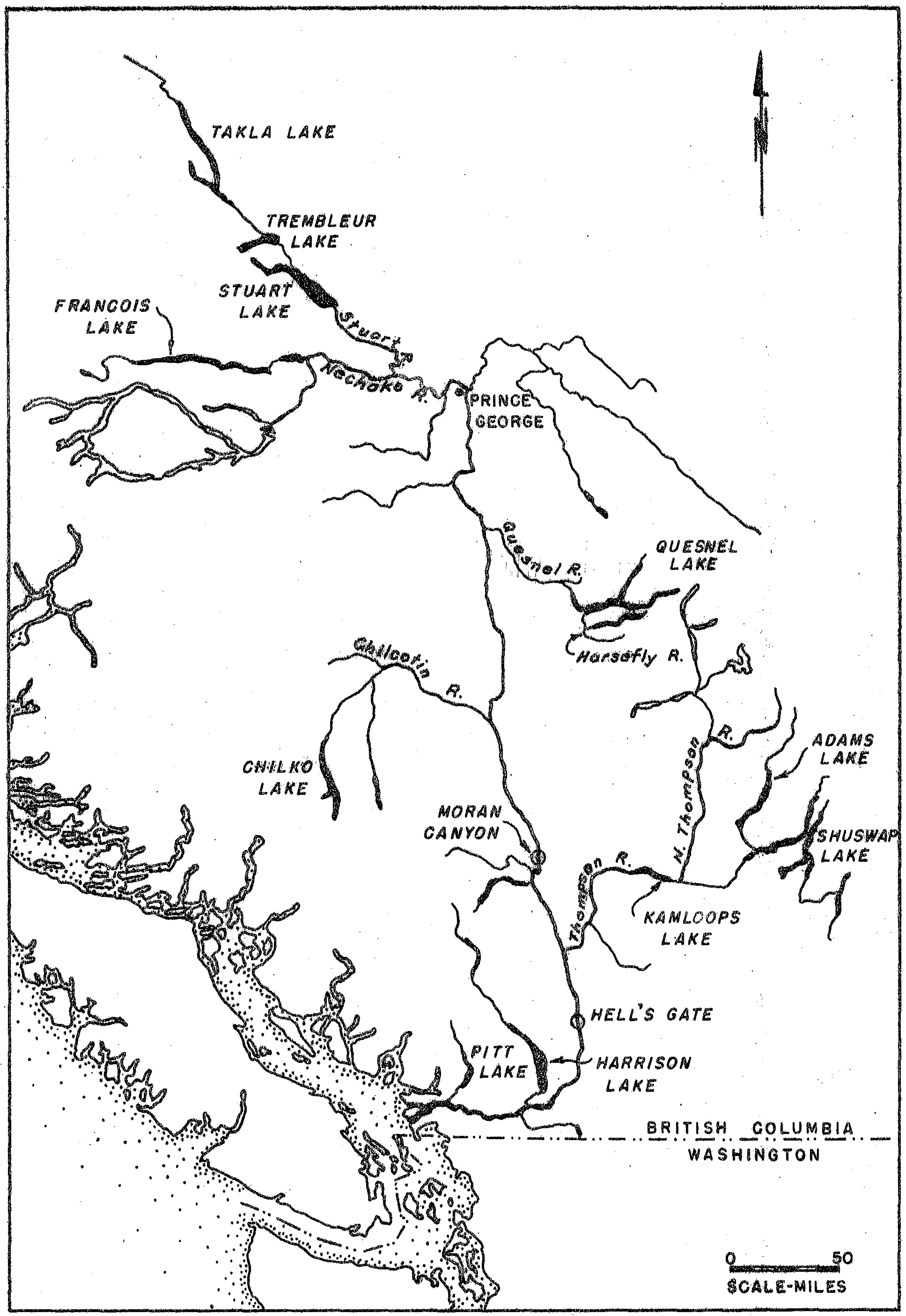

FIGURE 1 - Location of Moran Canyon in relation to the salmon-producing areas of the Fraser River watershed.

proposed to build a 700-ft concrete gravity dam, with auxiliary power, storage and diversion dams on the Fraser River and its tributaries and on the Babine and Peace rivers. The primary objective of the development was the establishment of metallurgical industries requiring large amounts of electric energy. At that time Provincial Government authorities advised the Company that the application for a water licence could not be received because of a reserve placed on the Fraser River between Lytton and Quesnel. They also advised that it would be necessary to obtain approval of the various fisheries agencies that would be concerned under the authority of Provincial and Federal legislation. The fisheries problems associated with the dam proposed by the Company were studied in the following two years and it was concluded from these studies that the dam would destroy a large segment of the Fraser River salmon fishery. In view of the policy of the Provincial Government that no dams would be permitted on major salmon streams unless ways could be found to protect the fish, the proposals of the Company did not proceed.

Comprehensive studies of possible hydroelectric development and flood control on the Fraser River system have been conducted by the Federal-Provincial Fraser River Board. The Board considered both a high and low dam at Moran in preliminary evaluation of various systems, but did not recommend a dam at this site in the final report released in 1963. This report recommended reconstruction of dykes as a primary requirement for protection from floods, with a series of flood storage and hydroelectric projects at locations that would avoid major interference with salmon. This proposal, called System E, would provide complete flood protection without requiring any dams on the main stem of the Fraser River downstream from the Grand Canyon above Prince George.

Current study of the power resources of British Columbia by the British Columbia Energy Board has revived interest in the power potential of the Fraser River, and specifically the Moran site. This report is intended to provide information required for assessing fisheries problems associated with the Moran development.

The basic incompatibility of fish and dams, especially with respect to Fraser River sockeye and pink salmon, has been discussed comprehensively in Bulletin XI of the International Pacific Salmon Fisheries Commission, published in 1960. Bulletin XI reviewed available information concerning ecological requirements, possible effects of environmental changes and methods of passing adult and juvenile salmon over dams. The complex nature of fish-dam problems and the impossibility of predetermining all of the consequences of altering the natural environment were pointed out. These problems discussed in Bulletin XI are not discussed again in detail in the present report but the pertinent fish-dam research completed in the 10 years since publication of Bulletin XI is reviewed and foreseeable problems that would be created by a high dam at Moran Canyon are described.

It must be emphasized that while this report considers the fisheries problems that would be associated with Moran Dam, many of the problems would also be encountered at other dams of lesser height that might be considered as alternatives or supplements to Moran Dam. Much of the available information on the fisheries problems at dams has been obtained from existing installations in the Pacific Northwest, particularly on the Columbia River and its tributaries. Moran Dam would be considerably higher than any of these installations and much larger salmon and trout populations would be involved. The fisheries problems associated with a series of dams on the Fraser River and associated upstream storages on several lakes were considered by the Fraser River Board in its Preliminary Report (1958) and led to the selection of the System E projects in the Final Report mentioned above. The inclusion of storage projects on major lakes, such as Stuart or Quesnel lakes, would require separate investigation, as previously done for a storage proposal on Stuart Lake (Canada Dept. Fish., Internat. Pacific Salmon Fish. Comm., 1962) and in addition would necessitate reappraisal of the problems associated with Moran Dam.

DISCUSSION

The total cost of the Moran hydroelectric project, exclusive of fish facilities, was estimated by the Fraser River Board to be $493 million at 1956 prices. Updating this cost to 1970 would increase it by approximately 50 percent to $740 million and further increases would be anticipated in the period before the earliest date that construction could start. The actual cost would also depend on design of the facilities, which would be expected to differ considerably from the design suggested by the Fraser River Board in its 1958 report. A comprehensive economic analysis of the total project cost would have to take many factors into consideration, including the cost of the project at the time of construction, interest rates and operating costs at that time, the probable increased value of the salmon and steelhead resources, the increased numbers of fish that would be expected at that time due to technological advances, and the increased recreational value of the fishery at that time. Such an analysis is beyond the scope of this report. The following preliminary cost analysis, based on 1970 prices, indicates more favourable power costs than would be obtained by projecting the costs to a future construction and operating period. As such, it significantly under-estimates the mill rate that could be expected if the proposal were to proceed.

The several components of the total power cost estimated for 1970 are listed in Table 50. The annual costs are estimated on the basis of the Fraser River Board annual cost factor of 7.4 percent, as derived in the 1958 report, increased by 2.2 percent to provide the previously discussed 1970 interest rate of 7.7 percent (B. C. Hydro, 1970). Transmission lines to deliver the power to a distribution center in the southwestern section of the Province would cost approximately $284 million on the basis of the 1956 Fraser River Board cost estimates updated to 1970. On the basis of the same annual cost factor as for power generation, the transmission cost would add approximately $27.3 million annually to the cost of power. The expected minimum loss of all stocks above Moran would add at least $10.9 million to the power cost and the probable loss of 50 percent of the commercial and Indian food fishery for salmon and steelhead stocks originating below Moran Dam would increase this cost to $24.1 million. At potential production levels, the fishery loss would add $71.7 million to the cost of power, not including any allowance for loss of marine species or other salmon and steelhead stocks due to environmental changes in Georgia Strait. Inclusion of the preliminary estimate of recreational fishery losses would add $22.2 million to the annual power cost. The total power cost would therefore range from about $192.7-$214.9 million annually. Based on the estimated average output of 1,937,000 kw f[illegible] less 7 percent for transmission losses, the total annual power production would be approximately 15.75 billion kwhr. The cost of this power at the distribution center would thus range from 12.2-13.6 mills/kwhr. It must be emphasized that this is only a preliminary analysis and that it understates the power cost since costs in the construction and operating periods would be higher than present-day prices and since future fishery and recreational values would also be higher.

Table 50. Summary of estimated Moran power costs

	Annual Cost Millions	Cumulative Annual Cost Millions
Plant cost for on-site power	$71.1	
Transmission to Lower Mainland	27.3	
Fish facilities	22.6	$121.0
Minimum loss of commercial and Indian fishery values		
For existing populations	10.9	
For potential populations	40.8	
Probable loss of commercial and Indian fishery values		
For existing populations	24.1	
For potential populations	71.7	192.7
Possible loss of recreational fishery value		
Above-Moran portion only	1.5	
Above-Moran plus 50% below-Moran	22.2	214.9

Moran Dam is not required for ensuring adequate flood protection for the Fraser Valley, since dykes could provide this protection in the same way as is presently done in the densely populated area below New Westminster, where water levels are determined primarily by the tide rather than by river discharge. With an adequate dyking system for flood protection it is questionable if the cost of power from Moran could be reduced by assigning part of the project cost to flood control benefits.

Recent study of the economics of thermo-nuclear power plants of 1.0 million kw output capacity in the Pacific Northwest area of the United States has estimated the cost of on-site power to be 3.0 mills/kwhr (Harty et al, 1967). Since these plants could be built relatively close to the main load centers, the transmission cost would add only a fraction of a mill/kwhr. The cost of the plants studied ranged from $132,714,000 to $145,060,000 for 1.0 million kw output at 1967 prices. Testimony before a United States Senate Sub-committee (Kolflat, 1968) indicated that the cost of thermal power plants ranged from $100-130/kw for a 1.0 million kw plant, exclusive of cooling towers. A report to the Joint Committee on Atomic Energy (Sporn, 1967) lists costs of thermo-nuclear power plants between $115.00 and $152.55/kw of installed capacity with production costs ranging from 3.78 to 4.55 mills/kwhr. The coal-fired Centralia steam-electric plant in Washington is reported to cost $142.86/kw of installed capacity, including the cost of facilities for controlling air and water pollution (Centralia Steam-Electric Project, 1970). Data shown in the Fraser River Board 1958 report indicates the cost of fossil-fired thermal power to be 5.78 mills/kwhr for firm power on the basis of a capital cost of $200/kw capacity.

Using the Centralia Project cost estimate, the firm power capability of Moran Dam could be provided by means of thermal power for about $164 million and the suggested installed capacity of 3,600,000 kw could be provided for about $514 million. Thermal power plants, properly designed and located, need not have any adverse effect on Fraser River salmon fisheries. It is not the purpose of this report to consider the relative merits of various alternative sources of power but the foregoing comparison of costs has been made to show that alternatives are available which, for the same output capability, would require far less capital investment and would produce power at a lower unit cost than the Moran development. These alternate power sources, properly located and controlled, would have relatively little effect on the environment and would permit full development of the fisheries resources of the Fraser system.

There are no proven means by which extremely high losses of Fraser River salmon could be prevented if the river were harnessed for power production. Conditions affecting survival of the sockeye runs that spawn above Moran would be more adverse than those on the Columbia River below the confluence with the Okanagan River, even with the provision of all known protective facilities. On the Columbia River, sockeye now pass over a succession of 9 dams from Bonneville to Wells, with a total head of 687 ft (Table 51).

Table 51. Heads at Columbia River Dams from Wells Dam to Bonneville Dam

Dam	Head ft	Year Completed
Wells	68	1968
Rocky Reach	93	1960
Rock Island	38	1933
Wanapum	84	1963
Priest Rapids	80	1959
McNary	75	1954
John Day	104	1968
The Dalles	86	1957
Bonneville	59	1938
TOTAL	687	

The turbine mortality at each of these dams has not been reported, but on the basis of tests at McNary, Bonneville, Ruskin and Seton plants, an average rate of 10 percent would be a reasonable assumption. Application of a 10 percent loss of smolts at each of the 9 dams would result in an aggregate survival of only 38.7 percent. Spillway mortalities would be much less than at Moran Dam, and the reservoirs would not cause as much delay to the migrations. The trend of the sockeye runs to the Columbia River since

1938, on the basis of production per spawner and catch per spawner, are summarized by cycle years in Table 52.

Table 52. Total run production and catch per spawner for sockeye salmon on the Columbia River 1942-65

Year of Return	Total Run per Spawner	Catch per Spawner
1942	5.5	3.34
1946	9.0	3.40
1950	2.4	1.13
1954	3.8	1.49
1958	3.6	2.26
1962	0.4	0.15
1943	4.3	2.51
1947	21.3	13.75
1951	2.7	0.68
1955	2.5	0.66
1959	1.8	1.24
1963	0.9	0.20
1944	1.8	1.23
1948	29.0	7.05
1952	4.0	2.12
1956	1.8	0.76
1960	2.0	1.36
1964	1.8	0.35
1945	92.2	22.40
1949	7.4	1.15
1953	14.3	2.51
1957	1.0	0.46
1961	0.9	0.60
1965	2.9	0.32

From Davidson, 1966.

Davidson (1966) commented as follows on the trend in production per spawner:

"The high ratios of return on the first two cycles of each cyclic series greatly assisted in the establishment of the blueback (sockeye) populations during their transplantation from above Grande Coulee Dam. Had these high ratios of return been maintained the runs would have continued to improve in spite of the generally less than 50 percent escapements. Instead, the ratios of return steadily declined and in some years to less than 1:1 at the end of each cyclic series. This brought about a corresponding decline in the runs. From 1962 to 1965 the commercial fishery was curtailed to a point where the escapements ranged from 66 to 99 percent of the total runs in an effort to stem the decline in the runs. The low ratios of return toward the end of each cyclic series may be attributed to a number of causes, one of the most influential being the hazards, both physical and biological, that are developing in the reservoirs above the dams."

It is significant that the extensive sport fishery and the Indian fishery, as well as the commercial fishery, were severely curtailed on the Columbia River in 1971 due to an exceptionally poor return of adults caused, at least in part, by environmental changes. The decline in Columbia River salmon populations shows that a series of low dams can create environmental changes that deplete the fishery resource in the same way as would be expected from a single high dam.

The reduced survival rates that would occur from environmental changes caused by Moran Dam, or even a series of low dams, give added weight to the previously drawn conclusion that alternative methods of production would not compensate for salmon and steelhead populations lost by construction of the dam. Because of the inefficiency of hatchery culture for sockeye, there appears to be no way of replacing the loss of any part of the existing sockeye resource above Moran. Hatcheries could probably be used to replace at least part of the lost chinook and steelhead resource but hatchery production might be uneconomic after dam construction. Furthermore, the available sites for construction of chinook and steelhead hatcheries are limited by the stringent water requirements and by the physical site requirements for rearing ponds and trapping, holding and egg-taking facilities for adults. Favourable water sources are not always available and these are essential to successful hatchery operation. Good groundwater sources are often essential in modern hatchery technology for temperature and disease control. Since survival of the hatchery product in the Fraser River system would probably be lowered in the smolt to adult stage if the environment was subjected to the artificial controls that would be imposed by hydroelectric development, the available hatchery sites would be more profitably utilized under existing natural conditions. If the available sites could be economically developed for hatchery production to maintain part of the fishery resource that would be lost by construction of Moran Dam, the same hatchery program would yield higher benefit/cost ratios without Moran Dam. Since the hatchery sites are limited and since hatcheries presumably would be constructed by government funds, it is questionable whether hatcheries could be considered as compensation for lost fisheries values.

SUMMARY

1. Moran Canyon is located on the Fraser River 23 miles upstream from Lillooet. The discharge from about 60 percent of the Fraser watershed flows through this canyon. With a maximum head of about 730 ft, a dam at this point would create a 170-mile reservoir that could be drawn down as much as 292 ft to provide 9,582,000 acre-ft of usable storage. The firm power output would be 1,191,000 kw, based on the lowest discharge in 19 years of record. At maximum capacity, the plant would produce 3,600,000 kw, which would require a discharge of 74,000 cfs at full reservoir or 102,000 cfs for a drawdown of 200 ft. The maximum power output at the lowest reservoir elevation would be 2,200,000 kw.
2. The annual commercial catch of Fraser River sockeye averaged 4.0 million in the period 1952-69. Fraser River sockeye provided 46 percent of the total British Columbia sockeye pack during this period and sockeye from above Moran provided 20 percent of the total Provincial pack. About 44 percent of the Fraser River catch originated from races that spawn above Moran and they had an average annual landed value of $4.5 million and a wholesale value of $8.9 million. Sockeye stocks from below Moran contribute annual landed and wholesale values of $5.9 million and $11.5 million respectively.

3. Production of chinook salmon above Moran also contribute a substantial share of British Columbia's salmon catch. The commercial catch of Fraser River chinooks averages about 480,000 annually. This represents about 15 percent of the total British Columbia chinook salmon catch. At least one-third of the Fraser River chinooks spawn above Moran, and the catch attributable to these stocks has an average landed value of about $1.2 million and a wholesale value of $1.5 million. Stocks spawning below Moran contribute an average annual landed value of $2.5 million and wholesale value of $3.1 million in the commercial fishery. There is not sufficient data available to make a meaningful estimate of the value of the important chinook sport fishery attributable to the Fraser River stocks.

4. The total commercial catch of sockeye, chinook, pink, and steelhead that presently spawn above Moran has an average annual landed value of $5.7 million and wholesale value of $10.4 million. Present populations of all five species of Pacific salmon and steelhead trout spawning below Moran provide commercial catches with an average annual landed value of $13.4 million and a wholesale value of $25.9 million.

5. The recreational values associated with the Fraser River system are the subject of a two-year study now in progress. A superficial estimate indicates an annual value in excess of $40 million.

6. In addition to supporting a valuable commercial fishing industry and recreational demands, the salmon resource is highly valued as a food supply by native Indians living in the interior of British Columbia, who capture an average of 100,000 sockeye annually from those races that spawn above Moran. About 42,000 sockeye are taken annually from populations that spawn below Moran. An estimated 10,000 lb of chinooks are taken from above-Moran populations and about 140,000 lb from below-Moran populations. The true value of this fishery cannot be determined at this time but it is assumed that the equivalent wholesale value of $483,000 and $480,000 for the present catches of above- and below-Moran stocks would provide a minimum estimate of resource value.

7. The potential sockeye production from areas above Moran would provide an average annual catch of 7.76 million, which would have a landed value of $18.8 million and a wholesale value of $37.3 million at 1970 prices. Information on the spawning and rearing environment of other anadromous species above Moran is not adequate at the present time for estimating the potential level of production. There is little doubt, however, that the available area is only partially utilized at present. Even without realizing an increase in production of chinook, pink, and steelhead above Moran, the potential

commercial catch would have a total annual landed value of $20.0 million and wholesale value of $38.8 million. Similarly, assuming no increase in the production of chinook, coho, and steelhead, the below Moran populations would produce a potential catch with total annual landed and wholesale values of $26.4 million and $60.9 million respectively.

8. Moran Dam would create many serious fishery problems related to environmental change and passage of fish over the dam. These problems may be summarized in three broad categories: those which are unavoidable or for which there is no known practical solution, those with no proven solution, and those for which a solution is possible.

9. Fisheries problems for which no practical solution can be foreseen include the following:

(a) The large reservoir would delay the migration of seaward migrants by 11-21 days. As a result, residualism and predation would significantly reduce the number of fish leaving the reservoir. Observations of the migration of chinook fingerlings in Brownlee reservoir on the Snake River suggest that 25-85 percent of the fish would be lost in Moran reservoir.

The theoretical travel time of water passing through the reservoir in April would be between 46 and 64 days compared to about 2 days in the existing river.

In May, the travel time would be between 18 and 52 days, compared to less than 1 day in the existing river. Surface velocities would normally be higher than the theoretical average velocities but since there is a predominant upriver wind in this area during spring and summer months, surface velocities affecting the migration of young fish could be considerably lower than indicated by theoretical calculations.

The anticipated loss of up to 85 percent of the downstream migrants in the reservoir could only be overcome by capturing the fish before they enter the reservoir, either at the head of the reservoir, at the lake outlets, or in the numerous tributary streams. The fish would then have to be safely transported by trucks or pipelines to the river below Moran Dam. Construction and operation of such a screening and transportation system would be so costly and would involve so many biological and physical operating problems for which solutions are not apparent at the present time that attempting to conserve the downstream migrants in this way does not appear feasible. Some loss of migrants in the reservoir would therefore be inevitable. If the loss of migrants was as high as indicated by the tests on Brownlee reservoir, commercial sport, and Indian fishing would have to be prohibited on those runs destined for spawning areas above the dam. However, important downriver populations migrate through the commercial and other fisheries at the same time and it would therefore be impossible to protect upriver runs and coincidentally harvest downriver populations.

(b) Altered water quality within the reservoir could have a serious effect on both upstream and downstream migrant salmon. The beneficial effect of river aeration would be lost for a distance of up to 170 miles due to creation of the reservoir. Oxygen replenishment in the reservoir would be restricted primarily to wave action and limited photosynthesis. Decay of plant and animal material could cause oxygen depletion both in the reservoir and in the river below the dam. The loss of the aerating effect of the river would have an increasingly pronounced influence in future years, with increased industrialization, urbanization and more intensive agricultural development of the upper Fraser system.

Surface layers of the reservoir would be warmed during spring, summer, and early fall months due to increased exposure to solar radiation. The resulting temperature change, especially during August and September, could alter the migrational behaviour of both adult and seaward migrant salmon. If adult salmon sound to depths of 20-50 ft to avoid high surface temperatures, they could encounter nitrogen supersaturation that would cause gas embolism when they return to the reservoir surface. Substantial numbers of fish might thereby be killed or injured in the reservoir.

(c) An extensive change in the discharge regime of the Fraser River would be an inevitable consequence of the construction of Moran Dam and would cause pronounced environmental changes, some of which could vitally affect salmon and steelhead production.

Seasonal, daily and hourly variations in power requirements would change the river discharge. Plant discharges could range from 0 (under conditions of emergency shutdown) to 102,000 cfs depending on the amount of power generated. The mean monthly discharge during June, the usual flood period, would be only 42-45 percent of normal river discharge at Moran and this reduction would cause the flow at Hope to be only 71-73 percent of normal river flow. The mean monthly discharge in winter months would be four or five times normal river flow at the dam. This would result in up to 2.5 times normal mean monthly flows at Hope.

Available data indicate that the reduction in total volume of flow from June 1 to Sept 15 would extend the period of migration of adult sockeye from the estuary, which could result in an average 9-day extension of the migration period for Adams River sockeye and possibly for other races also. The productive potential of these late-migrating fish would be reduced because spawning, egg incubation and fry emergence would be delayed in relation to the environmental cycle.

Reduced river discharge from July to September would interfere with migration of salmon through Hell's Gate, Bridge River Rapids and possibly other points of difficult passage. Additional fishways would probably be required at several locations. Despite the provision of such fishways, rapid fluctuations in water level caused by changes in power output at the dam, would deter the passage of adults and further aggravate problems caused by delayed spawning.

An observed correlation between marine survival of Chilko River sockeye and river discharge during smolt migration indicates that the lowered discharge during spring months would reduce sockeye production by 20-50 percent. The reduced discharge, through its effect on river velocities or estuarial conditions in Georgia Strait, could lower the smolt-to-adult survival rate for all salmon and steelhead runs to the Fraser River, not just those that spawn above the dam site. The effect of reduced freshet discharge on the environment in Georgia Strait might also reduce the survival of fry from pink and chum salmon runs of the Fraser River system. There is also some indication that the supply of certain essential nutrients in Georgia Strait is partly dependent on Fraser River flood discharges and the inevitable flow stabilization that would occur following construction of Moran Dam could have a serious adverse effect on production of Fraser River salmon and steelhead populations, marine species resident in Georgia Strait and other salmon and steelhead stocks that utilize Georgia Strait during part of their saltwater rearing period.

The altered discharge regime would tend to stabilize environmental conditions for resident predatory species well downstream and predation losses in the lower river would be expected to be much higher than under natural conditions.

Variations in the Fraser River discharge at Hope due to fluctuations in power generation at the dam would cause severe fluctuations in water elevation and river velocities, which would greatly reduce spawning efficiency and egg-to-fry survival in the extensive salmon spawning areas in the main stem of the Fraser River below Hope. In a low-water year, such as 1938, the daily change in water level could be as much as 7.7 ft during the spawning period and up to 10.0 ft during egg incubation.

(d) Moran reservoir would collect the river bedload and reduce the turbidity below the dam by settling out 85-95 percent of the normal suspended sediment load. The increased water clarity would probably increase predation loss of downstream migrants in the lower river, especially in view of the moderated discharge and temperature regimes below the dam. Sudden increases in the silt load of the river, resulting from the landslides likely to occur in the reservoir, could disorient downstream migrants and make them more susceptible to predation, deter upstream migrating adults and interfere with the spawning of salmon in the Fraser River below Hope.

(e) Predation losses would be increased due to the concentration of seaward migrants immediately above and below the dam. Assuming that a practical method could be devised for collecting downstream migrants in the forebay of the dam and for transporting them to tail-water, it is inevitable that predators would feed heavily on the milling fish in the forebay and on injured or disoriented fish released below the dam.

(f) Even with application of the most efficient methods for controlling temperatures below the dam and for passing adult salmon over the dam, there would be unavoidable delays and could affect reproductive productivity. The movement of adult salmon would be subject to the following delays: (i) an undetermined period by variable discharge resulting from hourly and daily changes in operation of the turbines, (ii) 1-2 days finding entrances to the fish facilities, (iii) 1-2 days passing through the fishway, (iv) an undetermined period of meandering and disoriented swimming in the reservoir, (v) an undetermined extent by the disorientation caused by environmental changes such as altered water quality below the dam, turbidity changes, and increased water temperatures at the reservoir surface.

The determinate delay of 2-4 days could prevent early migrating sockeye populations from reaching their spawning grounds and the additional delays of undetermined amount would increase the probability of the loss of spawners. Any delay would reduce the productive potential of the fish even if they were able to spawn, since the spawning time would not coincide with the environmental conditions to which each race is adapted.

10. Some of the fisheries problems that would be created by construction of Moran Dam might be solved by application of biological and engineering data secured at existing hydroelectric installations. Even with the extensive research that would be required before the experience gained at other installations could be applied at Moran, total solution of these fisheries problems could not be guaranteed. Fraser River sockeye, especially the upriver runs that would be directly affected by Moran Dam, appear to be particularly sensitive to migrational delay. There is no precedent for facilities to pass the large numbers of adult salmon that would have to be passed at Moran and there is no precedent for preservation of any salmon resource upstream from

a dam as high as that suggested for Moran. However, it is conceivable that the following problems might be solved on the basis of research data and experience at dams on other river systems and with other species of salmon:

(a) A conventional powerhouse collection system, with auxiliary entrances on each bank to attract fish during periods of spillway operation, appears to be the most practical method of collecting adult salmon below the dam. However, fish have been observed to reject passage facilities at high dams and the same might occur at Moran unless the water issuing from the fish facilities had the same characteristics as water in the river. Temperature is known to be an important characteristic but chemical differences may also be important.

(b) A weir fishway would appear to offer greater chance of success in passing adults over the dam than other possible transportation methods such as elevators, locks or tank trucks. However, the height of the dam, extent of reservoir drawdown and numbers of fish to be handled are so unlike conditions encountered at existing installations that the effectiveness of a fish collection and transportation system at Moran Dam cannot be predicted with certainty. Extensive studies, including prototype tests of certain aspects of the passage facilities, would have to be completed before construction was undertaken. The facilities would have to be designed to operate at all times of the year to pass present runs of 200,000 fish/day and up to 750,000 fish/day in future years.

(c) Preservation of the fisheries resources above Moran would require that downstream migrants be prevented from passing over the spillway or through the turbines because, on the basis of tests at other dams, the mortality rates would probably be so high that the survivors would not support commercial, sport and Indian food fisheries. Deeply submerged spillway and turbine outlets could not be used to prevent fish from entering these outlets because it would then be impossible to maintain suitable river temperatures below the dam. Collection of downstream migrants in turbine gate wells or the use of artificial guiding stimuli to lead the fish to bypasses would not effectively prevent the loss of fish in spillway and turbine discharges.

A self-cleaning wire screen barrier appears to be the only possible method of preventing emigration of seaward migrants from the Moran reservoir via the spillway and tunnel outlets. However, this method would involve unprecedented design and operating problems because of the large screen area required, the extremely large reservoir drawdown, and the problem of attracting fish to a bypass. The system would have to be designed to handle as many as 180 million fish/day.

(d) A pipeline from the bypass to tailwater appears the most feasible method of transporting the very large number of downstream migrants involved. Temperature change from the forebay to tailwater could cause a significant mortality among downstream migrants but the temperature difference could be minimized or eliminated by control gates in the forebay.

(e) Spilling of surplus water at the dam would cause supersaturation if aerated water from the spillway plunged into a deep energy dissipating pool below the dam. The resulting formation of gas emboli in adult and young fish passing through this water could cause blindness, injury and death. A large proportion of the fish could be injured and possibly killed not only immediately below the dam but possibly as far downstream as Seton Creek and Thompson River. The effects of supersaturation in the river below the dam would be accentuated among adult salmon if water temperatures in the fish passage facilities at the dam were higher than in the river. The supersaturation could theoretically be solved by careful design of the spillway but proof of successful application of the hypothesis has not yet been obtained.

(f) Protection of fish during the 5-year construction period would require temporary fish passage facilities, including a collection system below the construction area, a long bypass channel and weir fishway through the construction area and special headgates would be required on the diversion tunnels for controlling river elevation upstream from the construction site. Problems of collecting and safely transporting the adults would be at least as difficult to overcome during the construction period as during normal plant operation. Since it would be extremely difficult to collect the adults below the construction area if the cofferdams were overtopped during high water, the diversion tunnels would have to be large enough to carry the expected maximum discharge during the period of adult migration.

(g) Following completion of the dam, the reservoir would have to be filled to the minimum operating level of the permanent fish facilities as quickly as possible. It would theoretically be possible to minimize the interference to fish populations by filling the reservoir during the period from June 10 - 25, at which time the flow below the dam would have to be reduced to about 2,500 cfs. This flow reduction might affect smolt survival or the timing of migration of adults from the estuary.

11. Some of the fisheries problems that would be created by the dam could be overcome provided they were given adequate attention in early stages of the design of

the dam and provided enough money was made available for construction and operation of the necessary facilities. Problems in this category include the following:

(a) The natural temperature regime below the dam would have to be maintained by using a variable-depth outlet works for both the spillway and turbine discharges. With the powerhouse and spillway outlet structure suggested by the Fraser River Board, river temperatures below the dam would be somewhat colder than existing river temperatures from April to September and warmer than existing temperatures in October, November, and December. The temperature in July and August would be 8-19°F colder than temperatures in the existing river and up to 21° colder than the reservoir surface temperature. In October and November, temperatures below the dam would be 2-11°F warmer than the existing river. Release of cold water during summer months could lower the water temperatures in the Fraser River at least as far downstream as Hope. Warm water released in November would raise river temperatures over the whole length of the river. From December to March the release of warmer water at the dam would affect river temperatures as far downstream as Hope but would have little effect on natural river temperatures below Hope because the water would be cooled in the intervening section of river.

The lower-than-normal temperatures in the river the dam and higher-than-normal reservoir surface temperatures during summer and early fall months would reduce the swimming ability of upstream migrating adults and the resulting migrational delay could reduce the reproductive potential of the fish.

Increased river temperatures in the Fraser River below Hope in October and November would reduce the productivity of the large pink and chum populations that spawn between Hope and Vedder Canal.

Preliminary examination indicates that it would be possible to control the depth of flow from the reservoir into the suggested outlet channel at the dam by constructing a wall of segmental gates at the upstream end of this channel. With such control, it is estimated that the available water temperatures in the reservoir would provide the necessary temperature regulation below the dam.

(b) The altered discharge regime of the Fraser River below Moran would change the water levels during the time of migration of adult salmon through Hell's Gate, Bridge River and other points of difficult passage but additional fishways could be constructed at these locations to avoid delaying the migration.

12. Alternate methods of producing salmon appear to be completely impractical as a means of replacing the losses that would occur if the hydroelectric potential

of the Fraser was developed. It would be impractical, if not impossible, to substitute for the natural production of sockeye above Moran. Artificial spawning channels or other means of increasing the production of sockeye fry would be useless in the area below Moran unless associated with a lake rearing area. Most of the available rearing capacity for sockeye in the downstream lakes is already utilized and nearly all of the remaining capacity will be used by planned development projects.

Since natural rearing areas are therefore not available below Moran, total artificial rearing in hatcheries would be the only available means of replacing the loss of natural rearing areas above Moran. The fish would have to be reared for a full year until the normal time of seaward migration. Hatchery culture of sockeye has not achieved the success noted for certain other species since nutrition and disease problems frequently cause epidemic losses just prior to smoltification. Even if the techniques of hatchery culture of sockeye could be improved so that production rates would equal those for chinook and coho salmon, the hatchery would have to be located in the lower river area and it would be impractical to reproduce the early and mid-season stocks of sockeye that currently spawn above Moran. The present races would have to be replaced by later runs, which have a lower commercial value. Assuming that hatchery production of sockeye could be made as effective as for other species, a hatchery to produce a catch of 7.76 million sockeye, the annual potential of natural rearing areas above Moran, would cost about $206 million and annual operating and capital recovery costs would be about $27 million.

Since pink salmon do not require freshwater rearing, the pink salmon production potential above Moran could conceivably be replaced by artificial spawning channels in the lower river area. However, altered environmental conditions in the river and estuary could cause a marked reduction in fry-to-adult survival for all pink salmon populations. Spawning channels to offset this loss of production would subtract from the limited area available in the lower river for spawning channels that have been planned as development projects for increasing the total production of pink salmon.

Hatchery culture of chinook and steelhead has become more efficient in recent years and, although the cost would be very high, it is possible that the above-Moran populations of chinook and steelhead could be replaced by hatchery culture in the lower river area provided the river and estuary environment were not affected to such an extent that survival of the hatchery product was greatly reduced. Assuming the same rate of survival as in other hatcheries, the minimum cost of hatchery facilities would be $5.4 million and the annual cost would be about $700,000. It is probable that Moran Dam would greatly reduce the productivity of below-Moran salmon and steelhead populations and it would not be feasible to attempt to compensate for the expected losses of all five species of salmon as well as steelhead by means of hatcheries or artificial spawning channels. Expenditure of a minimum of $5.4 million for chinook and steelhead hatcheries might compensate for the $1.55 million annual value of the chinook resource above Moran but would not protect the $9.39 million annual value of the above-Moran sockeye resource, nor the $26.41 million annual value of populations spawning below Moran. The potential for increasing salmon and steelhead production would also be lost for all time.

13. Fish-passage and temperature-control facilities at Moran Dam are estimated to cost about $214 million but there appears to be no feasible method of avoiding losses of seaward migrants due to residualism and predation in the reservoir. If these losses proved to be as high as indicated by

measurements in Brownlee reservoir, the commercial, Indian food fishery and sport fishery values of above-Moran populations would eventually be destroyed.

14. It is estimated that the minimum effect of Moran Dam would be the loss of above-Moran salmon and steelhead production. It is probable that the commercial and Indian food fisheries on stocks spawning below Moran would be depleted by about 50 percent due to the environmental changes that would inevitably occur in the river and estuary. Based on minimum values of the Indian food fishery and with no allowance for the expected loss of sport fishery values, the probable annual loss due to Moran Dam is estimated to be $24.1 million based on wholesale value of present catches and $71.7 million based on potential catches.

15. Preliminary calculations based on 1970 prices indicate that the cost of power from Moran Dam delivered to the Vancouver area, including the cost of fish facilities and the value of the fishery resource that would probably be lost, would be about 12.2-13.6 mills/kwhr. This power cost would be higher than alternative thermal power generation.

CONCLUSIONS

1. The minimum effect of Moran Dam would be the destruction of all salmon and steelhead trout populations that spawn upstream from the dam.

2. It is probable that the catches in commercial, sport and Indian food fisheries of salmon and steelhead trout populations that utilize the Fraser River and its tributaries downstream from Moran would be reduced by about 50 percent due to environmental changes in the river and estuary.

3. Hatcheries and other alternate methods of production could not be used to compensate for existing natural production.

4. The resource values represented by existing runs of salmon and steelhead that would be lost if Moran Dam were constructed would increase the cost of Moran power to the extent that alternate power sources would be more economical.