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

PREPARED BY THE
TECHNICAL STAFFS OF THE DEPARTMENT OF FISHERIES OF CANADA AND THE INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

IN COLLABORATION WITH
THE BRITISH COLUMBIA GAME COMMISSION AND THE BRITISH COLUMBIA FISHERIES DEPARTMENT

VANCOUVER, B. C.
APRIL, 1958

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FISHERIES PROBLEMS RELATED TO

THE PROPOSED MORAN DAM ON THE FRASER RIVER

INTRODUCTION

At a meeting on November 17, 1955, fisheries agencies in British Columbia were advised that Moran Power Development Limited had been formed for the purpose of constructing a large hydroelectric dam on the Fraser River at Moran. Auxiliary power, storage and diversion dams would be constructed on the Fraser River and its tributaries and on the Babine and Peace Rivers. The primary object of the development would be the establishment of metallurgical industries requiring large amounts of electric energy, although surplus power could be made available for other uses.

The company reported that it had applied to the Provincial Government for a water license for the initial stage of the proposed development, Moran Dam, but had been advised that the application could not be received because of a reserve which the government had placed on the Fraser River between Quesnel and Lytton. Provincial authorities also advised the company it would be necessary to obtain the approval of the various fisheries agencies that would be concerned under authority of Provincial and Federal legislation. Subsequently, several meetings were held with the company to obtain information on which to base studies of the fisheries problems. The fisheries agencies indicated considerable time would be required to make an adequate appraisal of the fisheries problems and to investigate possible solutions to them. It was agreed that when such studies had been made, a report of the findings would be submitted to the company.

Since the initial meeting biologists and engineers have been studying the fisheries problems related to one particular phase of the proposed project: the protection of salmon and trout at the proposed high dam at Moran. The additional problems that would be created by the many storage and auxiliary dams proposed for construction after Moran Dam is completed have not been studied in detail although they may be as difficult to solve as those associated with Moran Dam. This report, dealing solely with Moran Dam, describes the fisheries problems that would be created at Moran Dam and reviews the status of present knowledge of various means that might be considered for overcoming these problems.

DESCRIPTION OF THE PROPOSED MORAN DAM

The following information, which is pertinent to the evaluation of fisheries problems at Moran Dam, is taken from a report - "Moran Dam Brief" - which was transmitted to the Federal Department of Fisheries on January 24, 1956. The preliminary plan and sections of the dam are shown on Figures 1 and 2.

Moran Dam would be constructed on the main stem of the Fraser River 25 miles upstream from Lillooet. It would be a concrete gravity-arch structure having a total height of nearly 800 feet and a total crest length of about 3,200 feet. Maximum head at the dam would be

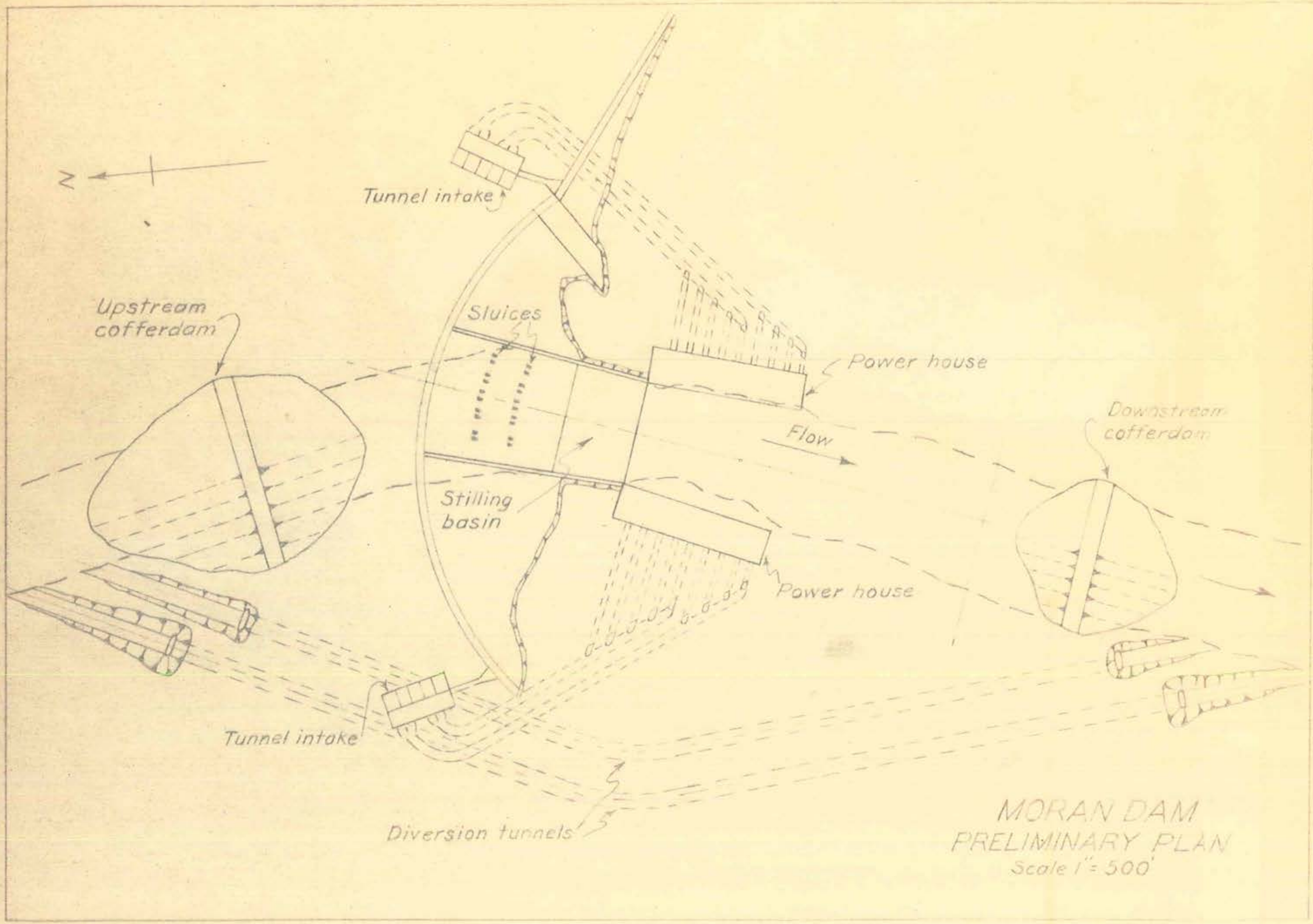
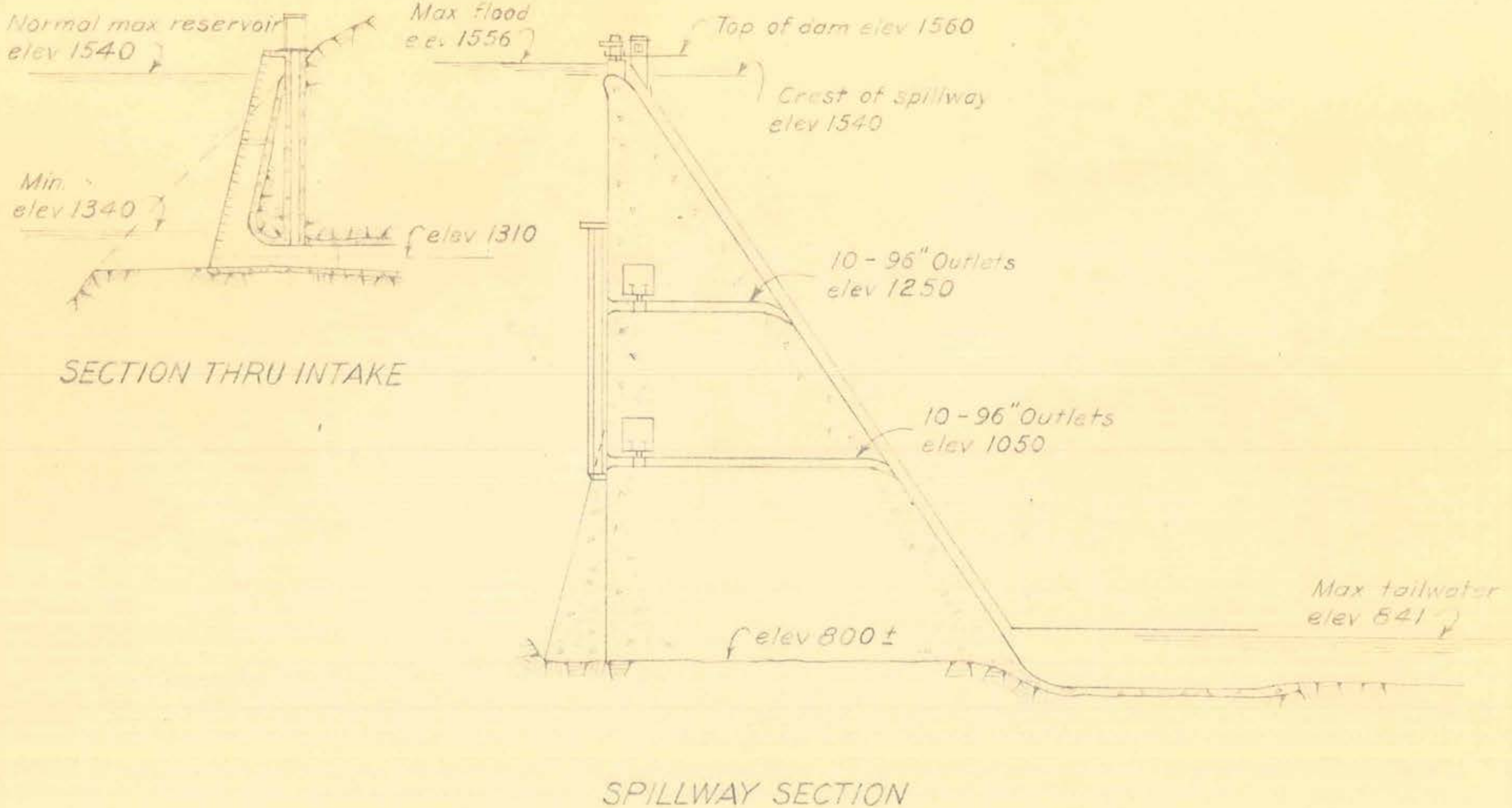

N
Tunnel intake
Upstream cofferdam
Sluices
Power house
Flow
Stilling basin
Downstream cofferdam
Power house
Tunnel intake
Diversion tunnels
MORAN DAM
PRELIMINARY PLAN
Scale 1" = 500'

FIGURE-1



MORAN DAM
SECTIONS
Scale 1" = 200'

FIGURE - 2

750 feet, but for substantial portions of each year the head would be less than this due to reservoir draw-down and increased tailwater levels. The reservoir would extend upstream for a distance of 172 miles, almost to the town of Quesnel. The average width of the reservoir would be 3,140 feet and the area of the reservoir at maximum elevation of 1,540 feet would be 65,000 acres. At this elevation the water would also flood approximately 9 miles up the Chilcotin valley. It is proposed that a live storage of 9,000,000 acre-feet would be obtained at Moran Dam and that water would be removed from storage from October through March and probably in April. The dam would be designed for a maximum reservoir draw-down of 200 feet. In an average water year, the reservoir would not be full until some time in July.

The proposed initial stage of development would consist of 18 turbine-generator units, 9 on each bank. Each turbine would be designed for a flow of 2,850 cfs. These turbines would be placed in two powerhouses facing each other on opposite sides of the river below the dam. It is stated that in the ultimate development, which might be reached within 15 to 25 years from the start of the original project, 30 units would be required. However, upstream storage plus diversions into the Fraser system from other watersheds would be required to provide sufficient regulated flow for this ultimate development.

Water for power generation would be drawn from the forebay through two tunnel intakes on each bank located 230 feet below the maximum reservoir elevation. The initial development would require the construction of two 30-foot diameter tunnels on each bank but provision would be made for the future construction of a third tunnel on each bank.

Surplus water would be spilled by means of twenty 8-foot diameter regulating valves or pipes through the dam, 10 of which would be placed 490 feet below the crest of the dam and the other 10 would be 290 feet below the crest. If the reservoir rises higher than the crest of the dam, spilling would occur along a 500-foot length of crest. The spill discharge valves would have a capacity of 100,000 cfs, and the crest overflow a capacity of 100,000 cfs. The spillway would be designed so that considerably greater flows would not harm the structure.

Upstream diversions and supplementary storage dams would add to the power potential at Moran. It is proposed that 8,550,000 acre-feet of storage be obtained at Babine Lake, Stuart Lake, Grand Canyon, Cottonwood Canyon and Quesnel Lake. If these upriver storages were developed, the Moran reservoir could be operated with a maximum draw-down of about 100 feet. The proposed diversions would consist of a low dam on Babine Lake to divert 2,080 cfs into Stuart Lake by a canal and tunnel, and a high dam on the Peace River to divert a regulated flow of about 15,000 cfs to the Fraser River.

It has also been suggested that a power dam having a head of 125 feet would be constructed 10 miles downstream from Moran in order to take advantage of the regulated flow provided by Moran Dam.

EXPECTED FLOW CONDITIONS AT MORAN DAM

Moran Dam, like other large hydroelectric projects, would probably be developed initially to produce a relatively small amount of power, with additional generating units being installed later from time to time when needed. Eventually, however, the full potential of the Moran reservoir would be reached, and it would not be possible to increase the plant output without the benefit of additional storage. The large upriver storage sites that have been proposed would be developed as they were needed.

It is evident, therefore, that operating conditions at Moran Dam would be changing constantly for a number of years. As the plant operation altered, so too would the reservoir levels, tailwater elevations, plant flows, spillway discharges, forebay velocities, etc., all of which are important considerations in evaluating fishery problems and in designing necessary fish facilities at the dam. Since these facilities would have to be operable at all stages of the development, the operating limits can be estimated by analyzing the plant characteristics and operations during initial development, maximum development without auxiliary storage, and maximum development with auxiliary storage.

It is anticipated that upstream storages would be utilized chiefly to maintain full reservoir at Moran in order to benefit from maximum head on the turbines at this site. Thus, since the net effect of upstream storages and diversions would be to reduce reservoir drawdown and to make more water available for power generation, the effects of upstream storages need not be considered in this analysis except in that they would increase the plant discharge at certain times of the year.

Daily discharges of the Fraser River at Jesmond have been recorded by the Water Resources Division since 1935. Flows at Moran can be assumed to be the same as those at Jesmond. However, for the purpose of this analysis, the discharges recorded prior to October, 1952 must be reduced to compensate for the Nechako River diversion.

Examination of the discharge records, adjusted for the Nechako diversion, discloses that the lowest mean annual flow occurred in the water year 1943-44, whereas the highest mean annual flow and the highest daily flow occurred in the water year 1947-48. The computations show that in 1943-44, with 9,000,000 acre-feet of storage available in the Moran reservoir, the mean daily plant discharge at full development with 18 turbine-generator units but without additional upstream storage would have varied between 35,000 cfs and 45,000 cfs, depending upon the prevailing head. There would have been no wastage or spill. To maintain these flows, however, the reservoir would have to be drawn down 180 feet at the end of April. Since this estimate is based on only 20 years of record, however, it would seem logical to assume that the proposed full draw-down of 200 feet could occur at Moran Dam.

For the production of the same quantity of prime power in 1947-48, plant discharges would be smaller than in 1943-44 because of higher prevailing heads. Computations with regard to spill are based upon the supposition that the reservoir would be filled as soon as possible after draw-down in order to be assured of that quantity of water, as well as to operate at the highest possible heads. Thus, it was found that in 1947-48 the reservoir would have been filled by June 3, 1948. Natural flows would have prevailed below the dam for some time thereafter, with part of the flow passing through the plant and the remainder being wasted as spill. Calculations show that under these conditions the maximum daily flow to be passed at full reservoir in 1948 would have been 219,000 cfs. At full head the mean daily plant flow would have been approximately 35,000 cfs, so the remainder, or 184,000 cfs, would have been wasted as spill.

The maximum recorded daily discharge of the Fraser River at Jesmond occurred on May 31, 1948, when it reached 289,000 cfs. If the Nechako diversion had been operating at this time, it is estimated that the flow at Moran would have been approximately 266,000 cfs.

On the basis of discharge records, the 50-year flood of the Fraser River at Jesmond, allowing for the Nechako diversion, has been calculated to be about 285,000 cfs. It is possible that a flow of this magnitude might occur at a time when the reservoir is full. Prior to development of additional upstream storage the mean daily plant flow would be about 35,000 cfs. It is conceivable, however, that mean daily flows might be as low as 15,000 cfs during the initial stage. Therefore, during all stages of development, it is expected that daily flows below the dam might vary from 15,000 cfs to 285,000 cfs. Preliminary plans of the Moran Power Development Limited include the ultimate installation of 30 turbines, each discharging 2,850 cfs. Thus the maximum instantaneous plant discharge might be as high as 85,500 cfs. For a fluctuation in discharge from 15,000 cfs to 285,000 cfs, the tailwater would vary between elevation 782 and elevation 828 - a range of 46 feet.

In summary, the foregoing analysis has shown that the following estimates outline part of the design criteria for fish facilities at Moran Dam:

Minimum daily plant discharge - 15,000 cfs.

Maximum instantaneous plant discharge - 85,500 cfs.

Maximum discharge through reservoir - 285,000 cfs.

Maximum spill discharge - 270,000 cfs.

Headwater fluctuation - elevation 1340 to elevation 1540.

Tailwater fluctuation - elevation 782 to elevation 828.

VALUE OF THE FISHERIES RESOURCES

At the present time a substantial number of spring salmon and steelhead trout and about 39 per cent of the Fraser River sockeye salmon originate above the site of the proposed dam. As a result of efforts being made to rehabilitate certain races in this area that were decimated by the obstruction at Hell's Gate, the populations originating upstream from the proposed dam have a tremendous potential for future expansion. Removal of obstructions to migration, rehabilitation of sockeye populations in depleted areas, and scientific regulation of the commercial fishery to ensure adequate escapements of fish to the spawning grounds have brought about substantial increases in production. By continued application of scientific management procedures, and by constant attention to the maintenance of proper environmental conditions along the migration routes and on the spawning grounds, the commercial catch can continue to increase and the tremendous catches made prior to the disaster at Hell's Gate in 1913 might again be realized or even exceeded in the near future. Table 1 presents statistics on the catches of sockeye in the period 1910-13 and the period 1953-56. It will be noted from this table that at current production levels approximately forty per cent of the commercial catch of Fraser River sockeye is taken from runs originating above the dam site. This catch is valued at $7,343,966 annually at 1956 domestic wholesale prices. However, the sockeye catches for the four years prior to the Hell's Gate slide (1910-13) were almost double present catches. On the basis of the distribution of present production and known areas in which former large runs occurred, it is estimated that at potential levels of abundance 60 per cent of the production of Fraser River sockeye will come from the watershed above the Moran Dam site (1). The catch from these runs would be valued at $21,688,579 annually at 1956 wholesale prices.

Value of the Sockeye Runs

Originating Above The Proposed Moran Dam Site

In The Periods 1910-13 and 1953-56

Year	Total Sockeye Production in Cases (B.C. Origin)	Total Sockeye Production in Cases (Fraser R. Origin)	Total Sockeye Production in Cases Origin Above Dam Site	Percentage B.C. Origin From Above Dam Site	Percentage Fraser R. Above Dam Site	Value Above Dam Site	Mean Value Per Year
1910	680,884	398,446					
1911	511,270	186,248					
1912	629,442	308,559					
1913	2,645,277	2,392,895					
Totals	4,466,873	3,286,148	1,971,689	44.1	60.0 (1)	$86,754,316	$21,688,579
1953	688,470	354,420	322,522	46.8	91.0	$14,190,977	
1954	1,182,214	988,301	128,479	10.9	13.0	$ 5,653,082	
1955	329,957	180,513	87,007	26.4	48.2	$ 3,828,320	
1956	404,176	168,348	129,628	32.0	77.2	$ 5,703,632	
Totals	2,604,817	1,691,582	667,636	25.6	39.5(Mean)	$29,375,984	$ 7,343,996

All Values Based on Mean Domestic prices - 1956.

The present wholesale value of the Fraser River spring salmon run is approximately $3,000,000 annually (1). Since about 50 per cent of these fish spawn above Moran, the present annual value of the spring salmon runs that originate upstream from the proposed dam is approximately $1,500,000. No information is available concerning the potential or historical production of spring salmon in these areas but it is likely that the present production could be exceeded.

It is very difficult to assess the commercial and recreational values of the steelhead and other trout fisheries that would be affected by the proposed dam. In 1954, the commercial catch of steelhead in the Fraser River gill net fishery had a wholesale value of $22,600 but this amount is insignificant in comparison with the recreational value of this species. It has been estimated that the present salt-water sport fishery in the Vancouver, Howe Sound and Sechelt areas is worth $3,000,000 annually. In addition, a substantial fresh-water sport fishery would be affected by the proposed Moran Dam.

The sockeye runs to the Fraser River above the Moran site have been for centuries and still are a principal source of food for many native Indian families. Each year substantial numbers of sockeye are caught at numerous ancestral fishing sites all along the Fraser River from Hope to Fort St. James (32). While it is difficult to assign a monetary value to these catches, they are nevertheless a significant contribution to the total income of these families.

In summary, the present annual wholesale value of the commercial fishery for sockeye and spring salmon originating above the Moran Dam site, is approximately $8,800,000 and the potential annual value at today's prices probably exceeds $23,188,579.

The present wholesale value of the Fraser River spring salmon run is approximately $3,000,000 annually (1). Since about 50 per cent of these fish spawn above Moran, the present annual value of the spring salmon runs that originate upstream from the proposed dam is approximately $1,500,000. No information is available concerning the potential or historical production of spring salmon in these areas but it is likely that the present production could be exceeded.

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In summary, the present annual wholesale value of the commercial fishery for sockeye and spring salmon originating above the Moran Dam site, is approximately $8,800,000 and the potential annual value at today's prices probably exceeds $23,188,579.

It should be noted that this potential value is conservative and that a much larger value could be derived on the basis of the evaluation made by the Gordon Economic Commission. The value of the salt water and fresh water fisheries and the Indian catches must also be added to the totals, although it is difficult to determine their actual monetary value.

PROBLEMS ARISING DURING THE CONSTRUCTION PERIOD

The first problems involving the protection of fish at the proposed Moran Dam would arise during the construction period, which is expected to last about five years. During this period, facilities would have to be provided to ensure the safe and undelayed passage of both downstream migrants and adults. The numbers of adult salmon to be passed would depend upon the timing of construction with respect to the progress in rehabilitation of the sockeye salmon runs. At the present time, the maximum daily escapement consists of approximately 140,000 sockeye, but in a very few cycles this may be increased to 750,000 sockeye (1) as a result of current rehabilitation of depleted runs.

It has been proposed that two cofferdams be constructed across the river about 3500 feet apart, above and below the work site and that all river flows up to 100,000 cfs would be diverted through two diversion tunnels, each approximately one mile long. The upper cofferdam would be at least 100 feet high to create the necessary head on the diversion tunnels. Two 50-foot diameter unlined circular tunnels have been proposed for the diversion and it has been suggested by Moran Power Development Limited that these tunnels could be utilized for upstream and downstream passage of salmon and trout.

Downstream migrations of sockeye, spring and steelhead smolts occur each year in the period April 15 to July 15. After deducting the

Nechako diversion river flows in this period would range from 13,000 to 61,000 cfs at April 15 to a maximum of 94,000 to 285,000 cfs at the flood peak in May or June. Adult migrations of sockeye occur in the period July 2 to October 2, spring salmon in the period March 1 to November 15, and steelhead trout possibly throughout the year. Thus, adult salmon and trout would require upstream passage at the dam during all river stages, from the minimum low flow to the maximum flood discharge of 285,000 cfs.

Since the diversion tunnels as specified are designed to pass only 100,000 cfs, there would be a period, at least in the first year of construction, when the cofferdams would be overtopped and water would flow through the construction area during both the upstream and downstream migrations of salmon. Overtopping could also happen in one or more subsequent years, depending on river flows and the height of the partially constructed dam. The head on the diversion tunnels could be 70 feet or more before the cofferdam was overtopped, and velocities through the tunnel 30 fps or more. Because of these high heads and velocities, the diversion tunnels could not be considered as a means of passing adult salmon and steelhead trout around the construction area, nor could they be considered as satisfactory for the passage of downstream migrants.

Furthermore, passage of downstream migrants through the construction area could not be considered satisfactory due to the mortalities that would be incurred by the fish in falling up to 70 feet or more over the rough surface of the cofferdam. Trapping of the migrants between the two cofferdams would also have to be avoided.

Because of the large size of the fishways necessary during the construction period it is considered impractical to attempt to provide passage for the adults through a tunnel, even if it could be so constructed and suitably baffled to operate over the anticipated range of heads, since in effect it would be necessary to construct a special third tunnel. This tunnel would be approximately one mile long and it is not known to what extent fish would use it since it would be dark throughout most of its length. Current information does not indicate to what extent artificial lighting would be successful in promoting migration, even if the practical difficulties of such lighting could be overcome. Therefore it is considered that the most feasible solution would be to provide suitable fishways passing through the two cofferdams and the construction area.

Construction phase fishways would have to be operable throughout the year right up to the time when the diversion tunnels are closed and reservoir filling commences. Thus the dam would have to be constructed around the fishway and necessary closures would have to be made when the diversion tunnels are closed.

In order to permit these fishways to operate over the expected range of river flows and to prevent mortality to downstream migrants at the two cofferdams, the diversion tunnels and upstream cofferdam should be constructed to permit the entire maximum river flow to pass through the tunnels without overtopping the cofferdam. Moreover, in order to prevent delaying the downstream migrants and to reduce velocities and heads in the tunnels during the period of downstream migration, tunnel intake submergence should be limited to 30 or 40 feet at maximum flow.

It might also be necessary to line the tunnel walls, since at higher water velocities there might be considerable mortality to migrants in passing through tunnels with rough walls. Reference to the measured mortalities to young salmon passing over the spillways at Baker and Elwha Dams emphasizes the severe mortalities which can be caused by abrasion on rough surfaces (2, 3).

It is estimated that these requirements could be satisfied by two 70-foot diameter tunnels with upstream invert at elevation 785 and an upstream cofferdam high enough to provide sufficient freeboard above elevation 896. With this arrangement, the construction period fishways would have to overcome heads varying from a minimum of about 13 feet to a maximum of about 70 feet. The operating range would be 47 feet at tailwater and 104 feet at headwater.

Because of the attraction of the outflow from the diversion tunnels, it would not be feasible to attract the migrating adults to a fishway entrance in the vicinity of the tunnels or upstream from them. It is considered that the only feasible method of collection would be to install a low barrier dam downstream from the diversion tunnels which would create impassable velocities across the midsection of the river and thereby lead the fish naturally to fishway system entrances located on each bank. This collection system could become part of any permanent fish facilities considered feasible. While two fishway entrances would be necessary, it may be possible to design the collection system to lead into one fishway structure.

The fish exit would have to be located well upstream from the diversion tunnel portals and should be designed to prevent fish from being carried downstream through the tunnels. Even at Bonneville Dam, where there is a wide forebay with low velocities, there is evidence that adults pass downstream over the spillway. There is no known method of ensuring that adult salmon would not be swept downstream through the tunnels after passing through the fishways at Moran and it seems inevitable that a proportion of the fish would be lost in this way. The only method of alleviating this problem would be to release the fish in a relatively low-velocity area as far upstream from the tunnels as possible.

Thus the entire fishway system from entrances to exits would be over $1\frac{1}{4}$ miles long. There is no precedent for such structures, either in length or in operating requirements. Because of the large difference in headwater and tailwater variations, it would not be possible to use the Hell's Gate type fishway baffle. It is possible that either the weir type of fishway with segmental weirs, or the vertical slot type with adjustable width slots, could be used. Extensive hydraulic model studies would be required to determine the feasibility and design of the hydraulic features of such fishways. Detailed consideration of operating problems would also be required before an acceptable design could be made.

It must be emphasized that these construction phase fishways would have to overcome a head greater than that at Bonneville Dam and would have to operate through more severe ranges of water level. While the Bonneville fishways do provide passage for adult salmon, there are still unexplained differences in the counts of salmon at Bonneville and McNary Dams which indicate a considerable loss of salmon between the two dams. Whether or not this is due to the effects of passage over Bonneville Dam is not known. However, it is such unknowns that make it impossible at this time to determine the effectiveness of the fishways required for the construction period at Moran Dam. It is possible that the fish would be reluctant to remain in such a long fishway system and would drop back. Variations in flow pattern are known to interrupt the movement of fish causing large numbers of them to retreat down the fishway. It is essential that all such interruptions be avoided, but it may be difficult to do this when continuous adjustments to the fishway are necessary to meet constantly changing hydraulic conditions.

The barrier dam suggested as a means of leading fish naturally to fishway entrances is unprecedented in scale. Hydraulic model tests would have to be made to design and test the spillway and fish entrances to ensure that the desired flow patterns would be obtained.

Thus, it is evident that considerable investigation and study would be required before the fish protective facilities for the construction phase alone could be designed.

PROBLEMS DURING RESERVOIR FILLING PERIOD

Since the construction phase fishways could not be in operation when the reservoir is filling, the permanent fish facilities would have to be operable as soon as the temporary ones are abandoned. This requirement would extend the operating range of the permanent facilities beyond that which would otherwise be required, since the initial forebay level could be 450 feet or more below normal minimum operating forebay elevation. However, if the reservoir filling period is properly timed with respect to upstream and downstream movements of sockeye, this requirement could be modified without interference with essential performance of the facilities.

Interference with the salmon migrations at the dam during the filling period could be held to a minimum if the reservoir were filled in the period between the end of downstream migrations of sockeye and the beginning of upstream migrations of sockeye or conversely, between the end of the upstream migrations of sockeye and the start of downstream migrations of sockeye. Interference with the migrations could not be completely avoided since adult migrations of other species occur throughout most of the year. Therefore, even though these periods are used for filling, auxiliary facilities would be required for the other species.

Approximately 5 million acre-feet of water would be required to fill the reservoir to normal minimum forebay elevation of 1340 feet. The entire flow of the river could not be impounded during the filling period, since a residual flow would be required for transportation of adult salmon, maintenance of flow over pink salmon spawning grounds in the Fraser River below Hope, and possibly to protect other interests downstream.

In determining the magnitude of the residual flow consideration must be given to the effect of reduced flows in the reach from Moran to Lytton and from Lytton downstream. In the Moran to Lytton reach, two rapids near the confluence of Bridge River with the Fraser River formerly obstructed the passage of sockeye. These obstructions were remedied by two fishways constructed at the site in 1945. These fishways are designed to operate over a range in river flows from 90,600 cfs to 19,200 cfs and a range in water surface drops ranging from 2.75 to 1.5 feet at the upper limit to 9 to 10 feet at the lower limit. While the fishways were designed to provide passage for sockeye salmon, they also assist spring salmon and steelhead trout. Since the drops continue to increase as river flow decreases, additional remedial action may be required if the river flow is artificially reduced below 19,000 cfs. Additional information on extreme low water profiles at these points would be necessary for assessment of a possible low water obstruction.

In the reach below Lytton, fishways at Hell's Gate provide passage at all discharges between 64,000 cfs and 282,000 cfs for salmon runs to the Thompson River system as well as those to the Fraser River system above Lytton. Sockeye migrations in this reach start on July 9 and in some years continue until October 26. Spring salmon and steelhead migrations have about the same duration as at Moran. Pink salmon migrations start on about September 1 and continue until October 15, and coho salmon migrate between August 1 and November 30. If the Fraser River were shut off at Moran during these migrations the discharge at Hell's Gate would be reduced below the operating range of the fishways. This flow reduction would have no special significance at Hell's Gate if it occurred after October 15 since this is a normal occurrence in 60 per cent or more of the years of record. The populations of fish in the river that would be affected after that date would be small and could find adequate passage on the left bank at Hell's Gate. Such reductions in flow prior to October 15, however, could result in a serious obstruction to passage at Hell's Gate due to the large number of salmon that would be affected by the abnormal river levels. In order to avoid such an occurrence it would be essential, therefore, that the dam not be closed during the adult migration prior to October 15. This requirement limits the two possible filling periods to between October 15 and April 15 and from about June 15 to July 1.

Reductions in flow in the period October 15th to April 15th could very seriously affect the success of spawning and incubation of large pink and chum salmon populations which spawn in the Fraser River below Hope. Pink salmon are present only in odd numbered years but chum salmon are present every year. Careful consideration would have to be given to the timing of the closure of the dam with respect to the spawning times of these fish and to the required residual flows to minimize loss of deposited eggs through exposure.

It is tentatively suggested that at least the minimum river flow of 4000 cfs be passed through the dam at all times, although this may have to be increased on the basis of analysis of the flow requirements in the Fraser River below Hope during the spawning and incubation period of pink and chum salmon. If the reservoir filling could proceed so as to reach the minimum operating level of 1340 before the downstream migrations start about April 15, it would not be necessary to extend the operating range of the downstream migrant facilities to water levels prevailing at the start of filling. On the basis of 4000 cfs residual flow, the necessary storage could have been obtained between October 15 to April 15 in fifteen out of twenty years of recorded flows. However, even in the year of lowest recorded runoff for the period, the required minimum storage could have been completed by about May 5, which would still be in advance of the bulk of the downstream migrations. Reservoir filling during this period thus would provide a means of avoiding extension of the operating range of the downstream migrant facilities. However, spring salmon and steelhead trout would be migrating in part if not all of this period. Since the numbers of these fish involved in any particular year would not be large in comparison to the sockeye runs, temporary measures to handle them during the filling period might be considered. These measures might involve the use of an aerial brail or tank trucks or similar devices. Alternatively, if these measures are not possible, it would be necessary to extend the operating range of the adult facilities.

If the reservoir could be filled to minimum forebay elevation in the period June 15 to July 1, the same conditions as above would prevail with respect to upstream and downstream migrations. Allowing the 4000 cfs residual flow as before, examination of the flow records for the period shows that the reservoir could not be filled to minimum forebay in this period in any year of record.

Thus it appears that the time of filling of the reservoir could be scheduled so that the adverse effects on the fishery could be held to a minimum, at the same time avoiding excessive operating requirements for any permanent fish protective facilities.

It should be emphasized, however, that the conclusions reached in this section are based on preliminary estimates of the actual depth-volume relationships in the proposed reservoir, and that the length of the filling period, and storage volume required may be modified when more accurate estimates become available.

PROBLEMS RELATED TO DOWNSTREAM MIGRATION

A. Reservoir Environment

Each year young sockeye and spring salmon and steelhead trout migrate down the Fraser River past the site of the proposed dam at Moran. The sockeye are principally one year old fish which originate in the rearing areas of the Chilcotin, Quesnel, Bowron, Stuart and Nechako River systems. The exact timing of these migrations is not known for all of these rearing areas, but at Chilko Lake the seaward migrations commence about April 15 and continue until June 15. These migrations are associated with rising water temperature and the river freshet. Periodic sampling indicates that similar dates apply to the other rearing areas. Most spring salmon migrate to sea as advanced fry although some remain in the rearing streams for a year and migrate as yearlings or smolts. The timing of these migrations is from April 15 to June 30. Young steelhead trout migrate seaward after two or three years residence in fresh water rearing areas. In the Nicola River system these migrations start on about April 15 and continue to July 15 and it is believed that the same timing applies to the runs in the Fraser above Moran.

The mechanisms that initiate the seaward migrations and lead the fish through and from lakes are not completely understood at the present time, but it is known that these migrations are related to the environmental cycle and complex physiological processes.

There is a considerable range in length of the various species as they migrate downstream. Yearling sockeye usually range in length from 2 to 5 inches, but sockeye that spend more than one year in fresh water are sometimes as long as 7 inches. Some spring salmon and steelhead trout are as much as 8 inches long, but most spring salmon migrants have about the same range of length as year-old sockeye.

Of the several species of salmon and trout that migrate downstream past the Moran Dam site, sockeye are the most abundant. At the present time, in the years of maximum abundance, the Chilcotin system produces about 30,000,000 migrants, the Nechako system about 15,000,000, the Stuart system about 40,000,000, and the Bowron system about 1,000,000. The Quesnel system runs are now being rehabilitated and it is currently estimated that at least 100,000,000 and possibly 150,000,000 migrants will be produced in the maximum year when these runs are restored to historical levels. The adult runs to the Stuart system are also increasing and it is estimated that these runs will produce at least 75,000,000 migrants in the dominant cycle. Studies at Chilko Lake have shown that about 35 per cent of the migrants leave the lake in a single 24-hour period. If the Quesnel system migrants behave in a similar manner, an estimated maximum of 45,000,000 migrants may be expected to leave Quesnel Lake in a 24-hour period. It is possible that, due to climatic conditions, the peak migrations from the various rearing areas may be concurrent, and taking into consideration the different years of cyclic production in the individual runs, the peak daily migration at Moran could be far in excess of 45,000,000 and possibly as much as 100,000,000 migrants.

The variability in the timing of the migrations of the various species has been mentioned. Since most of the migrations occur in the period April 15 to June 30, this period will be used as the basis for considering the problems related to the passage of young salmon and steelhead trout through the reservoir and over the proposed dam. The problems associated with migrations at other times of the year will be essentially the same, although perhaps modified in detail, and will not be dealt with separately except where it is known that special problems might arise.

Assuming as previously discussed, that the reservoir is filled initially to reach a minimum forebay elevation of 1,340 by April 15, the vanguard of the first downstream migration would enter the reservoir in the vicinity of the mouth of the Chilcotin River. As the reservoir continues to fill, the point of entry would move upstream until at maximum reservoir elevation it would be in the vicinity of Quesnel. In subsequent years, the point of entry would vary between these limits and would be determined by the reservoir draw-down during the winter and the rate of filling in the spring. This reservoir would produce an entirely different environment for the migration than that of the existing river and the effects of this different environment on the migration must be carefully considered.

One of the important changes would be a reduction of velocities in the flooded section of river. During the period of downstream migrations recorded discharges in the Fraser River range from a minimum of 12,600 cfs below Quesnel and 13,000 cfs at Jesmond to a maximum of 205,000 cfs below Quesnel and 266,000 cfs at Jesmond, after deducting the Nechako River diversion. Data concerning the Fraser River between Quesnel and Moran is insufficient to make precise estimates of the time required for water to traverse this reach. On the basis of the river sections at Quesnel and Jesmond and the average river slope for the reach, it is estimated that at minimum flow for April 15, the travel time from Quesnel to the Chilcotin River would be 26 hours and from the Chilcotin River to Moran would be 19 hours, or a total of 45 hours from Quesnel to Moran. At maximum river flow the travel time from Quesnel to Moran is estimated to be 18 hours. Recently completed surveys in the Chilko River have shown that the rate of movement of migrants downstream is approximately the same as river velocity. It was also found that the fish feed during the migration.

Velocities in the forebay of the proposed dam would range from 3 to 14 fps in the normal river at the head end, down to 0.026 fps or less near the dam depending on forebay elevation and river and plant discharge. It is not considered necessary at this time to study in detail the velocities that would occur with different combinations of plant and river discharge and reservoir elevation. Sufficient indication of the magnitude of the difference in velocities can be obtained by considering an average water year with average plant discharge and an allowance for by-pass discharge. Assuming a minimum reservoir elevation on April 15 consistent with an average water year the average time water would take to travel from the head end of the reservoir to the dam during the period of downstream migration would be as shown in Table 2. These estimates show, that for an average year, the time required for water to travel from Quesnel to the Moran site would be increased from less than 2 days in the natural river to at least 57 days in the reservoir, an increase of almost thirty times. Figure 3 shows the travel time from the upper end of the reservoir to the dam for the various conditions of inflow, outflow and storage listed in Table 2.

Table 2

Estimated Total Elapsed Time for Movement of Water Through the Proposed Moran Reservoir in an Average Water Year

Starting Period	Reservoir Elevation At End Of Period	Average Inflow cfs	Average Outflow cfs	Average Storage cfs	Total Time Hours	Total Time Days
April 15-20	1,410	43,000	43,000	0	1,609	67.0
April 21-30	1,420	55,000	43,500	11,500	1,535	64.0
May 1-15	1,440	73,700	43,500	30,200	1,425	59.4
May 16-31	1,490	113,000	43,500	69,500	1,369	57.0
June 1-10	1,515	121,000	43,500	77,500	1,436	59.7
June 11-30	1,540	113,500	61,100	52,400	1,621	67.5
July 1-15	1,540	101,500	101,500	0	2,253	93.8
July 16-31	1,540	85,000	85,000	0	2,778	116

It is not possible to predict with certainty what effect these reduced velocities will have on the downstream migrants. The migrations from the various rearing areas are timed to suit a relatively fixed environmental cycle. Complex physiological changes take place in the fish before and during these migrations to prepare the fish for their ocean environment. For each particular race of migrants these changes are probably adapted to the particular migration path and environmental changes encountered. Thus the Stuart River runs are probably adapted to long migrations through Stuart and Trembleur Lakes, whereas the Chilko, Horsefly and Stellako runs may not be. For any of these races, however, the addition of a 170-mile long artificial lake in the Fraser River would create an extreme change in environment to which the fish may not be capable of adapting themselves. The rate of migration of these fish through lakes is not known but it is certain that either they will have to swim through this reach of river which they are not now required to do, or they will be delayed from eight to ten weeks in their migration. Either of these alternatives could have serious effects on the fish. They may not have sufficient body energy to enable them to swim this distance and there may not be sufficient food in the reservoir to enable them to replenish their energy reserves. Alternatively, due to the genetic timing of the physiological changes the fish may not be able to tolerate an abnormal addition to the migration time to reach the ocean. Each race of sockeye has been genetically adapted over a long period to their particular environment. While it generally requires a major change to destroy a race, even a minor change in environment can seriously reduce a population of salmon. Consequently, a much better understanding of the environmental factors influencing downstream migrations is required before any evaluation can be made of the effect of extended migration time caused by the reservoir above Moran Dam.

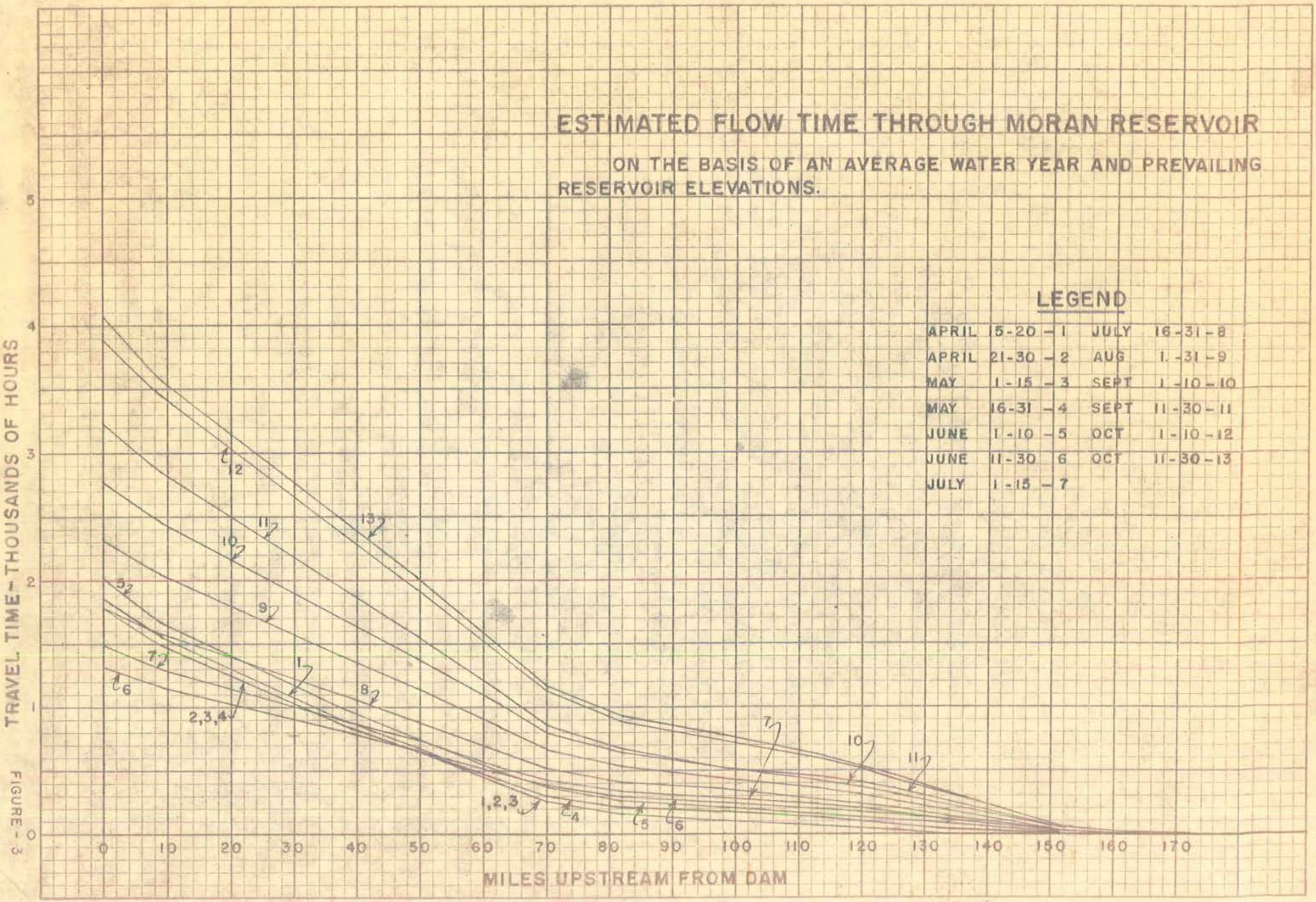

ESTIMATED FLOW TIME THROUGH MORAN RESERVOIR
ON THE BASIS OF AN AVERAGE WATER YEAR AND PREVAILING RESERVOIR ELEVATIONS.
LEGEND
APRIL 15-20 – 1
APRIL 21-30 – 2
MAY 1-15 – 3
MAY 16-31 – 4
JUNE 1-10 – 5
JUNE 11-30 6
JULY 1-15 – 7
JULY 16-31 – 8
AUG 1-31 – 9
SEPT 1-10 – 10
SEPT 11-30 – 11
OCT 1-10 – 12
OCT 11-30 – 13
TRAVEL TIME - THOUSANDS OF HOURS
MILES UPSTREAM FROM DAM
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
1
2
3
4
5

FIGURE - 3

Velocity would not be the only environmental change that would occur. Temperatures and possibly dissolved oxygen and other dissolved substances would be different in the reservoir than in the normal river. Water temperature records in the Fraser River in the vicinity of Moran are very meagre. However, several years of records (Figure 4) of water temperature are available from a thermograph station at Hell's Gate below Lytton, which can be used to estimate corresponding temperatures at Moran. In the period April 15 to June 15 the annual pattern of water temperatures at Hell's Gate is quite consistent within a 5° F range. Study of the relationship between temperatures at Hell's Gate, Lillooet and Dog Creek for years in which concurrent records are available indicates that during the period April 15 to May 30 water temperatures at Moran would be almost identical to those at Hell's Gate. In the period June 1 to possibly as late as November 30, temperatures at Hell's Gate are higher than those at Moran due partly to heating of the river as it flows downstream and partly to the effect of the Thompson River which delivers a substantial volume of warmer water drained from a large lake system. The annual pattern of temperatures in this period is more variable than during the remainder of the year, the temperature range being 5°F to 13°F for a given date. The relationship between temperatures at Hell's Gate and Moran is also variable, with temperatures at Moran being as much as 6.5°F cooler. Figure 4 also shows the average annual water temperature cycle at Hell's Gate and the estimated corresponding water temperature cycle at Moran.

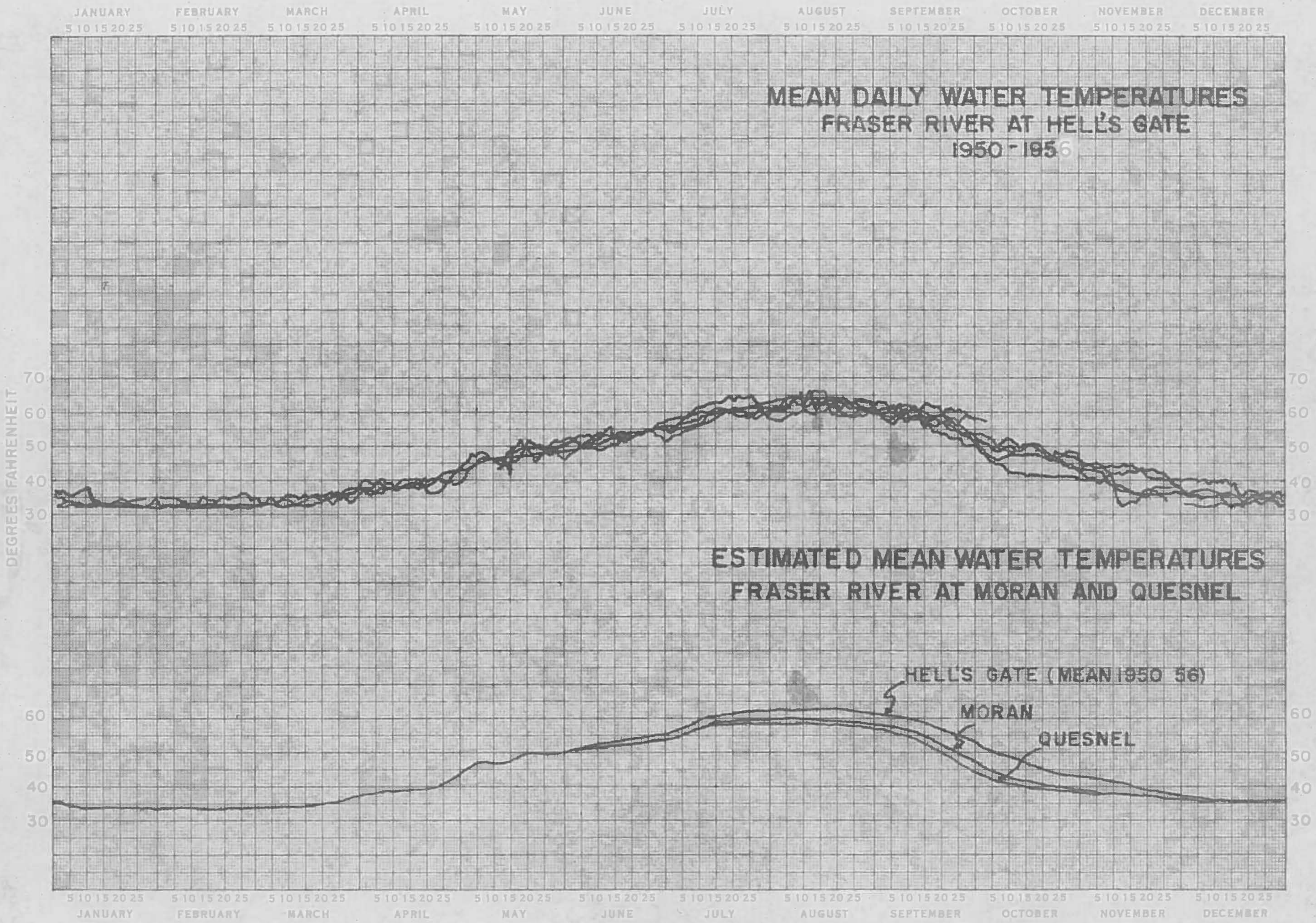

MEAN DAILY WATER TEMPERATURES
FRASER RIVER AT HELL'S GATE
1950 - 1956
ESTIMATED MEAN WATER TEMPERATURES
FRASER RIVER AT MORAN AND QUESNEL
HELL'S GATE (MEAN 1950 56)
MORAN
QUESNEL
DEGREES FAHRENHEIT
70
60
50
40
30
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
5 10 15 20 25

FIGURE - 4

Also shown is the average water temperature cycle at Quesnel, which was estimated from the temperature change recorded between Dog Creek and Lytton.

It might be supposed from the wide range of temperature prevailing during the time of downstream migration that the seaward migrants have a wide tolerance to water temperature. A closer examination of the times of migration in relation to water temperatures is necessary to determine the actual environment of any particular migrant. Enumeration of the seaward migrant sockeye leaving Chilko Lake during the spring months of 1954, 1955 and 1956 has shown that the migrants leave the lake rearing area in the period April 15 to June 15, with peaks of migration occurring in late April, early and mid-May. Data on the concurrent water temperatures in Chilko River and the Fraser River at Hell's Gate are given in Figure 5. As previously noted, water temperatures at Moran are probably about the same as at Hell's Gate during the spring months. Hence it appears that migrants from Chilko Lake may encounter a temperature rise at the confluence of the Chilcotin and Fraser Rivers ranging from zero to not more than 8.5°F. It has been estimated that migrants take about five days to travel from Chilko Lake to the Fraser River. Thus, the temperature encountered by any given migrant may increase up to 12.5°F during the course of the migration; with a maximum temperature of about 56°F. Similar variations in temperature may normally be encountered by migrants from other upriver rearing areas such as Quesnel, Stuart, Fraser and Francois Lakes

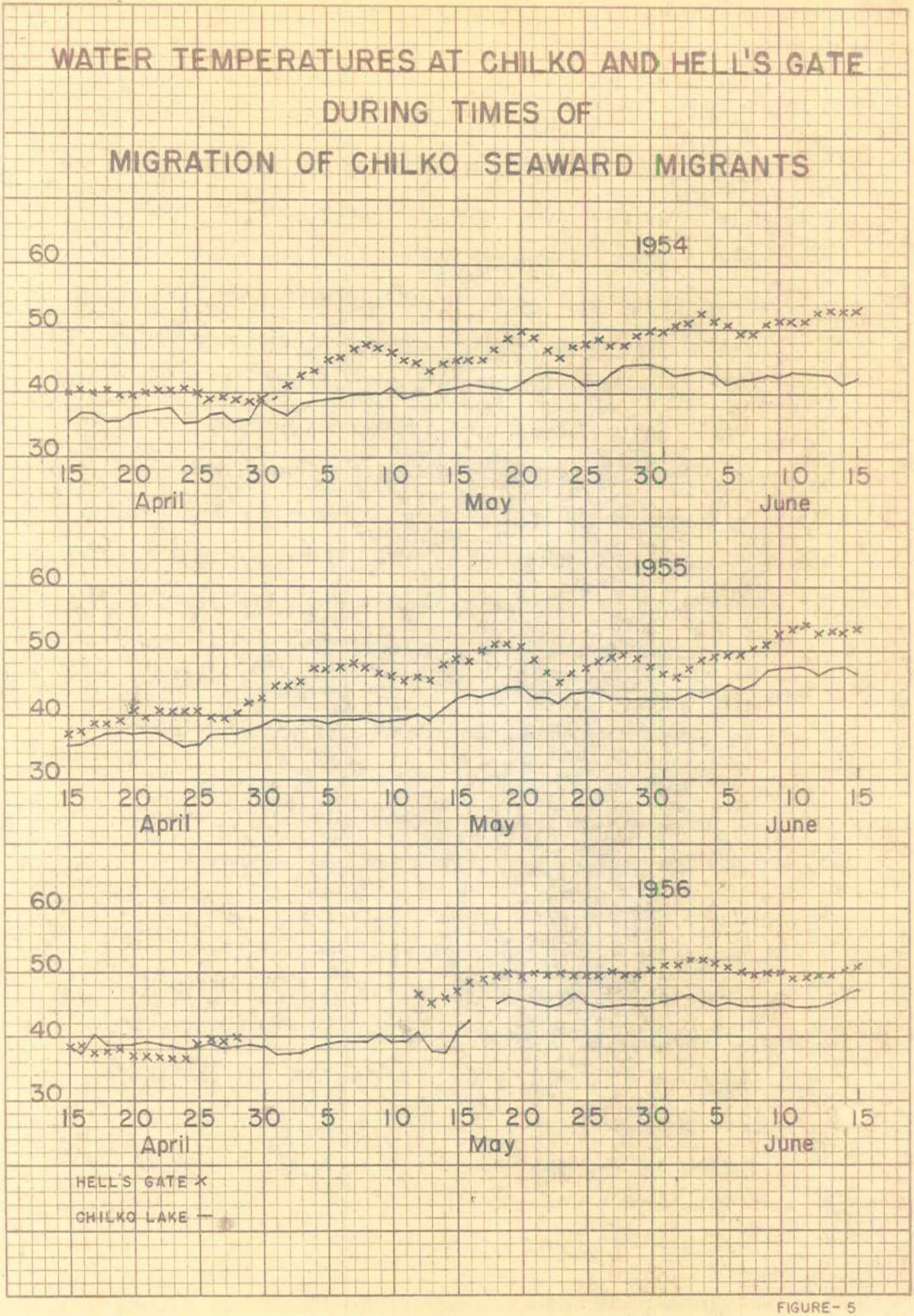

WATER TEMPERATURES AT CHILKO AND HELL'S GATE
DURING TIMES OF
MIGRATION OF CHILKO SEAWARD MIGRANTS
1954
60
50
40
30
15 20 25 30 5 10 15 20 25 30 5 10 15
April
May
June
1955
60
50
40
30
15 20 25 30 5 10 15 20 20 30 5 10 15
April
May
June
1956
60
50
40
30
15 20 25 30 5 10 15 20 25 30 5 10 15
April
May
June
HELL'S GATE ×
CHILKO LAKE —

FIGURE- 5

although the change may be spread over a longer period of time.

Due to the greatly increased time required for water to travel through the reservoir, the surface layers of the reservoir would be subject to more heating than they would be in the existing river, and consequently surface temperatures would be higher than in the existing river. The great depth and slow velocities probably would result in temperature stratification at least at certain times of the year. A study of meteorological and limnological conditions would be required to determine actual reservoir temperatures for any given set of conditions. At the present time little work has been done in analyzing the effects of meteorological conditions and river flow on thermal stratification in reservoirs and a lengthy study of existing reservoirs would be necessary to obtain sufficient background information for a study of the reservoir that would be formed by the proposed dam. Until such a study can be made, sufficient indication of the probable conditions in the reservoir can be obtained by referring to measurements available from Lake Roosevelt above Grand Coulee Dam on the Columbia River.

Table 3 lists the various characteristics of the two dams and reservoirs. It will be seen that the two reservoirs are about comparable with respect to longitude and elevation and while they are 3^{o} apart in latitude, they are both located in the continental climatic zone east of the Cascade Mountains and thus would have approximately similar exposures to climatic conditions, the one important difference being

Table 3

Comparison of Characteristics of
Roosevelt Lake and the Proposed Moran Lake

	Roosevelt Lake	Moran Lake
Latitude of Dam	48° N.	51° N.
Longitude of Dam	119° W.	121° 52' W.
Reservoir Elevation	1,290 feet	1,540 feet
Drainage Area	74,100 sq. miles	50,000 sq. miles*
Average River Flow	104,150 cfs	48,300 cfs*
Maximum River Flow	637,800 cfs	266,000 cfs*
Mean Annual Runoff	77,200,000 a.f.	34,480,000 a.f.*
Head at Dam	348 feet	720 feet
Dam Crest Width	4,173 feet	3,200 feet
Drawdown	80 feet	200 feet
Drawdown Per Cent of Head	23%	27.8%
Reservoir Area	85,000 acres	65,000 acres
Reservoir Length	151 miles	172 miles
Average Width	4,650 feet	3,140 feet
Shore Line Length	600 miles	--
Reservoir Volume	9,700,000 a.f.	13,300,000 a.f.
Active Volume	5,165,000 a.f.	9,000,000 a.f.
Per Cent Active Volume	53%	67.5%
Ratio of Runoff to Active Volume	14.9	3.82
Average Cross Section (estimate only)	530,000 sq. ft.	640,000 sq.ft.
Velocity at Average Section at Maximum Flow	1.2 fps	0.42 fps
Average Turbine Discharge	65,000 cfs (1950)	37,400

* After deducting Nechako River Diversion.

that Roosevelt Lake runs generally East to West, whereas the Moran Lake would run from North to South. Moran Lake would have a 37 per cent larger volume than Roosevelt Lake and a mean annual outflow 54 per cent less than Roosevelt Lake. Consequently there would be much greater opportunity for heating and thermal stratification in Moran Lake than in Roosevelt Lake.

Figure 6 presents some data on depth-temperature relationships in Roosevelt Lake at several locations for the period May to October (4, 5). There are definite periods of stratification in May, August and September. In May, the stratification resembles very closely that occurring in natural lakes, but in August and September, it is modified by the displacement of cold water which takes place during the freshet period. By October, continued turbine withdrawal of the colder waters results in nearly isothermal conditions, but at a much higher temperature than would occur in the normal river at that time due to the time lag in passage of water. Reference to Figure 6 shows that during May there can be as much as 15°F temperature difference between the top and bottom of the reservoir at Grand Coulee Dam and it can be predicted safely that a differential of at least this amount could occur during May in the Moran reservoir. Actual water surface temperatures in the Moran reservoir would be determined by the interrelationships of all the climatic and hydraulic conditions affecting the reservoir but there is strong circumstantial evidence that they would be at least as high as those in Roosevelt Lake and higher than in the normal river. The surface water temperatures for Shuswap Lake shown in

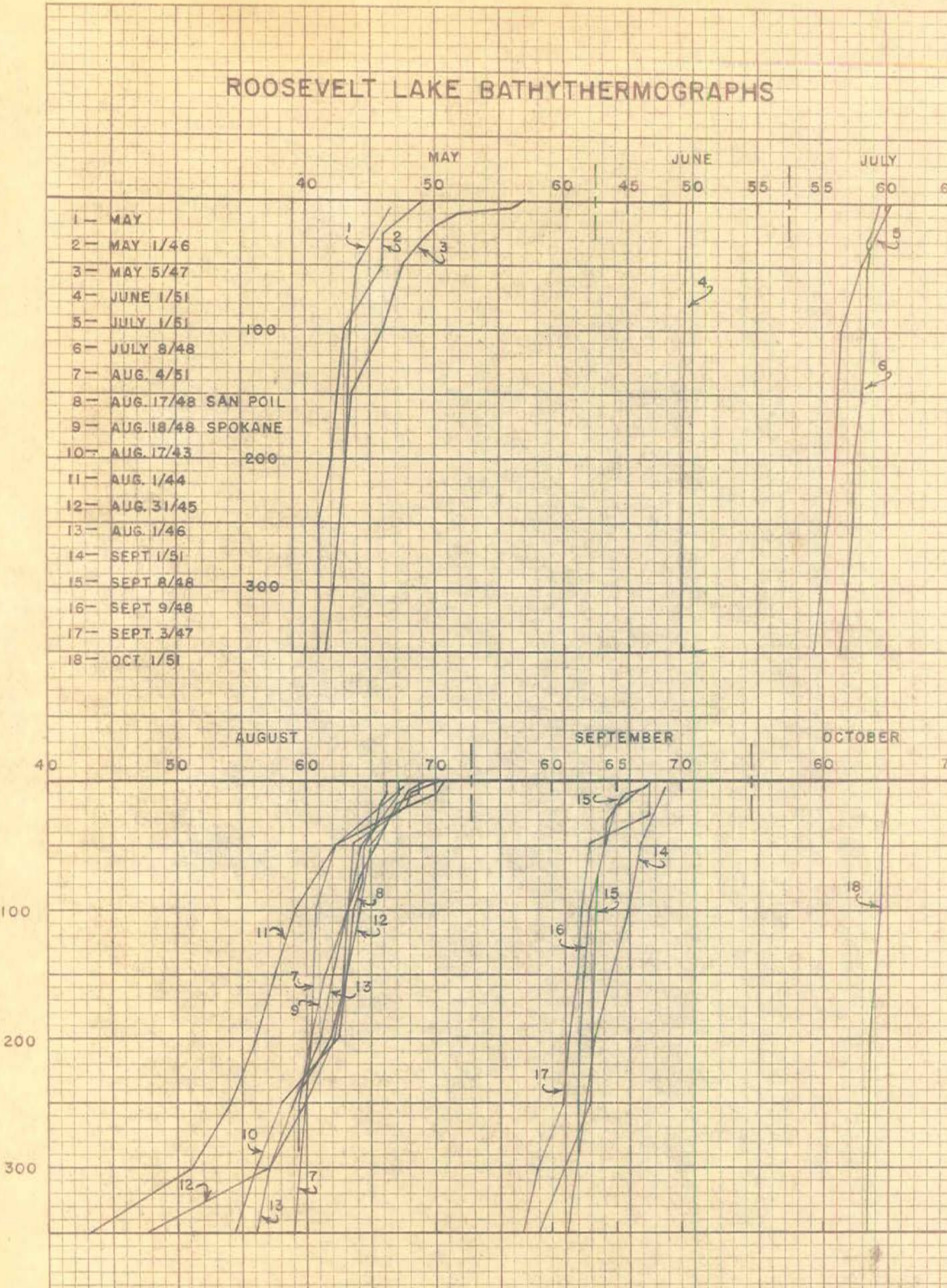

ROOSEVELT LAKE BATHYTHERMOGRAPHS
MAY
JUNE
JULY
40 50 60 45 50 55 55 60 65
1— MAY
2— MAY 1/46
3— MAY 5/47
4— JUNE 1/51
5— JULY 1/51
6— JULY 8/48
7— AUG. 4/51
8— AUG. 17/48 SAN POIL
9— AUG. 18/48 SPOKANE
10— AUG. 17/43
11— AUG. 1/44
12— AUG. 31/45
13— AUG. 1/46
14— SEPT 1/51
15— SEPT 8/48
16— SEPT 9/48
17— SEPT. 3/47
18— OCT. 1/51
100
200
300
AUGUST
SEPTEMBER
OCTOBER
40 50 60 70 60 65 70 60 70

FIGURE- 6

Figure 7 probably represent about the maximum surface temperatures that might be expected in Moran Reservoir.

The effect of such higher temperatures on the behavior of migrants will require careful study, since any change in behavior could have considerable bearing on the design of facilities for passing these fish over the proposed dam. It is known that there are optimum and preferred temperatures for various activities and developments during the life cycle of the fish, although the actual values of these temperatures have not been well established for all phases of the life cycle, particularly the downstream migrant phase. It is quite possible however, that if the surface water temperatures are not those suited to or preferred by the fish during their migration, they may alter the course of their migration to obtain such temperatures. Conversely if they do not alter their course, any deviations in temperature from normal may affect the migrants ability to swim through the reservoir. The new temperature may not be suited to maximum efficiency in the metabolic processes. It may also affect the survival of the fish since it is considered that unnatural environment is in a large measure responsible for the incidence of disease in fish that are artificially held or reared.

The possibility of other physical and chemical changes in the characteristics of the water in the reservoir must also be considered. In some reservoirs in the Tennessee Valley Authority system in the eastern United States, studies have disclosed that density currents of extremely low dissolved oxygen content pass through the reservoirs between 40 and 60

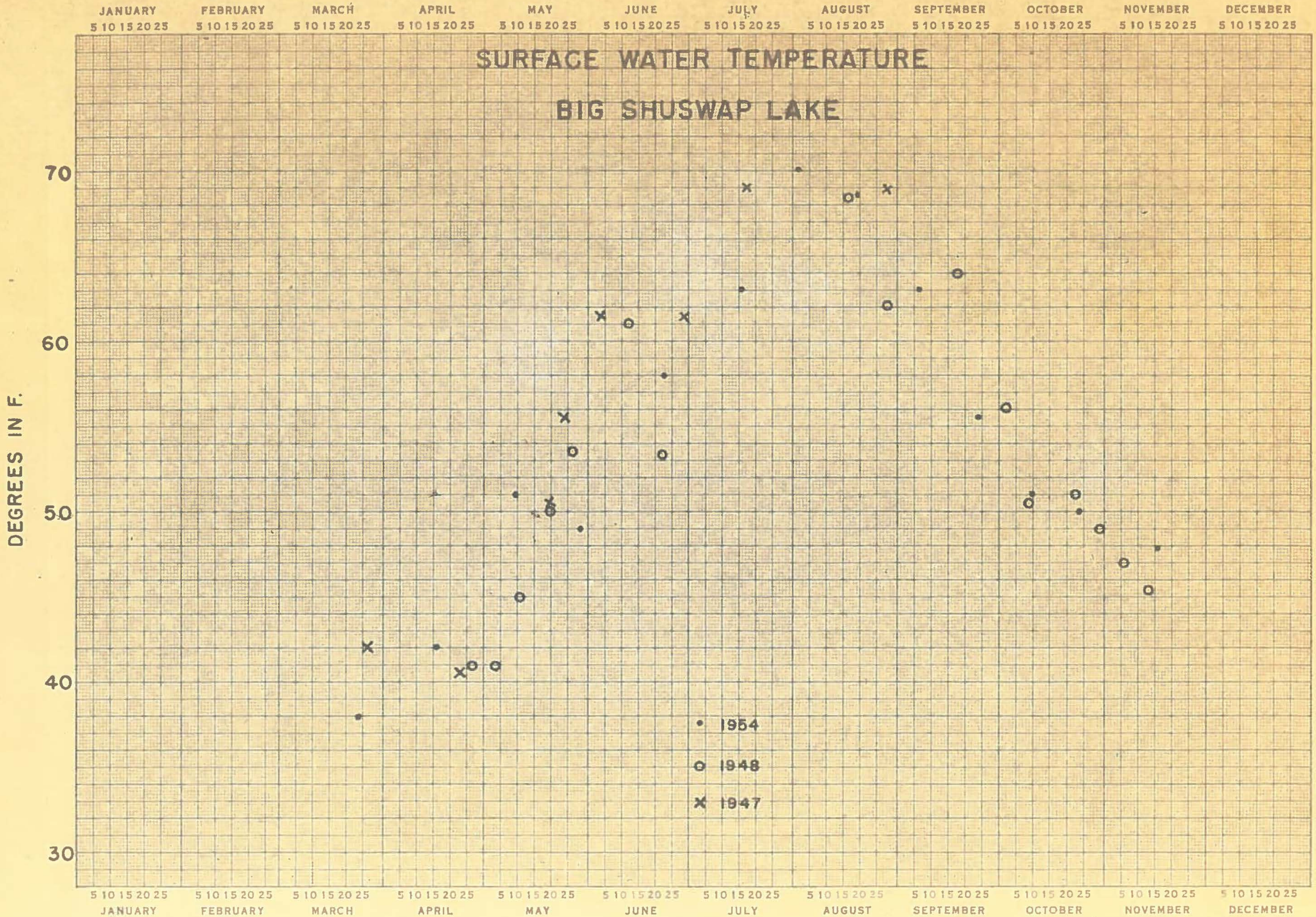

SURFACE WATER TEMPERATURE
BIG SHUSWAP LAKE
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER
5 10 15 20 25
DEGREES IN F.
70
60
50
40
30
• 1954
o 1948
x 1947

FIGURE - 7

40.

feet below the reservoir surface. In some cases the dissolved oxygen below 60 feet of depth was almost entirely depleted. These oxygen depletions are the result of high water temperatures and the oxygen demand of water-borne materials entering the reservoir (6). Fish kills have been observed as a result of fish entering the strata of low oxygen content. Tables 4 and 5 list some data available regarding the dissolved oxygen in Roosevelt Lake. These data show a gradual depletion of oxygen in the reservoir in a downstream direction, at the deeper levels, but there is no evidence of depletion below concentrations considered safe for salmon, nor is there any indication of density currents carrying oxygen depleted water. The available dissolved oxygen measurements for the Fraser River in the vicinity of Moran Dam are given in Table 6. The river is generally saturated with oxygen although there is a small depletion at Quesnel due to a small BOD of about 1.5 ppm (7). In view of the similarity between Roosevelt Lake and the proposed Moran reservoir, it is considered that the dissolved oxygen concentrations in the Moran reservoir would follow a pattern similar to that in Roosevelt Lake and should not give cause for concern insofar as migrations through the reservoir are concerned.

Tables 6, 7 and 8 provide additional data on the physical and chemical qualities of the Fraser River and Roosevelt Lake. Turbidities in Roosevelt Lake were less than 7 ppm in September 1952, compared with 19 ppm in the incoming Columbia River, indicating a considerable clarification of the incoming water. Similar effects may be expected in the proposed reservoir. This clarification of the river water probably would

Table 4

Dissolved Oxygen in Roosevelt Lake
September 23-30, 1952

Station	Depth Ft.	D.O. ppm	% of Saturation (a)
C-736 (River at Northport)	1	8.4	89.2
	40	8.4	88.2
C-703	1	8.2	88.2
	150	8.1	87.1
C-694	1	8.2	90.0
	150	7.4	81.4
C-674	1	8.3	91.2
	200	7.7	82.8
C-644	1	8.7	97.4
	200	8.0	87.5
C-641	1	8.0	91.0
	250	7.0	77.0
C-615	1	8.2	92.1
	200	7.4	81.1
	340	6.7	73.5
C-597 (Grand Coulee Dam)	1	7.9	90.3
	200	7.3	82.0
	350	6.3	69.4

(a) Computed on basis of normal barometric pressure at 1,250 feet altitude.

From: Ref. (4).

Table 5

Dissolved Oxygen in Roosevelt Lake

1948

Station	Date	Depth Ft.	D.O. ppm	% of Saturation (a)
San Poil River	July 8	0	10.2	106
		50	10.6	109
		100	10.4	107
		200	10.4	105
		300	10.4	105
	Aug. 17	0	8.8	98
		50	10.2	112
		100	8.6	93.5
		200	8.8	93.5

(a) Calculated on the basis of normal barometric pressure at 1,250 feet altitude.

Secchi Disk Readings in Roosevelt Lake
Measured in Feet

	Location At					
Date	San Poil River	Spokane River	Hall Creek	Colville River	Kettle River	Flat Creek
July 6-16	8.0	5.0	6.0	6.0	5.0	5.0
Aug. 16-20	16.0	15.0	-	-	10.0	-
Sep. 7-9	26.0	18.0	-	-	13.0	-

From: Ref. (5).

Table 6

Chemical Characteristics of the Fraser River at Selected Points

A. Lytton

D/M/Y	Dissolved Oxygen ppm	Dissolved Oxygen % Sat. (a)	PH	@ tC	CO_2 ppm	C.O.D. ppm (b)	Alkalinity ppm(c)	Na	K	Ca	Mg	Fe	PO_4	SiO_2	No_3	No_2	Cl	SO_4
29/8/50	9.4	102.0	7.8	23.0	4.0	-	52.0	-	-	-	-	-	-	-	-	-	-	-
4/10/50	12.0	102.5	7.94	9.0	1.7	1.5	55.2	1.3	1.2	-	3.4	0.27	-	0.14	0.14	-	-	-
15/2/51	14.5	100.8	7.48	6.9	6.0	1.3	28.6	3.2	0.4	21.6	9.2	0.21	-	-	-	-	0.7	15.9
19/4/51	13.6	100.0	7.7	11.0	2.8	8.12	61.1	3.9	1.7	19.5	8.9	1.6	-	-	-	-	1.15	54.2
29/5/51	12.1	105.0	7.53	11.6	4.2	4.97	41.8	2.8	1.3	16.2	2.1	0.42	-	-	-	-	0.83	6.9
9/7/51	10.7	106.8	8.0	18.0	2.0	1.0	43.1	0.72	1.05	17.8	4.5	1.83	-	-	-	-	0.96	5.57
3/8/51	10.0	108.0	7.95	28.1	1.92	0.30	49.5	2.1	0.6	16.5	4.25	0.46	0.06	-	-	Nil	0.78	7.70
3/9/51	10.8	107.1	8.0	21.5	1.7	1.9	54.9	1.6	1.33	18.9	4.2	1.31	-	4.7	0.16	-	0.34	10.9
8/10/51	10.7	94.7	7.75	17.5	3.35	1.4	61.0	2.1	1.3	21.5	5.6	0.36	Tr	-	0.017	Nil	1.0	12.9

B. Lillooet

D/M/Y	Dissolved Oxygen ppm	Dissolved Oxygen % Sat. (a)	PH	@ tC	CO_2 ppm	C.O.D. ppm (b)	Alkalinity ppm(c)	Na	K	Ca	Mg	Fe	PO_4	SiO_2	No_3	No_2	Cl	SO_4
27/9/50	11.3	107.5	7.92	12.5	1.8	0.5	47.0	1.4	0.3	-	3.2	0.27	Tr	-	0.14	-	-	-
11/4/51	14.9	107.8	7.6	15.8	4.8	7.17	63.5	4.1	1.6	21.1	6.3	9.5	-	6.4	0.61	-	1.86	40.6
5/7/51	10.7	109.8	7.95	19.0	1.9	0.43	43.7	1.0	0.72	17.5	4.2	1.7	-	3.2	0.47	-	0.88	6.45
30/8/51	11.1	112.0	8.0	19.5	1.7	0.97	50.7	1.6	1.4	18.9	4.2	1.56	0.021	-	-	Nil	1.10	8.0
3/10/51	11.8	101.5	7.75	12.3	3.3	0.64	57.2	2.0	1.3	21.9	4.4	0.64	Tr	4.6	0.06	Nil	1.2	12.0

Table 6 (Cont.)

C. Quesnel

D/M/Y	Dissolved Oxygen ppm	Dissolved Oxygen % Sat. (a)	PH	°C	CO_2 ppm	C.O.D. ppm (b)	Alkal-inity ppm(c)	PPM Concentration Na	K	Ca	Mg	Fe	PO_4	SiO_2	No_3	No_2	Cl	SO_4
2/10/50	10.9	94.8	7.96	12.0	1.8	1.6	57.2	1.2	0.2	-	3.3	0.23	Tr	-	0.17	-	-	-
17/4/50	12.6	96.5	7.6	8.9	3.0	3.36	51.5	2.9	1.7	17.1	4.0	8.8	-	-	-	-	2.33	39.9
8/7/51	10.0	101.8	8.2	17.0	1.1	1.6	42.5	1.0	0.66	18.4	4.5	1.6	-	-	-	-	1.18	3.70
2/9/51	9.8	99.0	7.85	14.2	2.5	2.9	54.9	1.44	1.4	18.9	4.2	1.24	0.037	-	-	0.013	0.68	6.85
5/10/51	11.1	96.5	7.55	9.7	5.15	2.5	65.2	1.6	1.6	21.9	5.37	1.36	Tr	4.7	0.28	Nil	1.1	12.1

From: Ref. (8).

(a) Estimated by International Pacific Salmon Fisheries Commission.

(b) $KMnO_4$ reduction oxygen consumption.

(c) Methyl orange alkalinity.

Table 7

Immediate Turbidity and Specific Conductance
Fraser River at Selected Points

A. Lytton

Date D/M/Y	Immediate Turbidity ppm(a)	Specific Conductance @ 25°C Micromhos
4/10/51	85	126.0
15/2/51	---	164
19/4/51	---	131
29/5/51	---	104.5
9/7/51	---	95
3/8/51	90	106
3/9/51	64	119
8/10/51	30	135
B. Lillooet		
27/9/50	78	116
11/4/51	4000	152
5/7/51	100	103.5
30/8/51	70	113
3/10/51	38	131
C. Quesnel		
2/10/50	53	123
17/4/51	---	110
8/7/51	---	94
2/9/51	70	118
5/10/51	52	137

From: Ref. (8).

(a) Estimated from Figure 8 in Reference (8).

Table 8

Characteristics of Roosevelt Lake Water, September 23-30, 1952

Station	Depth Ft.	PH @ tC	CO_2 ppm	Alkalinity ppm	Specific Conductance micromhos	Ca	Mg	Fe	SO_4	PO_4	NO_3	Total Solids
						Concentration ppm						
C-732	1	7.7-16.5	0	60	140	20	6.0	0.13	20	0.09	0.13	110
C-703	1	7.8-17.0	0.5	61	150	21	6.0	0.07	16	0.12	0.17	110
	150	7.6-17.0	1.0	62								
C-694	1	8.2-18.0	0	65	150	21	7.0	0.07	16	0.10	0.01	110
	100	7.9-17.0	0.5	62	140	21	6.0	0.08	15	0.09	0.09	110
	150	7.7-17.0	1.0	62								
C-674	1	8.2-18.0	0	59	140	20	7.0	0.07	15	0.04	0.13	110
	200	7.7-17.0	1.0	58								
C-644	1	8.0-19.0	0	58	130	19	4.7	0.09	12	0.04	0.25	66
	200	7.8-17.5	1.5	58								
C-641	1	---	0	58	130	19	4.8	0.05	11	0.03	0.07	63
	250		1.5	60	140	19	4.3	0.14	12	0.07	0.10	57
C-615	1	---	0	59	130	18	5.5	0.06	10	0.04	0.0	40
	200	---	1.0	58								
C-597	1	8.2-20.0	0	60	120	21	4.1	0.08	11	0.01	0.12	51
	350	7.4-18.0	4.0	58	130	19	5.0	0.14	10	0.06	0.16	54

From: Ref. (4).

not present any problem with respect to migrations through the reservoir, but in may provide increased opportunity for predators to feed on the migrating smolts and fry. The other physical and chemical properties listed in the tables do not show any significant differences between Roosevelt Lake and the Fraser River.

A biological examination of Roosevelt Lake has shown the plankton population to be extremely poor, although there were more zooplankton, on which sockeye feed, in the reservoir than in the river downstream (5). Bottom fauna were also found to be very limited due to the large winter drawdown and bottom deposit of silt and sand. Fish in the reservoir were found to be predominantly of undesirable and forage species. Food and game fish were present, but in relatively few numbers. It was concluded that Roosevelt Lake was biologically poor due to lack of incoming nutrients, deposition of sediment, frequent replacement of water, sparsity of shoreline shallows, and large winter drawdowns.

Since conditions in the proposed Moran reservoir would differ from those at Roosevelt Lake only by extent, it appears almost certain that the Moran reservoir would also be biologically poor and would support primarily coarse fish populations, some of which are known to be predatory in their feeding habits.

B. Passage over the Dam

1. Effect of Spillways and Turbines on Survival of Migrants.

If and when the migrating smolts and fry have traversed the length of the proposed reservoir, they must be collected and provided with safe passage over the dam without delay.

A great deal of evidence has been obtained in the last few years which shows that downstream migrants suffer a severe mortality rate in passing over spillways and through turbines. No experiments have been conducted at a dam as high as the proposed Moran Dam but at Baker Dam, which is about one third of this height, 64 per cent of the sockeye yearlings were killed in passage over the spillway and 34 per cent in passage through the turbines (2). On the basis of this information alone it may be concluded that conditions at the proposed Moran Dam would probably be so severe that practically all downstream migrants would be killed if they passed over the spillway or through the turbines. Mortalities measured at other dams are of interest in that they show the variation in mortality rates for different heads and different spillway and turbine designs. The available information is summarized in Table 9.

These investigations have revealed that the causes of mortality in passage over spillways are abrasion, pressure change, cavitation and turbulence. Probably most of the injuries sustained by fish passing over the spillway of Baker Dam are caused below the point where the free falling stream from the spillway gates impinges on the concrete spillway about 100 ft. below the crest of the dam. After impinging on the spillway face, the stream spreads out to a thin sheet of extremely turbulent and fast-flowing water. Since the concrete face is very rough, many injuries are caused by abrasion and cavitation. It was also determined that the violently turbulent pool at the base of the spillway causes mortalities. Obviously, mortalities caused by abrasion, pressure change, cavitation and turbulence would

Table 9

Measured Mortality Rates Suffered by Downstream-Migrant Salmon and Trout in Passage over Spillways and Through Turbines

Dam	Head (feet)	Species	Average Length (Inches)	Spillway Mortality (per cent)	Turbine Mortality (per cent)
Cleveland (9) (Capilano River)	295	Coho	?	57	—
		Steelhead		69	—
Baker (2) (Baker River)	250	Sockeye	3.75	64	34
		Coho	4.1	54	28
Puntledge (10) (Puntledge River)	350	Steelhead	4.9	—	42
		Kamloops	2.7	—	28
		Kamloops	1.8	—	29
		Pink, chum, coho, spring, kamloops	1.4	—	33
Glines (3) (Elwha River)	184	Coho	4.25	8*	30
		Spring	2.75	6*	33
Ruskin (11) (Stave River)	130	Sockeye	3.4	—	10
Elwha (3) (Elwha River)	100	Spring	2.75	37	0
Bonneville (12) (Columbia River)	60	Spring	?	15**	15**
McNary (13) (Columbia River)	90	Fall Chinook	2.4	0	11

Notes: * The spillway at Glines Dam consists of a free fall or ski-jump where a small quantity of water drops into a large, deep pool.

** It was not possible to separate spillway and turbine mortalities in this experiment at Bonneville Dam.

increase for higher dams.

Experiments at the two dams on the Elwha River (3) also showed that a large proportion of the mortalities could be attributed to pressure changes and mechanical injuries. The relatively low mortality rates measured at the 200-ft. free-fall spillway at Glines Dam may be explained on the basis that pressure changes and mechanical injuries were virtually eliminated because most of the drop occurred through air. Nevertheless, there was a significant mortality, possibly caused by impact and turbulence in the pool below the spillway and by inhibition of respiration. Mortalities of 17 to 32 per cent were measured in dropping hatchery-reared coho yearlings 250 ft. over an experimental ski-jump spillway at Baker Dam (14). At Cleveland Dam on the Capilano River, the water drops 295 ft. but about one-third of this drop is a free fall. It is believed that the very high mortality of 57 to 69 per cent was caused by insufficient depth in the tailwater pool and abrasion on the spillway face and canyon walls.

In general, mortality rates suffered by downstream-migrant salmon in passage through Francis turbines are lower than those suffered in passage over spillways having the same head. However, it can be seen that the turbine mortality, like the spillway mortality, increases as the height of the dam increases. It may be concluded, therefore, that the mortality to sockeye yearlings passing through the proposed 750-ft. head Francis turbines at Moran would be considerably higher than the 34 per cent measured mortality rate in the 250-ft. head Francis turbines at Baker Dam.

One very important aspect of fingerling mortalities during the seaward migration is the fact that they cannot be compensated for by a higher survival rate in later stages of the life cycle. Furthermore, it seems likely that the actual mortality rate of fingerlings would be higher than the mortality rate measured at a dam because some fish that survive passage over the dam would be weakened to the extent that they would not be able to withstand subsequent additional stresses such as those imposed in escaping from predators, withstanding the effects of pollution and in making the transition from fresh to salt water. There is no immediate prospect that the design of turbines and spillways can be sufficiently improved to eliminate mortalities to downstream migrants.

It may be concluded, therefore, that in order to preserve the fisheries resources originating in the Fraser River watershed above the proposed Moran Dam it would be necessary, among other things, to ensure that none of the downstream-migrant salmon and trout would pass through the spillway or turbine outlets. Methods would have to be devised for attracting or diverting these fish to effective by-pass outlets in preference to spillway and turbine outlets and for transporting them from the forebay to tailwater without delay or undue stress.

2. Artificial Guiding Stimuli.

In recent years, considerable work has been done on means that might be employed to divert downstream migrant salmon and trout away from hazardous paths at dams to safe by-passes. Most of this work has been directed toward development of artificial stimuli to control the movements of the fish in anticipation of finding a more economical and more satisfactory method than physical barriers such as screens. Stimuli such as light, sound, magnetism, electricity, air bubbles, moving objects, chemicals and louvres, have been tested by different experimenters. Sound and magnetism produced no response by the fish. Other stimuli, such as light, electricity, moving objects and louvres have shown varying degrees of success under the conditions of the experiment and it is not inconceivable that such stimuli or devices could be developed for practical application in situations where the prevailing conditions would be similar to those of the experiment. The practical limitations (i.e. turbidity and structural problems) on the use of light, moving objects and louvres at large dams are apparent and no large scale experiments with these methods have been attempted at large dams. Laboratory and small scale field experiments have shown a high degree of success with various forms of electrical stimuli, but the only large scale experiment to date with electricity (15, 16) has proven to be unsuccessful and after four years, the International Pacific Salmon Fisheries Commission has decided to discontinue further investigation of electrical stimuli in favor of other approaches to the problem.

It is concluded, therefore, on the basis of all available experimental evidence, that no artificial stimuli have yet been developed which could be recommended for practical application to the problem of guiding downstream migrants at large dams such as Moran.

3. Screen Barrier.

Fixed and mechanical wire screens have been employed for many years with varying success to keep young salmon out of river water diversions for power, irrigation, and water supply projects. The success of such screens depends on the type of screen employed and on the provision of suitable water approach velocities. Where approach velocities are low and the screens are protected from clogging, either fixed or travelling belt types of screens can be successfully employed with a minimum of mortality to fish. If these criteria are violated significant mortalities or carry-over can occur. Due to the fine mesh screen necessary to exclude salmon fry and the problems of keeping the screens clean, as well as the cost of providing the required screen area and the alignment to satisfy the velocity criterion, and the structure to support the screen, such screens have not been used as a means of guiding migrants in the forebay of large dams.

Recently, experiments have been conducted at Baker Dam to study the effectiveness of screen barriers where forebay velocities are very low. It was known from previous experiments (17) that majority of the sockeye and coho yearlings migrated in the top 15 feet of the reservoir, and an experiment was made to determine the guiding efficiency of a webbing barrier 15 feet deep and 240 feet long angled across the forebay of Baker Dam to a surface by-pass trap. This barrier significantly increased the percentage of coho migrants entering the by-pass trap and further experiments were conducted in 1957 with a barrier 30 feet deep when both sockeye and coho were present. The results of this experiment are not completely analysed, but an important difference in the behavior of sockeye and coho migrants was observed. In all the tests the success of guiding sockeye was less than for coho, particularly when the sockeye were not intermingled with coho. Sockeye showed a greater tendency to sound under the barrier than did coho. Similar observations of behavior differences between spring salmon fry and coho yearlings were made in recent tests at Mud Mountain Dam on the White River (19), where the spring salmon fry were found to be more reluctant to sound than the coho yearlings. These observations are extremely significant in that they emphasize that experimental results obtained with one species of salmon do not necessarily apply to all species and that they require careful and cautious interpretation.

Extensive model studies of the forebay of the proposed Moran reservoir would be required to determine the actual approach velocities for the proposed location of turbine and spill outlets, but on the basis of a maximum flow of 285,000 cfs, the average approach velocity at full reservoir would be 0.2 fps which would closely duplicate the experimental condition at Baker Dam. However, the length of screen required at Moran Dam would be perhaps twenty times that used at Baker Dam, and even if additional experiments prove this type of barrier to be successful at Baker Dam, further investigation would be required to determine the effect of greatly increasing the barrier length. Also, as previously mentioned, before any guiding device could be recommended, the effect of reservoir environment on the behavior of migrants must be known. Much additional information is necessary, therefore, before any decision could be made regarding the probable effectiveness of screen barriers as a practical means of guiding migrants in the forebay of Moran Dam.

4. Deeply Submerged Turbine and Spill Outlets.

In the Moran Dam Brief, and in discussions with Moran Power Development Limited, the Company representatives have suggested that the spill and turbine outlets be placed at great depth below the crest of the dam, in order to prevent migrants from being attracted to these outlets. Surface by-passes would be used to provide the migrants a path over the dam to tailwater.

Observations at Baker Dam (2) have shown that only a small proportion of the downstream-migrant sockeye and coho salmon migrated through the 95-foot deep turbine intake when a surface spill was available, but that significant numbers did sound to this depth when there was no surface exit. At the Glines Dam (3), hatchery-reared spring salmon readily sounded to a depth of 65 feet when no surface exit was available, but very few hatchery-reared coho yearling sounded under the same conditions. Both species preferred the surface outlets when they were available, although the depth of intake submergence was not sufficient to prevent migration through the tunnel.

The arrangement of turbine intakes proposed for Moran Dam would place them at elevation 1,310, or only 30 feet below the minimum anticipated forebay elevation. Since the maximum drawdown would occur in April prior to the spring freshet, at the same time downstream migrations occur, it is apparent that the proposed arrangement would not prevent migrants from passing into the turbine outlets even if surface outlets were provided at the elevation of maximum drawdown.

It cannot definitely be determined at this time whether or not it would be possible to design an arrangement of deeply submerged outlets and surface by-passes which would successfully prevent downstream migrants from entering the spill and turbine outlets and lead them to safe surface paths.

In the absence of any proven means of preventing migrants from entering the surface spillway proposed for the dam in addition to the submerged spillway outlets, it would be necessary that the submerged spillway outlets have sufficient capacity to prevent surface spills for all inflows up to and including a 50-year flood. The design of the actual capacity of these outlets would depend upon the stage of development considered and the assumed manner of operation of the reservoir. It is unlikely that this project would reach its full initial stage development of 18 turbines in the first few years of operation, whereas it is always possible that 50-year flood could occur in any year. Since the reservoir would remain almost full throughout the year when only a few turbines are operating, it is considered essential, if no surface spills are to occur, that the submerged spillway outlets have a capacity equal to a 50-year flood at Moran or about 285,000 cfs. The twenty 108 inch ring-follower valve spill outlets proposed have a capacity of 193,000 cfs at full reservoir and therefore would not be adequate to prevent surface spill. At least thirty such outlets would be required.

The information available regarding conditions in the forebay of Baker Dam is not sufficient to delineate the various factors influencing migration and the relative effect of each. Velocity, temperature gradients, and turbulence are believed to be the principal factors involved.

In the forebay of Bonneville Dam, where velocities and turbulence are presumably relatively high due to the large discharge and shallow river depth, the downstream migrants have been observed to be distributed over the entire 60 feet of depth at the dam (18). As already noted, most of the migration at Baker Dam is in the top 15 feet of the reservoir, with only very few fish found below 30 feet of depth. At full load, full forebay, and no spill the average approach velocity upstream from Baker Dam is about 0.06 fps. At Bonneville Dam with a discharge of about 300,000 cfs on the first of May, the average velocity at a section just upstream from Bradford Island would be more than 3 fps. The Baker Dam reservoir also develops a well defined thermal stratification during the period of downstream migration (2) whereas there is no evidence of thermal stratification in the Bonneville reservoir (4). These significant differences in the characteristics of these two reservoirs undoubtedly are the principal reasons for the differences in the characteristics of the respective migrations through them.

Measurements of the numbers of migrants using the submerged tunnel intake at Baker Dam during periods of no spill and variable forebay elevation indicate an inverse relationship between the numbers of fish and the depth of submergence (2). Since fish continued to use the tunnel at Baker Dam at full reservoir elevation even when spilling occurred, the tunnel submergence and its approach characteristics are not such that migration is prevented.

Recent observations at Mud Mountain Dam have also indicated an inverse relationship between depth of outlet submergence and percentage of migration using the outlet (19). These experiments indicated a very small percentage of the fish (coho yearlings and spring fry) leaving the reservoir when the outlet was submerged 160 feet. Again, these results are not applicable to sockeye, which are known to sound more readily than coho.

The apparently normal approach of a large proportion of the downstream migrants to Baker Dam is to first traverse the face of the dam in search of an outlet. This traverse may be made by swimming directly along the face or by randomly approaching it at various points along its length. This pattern of search suggests that the water velocities adjacent to the tunnel intake in the surface layers normally frequented by the migrants are not sufficient to attract them and that it is only by sounding that they encounter velocities that attract them.

Data on water velocities and temperatures at Baker Dam show that in the top 30 ft. of water adjacent to the intake, velocities are too low to be measured by a regular Price current meter (in this instance less than 0.1 ft. per second) (2). At the time the measurements were taken (May 1950), this depth coincided with the thermocline. The data also indicates that below the 20 foot depth velocities increase at an average rate of 0.0154 fps per foot down to the top of the tunnel. The distribution of isovels at the intake, and temperatures in the powerhouse tailrace indicate that the tunnel draws water principally from the layer between 60 and 110 feet below the surface. Much additional information must be obtained regarding the effects of velocity and temperature gradients in the Baker Reservoir and other deep reservoirs in order to establish the criteria that govern the movements of fish toward submerged outlets. Once the criteria are known, it should be possible to examine, by means of a large hydraulic model, the methods that might be employed to duplicate these criteria in the proposed Moran reservoir. Until the factors influencing the sounding of migrants to submerged outlets are fully understood, and the hydraulic conditions created by submerged outlets can be predicted, there is no rational basis for any suggestions as to depth, placement, and number of submerged outlets that might be provided at the proposed

Moran Dam as a means of preventing downstream migrants from passing through such outlets. It will be shown in subsequent sections of this report that such deeply submerged outlets would also present problems in maintaining a suitable temperature in the river below the dam.

Mere exclusion of the migrants from these outlets is not the full answer, however, since by-passes must be provided to attract the fish to safe paths over the dam.

5. Surface By-pass Requirements.

Whatever device or combination of devices, if any, may be proven to be an acceptable means of excluding migrants from hazardous paths at the proposed dam, by-passes would be required to lead the fish to safe paths. Since these by-passes would have to be provided over the full 200-foot range of drawdown, and possibly more depending on accurate estimates of conditions during the initial filling period, the design of these by-passes is important not only for the successful passage of migrants, but possibly also for the structural design of the dam.

There are no known successful by-pass installations at large dams that provide any precedent for the design and operation of by-passes at Moran. Four experimental migrant by-passes were incorporated in Bonneville Dam but those have not been successful in attracting significant numbers of fish away from the turbine intakes and spillway.

Some indication of the requirements of a successful by-pass can be obtained by considering natural lake outlets, where the fish are gradually confined to the surface waters and there is a very gradual acceleration of water velocity. Under such circumstances the fish do not exhibit any reluctance to leave the lake and enter the stream.

Reference has already been made to the inverse relationship between the proportion of the migrating fish sounding to the tunnel intake at Baker Dam and the depth of submergence of the intake. When the reservoir at Baker Dam is full, there is also a relationship between relative proportions of migrants sounding to the tunnel and the magnitude of spill (15). The results of observations made in 1955 are shown in Table 10. The spillway gates at Baker Dam are 9.5 feet wide by 13 feet deep and discharge about 1700 cfs each. The tunnel discharge is 2200 cfs.

Table 10

Percentage of Migration Using Tunnel During Surface Spills

Species	Spill Condition		
	One Gate	Two Gates	Three Gates
Native sockeye	6.2	4.0	2.4
Native coho	1.7	1.4	4.0
Hatchery springs	9.0	2.0	---

These figures are significant in that they indicate the relative magnitudes of spill and tunnel discharges required for the relatively narrow 350-foot crest width of Baker Dam to provide attraction to the surface outlets.

Experiments at Baker Dam with a 24 cfs by-pass (15) were not successful in passing migrants, probably because of the rapid acceleration of water into the by-pass opening. Further experiments (16) with a 265 cfs by-pass with more gradual acceleration of approach velocities still did not attract a significant proportion of the migration except when aided by a long webbing barrier to divert the migrants to it. Even with this by-pass the migrants showed reluctance to enter. Other experiments in the design of attractive by-passes have been conducted at the Lakelse River (20). This by-pass was constructed to provide gradual acceleration of flow with mirrors installed on the sidewalls to reduce or eliminate reference points and to lessen the tendency of fish to be alarmed by the accelerating flow. This by-pass was used in conjunction with a travelling cable guiding device but was considered only moderately successful since it was not efficient enough to prevent the accumulation of fish in the deflection area. It must be emphasized that this experiment was conducted in a river with only 3 to 4 feet depth of water and therefore cannot be considered indicative of the efficiency that would be obtained in the forebay of a large dam.

Present knowledge of by-passes is not adequate to permit any determination of the size, shape, number and distribution of them at the proposed Moran Dam. Research on the requirements of a successful by-pass is being accelerated and new developments are being followed closely.

In the absence of proven means of guiding migrants to by-passes, it appears that one essential requirement of any by-pass at a large dam would be a relatively large flow of water. The magnitude of flows required for Moran Dam cannot be predicted with certainty at this time, but there is a possibility that the flows would be a considerable portion of the flow for power development. In this case it would probably be suggested that some means be sought to recover a large percentage of the by-pass flow either by recirculation or by diversion to the power turbines. Such a proposal has already been made for the proposed Mayfield Dam on the Cowlitz River, but the device proposed has been designed solely on the basis of hydraulics and there is no guarantee that it will achieve the desired results or that it will not cause injury or mortality to the migrants. At this installation, forebay levels would be controlled over a very narrow range. At Moran Dam, a similar device would have to operate over a 200-foot range in water levels and would require a very complicated structure. However, the principal difficulty concerns the design of a screen to separate the migrants from the flow to be recirculated or diverted. Not only would such screens present a serious operational problem of cleaning, but they also would have to be designed to prevent fish from being plastered on them due to head differential.

This requires that velocities through the screen by very low, and consequently, if large flows are to be handled, the screening structure required could become immense. In essence, the completed structure would be a section of spillway crest moveable over a 200 foot range of forebay levels. The practicability of such a moveable structure with respect to engineering design and biological effectiveness remains to be proven.

Recently, several experiments have been conducted with floating by-passes or "skimmers" utilizing pumps to create a flow of water into a trap in which migrants would be separated from the main flow of water. These devices are experimental variations of the by-pass proposed for Mayfield Dam which are being tested to determine their efficiency. In essence, they are no different than the by-pass trap used at Baker Dam, but they are limited to much smaller discharges due to the limitation of pump capacity. Results to date do not indicate sufficient efficiency to warrant practical application at large dams. In view of the previously stated observation that large flows would be required to attract the migrants away from turbine or spill outlets, it seems certain that by-passes using small flows will never be successful at large dams except possibly when used in conjunction with an efficient and practical device for guiding migrants to it. The results of current research do not provide any basis for concluding that any form of by-pass or guiding device has been developed which could be recommended for practical application at large dams.

6. Transportation to Tailwater.

Once the migrants have been collected in a by-pass they must be safely transported to tailwater, a vertical distance of 520 to 720 feet depending on forebay elevation. Again there is no precedent for such facilities for this magnitude of drop.

A number of methods of transporting the migrants to tailwater might be suggested, such as flumes, pipes, elevators, free drops and gravity locks, but at the present time there is little or no basis on which to make a design or to determine the suitability of any of these methods. On the basis of available information, however, a number of observations can be made regarding the problems associated with each of these methods.

All, except gravity locks and possibly conveyors, would require a large number of openings through the dam to provide continuous operation through the entire 200 feet or more of forebay fluctuation. This requirement may or may not present a structural problem in designing the dam, but it would certainly necessitate a complicated system of valves or gates to regulate the flow through the openings to correspond to the by-pass inflow and to maintain suitable water levels for the fish after they have entered the by-pass. The submergence of any opening in use would also have to be limited to prevent possible harmful pressure changes in passage through the openings. The limitation on submergence would determine the vertical spacing of the openings. While it may be possible to prepare an engineering design that would function hydraulically, it is a more difficult task to assess the effectiveness of any design in providing safe and suitable passage for the migrants. Such factors as turbulence, abrasion, local pressure changes, and stresses on the fish created by a suddenly changed environment must all be considered in evaluating a particular design, and at the present time it is not possible to assign any permissible maximum numerical values to many of these factors against which to judge a design.

Gravity locks or an enclosed vertical conveyor system operating on the upstream face of the dam would require only one opening through the dam at tailwater elevation for each lock or conveyor. These methods of handling fish have other problems however, which will be discussed in following sections.

(a) Flumes, Canals or Chutes.

Free water surface conduits of suitable design would have the advantage of providing flow paths most nearly resembling the normal river environment and therefore might be expected to minimize stresses due to environmental change.

Some experimental work on steep flumes has been done at Alder Dam (21). A semi-circular smooth steel flume, 36 inches in diameter was constructed to transport fish over a drop of 135 feet and deposit them in a tailwater pool approximately 90 feet deep. The flume was 400 feet long and the calculated velocity of the water was about 40 fps. Various sizes of migrant fish were passed down this flume with discharges of 5, 10 and 15 cfs and no measurable mortality was observed. It was considered that the best hydraulic conditions at tailwater were obtained when the discharge at the end of the flume was directed upward at an angle 30 degrees above horizontal.

The results of this experiment cannot be extrapolated to much larger by-pass flows and heads and steeper slopes. Additional information would be required on the effect of these variables to assess the suitability of flumes or chutes as a means of transporting migrants at the proposed Moran Dam. Experimental evidence obtained from investigations of mortality to migrants passing over spillways indicate that limitations on head, slope, roughness and tailwater pool size and depth could be expected beyond which there would be significant mortalities to the migrants.

(b) Pipes.

Experimental evidence on the mortality to migrants passing through turbine penstocks indicates low mortalities (0-15 per cent) when the heads are 100 feet or less. Probably all of the mortality can be attributed to the turbine itself, but the significant fact in this data is the maximum sudden pressure gradient that the fish can withstand without injury. The available data is too meagre to make any specific conclusions regarding the relationship between pressure change and mortality but the indications are that pressures below atmospheric in the turbine draft tubes have an important bearing on the mortality.

Tests conducted by the U. S. Fish and Wildlife Service and the Corps of Engineers, U. S. Army, indicate that fish subjected to a sudden increase in pressure lose buoyancy and swimming equilibrium (22). The fish appeared to become acclimated to the pressure after about 16 hours exposure, but then only if a "head space" of compressed air was provided in the test vessel. Once the fish were acclimated to the test pressure, a sudden release of the pressure caused mortality among them that varied from zero to 65 per cent. In general, the higher mortalities occurred when the pressure dropped below atmospheric during pressure releases. The test pressures used were 40 and 18 psi above atmospheric. The duration of the pressure release period also has bearing on the rate of mortality. Fast releases in a fraction of a second cause higher mortalities than releases longer than a second. In other tests, however, it was found that fish were not killed by rapid increase and release of pressure if they were not acclimated to the raised pressure. All these data, however relate to pressures of 100 feet of water or less and cannot be extrapolated to draw conclusions as to the effect of the pressure from 720 feet of head.

Therefore, the application of pipes as a means of transporting migrants for a head of 720 feet in a single drop or in stages would have to be fully investigated experimentally before any rational decision could be made as to the probable success of the method.

(c) Free Fall.

Evidence collected during experimental testing of the mortality to downstream migrants passing over high dams indicates a relationship between height, type and condition of the spillway and the mortalities incurred. For comparable heights, mortalities are not as severe for a free fall to a deep pool as they are for a spill over an inclined concrete surface, although mortalities are not eliminated.

As previously stated, the mortality at the 184-foot free fall spillway at Glines Dam was from 6 to 8 per cent. Experiments have been conducted at Baker Dam (14) with a free fall spillway to investigate meare of reducing mortality to migrants at that dam. These experiments indicated a minimum mortality of 17 per cent for the 250-foot fall, as compared to mortalities of 54 to 64 per cent over the existing spillway. In some tests mortalities as high as 32 per cent were recorded.

During all these tests it was observed that some fish fell or swam out of the main body of the water and landed on the face of the spillway. A strong up-river wind was an important factor causing the fall-out of fish. The effects of turbulence in the tailwater pool and of predation on impaired fish have not been measured, nor has any indication been obtained of the volume of the stilling pool required to provide conditions necessary for good survival of migrants.

Drops of fish from helicopters onto lake surfaces have provided additional information regarding free-drops (23). These drops however, do not take into consideration the effect of turbulence in the stilling pool and the limitations in size of the stilling pool into which the fish must be directed. Since only very small quantities of water are involved in such drops from aircraft, the fish fall freely through the air, a much different circumstance than would occur at a dam.

At the present time, therefore, the evidence available indicates that a single free fall drop of the magnitude that would prevail at Moran Dam would result in considerable mortality, either due to fall out onto the dam or adjacent structures, or due to the effects of turbulence in the stilling pool. Much additional study would be necessary to determine the feasibility of this means of transportation as applied to a single drop or to a series of smaller drops.

C. Tailwater Environment.

In discussing the means that might be considered for transporting downstream migrant salmon over the proposed Moran Dam, it has been stressed that by-passes at the surface of the reservoir would be essential, provided that the migrants maintain a normal path of migration as it occurs at Baker Dam and in lakes. It has also been mentioned that temperature stratification can be expected in a reservoir such as would be formed by Moran Dam. During the time of downstream migration, the surface by-passes and the turbine discharge would be the only outflows from the dam, except possibly in the initial years of operation or in unusual climatic years when there may be spills. Since the turbine outlets would draw water from a considerable depth in the reservoir there would be a difference in temperature between the colder turbine water and the warmer surface water spilled through the by-pass. The magnitude of this difference would depend on the depth of submergence of the turbine intakes and on climatic conditions, but it would range from almost zero at the start of the downstream migrations to about 15°F to 24°F or more at the end of the migrations. Figure 11 presents the results of estimates of tailwater river temperature compared with reservoir surface temperature and existing river temperature assuming turbine intakes at elevation 1310 and spill outlets at elevation 1250. Thus, migrants passing over the dam in the relatively smaller by-pass flow would be subjected to a sudden decrease in temperature of their environment when they entered tailwater at the powerhouse. Table 11 illustrates the probable differences in temperature that would occur.

It has been shown (24) that sudden changes from the acclimation temperature can cause mortality to young sockeye and other species of salmon. The severity of the mortality depends on the acclimation

Table 11

Reservoir Surface and Tailwater Temperatures, Moran Dam
During Period of Downstream Salmon Migration

Date	Reservoir Surface °F	°C	Tailwater °F	°C	Difference °F
May 1	42-43	5.6-6.2	39-40	4-4.4	2-4
June 1	50-58	10-14.4	40-42	4.4-5.6	8-18
June 30	58-66	14.4-18.9	42-43	5.6-6.2	15-24

temperature, the amount of change in temperature, and the time of exposure. Figure 8 shows the relationships between these variables which produced a 50% mortality in the test specimens. For a temperature of 4°C a 50% mortality occurred in from 1 to 3 days depending on the acclimation temperature.

While the temperatures listed in Table 11 may not be precise estimates for any given year, they nevertheless are of the correct order of magnitude on the basis of recorded temperatures on Roosevelt and Shuswap Lakes and in the Fraser River at Hell's Gate. It is evident that if deeply submerged turbine outlets are used exclusively, severe mortalities to downstream migrants could occur in the tailrace. It would be necessary, therefore, to provide a means of regulating the temperature of the water drawn to the turbines so that there would not be more than a 2 to 3°C differential in tailwater temperature and the temperature of any surface by-pass water carrying downstream migrants. This requirement would necessitate locating the turbine intakes in a manner that would ensure withdrawal of a large proportion of water of the same temperature as the water in the by-passes. This precludes the possibility of using deeply submerged tubine outlets

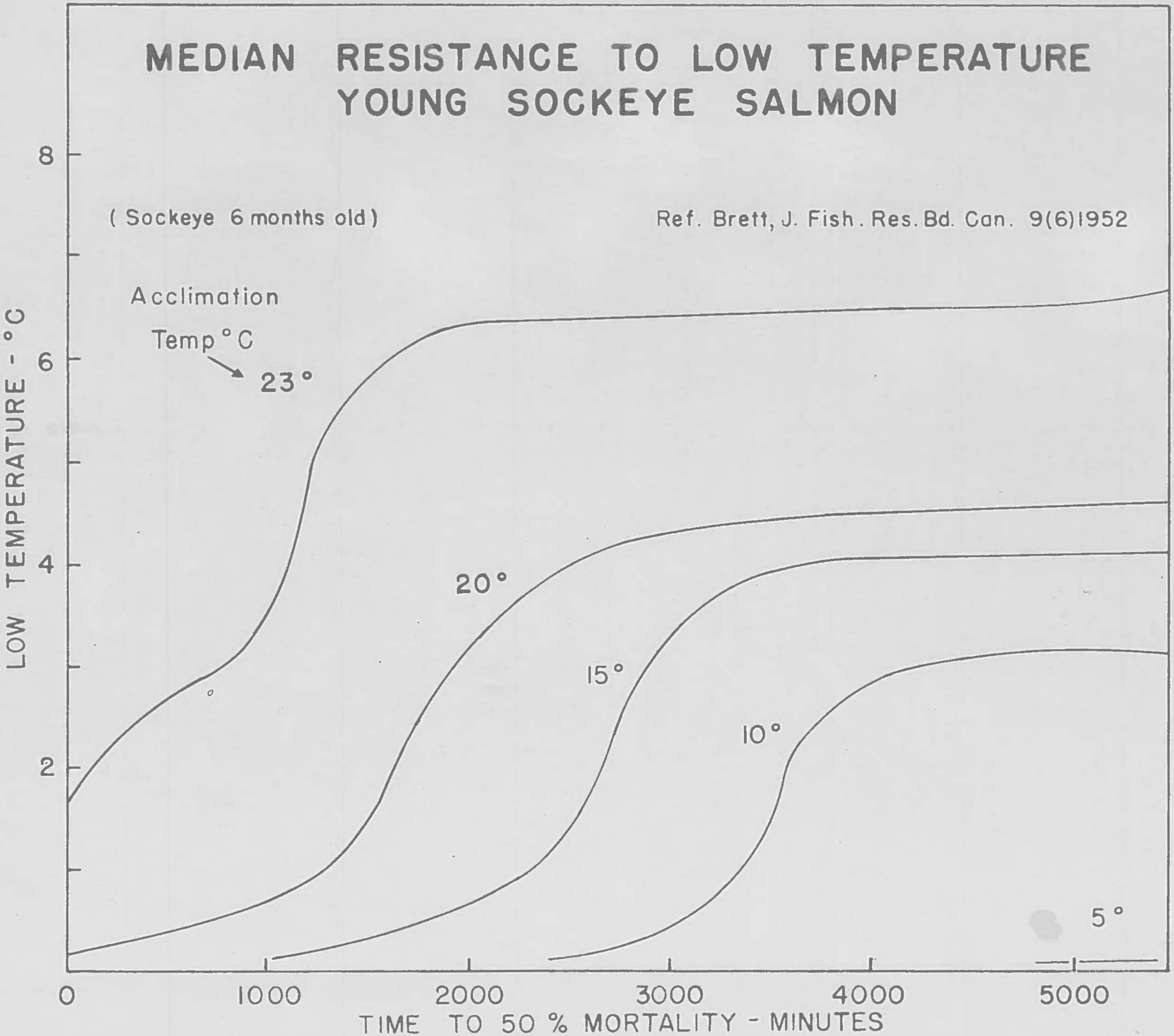

MEDIAN RESISTANCE TO LOW TEMPERATURE
YOUNG SOCKEYE SALMON
(Sockeye 6 months old)
Ref. Brett, J. Fish. Res. Bd. Can. 9(6)1952
Acclimation
Temp °C
23°
20°
15°
10°
5°
LOW TEMPERATURE - °C
8
6
4
2
0
1000
2000
3000
4000
5000
TIME TO 50 % MORTALITY - MINUTES

FIGURE - 8

as a means of preventing migrants from being attracted to such outlets and also the possibility of using deeply submerged spillway outlets, except during the early period of downstream migration before the surface layers of the reservoir have opportunity to warm up. It will be shown subsequently that such deep outlets would also create temperature problems during the period of upstream migration of adult salmon.

Another important factor to be considered in the tailwater environment is the effect of predation on the downstream migrants. In the normal migration pattern, a large proportion of the downstream migration occurs in a relatively short time and the fish are distributed throughout the river. Thus, the opportunity for predation on this segment of the migration is minimized. It is possible that the reservoir and the collection and by-pass systems may tend to spread the migration more evenly throughout the migration period and thus afford more opportunity for predation. The by-pass system would also deliver the migrants to a fixed position at tailwater, and would concentrate the migrants and make them more available to predators.

The mortality to migrants inflicted by predators is difficult to measure, and no accurate assessment of it is available. It is believed that any impairment of the migrants swimming ability as a result of passage over a dam makes the fish more susceptible to predation. No information is available on predator populations in the Fraser River, but, taking the Columbia River as an example, it can be expected that substantial numbers of predatory fish would be present. At Bonneville Dam these fish accounted for 29.2 per cent of the fish counted through the fishways in 1953 (29).

PROBLEMS RELATED TO UPSTREAM MIGRATIONS

A. Timing and Magnitude of Adult Migrations

Adult sockeye salmon migrate up the Fraser River past the site of the proposed Moran Dam to reach spawning grounds on the Chilko, Quesnel, Bowron, Stuart, and Stellako River systems. The runs to these rivers comprise all the major early runs to the Fraser River system, with the first arrival at the Moran site on July 1 and continuing through to September 30. It is these early sockeye runs that were most severely affected by the blockade at Hell's Gate and they contain the greatest potential for increasing production back to pre-1914 levels, particularly in the Horsefly and early Stuart runs. It is estimated that by careful management of the fishery and preservation of natural environment through watershed protection, the runs to the spawning grounds on tributaries upstream from the Moran site can produce an average of $6\frac{3}{4}$ million sockeye annually. It has been conservatively estimated (1) that with all these early runs fully rehabilitated, escapements during closures in the commercial fishery could be at least 750,000 sockeye in a <u>single day</u>. It is noteworthy that this is more than all species of salmon passed over Bonneville Dam in a <u>whole year</u>.

Adult spring salmon migrate past the Moran site from about March 1 to November 15 of each year. In total numbers of fish, spring salmon escapements are much smaller than sockeye escapements, and the design of facilities for upstream passage of spring salmon would not be appreciably affected by considerations of spring salmon except with respect to details that may be affected by size of fish or other limitations peculiar to spring salmon such as temperature and pressure tolerances.

However, the extended period of migration of these species does have a bearing on the operating requirements of any fish facilities that might be considered.

Steelhead trout migrate past the Moran site throughout the entire year. The total number of this species is also small relative to sockeye and their effect on design of fish facilities would be similar to that of spring salmon.

Thus any permanent fish facilities for the upstream passage of adult salmon and steelhead trout would have to be capable of handling 750,000 fish per day without delay, and they would have to be operable throughout the entire year although not necessarily at maximum capacity. Following sections of this report will present more detailed considerations of the problems associated with upstream passage of adults.

B. Maintenance of River Environment

It has been proposed that the turbine intakes at the proposed dam would be located 230 feet below maximum forebay elevation and about 30 feet below minimum anticipated forebay elevation and that the spill outlets be located 60 and 260 feet deeper still. Regardless of reservoir level, the turbine and spill flow would be withdrawn from a fixed elevation. It has already been pointed out that the withdrawal of turbine water from great depth would create a serious problem in maintenance of a suitable environment in the river for downstream migrant salmon, and it will be seen that the same would be true for adult migrations.

It is difficult at this time to make precise estimates of the distribution of water temperature in the reservoir behind the proposed dam, since the factors controlling such distribution are not fully understood. It is known that meteorological and hydrological conditions and river inflow temperatures are the principal, if not the only, factors involved and that because of this, temperature distributions can be expected to vary considerably from year to year. This is well illustrated by the data for Lake Roosevelt, particularly in August, as shown in Figure 6, where there is a spread of temperature from 51°F to 59.5°F at 300 feet depth, compared with 66°F to 70.5°F at the surface. The highest temperature at the 300 foot depth occurred in 1948, a year of high discharge which presumably resulted in greater than average replacement of the water in the reservoir and consequently introduced warmer water to the bottom of the reservoir. In the months illustrated in Figure 6, none of the water is at the temperature of maximum density (39.4°F) common in most deep lakes in British Columbia (Figure 9) nor is there any thermocline. Since the rate of volume change in the proposed Moran reservoir would be between that for Roosevelt Lake and that for Shuswap Lake, it is indicated that the depth-temperature relationship at Moran Dam would lie between these two limits. Limited data for Lake Shannon (Figure 10) behind Baker Dam in the Skagit River illustrates such an intermediate type of depth-temperature relationship.

Preliminary estimates of the probable depth-temperature relationships at Moran Dam have been prepared for an average year on the basis of river inflow temperature, travel time, rate of replacement of reservoir volume and using the surface temperature of Shuswap Lake as a guide to reservoir surface temperature. These estimates indicate that the temperature of the water discharged from the reservoir through spill and turbine outlets during the period ofadult migrations would range

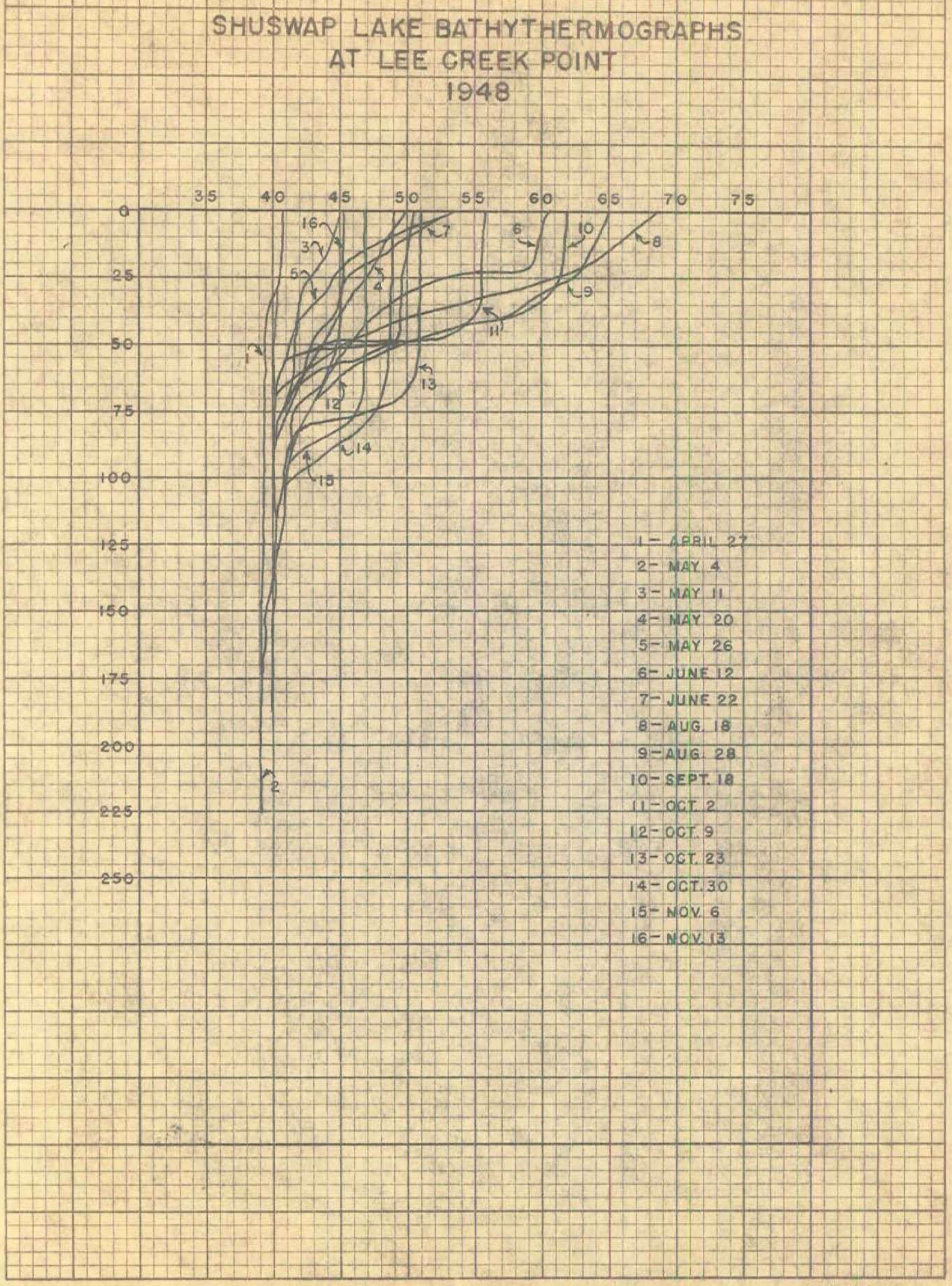

SHUSWAP LAKE BATHYTHERMOGRAPHS
AT LEE CREEK POINT
1948
35 40 45 50 55 60 65 70 75
0 25 50 75 100 125 150 175 200 225 250
1 - APRIL 27
2 - MAY 4
3 - MAY 11
4 - MAY 20
5 - MAY 26
6 - JUNE 12
7 - JUNE 22
8 - AUG. 18
9 - AUG. 28
10 - SEPT. 18
11 - OCT. 2
12 - OCT. 9
13 - OCT. 23
14 - OCT. 30
15 - NOV. 6
16 - NOV. 13

FIGURE - 9

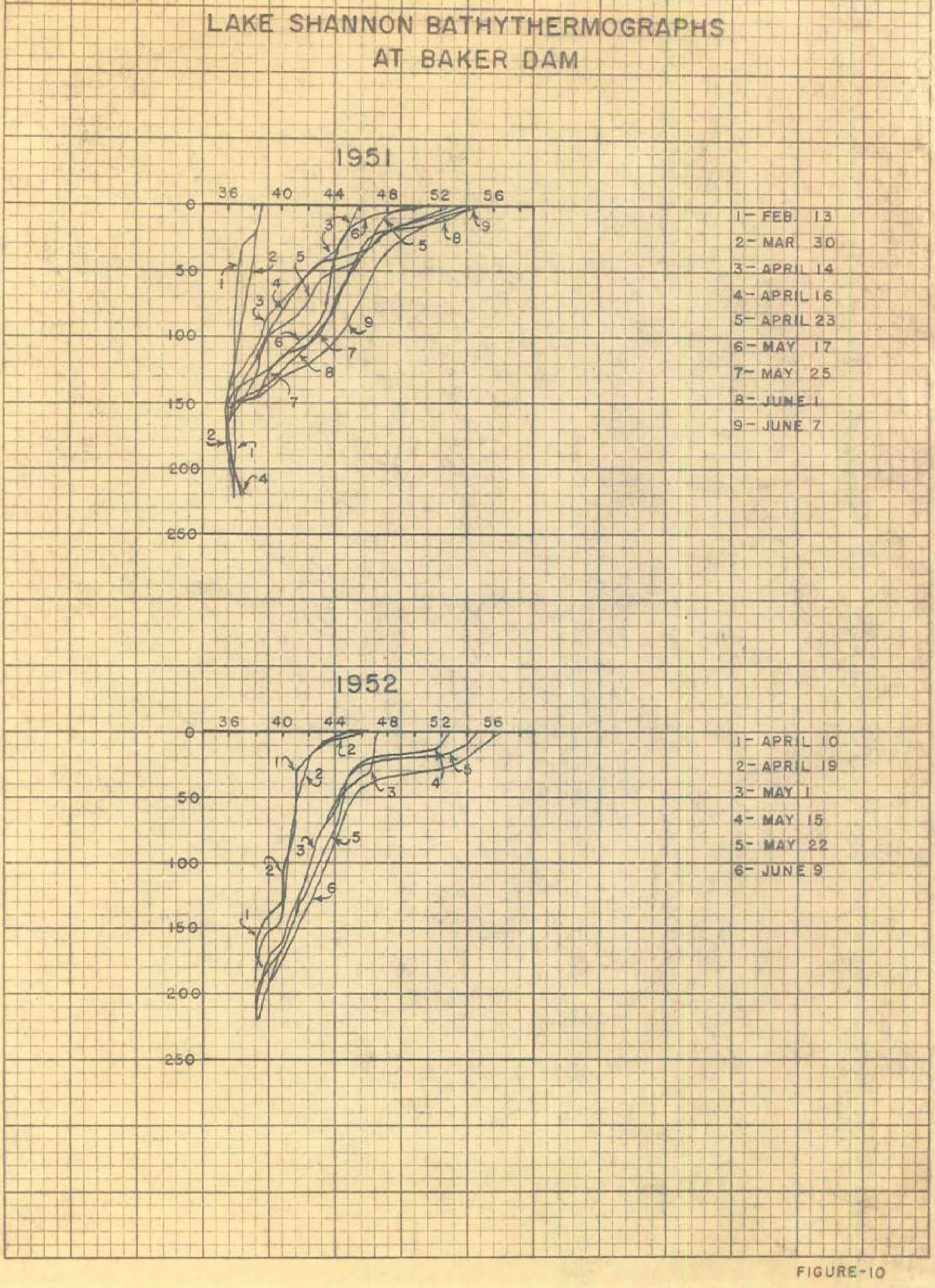
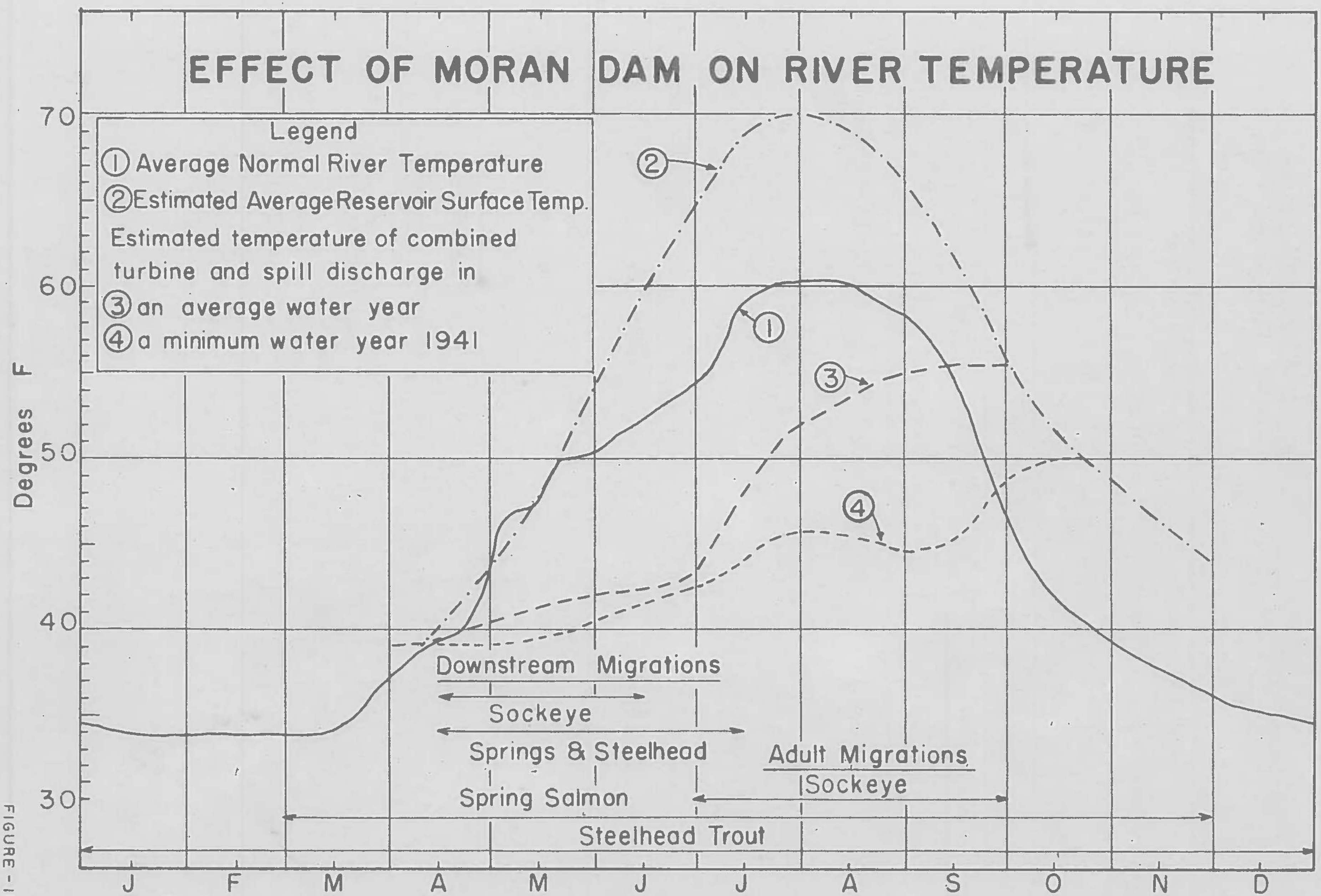

LAKE SHANNON BATHYTHERMOGRAPHS
AT BAKER DAM
1951
36 40 44 48 52 56
0 50 100 150 200 250
1– FEB. 13
2– MAR 30
3– APRIL 14
4– APRIL 16
5– APRIL 23
6– MAY 17
7– MAY 25
8– JUNE 1
9– JUNE 7
1952
36 40 44 48 52 56
0 50 100 150 200 250
1– APRIL 10
2– APRIL 19
3– MAY 1
4– MAY 15
5– MAY 22
6– JUNE 9

FIGURE-10

from 43°F on July 1 to 56°F on September 30. These temperatures are 11°F colder and 9°F warmer respectively than average normal river temperatures at those dates. Figure 11 depicts the estimates of the combined temperature of all outflow from the dam compared with normal river temperatures for an average year. River temperatures downstream from the dam to the confluence with the Thompson River would gradually be modified by the weather and by tributary inflow. On the basis of records of river temperatures at Gang Ranch and above Lytton it could be expected that during July, August, and September there would be a rise in temperature of 0.3, 1.5, and 2.0°F respectively between Moran and Lytton. Mixing with the flow of the Thompson River would further reduce the differential. On the basis of maintenance of average flow in the Fraser River, and the average flow of the Thompson River, the temperature differential below Lytton would be 62 per cent or more of the temperature differential above Lytton. These calculations are based on averages only and there would be variations from year to year depending on river flows and temperatures. In a year such as 1941, for example, when the reservoir would not be refilled until the end of September, the subsurface waters in the reservoir would remain colder than in the average year and outflow would be lower than for the average year.

It is well established that the effective spawning of various "races" of sockeye takes place within a narrow range of temperatures and that the timing of the various races up the river system is critically adjusted so that the fish will arrive on their respective spawning



EFFECT OF MORAN DAM ON RIVER TEMPERATURE
Legend
① Average Normal River Temperature
② Estimated Average Reservoir Surface Temp.
Estimated temperature of combined turbine and spill discharge in
③ an average water year
④ a minimum water year 1941
70
60
50
40
30
Degrees F
Downstream Migrations
Sockeye
Springs & Steelhead
Adult Migrations
Sockeye
Spring Salmon
Steelhead Trout
J F M A M J J A S O N D

FIGURE - 11

grounds at the optimum water temperature, regardless of the distance from the sea. Consequently, the water temperatures encountered in the Fraser River by different races enroute to their spawning grounds vary from about 35°F to 66°F, but the temperatures encountered by the early migrating races that pass Moran varies within the much narrower range of 50°F to 66°F from year to year and the temperature range encountered by individual races is even less. For instance, during August, when the Chilko and Horsefly runs are passing, the temperature range is 57°F to 66°F from year to year. The metabolic rate of fish is known to vary with temperature, reaching a maximum value at a certain optimum temperature, and declining with increased or decreased temperatures. Data for sockeye are not currently available, but data (Figure 12) for lake trout (Salvelinus namaycush) indicate that for the temperature range of 57°F to 66°F the metabolism rate of these fish is 90% or more of the maximum rate, which occurs at 61°F. At a temperature of 43°F, the metabolism rate is only about 55% of the maximum (25). These changes in metabolic rate are reflected in a similar relationship in the steady swimming speed of the fish.

It has been established that the early migrating sockeye runs migrate faster than the late runs (26), and it may well be that the recorded variations in rate of migration are a function of metabolic rate, as determined by water temperature. From the above data for trout, it is evident that the lowered water temperatures resulting from operation of the dam in the proposed manner would greatly reduce the metabolic rate of the affected sockeye, perhaps to 55% or less of the maximum rate. Such a reduced metabolism rate can only result in a longer migration time in the river up to the dam, which would add to the total

STEADY SWIMMING SPEED AND ACTIVE STANDARD METABOLISM LAKE TROUT

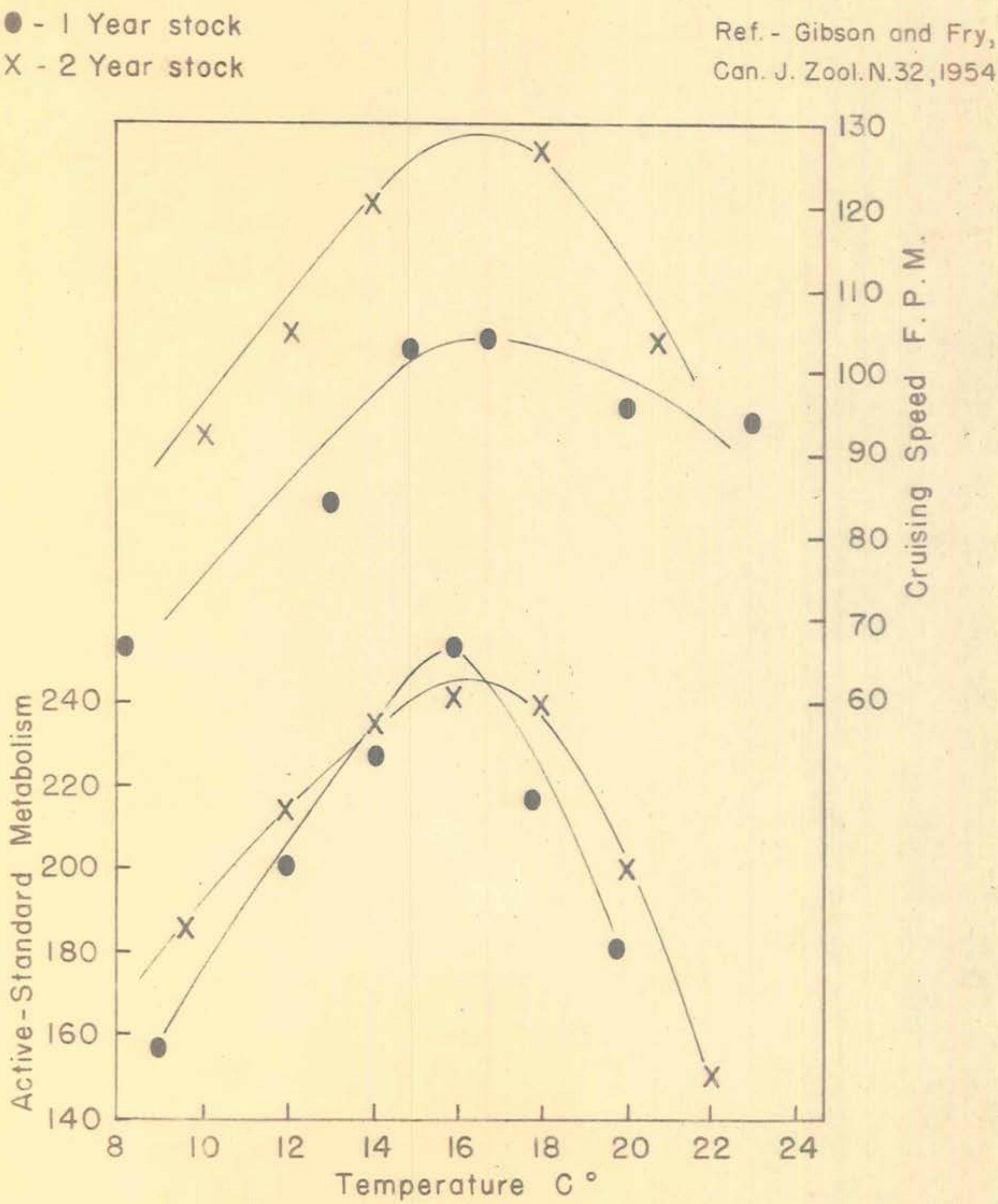


FIGURE - 12

delay caused by the proposed dam. A similar problem could exist in the forebay of the dam due to the increase in surface water temperature over normal river temperature, although in this situation the fish would be able to select a more optimum water temperature by sounding, if they are able or willing to do so.

On the basis of the available evidence, therefore, it is considered essential that the temperature of the Fraser River downstream from the proposed dam should remain within the normal range of temperatures in the existing river. To satisfy this criterion, it would be necessary that the turbine and spill outlets be capable of withdrawing water from various levels to obtain the desired temperatures in the combined discharge. There can be no control of forebay temperatures, and the willingness of fish to sound to avoid high temperatures cannot be predicted. It is evident that this requirement would necessitate withdrawal of turbine and/or spill discharge from a wide range of reservoir levels with great flexibility of control.

C. Collection of Adults

Before upstream migrating salmon can be passed over any obstruction, it is first necessary that they be suitably collected or led to the fish passage facility. At natural river obstructions this is not normally necessary, since the turbulence and velocity of the river are sufficient to confine the fish to a narrow path along the river bank where they are easily collected. At large dams, however, this condition is not always readily achieved and in many cases elaborate collection facilities are required to minimize, insofar as possible, delays in leading the fish to the fish passage facility. Bonneville, The Dalles, and McNary Dams in the Columbia River provide examples of this type of collection system. It has been suggested in the Moran Dam Brief that such collection facilities be placed at the downstream end and along the tailrace face of the two powerhouses immediately below the dam. This arrangement, however, is not considered feasible since fish could swim past the powerhouses into the spillway stilling basin area, particularly when there is little or no spill, and may be delayed several days before dropping downstream to reapproach the facilities. A much more positive means of collection is considered essential. In connection with the construction phase problems, it has already been suggested that the most effective means of collection would be a low barrier weir at a point downstream from the diversion tunnel exits. Such a structure would be constructed to create conditions resembling natural river obstructions so that the fish would be led naturally to the river banks below the obstruction where they could be attracted more readily to fish passage facilities.

The design of such a structure will not be attempted here, since it would depend to a large extent on river bottom topography and could best be determined by hydraulic model studies. The basic requirement would be that the structure create a concentrated fall of 15 feet at all times, and that suitable areas be provided at both banks from which the fish can be led to the fish passage facility. This type of structure is not new in principle, but application to a river of the magnitude of the Fraser River has not been attempted.

From this collection structure, a transportation channel would be required, on one or possibly both banks, leading to fish passage facilities. The decision on whether facilities would be required on both banks could not be made until the form of barrier dam structure is established. It would be most desirable that facilities be provided on both banks in order to minimize delay, but it might be possible to design the barrier dam in such a manner as to lead the fish to a transportation channel on one bank only.

The present river level at the Moran Dam site, which would correspond with tailwater level, ranges from elevation 828 at 285,000 cfs flow to elevation 780 at 4,000 cfs flow, a range of 48 feet. Tailwater level variation with the dam in operation would be modified depending on the number of powerhouse units in operation and the effectiveness of the reservoir in controlling floods. Facilities provided in connection with the construction stage would be required to operate throughout the above range in water levels, and since the range in water levels in the initial period of operation of the dam may not be substantially different, it is considered that the same range in tailwater levels would apply to any permanent facilities. Such a large range in tailwater levels would create extreme complications in the fish entrances of any fish facilities and it is considered to be necessary, as well as most economical, to first raise the fish to a level where constant tailwater conditions can be maintained. Allowing 3 feet of drop in the river between the dam and the collection barrier, it would be necessary to raise the fish 51 feet to get them into a tailwater chamber with a constant elevation equal to the maximum tailwater elevation below the dam. Thus, regardless of what type of facility might be considered for passing adult salmon over the dam, the first step after the collection system would be a fishway (or fishways) leading to a transportation channel. This fishway would consist of 52 weirs with pools 16 feet long by 10 feet deep with a total width of 130 feet. Water for the fishway and transportation channel would be pumped from the forebay of the barrier dam, and auxiliary water necessary to maintain a transportation velocity of 2 fps at the downstream end of the fishway would be obtained by gravity from the same source. It is possible the fishway could be subdivided longitudinally and certain sections closed off when the full capacity of the fishway is not required.

D. Adult Salmon Facilities

There are three general types of facilities that might be considered for moving adult salmon over the proposed dam, conventional fishways, pressure and gravity locks, and elevators.

1. Fishways.

The conventional method of providing passage for adult salmon would be one or more fishways of the weir or vertical slot type. Such structures would be approximately 2.3 miles long exclusive of holdover pools, which might be necessary because of the length of time required for the fish to negotiate the fishway. Assuming that the rate of migration observed on the Columbia River fishways, i.e. an average of two hours for 35 pools (1), would apply, an average of 44 hours would be required for fish to ascend the fishway. Since the daily migrations are limited to the daylight period, about 15 hours, an average of three days migration would be required and the fish would have to spend at least three nights in the fishway system. It must be emphasized that these are average times and that a substantial number of fish will require double that time or six days to ascend the fishway. There is no precedent in fishway operation for this situation, but on the basis of observation of the migration pattern in the Fraser River, combined with present knowledge of adult passage through fishways, it is considered that the fish could not be expected to maintain their position overnight in the typical fishway pool, and that large resting pools would have to be provided. Two or possibly three such pools would be required for each days's migration, each proportioned on the basis of the hourly rates of migration and the number of hours migration expected to be held over. If each pool is made the same width and depth as the fishway, the total length required for each day's migration would be about 2200 feet. Thus the total length of the fishway would be about 3.6 miles. Due to the expected 200 feet variation in headwater elevation at the dam, approximately 3200 feet of the fishway length at the upper end would have to be designed to accommodate such a variation. Since a slot 130 feet wide by 200 feet deep through the dam appears structurally infeasible, this upper portion of the fishway would either have to be constructed within the forebay of the dam, or in a channel through the canyon wall around the abutment of the dam.

Alternatively, the fishway system might be carried to approximately maximum forebay elevation before passing through the dam into the forebay, and a number of segmental weirs provided to accommodate a range of forebay levels for which structural design of a slot through the dam is feasible.

It would then be necessary to provide a pumped water supply for forebay elevations below the selected range to supply not only the fishway but also locks or possibly a channel in which the fish could be lowered to the prevailing forebay elevation. While this scheme might simplify the structural problems, it is not biologically sound since it would create a variable flow pattern at the upper end of the fishway and would involve additional handling of the fish in a manner for which there is again no precedent and no assurance of success. It is not intended to determine here the practicability of any of these schemes, but merely emphasize that the provision of adequate fishways, if considered biologically sound, would present serious structural and hydraulic design problems which cannot be overlooked.

In addition, there are several objections, physiologically, to such a fishway system. The ascent over the dam could represent, the equivalent in energy expenditure of the 176 mile swim through the normal river from Moran to Quesnel, which would normally take the early sockeye runs about six days. The three or more days involved in ascending the fishway would require the expenditure of energy without commensurate advancement in their migration to the spawning ground. A further complication arises, in that if the water supply of the fishway comes from the surface of the reservoir, the temperature of the water in the fishway will differ from that normally encountered by the fish. The situation here would be the reverse of that encountered in the river below the dam in that temperatures would be higher than normal, by as much as 11°F, with a maximum temperature of about 70°F. Referring again to Figures 10 and 11 it will be noted that during the months of July and August, the time when most of the sockeye migrate past the dam site, the metabolic rate would be reduced to 55 to 72 per cent of the maximum. Under these conditions, the fish would not be able to expend their available energy at the maximum rate and may require more than three days average to ascend the fishway. Experimental evidence and data on rates of migration in the sea indicate that the low velocities in the forebay would not reduce the time required to swim from the dam to the head of the reservoir although there would be a considerable reduction in the energy required to traverse the 172 miles. There is also evidence on the Columbia River that there is no compensating increase in movement of spring chinook salmon through the slack pool after passing through the fishways at Bonneville Dam (33). It appears certain, therefore, that using fishways, the dam would result in the equivalent of at least three days average delay, and considering the effects of higher water temperatures in the fishway, it is reasonable to expect several additional days delay on the average. The significance of such delays has been mentioned in earlier reports. Thompson (27) in his studies of the Hell's Gate obstruction found that 12 days delay was sufficient to prevent sockeye from reaching their spawning grounds. Killick (26) found in studies of the Early Stuart sockeye runs, that death occurred from 8 to 14 days after arrival on the spawning grounds. Current studies of the rate of energy expenditure by sockeye indicate, from preliminary analysis, that a delay of three to six days could be critical for the Early Stuart runs. Such delays might allow the fish to reach the spawning areas but leave insufficient energy material to permit the fish to carry out the pre-spawning and spawning activities.

On the basis of the probable delay resulting from the use of fishways as a means of transporting salmon over the proposed dam and the established effects of such a delay, it is concluded that fishways would not be a suitable fish passage facility. In addition, there is a serious question of whether the fish would maintain their normal behavior pattern in such a long fishway. If any of the characteristics of the fishway caused an alteration in normal behavior and frightened the fish, or if the fish merely became reluctant to continue migrating up it, the consequences could be disastrous.

From the foregoing discussion on fishways, it is evident that the only facility that could possibly provide suitable passage for the adult salmon would be one that delivers them without delay from tailwater to headwater with little or no energy consumption by the fish. Locks or elevators therefore appear to be the only possible means of attaining this type of facility.

2. Gravity and Pressure Locks.

Gravity locks for passing fish over dams are in limited use at dams on the Columbia River (Bonneville, The Dalles, McNary) and at smaller dams in other countries, (chiefly Scotland and Ireland). Bonneville Dam has four locks each 20 feet by 30 feet in section with a lift up to 60 feet. Equipment of one of the original five locks was removed and installed in McNary Dam, where the lift is 85 feet. The Dalles Dam has one experimental lock 20 by 30 feet with an average lift of less than 90 feet.

The locks at Bonneville Dam are reported (28) to be unable to attract fish into the lock chamber. The lock at McNary Dam was placed in a location adjacent to the Washington shore fishway which it was considered would provide better attraction to the lock. Tests are being conducted to determine the optimum method of operating this lock. These locks, however, are used only infrequently (29) for demonstration purposes or trapping of fish other than salmon.

The Torr Achilty Dam on the River Conon in Scotland has a sloping gravity lock 12 feet by 6 feet in section with a lift of 50 feet (30). During an eight month period this lock passed 3,400 salmon as well as trout and eels. Three other similar locks (Borland type) were constructed (1955) at dams upstream from Torr Achilty, and a fourth is planned at the Orrin Dam. A similar lock with a 65 foot lift was installed in the Leixlip Hydroelectric development by the city of Dublin.

None of these existing gravity locks can be considered to provide any basis for optimism regarding their usefulness in passing the large numbers of salmon migrating in the Fraser River. Nevertheless, the physical and biological problems inherent in the use of locks must be considered and evaluated insofar as is possible.

The size and number of locks would depend on the operation cycle of the locks and the maximum rate of migration of the salmon. The maximum hourly rate of migration would be about 14 per cent of the total daily migration (1) or 105,000 fish per hour. The maximum fishing depth of a lock would be the same as for the fishway, 10 feet, on the basis of present knowledge. The lock dimensions should be the maximum practicable consistent with limitations on the necessary gates and openings through the dam.

Due to the artificial confinement of fish in the lock and the need for preventing impairment of fishing efficiency due to overcrowding, it is considered, as a preliminary estimate that 4 cubic feet of space should be allowed for each fish. A lock 50 feet square would thus be able to hold 6,250 fish, or about one-twentieth of the maximum hours migration. Since each lock would require at least a one hour cycle period (30 minutes for loading, 10 minutes each for filling, unloading and emptying), a total of twenty locks would be required. At any given time 5 locks would be in the same phase of operation. Thus, a flow of 15,000 cfs would be required merely to fill the locks when they were all operating. Because of space limitations it would not be possible to place such an array of locks on the face of the dam, unless they could be grouped in batteries of five locks each arranged in series, provided such an arrangement would maintain fishing efficiency. The number of high pressure gates required would be minimized with this scheme, although other structural problems may be complicated. The locks could be placed on either the upstream or downstream face of the dam, whichever would be most feasible structurally. Alternatively, the locks could be arranged in parallel along one or both banks of the canyon wall downstream from the dam with a special exit channel leading into the forebay. Whatever arrangement might be considered suitable, the same fish exit problems would be encountered as with the fishways due to the extreme range of forebay fluctuation. Water temperatures in the locks need not create any problem, however, since they could be controlled by multiple entrances in the forebay for the necessary water supply. Setting aside structural problems, the most critical problem in connection with such locks would be the lack of assurance that fish could be attracted into them in any substantial numbers without delay. Mechanical "forcing" screens might be employed to ensure continuous movement of fish into the locks from the transportation channel leading from the barrier dam. However such devices create an artificial movement which may injure fish due to crowding on the face of the screen, and which may be undesirable physiologically if the fish are excessively frightened. The excessive energy consumption resulting from fright, and the associated accumulation of body wastes may well nullify the purpose of the locks, which in part is to provide passage requiring little energy expenditure by the fish. The ill effects of handling and frightening must not be underestimated when considering the suitability of any fish facility. Mechanical injury to the skin of the salmon results in flooding of body tissues with excessive amounts of water, liberation of toxic materials from injured tissues and ready penetration of pathogenic organisms (31). Such injuries can result in premature death. Extreme exhaustion due to handling can also result in a delayed mortality, even though there may be no immediate symptoms. In order to avoid such ill effects, it is necessary that the fish facility avoid all possible sources of mechanical injury, and that it be operable in such a fashion as to provide ready acceptance by the fish. The fish themselves are the ultimate measure of the success of any facility, and predictions of the acceptance of a facility by fish are impossible. Such facilities can only be developed on the basis of experience. Considerable research on the design and acceptability of gravity locks would be necessary before any definite conclusion could be made regarding the application of such a facility at the proposed Moran Dam.

Pressure locks would be no different from gravity locks in respect to capacity. Their advantage lies in economy of water and possibly in reduction in required cycle time since the main shaft of the lock would not have to be filled and emptied each cycle. In addition to the problems already discussed for gravity locks, there would be the problem of the effect of 310 psi pressure on the salmon when the lock is pressurized. This problem would not exist in a gravity lock since a brail would be used to force the fish up the lock as it fills. Such a brail would probably be required in a pressure lock also, but the pressure problem would remain.

An experimental pressure lock has been incorporated in McNary Dam, with pressures up to 37 psi. This lock has no forcing brail, and experiments to date have been concerned with determining the optimum cycling time and with observations of fish behavior within the lock. The fish do not appear to suffer any ill effects in this lock, although no tests have been made to measure survival after leaving the lock and success of spawning. Extrapolation of experience with 37 psi pressure to 310 psi is obviously not possible. Therefore a thorough study of the effects of such high pressure would have to be made in order to permit assessment of the suitability of pressure locks as a fish facility at the proposed dam.

3. Elevators.

Elevators are essentially gravity locks in which the increments of water and fish are lifted mechanically, rather than hydraulically

Their advantage would lie in the economy of water use and consequent power saving.

Elevators are in use at the present time at some dams where the total number of fish to be handled is relatively small. At Baker Dam, sockeye and coho salmon are lifted about 270 feet in a small tank transported on an aerial cableway. The fish, until recently were then hauled up the reservoir several miles in a barge before being released. This process involved much handling of the fish which it is believed was the cause of a substantial mortality. It was known that many fish never appeared on the spawning grounds. An elevator system is also in use at the recently (1957) completed Beechwood Dam on the St. John River in New Brunswick. The lift at this dam is 50 feet and a small annual migration of Atlantic salmon is expected to be passed over the dam by a single elevator tank. The adult coho and spring salmon migrations in the White River are collected at a low power intake dam and transported by tank truck around Stevens (Mud Mountain) Dam, and similarly the coho migrations in the Capilano River are transported around Cleveland Dam by tank truck. In all of these operations, less than 25,000 fish are handled annually, and the facilities provided are able to cope with these numbers of fish without undue delay, but not without subjecting the fish to stress due to handling and transport.

Transport by tank truck is inconceivable at the proposed dam due to the large numbers of fish to be handled and limitations of tank capacity. Tank trucks used at Stevens Dam carry about 400 pounds of fish in a 1000 gallon tank, which is the equivalent of about 70 sockeye.

Thus during the maximum hour of migration at Moran Dam 1500 tank loads would have to be transported a minimum distance of about three miles.

Elevators consisting of tanks on hoists would operate in the same manner as described for gravity locks and would be subject to similar space and structural limitations, as well as the same biological problems.

For all of the foregoing types of facilities that might be used for transporting adult salmon over the dam, the limiting factors in determining their relative success are the unpredictable acceptance of the facilities by the fish and, if accepted, the relative efficiency in delivery of uninjured, unimpaired fish as compared with the normal river. Measures of these factors can only be obtained by experience with such facilities, and until such measures are available none of the facilities could be recommended for application at the proposed dam with any guarantee of success. It is possible to make engineering designs for a number of mechanical and hydraulic devices which would provide a theoretical means of passing adult salmon over dams, and which probably would pass fish to a certain extent, depending on the acceptance of the device by the fish. However, the fish facilities at any dam are costly and are of necessity a corporate part of the design of the whole structure. Failure of the facility to achieve the desired result could not be readily rectified, and would be synonymous with the loss of the fishery to the extent to which the facility was unsuccessful for whatever reason.

It is unlikely, on the basis of present knowledge, that any adult salmon facility could be provided which would not result in mortality to the salmon runs migrating past the proposed dam site. Until the bases are available for predetermining the extent of this mortality due to all causes, i.e. energy consumption, delay, fatigue, physical injury, and refusal to enter the facility, there could be no guarantee that the adult salmon could be passed over the proposed dam successfully.

It must be emphasized that the solution of one phase of the fishery problems at the proposed dam, for example the adult fish facilities, does not eliminate the need for solution of the remaining problems that have been discussed previously in this report. All of the requirements to ensure safe unimpaired passage of the salmon to and from their spawning grounds must be satisfied before the dam could be considered compatible with maintenance of the fishery. It cannot be sufficiently stressed that the solution to these problems cannot be based on wishful theorizing, but only on the basis of adequately proven scientific fact.

As previously stated, this report has considered only the effects of the proposed Moran Dam, since it would be the key element in the composite hydroelectric development proposed. However, each of the other elements such as additional power dams on the Fraser River, upstream storage dams, and flow diversions from other river systems would compound some of the problems associated with Moran Dam and would create additional problems affecting not only Fraser River salmon, but also the fisheries of the systems from which water is diverted. The economic effect of this proposed ultimate form of development must therefore include these additional fisheries. In the final analysis of the effect of the proposed dam it would be necessary to evaluate the composite effect on the fishery of all the auxiliary dams, storages and diversions. Any resulting limitations in the use of water could also limit the extent of development of the Moran site, and consequently alter the cost of power at that site. At the present time, however, in the interests of expediency and due to lack of details of the operation of these auxiliary developments, the extent of the fishery problems has been described only for the single dam at Moran.

CONCLUSIONS

It has been shown that the proposed Moran Dam on the Fraser River would create the following major problems in maintenance of the Fraser River salmon fishery for which there is no solution available on the basis of current knowledge.

1. The collection and transportation of downstream migrant salmon and steelhead trout from the forebay reservoir to tailwater by safe routes, and the prevention of migration through hazardous routes such as turbine and spillway outlets. It is expected that the use of such hazardous routes would result in mortalities considerably in excess of the highest known mortality rate of 70 per cent for a 295 foot head. The use of deeply submerged outlets, if proven to be a suitable means of preventing entry of migrants, does not appear feasible, due to the need for tailwater temperature control to prevent mortality to downstream migrants.
2. The collection and transportation of upstream migrant adult salmon and steelhead trout from tailwater to forebay elevation

without delay, injury, excessive energy consumption or other physiological impairment. Conventional fishways are not considered to be applicable to a dam of such height due to the three or more days required to ascend them and the critical energy reserves of the early sockeye runs which will not tolerate delays of more than 3 to 6 days. All the available evidence indicates that the low velocity forebay would not provide any compensation for delay incurred at the dam. The design criteria of other types of facilities or the acceptance of them by fish are not sufficiently known to permit assessment of their efficiency in handling the runs of up to 750,000 salmon per day which occur on the Fraser River. At the present time, therefore, no adult salmon facilities could be recommended for use with any guarantee that the salmon and steelhead trout runs of the Fraser River above the dam site could be maintained.

The circumstances creating either of these problems would be sufficient to destroy all of the affected salmon and steelhead trout runs which have a commercial value of $8,844,000 annually at current levels of production, and at potential production levels would be worth $23,188,000 annually at 1956 prices. In addition to these commercial values, these runs contribute substantially to the fresh and salt water sport fishery in the Fraser River and its estuarial waters and provide a valuable source of food for a large number of native Indian families.

In addition, the environment in the reservoir would create problems in connection with the migrations of both young and adult fish which cannot be fully evaluated at this time, but which potentially present no less hazard than migratory problems at the dam. Delay to downstream migrants due to the time required to traverse the 172 mile reservoir, and lack of suitable food in the reservoir could result in the death of downstream migrants. High water temperatures in the river below the dam during adult migrations could result in excessive energy consumption, and high temperatures on the surface of the reservoir could be lethal to the fish unless they are willing and able to descend to depths where such temperatures could be avoided. Water temperatures may also affect the swimming behavior of the migrants in the reservoir and thus influence the design and effectiveness of any facilities that might be considered for downstream migrants.

A host of other fishery problems would be created during the construction and operation of the dam, each of which could result in destruction of the salmon and steelhead runs unless careful attention is given to maintenance of the necessary environmental requirements. Such problems in many cases must be considered in combination with other concurrent problems rather than individually and, as with water temperature, can be a determining factor in the design criteria for fish passage facilities at the dam. Following are the most obvious of these problems as discussed in this report on the basis of the proposed form of development. Others may become apparent for different methods of development.

1. Adequate upstream and downstream passage during the construction period, which may last five or more years.
2. Timing of the initial reservoir filling period to reach minimum forebay level in the period between upstream and downstream salmon migrations.

3. Temporary facilities for passage of salmon and steelhead trout during the filling period.
4. Maintenance of necessary residual flows during the filling period to provide adequate water depths over pink and chum salmon spawning grounds in the Fraser River below Hope for transportation of salmon and steelhead trout.
5. The construction of possible remedial measures at blockades which may develop along the migration route at such residual flows at such places as Bridge River Rapids near Lillooet.
6. River temperature control to maintain the normal temperature cycle during the period of spawning migrations, and to prevent mortality to downstream migrants in the tailwater of the dam due to high temperature differential. Satisfaction of this requirement would necessitate the use of multiple depth outlets for both turbine and spillway discharges.

Finally, in summary, from review of all the fishery problems that would be created by the proposed Moran Dam, and of current knowledge of techniques for overcoming such problems where they are sufficiently understood on the basis of present knowledge of salmon behavior, it is concluded that there are no means currently available which could be utilized to maintain the affected salmon and steelhead trout runs in the Fraser at their present levels of abundance if the dam were built. Until all the varied problems are fully understood and techniques for solving them, if any, are available, the construction of Moran Dam would destroy a large segment of the Fraser River salmon fishery, which at potential levels of abundance would supply more than $23,000,000 annually of renewable food resource.

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