INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

BULLETIN III

1. A BIOLOGICAL STUDY OF THE EFFECTIVENESS OF THE HELL'S GATE FISHWAYS

BY

G. B. TALBOT

2. VARIATIONS IN FLOW PATTERNS AT HELL'S GATE AND THEIR RELATIONSHIPS TO THE MIGRATION OF SOCKEYE SALMON

BY

R. I. JACKSON

NEW WESTMINSTER, B. C.
CANADA
1950

DISTRIBUTION OF SOCKEYE SALMON SPAWNING GROUNDS IN THE FRASER RIVER WATERSHED

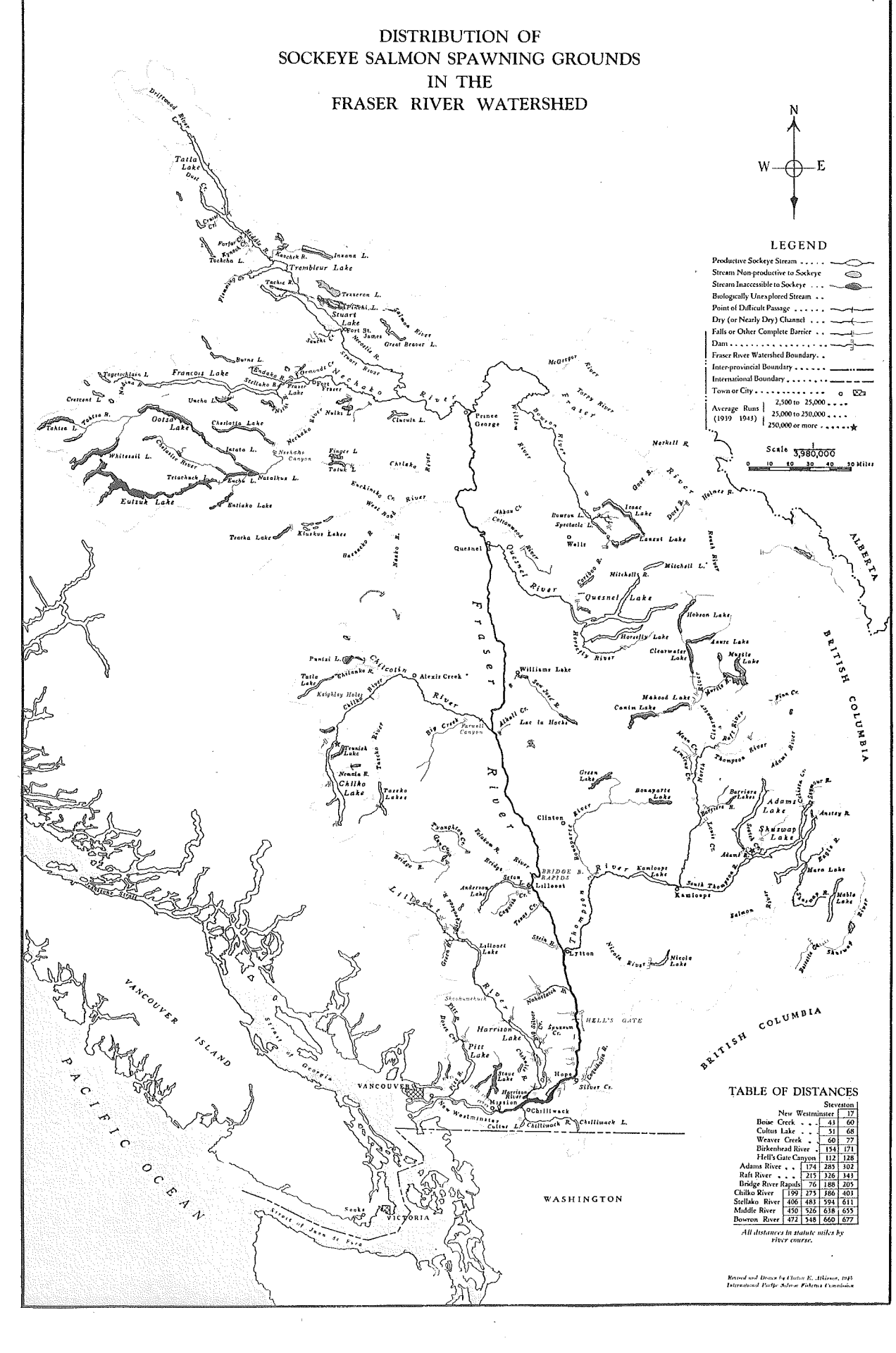

TABLE OF DISTANCES

	New Westminster	Steveston
Boise Creek	43	17
Cultus Lake	51	68
Weaver Creek	60	77
Birkenhead River	154	171
Hell's Gate Canyon	112	128
Adams River	174	285	302
Raft River	215	326	343
Bridge River Rapids	76	188	205
Chilko River	199	275	286	403
Stellako River	406	483	594	611
Middle River	450	526	638	655
Bowron River	472	548	660	677

All distances in statute miles by river course.

Revised and Drawn by Clinton E. Atkinson, 1945
International Pacific Salmon Fisheries Commission

FOREWORD

The International Pacific Salmon Fisheries Commission was created in 1937 following exchange of ratifications of the Sockeye Salmon Fisheries Convention between the Dominion of Canada and the United States of America. The Treaty was the culmination of the efforts of many men of both countries interested in restoring the once great Fraser River sockeye salmon runs which are shared by both countries.

The Treaty stipulates that the Commission shall consist of six members, three members from the United States and three from Canada. The purpose of the Treaty, based on the serious decline in the supply of sockeye salmon produced by the Fraser River system, was the protection, preservation and extension of the species. Certain powers to accomplish this were designated to the Commission and are specified in the Convention as modified by the Protocol of Exchange of Ratifications.

The Commission commenced its investigations in 1938. These investigations were directed among other things to determining the cause of the failure of the great run which disappeared after the disaster at Hell's Gate in 1913. Extensive tagging in fresh water disclosed the existence of a serious obstruction at Hell's Gate. The nature, extent and effect of the obstruction were then determined. A report including both the biological and engineering data pertinent to Hell's Gate was submitted to the governments of the two countries in 1944 with the recommendation that this hazard to ascending sockeye be removed. The results of the biological investigations of the Hell's Gate obstruction were published in 1945 in Bulletin No. 1 entitled "Effect of the Obstruction at Hell's Gate on the Sockeye Salmon of the Fraser River", by William F. Thompson. This report proved that the mortalities which occurred each year at Hell's Gate had been largely responsible for the continued depletion of the runs spawning above Hell's Gate and that remedial measures to eliminate the recurring mortality were necessary to the restoration of the Fraser River sockeye run.

Funds were made available by the two governments in 1944 and construction of fishways at Hell's Gate began that year. They were completed by the spring of 1946.

The first of the following reports is an analysis of the Hell's Gate tagging work carried out by the Commission between 1943 and 1947. This analysis was undertaken to determine the effectiveness of the new fishways in eliminating the periodic block to the passage of adult sockeye. In addition, information was desired as to the success of passage by sockeye at extreme high and low water levels which had not occurred during the Commission's investigations in previous years.

The second report in this Bulletin presents an analysis of the physical data obtained at Hell's Gate by the Engineering staff of the Commission. Engineering studies were begun at Hell's Gate shortly after evidence of the obstruction was obtained. These studies were designed to determine the causes of the obstruction.

The successful co-operation between the biological and engineering staffs of the Commission in solving problems relating to both branches of science has resulted in the alleviation of the Hell's Gate obstruction through installation of a new type of fishway designed by Commission engineers.

The following reports show that the recommendations made by the Commission were sound and fully justified, that the Hell's Gate fishways are operating successfully, and that the obstruction at Hell's Gate has been eliminated. The duties of the Commission in restoring the Fraser River sockeye runs as outlined in the Treaty are being successfully carried out.

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

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INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

BULLETIN III

PART I

A Biological Study of the Effectiveness of the Hell's Gate Fishways

By

G. B. TALBOT

NEW WESTMINSTER, B. C.
CANADA
1950

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A BIOLOGICAL STUDY OF THE EFFECTIVENESS OF THE HELL'S GATE FISHWAYS

INTRODUCTION

The combined Canadian-American catch of Fraser River sockeye (*Oncorhynchus nerka* Walbaum) up to 1914 showed a well-defined four-year cycle dominated by the "big" years of 1901, 1905, 1909, and 1913. After 1913, however, the "big" years failed to reproduce themselves, and even the catches of the "off" years fell to new low levels.

The failure of the 1913 and 1914 runs to reproduce themselves was blamed on railroad construction work done between 1911 and 1914 along the Fraser River Canyon between the towns of Yale and Lytton. In 1913 thousands of sockeye accumulated at several narrow and rapid places in the Canyon which had been made even more turbulent by the accumulation of rock and debris dumped into the river during the construction of the railroad. The Dominion government removed some of the rock that year and made temporary passageways for the fish by blasting out portions of the debris which had been dumped into the river.

In 1914 a large rock slide occurred at a narrow place in the Canyon called Hell's Gate where a railroad tunnel had been built. During that year sockeye had great difficulty in passing this place, and large accumulations of them were assisted by dip-nets and a flume. Removal of debris at this and several other difficult places in the Canyon was completed by the spring of 1915, and the river was declared to be as passable for sockeye as before the slides and debris went into the river (McHugh) (Babcock, 1915, 1916).

The return in 1917 from the 1913 spawners was only a fraction of the number of the latter (Fraser River sockeye are predominantly 4 years old when they return to spawn). The 1913 pack of Fraser River sockeye was about 2,400,000 cases, while that of 1917 was only slightly over 500,000. The runs of the other cycles also fell to new low levels so that between 1917 and 1937 (when the Sockeye treaty was ratified) the yearly pack of Fraser River sockeye salmon rarely exceeded 200,000 cases. Even though the apparent cause of the decline of the runs of 1913 and 1917 had been removed, the runs failed to rebuild themselves.

In 1938 the Commission began tagging sockeye at Sooke on the south end of Vancouver Island. Among other things, it was desired to trace the route of migration of the sockeye from the open seas to the spawning grounds of the Fraser River. So many of these tags were recovered in the commercial fishery that it was thought advisable to tag additional sockeye in the Fraser River itself. Several tagging sites were used in 1938. One of the sites was Hell's Gate (about 130 miles above the river mouth). Some evidence of difficult passage was found that year at Hell's Gate, and subsequently the river tagging was centralized there.

An analysis of the Hell's Gate tagging in the years 1938 to 1942 was prepared by the Commission in 1944. This report, published in 1945 as Bulletin No. 1, and

titled "Effect of the Obstruction at Hell's Gate on the Sockeye Salmon of the Fraser River" by William F. Thompson, gave proof that an obstruction to migrating sockeye still existed at Hell's Gate. It was shown that: "(1) The river at that point was impassable to most sockeye at certain water levels. (2) The consequent delay caused a mortality increasing with the length of delay. (3) The mortality occurred annually, varying in extent with the duration of the impassable water levels. (4) It was of such magnitude as to affect the maintenance of the catch". In Bulletin No. 1 it was recommended that the obstruction at Hell's Gate be removed because it was the principal cause of the present depleted condition of the Fraser River sockeye fishery.

A report including both the biological and engineering data pertinent to Hell's Gate was submitted to the governments of the two countries in 1944, and funds were made available that year for the construction of fishways at Hell's Gate. Work began in 1944, and by the spring of 1945 the right bank fishway and part of the left bank fishway were ready for use. These structures were completed during the winter of 1945-1946.

To provide such data as were necessary for designing the permanent fishways and to help a limited number of sockeye pass the Gate during block periods, a small temporary fish-ladder was blasted through the rock on the left bank of Hell's Gate in the fall of 1942. A brailer was also installed at Hell's Gate in 1942 to assist blocked sockeye. There was no hope of passing all delayed sockeye with these two temporary remedial measures, but it was hoped that at least a nucleus of each race would be able to pass so that outright destruction of races would not occur.

The ladder was of the conventional "step type", consisting of a series of pools each one a little lower than the other. Because of the rapidly changing water levels it was continually necessary to adjust the stop-logs which regulated the water levels in the various pools. It was found also that the river surge at the upper and lower ends of the fish ladder tended to "flood out" the pools, and destroy their effectiveness. Much information was obtained from this fish ladder, and it clearly demonstrated the need for a self-regulating fishway that would operate efficiently at all water levels.

This temporary fish ladder was only six feet wide; hence, the number of sockeye which it could handle was limited. It was found also that fish would not pass through it while adjustments were being made on the stop-logs. The sockeye used it to a limited extent, however, both in 1943 and 1944 until it was replaced by the permanent fishway in 1945.

During the seasons of 1942, 1943, and 1944 a brailer was used at Hell's Gate to assist blocked sockeye in passing this difficult reach. This device, powered by a small donkey engine, was designed to dip-net blocked sockeye from a pool just below Hell's Gate on the left bank and raise them above the river level into a large wooden tank which was filled with water by means of a power driven centrifugal pump. At intervals the water was released into a flume which carried the accumulation of fish back into the river several hundred feet above the obstruction. The brailer was in operation from July 25 to September 15 in 1943 and from August 21 to September 5 in 1944. During the 1943 period 1,097 sockeye were

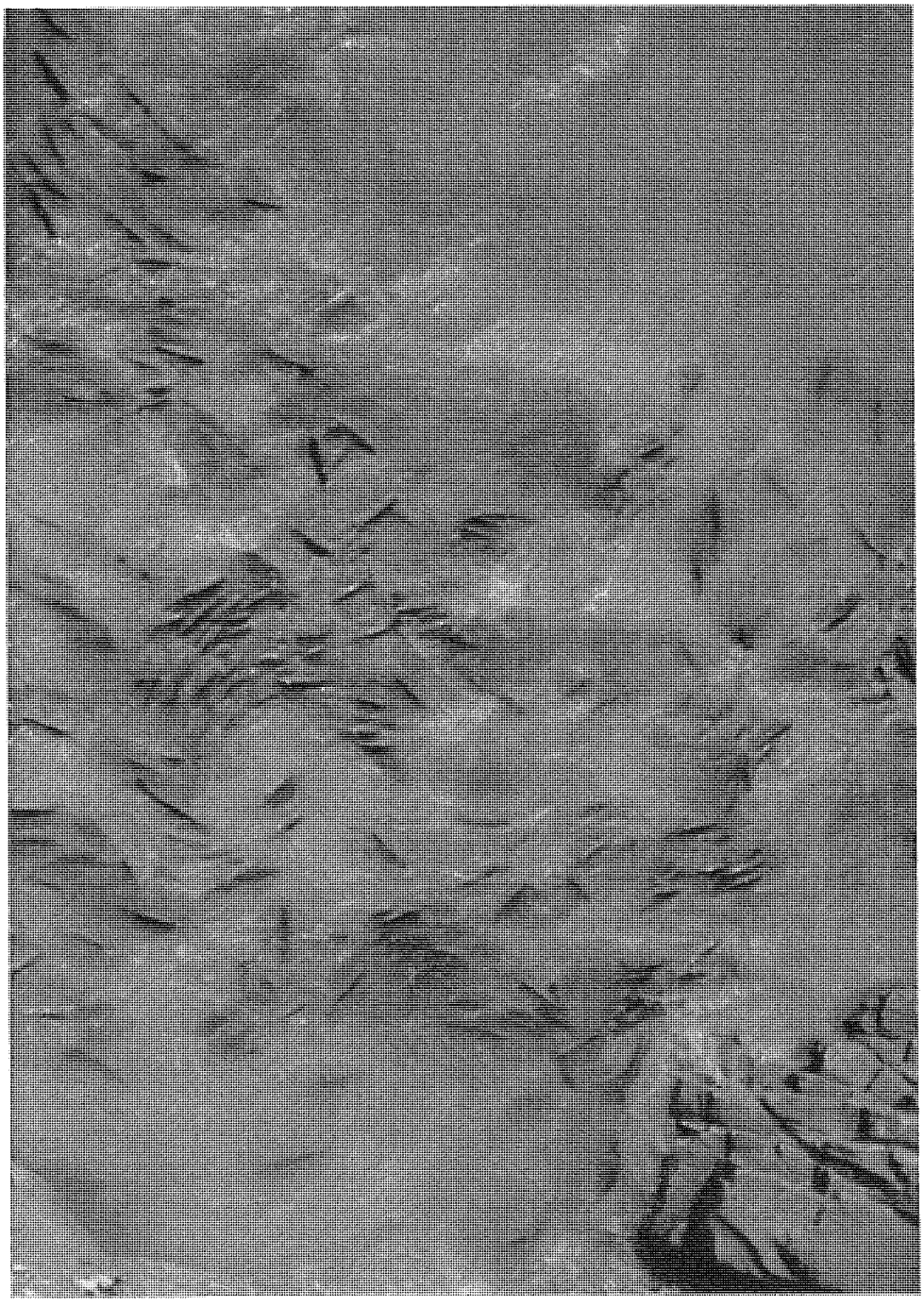

PLATE 1. Blocked sockeye resting in an eddy on the left bank below Hell's Gate, August 20, 1941.

brailed, and in the 1944 season 12,466 were helped past the obstruction by this method.

The type of fishway finally found suitable for conditions at Hell's Gate required a new application of fishway principles. The structures were designed to operate from elevation 23 feet to elevation 54 feet. (These elevations refer to a gauge established at Hell's Gate on which the zero is 224.03 feet above sea level). A full-depth slot is provided at both sides of each pool baffle. This slot is designed so that the water is directed through the slots and into the central portion of the next downstream baffle which creates pools with 10 to 12-inch steps from pool to pool. Fluctuations in river heights, which may be as much as 6 feet a day, do not affect the operation of this type of fishway. The right bank fishway which is 20 feet wide and 220 feet long was completed in the spring of 1945. The left bank fishway was constructed in two sections. The lower end which is 20 feet wide was completed in the spring of 1945, while the upper section, 12 feet wide, was not finished until the spring of 1946. The total length of this fishway is 460 feet.

The tagging of sockeye was continued at Hell's Gate after 1942. More information was desired as to passage on the right bank, for tagging was done on the right bank in 1942 only. The tagging of sockeye on the right bank was facilitated in that year by the installation of a footbridge so that easy access was provided for crossing the river. Additional information was desired also as to times of migration of the various runs and the delay and mortalities suffered by the sockeye at unusual water levels not yet tested. The main purpose for tagging after the fishways had been constructed was to determine if they were beneficial in reducing the sockeye mortality which was now known to have occurred each year at Hell's Gate since 1913 at least.

This paper is an analysis of the tagging experiments carried out at Hell's Gate from 1943 to 1947, inclusive.

METHODS

The fishing and tagging procedure at Hell's Gate was carried out in a manner similar to that described in Bulletin I (Thompson 1945, p. 97). Sockeye were caught with Indian dip-nets. The tags used were the Petersen type which consist of two celluloid disks about 13.5 mm. in diameter, one of which bears a serial number. The tags were attached, one on each side of the fish, by a nickel pin which ran through the upper part of the body just below the dorsal fin.

The tagging of sockeye was done at each bank of the river, both above and below Hell's Gate. The tagging stations were designated as Right Bank Above, Right Bank Below, Left Bank Above, and Left Bank Below. The conventional method of designating the river banks as Right and Left while facing downstream was used. At times, because of a small crew, it was not possible to fish in all these locations every day. In 1943 the tagging crews concentrated on tagging as many fish as possible; consequently, not as much fishing was done during the last part of the season on the right bank (where it was more difficult to fish) as would be desired for statistical purposes. During the 1944 season it was not possible to tag as often as was desired at all stations because of the hazard while construction of

the fishways was in progress. Starting with 1945, tagging was carried out in a systematic manner at all tagging stations.

A reward was paid for return of the tags. These were recovered by Indian fishermen who fish for salmon for their own use along the banks of the Fraser for almost its entire length and in the tributaries through which the sockeye migrate to reach the spawning grounds. Some Hell's Gate tags were returned by commercial fishermen who caught them while fishing near the mouth of the Fraser. These returns were most numerous during the years when difficult water levels prevailed for long periods, and weak and injured sockeye which could no longer maintain themselves drifted downstream with the river current.

Tags were also recovered on the spawning grounds by Commission observers from live and dead fish. Some tags were recaptured by the tagging crews while fishing at Hell's Gate.* The serial numbers of these were recorded and the fish released again with the tags intact.

RESULTS

An analysis of the tagging work at Hell's Gate is made difficult by the many variables which exist. The tagging between 1938 and 1942 showed that each "race" or run of sockeye bound for a certain spawning ground passed the Gate at approximately the same time each year. The size of each race, however, varied considerably from year to year, usually one or possibly two runs of the 4-year cycle of each race being comparatively large, while the other runs were smaller. Since the dominant years of each race did not all coincide with the dominant years of the other races, a different race tended to be present in numbers each year and, in consequence, the numbers of fish migrating at Hell's Gate varied from year to year. In addition, the time at which the greatest number of sockeye were migrating through Hell's Gate during the season in any one year depended upon which particular run was largest in that year.

For the years in which data are available (1912-1947), the water level at the time of the beginning of the sockeye migration (about July 1) varied from approximately gauge 78 feet to gauge 45 feet; at the end of the season (about October 31), the water levels varied from around 37 feet to 10 feet. During the season, while the fish were migrating, many variations have occurred, with levels as high as 93 feet and as low as 8 feet being recorded.†

Nevertheless, regardless of the size of the run, the time of migration, or the water levels occurring in any one year, the tagging experiment from 1938 to 1942 proved conclusively that at water levels between 26 feet and 40 feet as recorded on the Hell's Gate gauge, sockeye had great difficulty in passing Hell's Gate. At levels above 40 feet there was a partial obstruction, but sockeye could pass at stages around the 40-foot and near the 50-foot gauge levels. At gauge levels below 26

*Throughout this report the word "recapture" means the taking. *at* Hell's Gate, by a Commission tagging crew, of a sockeye which has previously been tagged there. The word "recovery" indicates the taking of a Hell's-Gate-tagged sockeye at any point *other* than Hell's Gate.

†The Hell's Gate water levels from 1912 to 1938 were calculated from the Dominion Water and Power Bureau gauge located on the Fraser River at Hope. After 1938 the levels during the sockeye migration were read directly from a gauge located at Hell's Gate.

feet to around 18 feet the fish migrated through this reach of the river with little or no difficulty.

The principal tagging data used to show the effect of certain water levels on migrating sockeye were (1) the tag recaptures made by the tagging crews at the point of tagging below Hell's Gate, (2) the percentage of each day's tagging recovered above and below Hell's Gate, and (3) the recovery of tags at Bridge River Rapids.

Tag Recaptures at Point of Tagging Below Hell's Gate

In all the years of tagging at Hell's Gate, a certain number of sockeye which had previously been tagged below the Gate were caught again below the Gate by the tagging crew. This number varied with the duration of the difficult water levels. The longer the time that sockeye were blocked below the Gate, the greater was the number of these recaptures. This was especially true if the number of sockeye migrating at the time of difficult levels was small. In this case the proportion of untagged fish became smaller as the length of delay progressed, and the chance of recapturing a tagged fish became greater. On the contrary, if the run of sockeye blocked below the Gate was large, the added increment of "new arrival" sockeye each day at the Gate increased the proportion of untagged fish, and the chance of recapture became less. In other words, since the number of tags which could be put on each day was limited, the tag density, and hence the chance of recapture, depended upon the size of the particular run or runs of sockeye which were migrating at the time of tagging. Regardless of the size of run, however, enough recaptures were always made to illustrate the blockade conditions at the Gate.

Since tagging was done on both banks of the river from 1943 to 1947, recaptures were made on both banks. These not only included sockeye tagged at the place where they were recaptured, but also many that were tagged on the opposite bank. The percentages of tagged fish recaptured which had crossed from one bank to the other are given in Table I. The figures presented in Table I and also in Table II differ slightly from similar data previously published by the Commission. In this paper only the tags affixed each year that were comparable in all years were used, while similar data previously published sometimes included tags used for special experiments not conducted every year. The same conclusions result regardless of which data are used.

As can be seen in Table I, the percentage of recaptured tags which had crossed from one side of the river to the other varied from 42.8 per cent to 84.6 per cent during these years, and for all recaptures made, 50.8 per cent had crossed from one bank to the other. It will also be seen that a higher percentage of "cross-overs" was usually recaptured on the right bank than on the left. No definite reason for this has been ascertained. Part of it may result from a difference in the numbers tagged at each bank and part because the tagging areas on the right bank below the Gate are farther upstream than those on the left bank below. No correlation was found between water levels and percentage of "cross-overs" during weekly periods in any year.

TABLE I.

Number of Tags Recaptured by Tagging Crews Below Hell's Gate And Percentage of These Which Had Crossed Over

Year	*Recapture Location*	*Total Recaptured*	*Total Cross-overs*	*Per cent Cross-overs*
1943	Left Bank	183	90	49.2
	Right Bank	298	144	48.3
1944	Left Bank	42	18	42.8
	Right Bank	101	45	44.5
1945	Left Bank	28	15	53.6
	Right Bank	19	14	73.7
1946	Left Bank	41	22	53.7
	Right Bank	54	37	68.5
1947	Left Bank	28	14	50.0
	Right Bank	13	11	84.6
Totals		807	410	50.8

Graphs of the recaptures made each year below the Gate are presented in Figures 1 to 6, inclusive. On these graphs each recaptured fish is represented by a line. The left end of the line represents the date of tagging; the right end the date of recovery, as shown along the bottom of the chart. The time elapsed between tagging and recapture is represented by the length of the line. The recaptures are listed in chronological order one above the other, and the water level at Hell's Gate throughout the season is shown at the top for comparative purposes. The recaptures for each year will be considered separately.

1943

The sockeye runs of 1943 were small and the number of recaptures large. Because of this large number of recaptures, those made on each bank are listed separately. Also, the recaptured fish out less than three days after tagging are omitted as these are of little value in depicting block conditions. The 3-day period was chosen arbitrarily.

The recaptures made on the left bank are shown in Figure 1. Tagging commenced this year on July 5, and ended October 13. Tagged fish were continually being recaptured almost from the start of the season until September 20 when the water level fell to 21 feet. Of these recaptures, none was made of fish tagged after September 9 when the water level was 29.3 feet. It is apparent from this chart that the fish tagged at some level of water between 29.3 feet and 21 feet were not in the recaptures made below the Gate after September 9 even though the tagging was continued after this time. It will be shown later that the fish progressed upstream easily after September 12 (page 96). The few recaptures made after this date were tagged during a time of difficult water levels and probably were fish that had become weakened by the long block period.

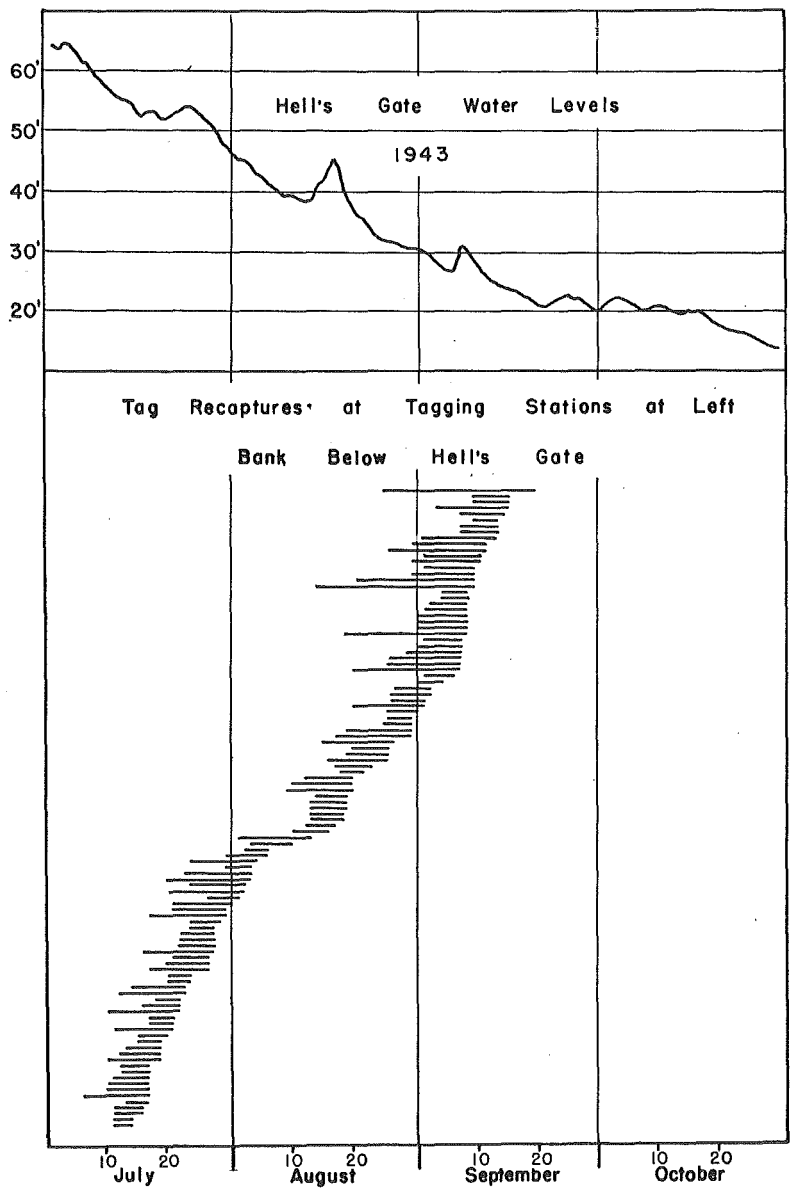

FIGURE 1. Tag recaptures at tagging stations at Left Bank Below Hell's Gate, compared with water levels, 1943. Each recapture represented by a line. Length of line shows number of days between tagging and recapture.

Another significant point illustrated by this graph is that there is a definite shift to the right in the tag recaptures between August 6 and 10 when the water level fell through the 40-foot level. It is evident that fish tagged between these dates were not among those recaptured. This is what would be expected, for in Bulletin No. 1 it was shown that sockeye could pass the Gate at levels around 40 feet and below 26 feet, but had difficulty at other water levels. The passable water levels at around 40 feet did not prevail long enough to allow all the sockeye blocked below the Gate to escape upstream; neither did those occurring August 14 and 19 when the water again passed the 40-foot level.

The recaptures made on the right bank are shown in Figure 2. Sockeye were tagged below Hell's Gate on this bank until October 13, but no recaptures were made on this bank after September 15 when the water was at a level affording easy passage. A shift of the recapture pattern to the right appears to have taken place approximately between August 4 and 9 which is similar to that shown for the recaptures on the left bank, but not so definite. The recaptures made on the left bank were not as numerous as those made on the right. This difference in number of recaptures on each bank probably results from the assistance given to the sockeye by the temporary fishway and brailer, both located on the left bank.

1944

The recaptures made in 1944 are shown in Figure 3. The sockeye runs this year were larger than in 1943 and recaptures were not as numerous. Tagging commenced on June 27, and was continued until November 3. The first recapture was made shortly after tagging began. Only 3 recaptures were made between July 1 and 24, during which time the water level varied from 46 feet to 36.2 feet, and none was made between July 9 and 24 at levels from 38.4 feet to 35.2 feet. Precise levels at which sockeye could pass at these times can not be interpreted from this graph because the numbers of fish tagged and recaptured during this period were too small. After July 24 recaptures of fish which were out long periods of time were made almost daily throughout the season until October 16. The water level dropped below 26 feet on October 14, but no tags affixed after October 12, when the water level was 28 feet, were recaptured.

The brief periods when the water levels rose above 40 feet, between July 27 and 30, and again between August 14 and 18 failed to clear the accumulation of tagged fish below the Gate. It will be shown in a later section (page 58) that for the period between August 14 and 23 many sockeye were able to pass Hell's Gate. It seems quite probable from this that only fresh or "new arrival" sockeye were able to negotiate the Hell's Gate reach at the higher water levels, while those fish that were delayed below the Gate for several days could not.

1945

The tag recaptures in 1943 and 1944 were very similar, both as to numbers and distribution, to those made from 1938 to 1942 and described in Bulletin 1. The recaptures in 1945, however, were especially significant because of the small number made. The right bank fishway was completed and ready for use in this season, and the lower section of the left bank fishway was in operation. It is evident that

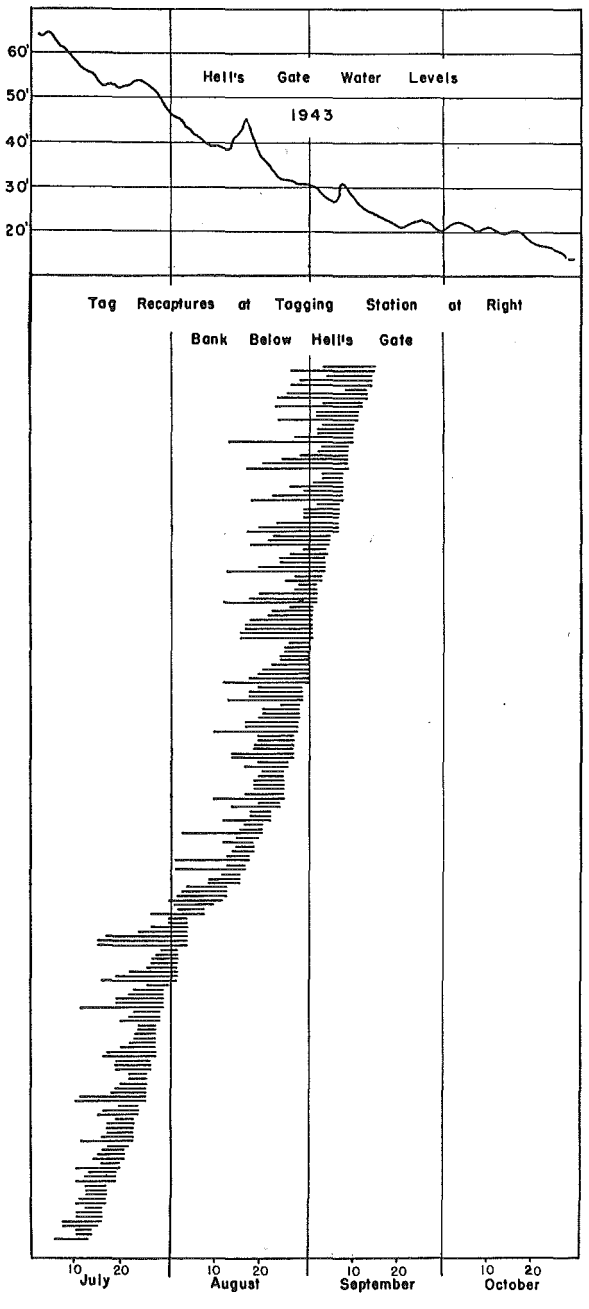

FIGURE 2. Tag recaptures at tagging stations at Right Bank Below Hell's Gate, compared with water levels, 1943. Each recapture represented by a line. Length of line shows number of days between tagging and recapture.

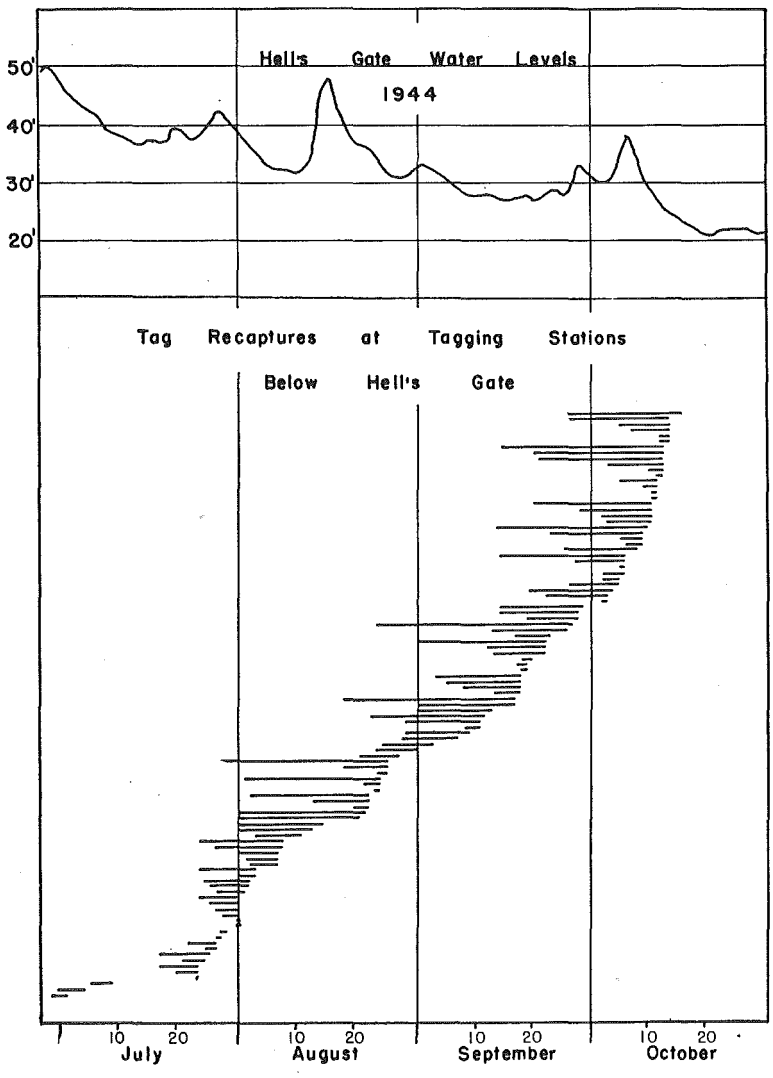

FIGURE 3. Tag recaptures at tagging stations below Hell's Gate, compared with water levels, 1944. Each recapture represented by a line. Length of line shows number of days between tagging and recapture.

these fishways were a great help to the migrating sockeye, for a total of only 47 recaptures was made even though one of the block periods lasted over a month. This was the smallest number of recaptures taken at the Gate since the beginning of the tagging work. The recaptures of 1945 are presented in Figure 4. As can be seen, many of those made were of sockeye tagged only a day or two before recapture. In fact, only 14 recaptures were of fish delayed more than 3 days.

The only period shown on this graph which might indicate that the sockeye were having any difficulty migrating upstream is that shown between the dates of approximately August 10 and September 7. During this time the water levels were between 31.2 feet and 22.6 feet. None of these recaptured fish was tagged later

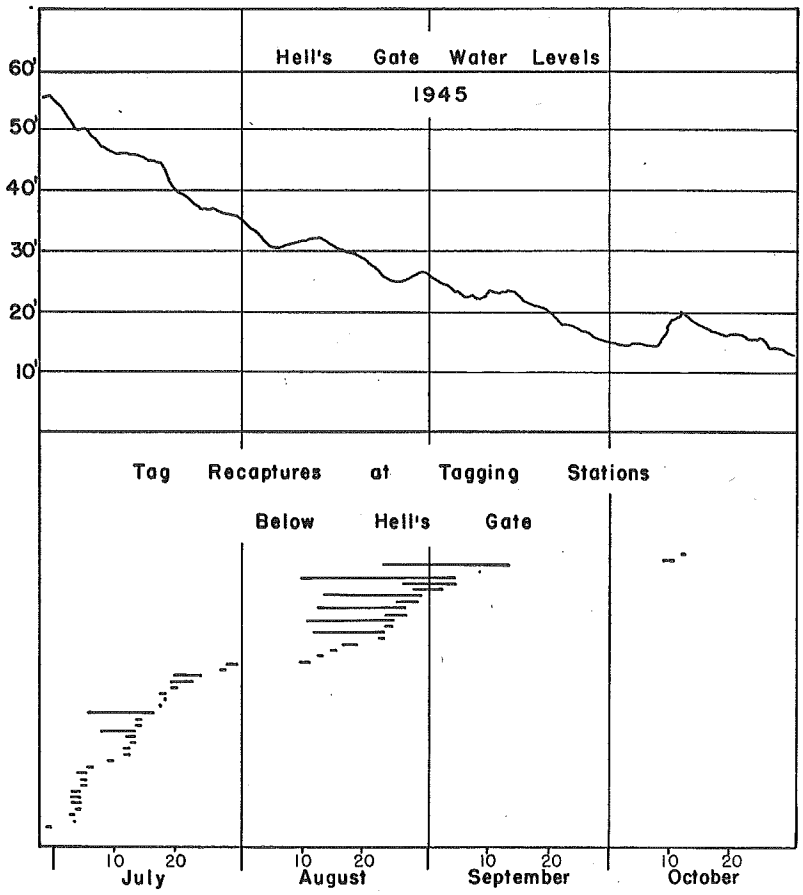

FIGURE 4. Tags recaptured at tagging stations below Hell's Gate, compared with water levels, 1945. Each recapture represented by a line. Length of line shows number of days between tagging and recapture.

than August 29 when the water level was below 26 feet. Inasmuch as 12 out of the 16 recaptures made during that period were recaptured on the left bank, it is probable that the unfinished left bank fishway did not operate entirely satisfactorily at that time.

The graph of the 1945 recaptures (Figure 4) indicates that the high water levels at the start of the season, and especially the levels occurring between August 10 and September 7, need critical examination to determine whether passage for sockeye could be made easier at those levels.

The scarcity of recaptures during the entire year, however, was good evidence that the partially completed fishways were helping sockeye pass Hell's Gate with much less difficulty than before.

1946

The 1946 season was characterized by extreme water levels at the beginning and end (Figure 5). In this respect it was somewhat similar to the levels of 1943

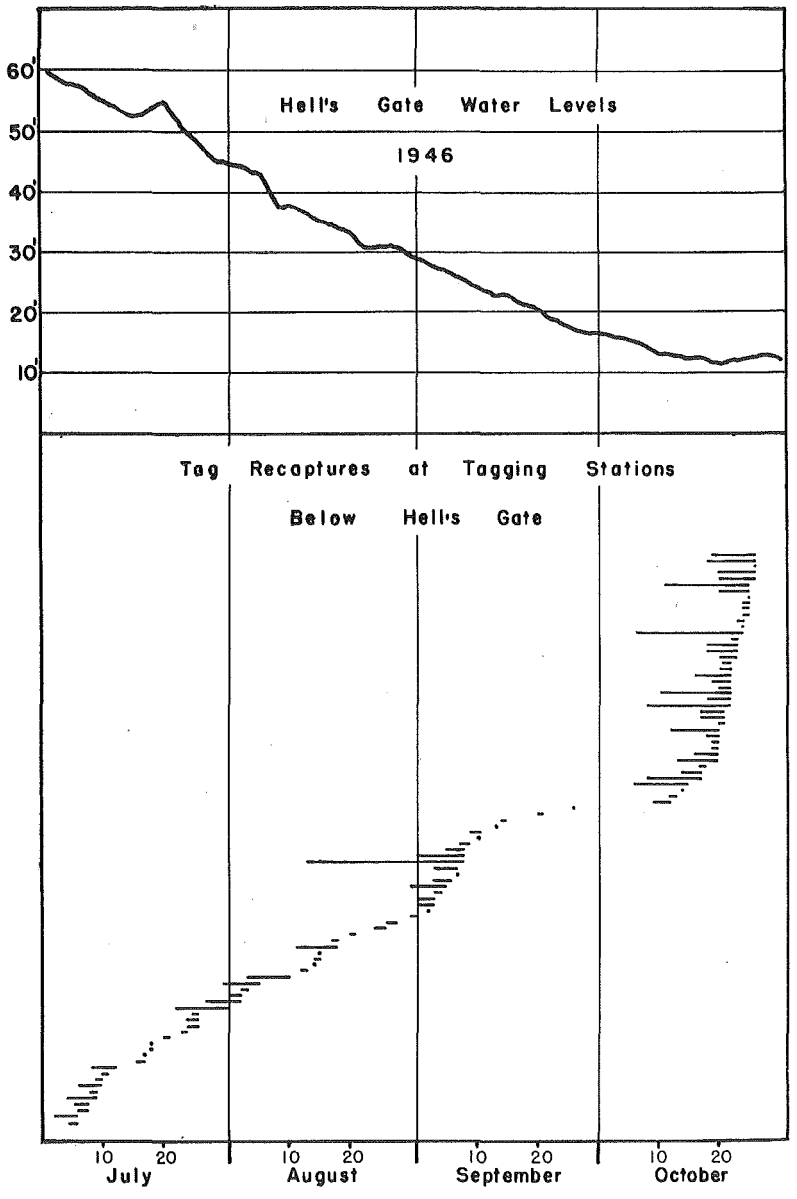

FIGURE 5. Tag recaptures at tagging stations below Hell's Gate, compared with water levels, 1946. Each recapture represented by a line. Length of line shows number of days between tagging and recapture.

(Figure 2), with the exception that in 1946 the passage of sockeye at water levels below 15 feet could be observed for the first time. Never, since the tagging work began in 1938, had water levels this low prevailed at Hell's Gate while appreciable numbers of sockeye were migrating. In 1946 a substantial number of recaptures was made after the water level fell to 15.2 feet on October 6 and continued to stay below this level until the end of the season.

Even with these additional low water levels which appear to be difficult for the sockeye, the total number of recaptures was only 95—lower than in any other year up to this time except 1945. The number of recaptures during water levels which ordinarily prevail during the season (above 15 feet) was only 53 which is comparable to the 47 made in 1945. It should be noted that few recaptured tagged fish were out for long periods of time during the usual water levels.

In 1946, as in 1945, a few recaptures were made early in the season when the water levels were high. No definite periods of difficult passage are shown, however, except those which occur at the end of the season at water levels around 15 feet and lower. Of the 42 recaptures made at these low water levels, 35 were made on the right bank, but because many of the recaptured fish had crossed from the left to the right bank after being tagged, it is difficult from this data to determine on which side of the river the fish had the greatest difficulty in passing upstream. It would appear, however, that the difficulty exists on the right bank. Other evidence will be given later (page 64) to show that this is the case.

1947

In 1947 fewer tagged fish were recaptured below the Gate than in any other year of tagging. A total of 41 tagged sockeye was caught, and Figure 6 illustrates that only a small number of these were out more than a few days. The majority of the recaptures were taken early in the season when high water levels prevailed. A short period of difficult passage is indicated between July 16 and 23 when the water level rose to 61 feet. All but one of the 17 recaptures occurring during this period were made on the left bank; hence, it would appear that the difficulty was on that side of the river at these high water levels.

It is difficult to account for the few recaptures made after October 15. These fish were caught at water levels at which sockeye previously had been passing quite easily. It may be that the sudden 10-foot rise in water level retarded the migration of a few of the last of the Adams River sockeye which migrate at this time. It has been noticed that even with passable water levels prevailing, the last fish of the late-running Adams sockeye are prone to be weak. Each year a scattering of these fish are found below the Gate too far advanced to continue their migration. Whatever the cause, the number recaptured late in the season of 1947 was too small to serve as the basis for any conclusions.

Table II shows the total number of recaptures taken below the Gate each year so that a comparison can be made of those caught before and after installation of the fishways. In this table the number of sockeye tagged below the Gate is listed also. If the recaptured fish out only a few days are not considered as showing serious blockades, the difference in tag recoveries before and after the installation of the fishways becomes even more noticeable. Three days have been chosen arbitrarily, and those out longer than that time are listed in column 4 of the table. *The few recaptures of sockeye below the Gate, and especially those out for more than 3 days during 1945, 1946, and 1947, stand in sharp contrast to the large numbers recaptured before the fishways were installed.* Since the size of the runs at Hell's Gate apparently affects the number of recaptures that are made, the commercial catch of sockeye each year is listed in column 5. This can be taken as

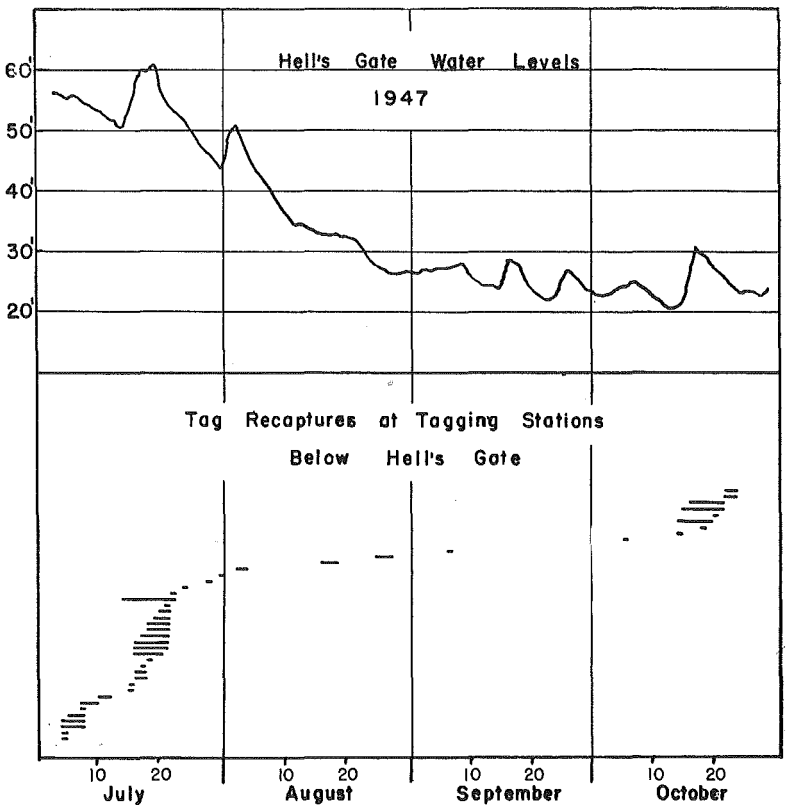

FIGURE 6. Tag recaptures at tagging stations below Hell's Gate, compared with water levels, 1947. Each recapture represented by a line. Length of line shows number of days between tagging and recapture.

a rough index of the size of the run migrating up the Fraser River each year. In 1946 and 1947 regulation of the sockeye fishery undoubtedly cut down the size of the catch. In 1942, however, a fishermen's strike occurred which probably compensated for the extra regulation in 1946.

It is estimated from the catch statistics of 1943 that the catch of 1947 could possibly have been 30 per cent to 50 per cent larger if the more stringent regulations had not been in effect. Hence, the runs of 1945 can be compared in size to those of 1944 and 1940; the runs of 1946 can be compared to those of 1942 and the runs of 1947 can be compared to those of 1943 or 1939. The comparatively small number of recaptures in 1941 resulted from the extremely large number of sockeye blocked below the Gate that year. Even though a large number of tags was affixed that year the ratio of tagged to untagged fish was small. The majority of the recoveries of the fish tagged in 1941 were recovered at places below Hell's Gate as shown later in Figure 8. In all cases, even taking into consideration the number of fish tagged, it is apparent that considerably fewer recaptures were made after the fishways were installed.

TABLE II

Number of Tags Recaptured‡ Below Hell's Gate Compared with Number of Sockeye Tagged and Commercial Catch in Treaty Waters

	Year	No. Sockeye Tagged Below	Number Recaptured Total	Out More than 3 Days	Commercial Catch in Cases
Before Fishways	1939	4,344	266	216	91,050
	1940	5,194	147	119	152,715
	1941	12,023	131	93	269,884
	1942	6,847	112	80	690,437
	1943	6,393	481	304	49,334
	1944	4,508	143	75	125,529
After Fishways	1945	4,044	47	14	132,836
	1946	6,756	95 (53)*	33 (13)*	611,310
	1947	3,163	41	12	35,930

Tags Recovered Above and Below Hell's Gate

The percentage of tags recovered above and below Hell's Gate for each day of tagging was used in Bulletin 1 to show the effect of block water levels. The per cent recoveries above the Gate are influenced by several factors other than water levels, such as the intensity of the Indian fishery and the race or races which are being tagged each day. For instance, a higher percentage of tags can be obtained from the early Stuart run since it spawns in small streams where it is possible to recover up to 85 per cent of the dead fish and examine them for tags. The Chilko run, on the other hand, spawns in a comparatively large river where only a small percentage of the dead fish, roughly estimated at 15 per cent, can be examined for tags. The size of run also affects the per cent of tags recovered, for if a large run of sockeye is in a river, the Indians will fish diligently for tagged fish in order to receive the tag rewards, whereas if a run is small, the tags are few in number, and it is not worth their while to do so.

It was shown in Bulletin 1 that when sockeye could not get through Hell's Gate because of difficult water levels, they would become weakened, eventually drop downstream, and be recovered at places below Hell's Gate. It has been previously mentioned that some of them were recovered over 100 miles below Hell's Gate by commercial fishermen near the mouth of the river. The calculated percentage of downstream recoveries was usually inversely proportional to those recovered upstream, but the ratio was complicated by the fact that sockeye dropping

‡See footnote, page 11.

*Figures in parentheses show number of recaptures caught during period of usual water levels (above 15 feet).

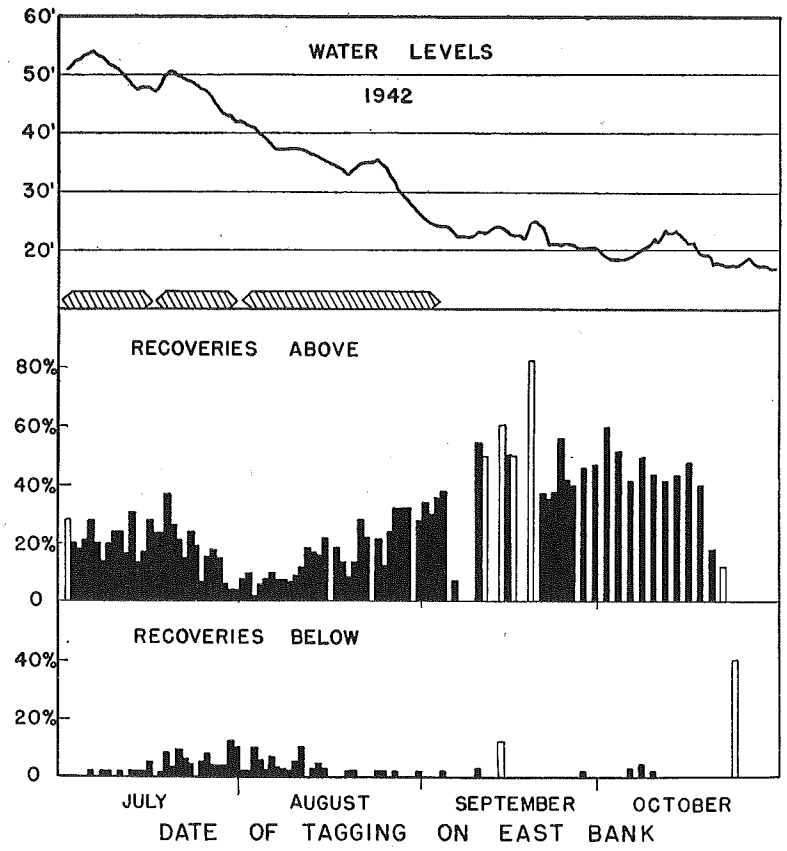

FIGURE 7. Percentage of tags recovered above and below Hell's Gate of those affixed daily at the left (east) bank of the river below Hell's Gate, 1942. The horizontal bars indicate periods of difficult water level. (Returns for days when fewer than ten fish were tagged are shown in open bars). (From Thompson, 1945, p. 153).

downstream during the early part of the season were less likely to be recaptured than those dropping down at the end of the season (Thompson 1945, p. 145).

In spite of all the factors which can influence the number of tags returned, the percentages of tags returned between 1938 and 1942 showed a similar recovery pattern each year. As the water level dropped from 40 feet to 26 feet, regardless of the date or the runs passing when this occurred, there was always a reduction in the percentage of each day's tags that was recovered upstream. This reduction was not uniform for each day of tagging. Instead, only a small percentage of those fish tagged at the beginning of the block water levels was recovered upstream, while this percentage increased toward the end of the block period when the water level fell below 26 feet. In 1941 the river remained in the block levels from September 4 until the end of the season with no open period. Practically no recoveries were made upstream during this time.

In order to illustrate this recovery pattern, the percentage of the tags recovered above and below Hell's Gate from the tagging on the left (east) bank in 1942 is presented in Figure 7. At the start of the season the water level was above 50 feet.

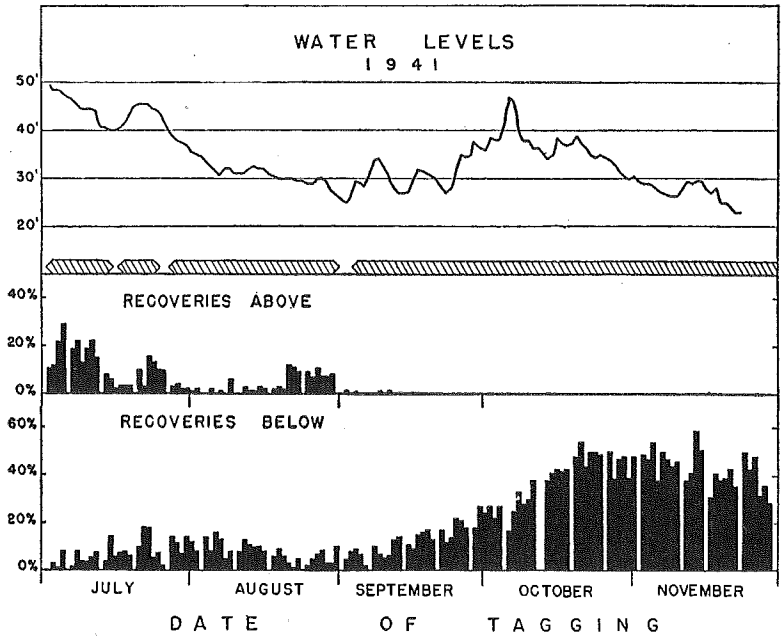

FIGURE 8. Percentage of tags recovered above and below Hell's Gate of those affixed daily at the left bank of the river below Hell's Gate, 1941. The horizontal bars indicate periods of difficult water levels. (Returns for days when fewer than ten fish were tagged are shown in opn bars). (From Thompson, 1945, p. 144).

Recoveries above the Gate were around 20 per cent until, as the water level approached 40 feet, the recovery dropped to near the 5 per cent level. When the water level fell below the block stage (26 feet), some of the accumulated blocked fish could pass upstream and the recovery above increased to 40 per cent. The longer the sockeye had been delayed, the smaller the percentage passing upstream; hence, the typical recovery pattern of low recoveries above Hell's Gate from tagging at the beginning of a block period to a comparatively high percentage at the end of the block period. The recoveries at places below the Gate during the block levels (these do not include the recaptures made by the tagging crew) were inverse to those made above.

The recoveries above and below Hell's Gate as presented in Figure 7 show the typical recovery pattern during a year of average conditions as far as water levels are concerned, and are similar to the recoveries of 1939 and 1940. During 1941 the water levels were in the block stage for almost the entire migration period and this resulted in a much different recovery pattern. This is shown in Figure 8. At the start of the season the water level was near 50 feet, and the percentage of tags recovered above was near 20 per cent—similar to the 1942 recoveries. As the water level dropped to 40 feet, the tag recoveries above the Gate dropped also. The rise in water level toward the end of July increased the recoveries above, but when the water again dropped below the 40-foot level, few tag recoveries were made above. The block levels persisted this year until the end of the season except for September 2 and 3 when the level dropped below 26 feet, and from October 5 to 7 when it rose

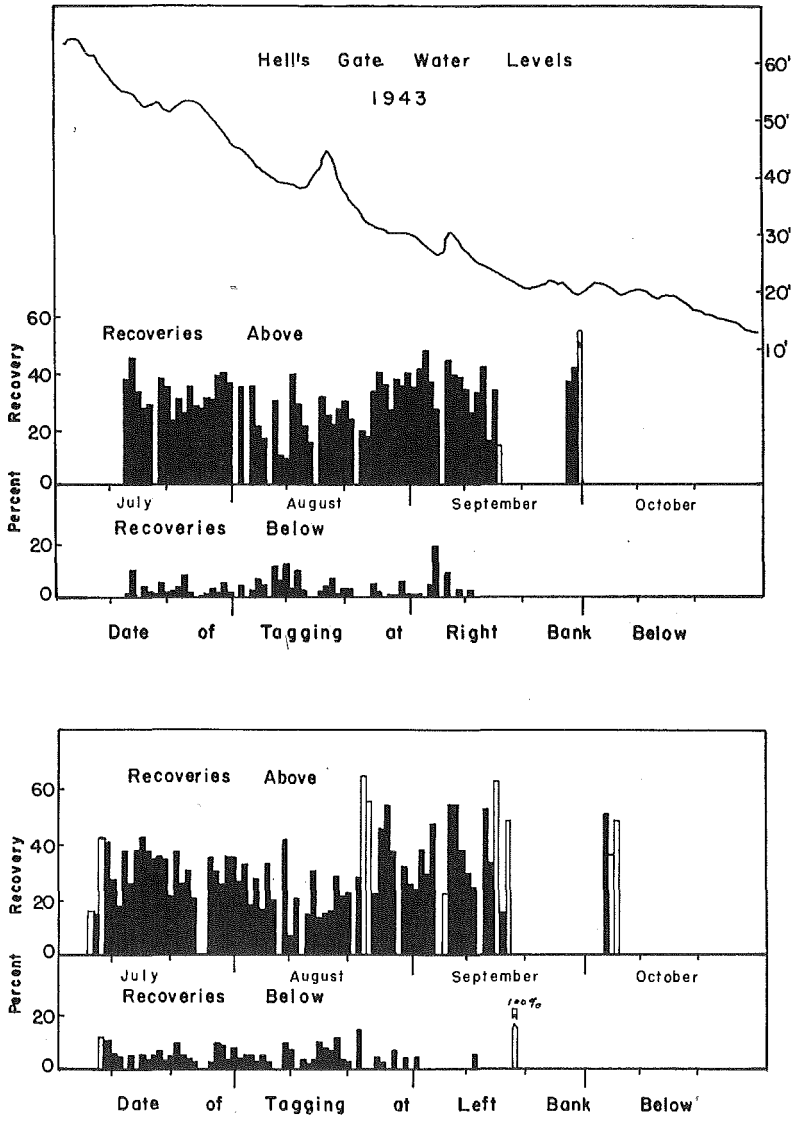

FIGURE 9. Percentage of tags recovered above and below Hell's Gate of those affixed daily at each bank of the river below Hell's Gate. 1943. (Returns for days when fewer than ten fish were tagged are shown in open bars).

above 40 feet. The open period at the first of September allowed some fish which had been tagged a few days previously to get upstream, but after that date practically none got through. Apparently the blocked fish were too weak by October 5 to pass at the levels above 40 feet. The recoveries below the Gate during July and August were similar to those made below the Gate in 1942 as shown in Figure 7. Starting the first of September, however, the recoveries below the Gate increased, and as seen in Figure 8, large numbers of them which had been tagged each day were recovered below the Gate until the last of November.

Graphs of the percentage recovery above and below the Gate for tagging in the years 1943 to 1947 do not all follow the same typical pattern as those for the earlier years of tagging. During 1943 and 1944 sockeye were assisted through the Hell's Gate reach by the temporary fish ladder and the brailer and after 1944 by the permanent fishways.

1943

The per cent recoveries above and below the Gate from each day of tagging in 1943 are presented in Figure 9. The recoveries from tags affixed at the left bank occupy the lower portion of the chart, while those tagged on the right bank are illustrated on the upper portion. The Hell's Gate water levels are also plotted for comparative purposes. The open bars on the graphs signify that less than ten fish were tagged that day.

Tagging commenced at the right bank in 1943 on July 13. The per cent recoveries above the Gate were comparatively high during all of July. Recoveries above during August were erratic, probably as a result of alternate difficult and easy periods caused by water fluctuations around 40 feet between August 6 and 20. Between August 19 and September 12, when the water level fell from 40 feet to 25.5 feet, there was a general rise in per cent recovery such as was indicated more clearly in the per cent recoveries of the earlier years of tagging. Tagging on this bank was done only on three other days during the balance of the season. Recoveries were high on these days as shown by the graph.

Recoveries below the Gate (these do not include those made by the tagging crew below Hell's Gate and presented in Figures 1 to 6) are shown in the lower portion of the upper graph. Recoveries were made throughout the season until the water level fell below 26 feet on September 12. This illustrates what has been shown already in Bulletin 1—that all levels above 26 feet were difficult for the ascent of sockeye even though levels around 40 feet and 50 feet appeared to be easier of passage than the other difficult levels.

The per cent recoveries above and below the Gate from each day's tagging on the left bank of the river are shown beneath that for the right bank. The per cent recovery above the Gate remains fairly high during July when high water levels prevailed, but, as on the right bank, the per cent recovery dropped when the water level fluctuated below the 40-foot level. Disregarding the high recoveries between August 23 and 28, there was a gradual increase in the per cent recovery up to September 13 as the water level fell below 26 feet. The high recoveries between August 23 and 28, when the water level was between 32.5 feet and 30.7 feet, were quite unusual. Observations at the temporary fish ladder indicated that it operated

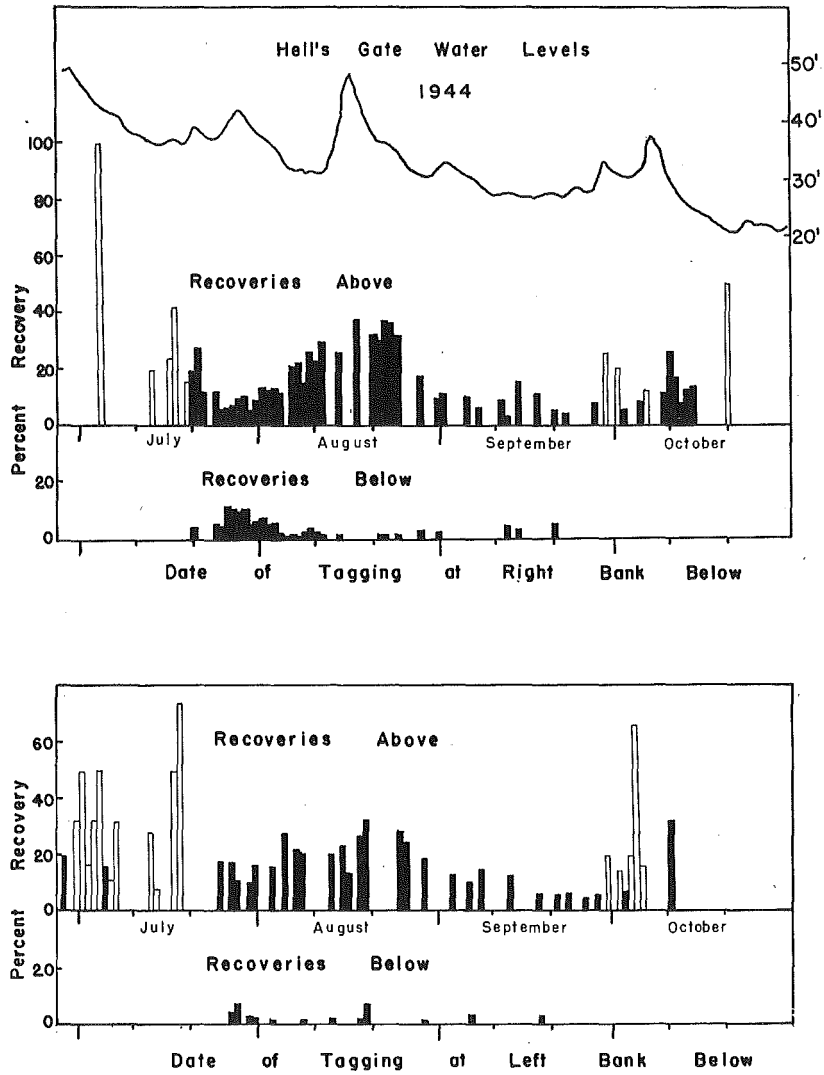

FIGURE 10. Percentage of tags recovered above and below Hell's Gate of those affixed daily at each bank of the river below Hell's Gate, 1944. (Returns for days when fewer than ten fish were tagged are shown in open bars).

most efficiently at this level, and that above this level it tended to "drown out" from the river surge. It is probable that this accounted for the increased percentage of tagged fish getting upstream during this period. As on the right bank, few fish were tagged toward the end of the season at the Left Bank Below areas. On three days that fish were tagged, relatively high percentages were recovered upstream.

Recoveries were made below Hell's Gate all season until September 11 when the water level dropped below the block stage. The graph shows one tag was recovered below the Gate after this date. This was tagged on September 18, but inasmuch as it was the only tag affixed on the left bank on that date, little significance can be attached to its recovery.

1944

The early runs were small in 1944 and sockeye were scarce at Hell's Gate at the start of the season. This is apparent by the open bars shown in Figure 10 for the recoveries above and below from tagging on each side of the river. It was not until July 20 that ten or more fish were caught and tagged each day on the right bank, and except for June 28 and July 5, it was not until July 25 that sockeye were caught in fair numbers on the left bank. Tagging was not done consistently on either bank this year because at certain times it became too hazardous as a result of the construction work on the new fishways.

As shown in Figure 10, the rise in water level to 42.8 feet on July 28 only slightly increased the percentage recovery above of those tagged on the right bank. On August 16 after a rapid rise in water level, the river reached 48.7 feet. During this high water sockeye were able to get through the Gate, and a comparatively high percentage was recovered. The exact time that they could pass is not indicated on the graph for the tagging was not done every day during this period.

The difference just seen in ability of the fish to pass upstream at gauge levels above 40 feet has been noticed at Hell's Gate in other years. The ability to negotiate the Gate at these high water levels probably depends upon the races of fish present and how long the fish have been obstructed before the easier water levels occur.

The recovery pattern between July 30 and August 17 is typical of those made from earlier tagging at the Gate when water levels dropped from 40 feet to 26 feet. In this case, however, the open period occurred at water above 40 feet. Recoveries were low around July 25 and reached a peak on August 17. The recoveries below during this period were approximately inversely proportional to those made above the Gate.

The recoveries made above Hell's Gate of the fish tagged on the left bank during this period showed a higher percentage of return at the beginning of the period than for those blocked on the right bank. The recoveries below the Gate were also less numerous. No doubt the temporary fishway helped enough sockeye on the left bank to raise slightly the percentage recovered above. During the high water level it would appear that sockeye passed more easily on the right bank as a somewhat higher percentage was recovered above than on the left bank.

After August 19 and until October 14 the river was in block levels. In this respect 1944 was similar to 1941 when practically no sockeye got through though thousands were present below the Gate. In 1944, however, a small percentage of those tagged at both banks of the river did manage to get through the Gate as shown in Figure 10. It is obvious when compared to the early years of tagging (see Figure 8) that the temporary fishway, and perhaps to some extent the brailer, were of help in preventing a complete block to sockeye in this year as occurred in 1941.

1945

The per cent of tags recovered above and below Hell's Gate during 1945 is shown in Figure 11. The runs going by the Gate during the first part of July were bound for the Stuart and Bowron districts. Counting fences were used this year

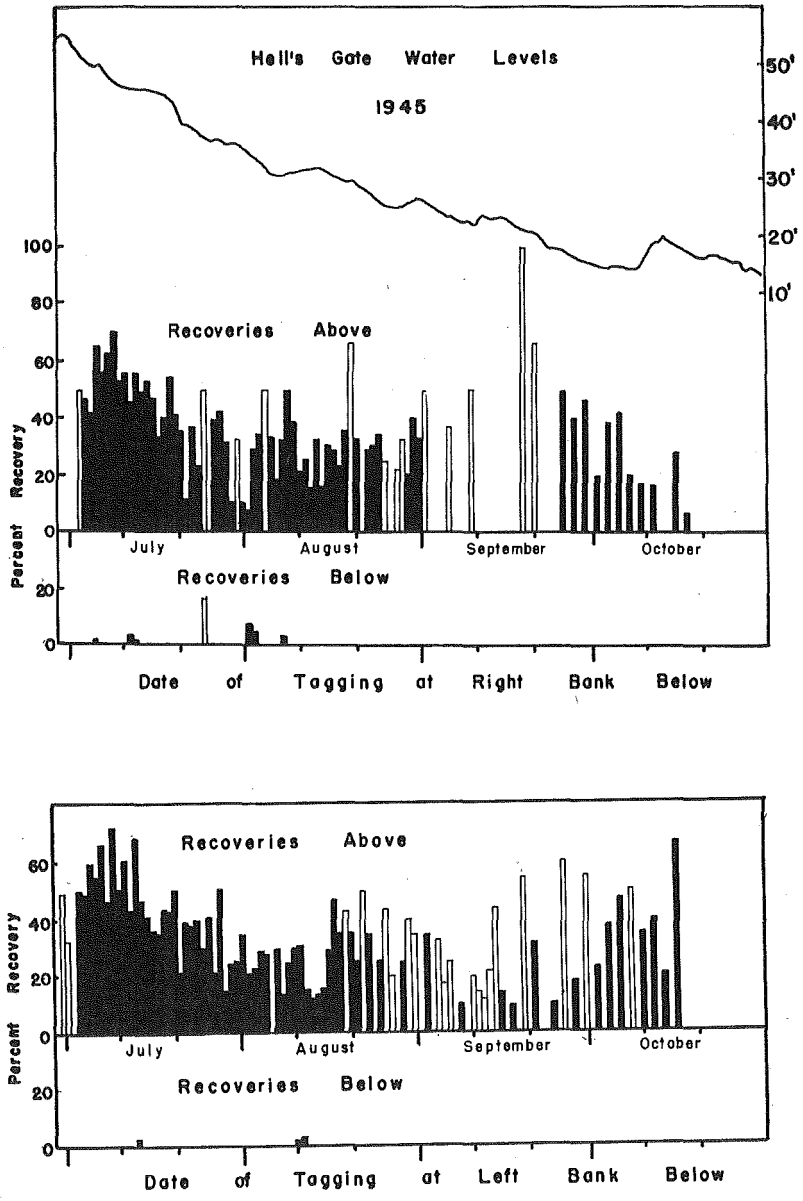

FIGURE 11. Percentage of tags recovered above and below Hell's Gate of those affixed daily at each bank of the river below Hell's Gate, 1945. (Returns for days when fewer than ten fish were tagged are shown in open bars).

in both of these districts so that each fish could be examined for tags. As shown, a high percentage was recovered of those tagged during this period. Later, as the Chilko, Stellako and late Stuart runs were migrating past the Gate, the per cent recovery dropped. For the recoveries from the tagging on the right bank the per cent recovery fluctuated in a more or less random manner until the end of August. At no time during this period was there any indication that sockeye had the same difficulty in getting by Hell's Gate as has been shown for the years 1938

to 1942. The few days where recoveries were low must be the result of chance for there is no way that low per cent recoveries for only a day or two could be the result of blockade water levels. Recoveries of tags at places below Hell's Gate during July and August were few in number.

The recoveries during July and August from tagging on the left bank are also shown in Figure 11. They were similar to the recoveries from tagging on the right bank, except that the per cent recovery was lower, in general, between August 2 and August 16 on the left bank than it was on the right. While from the appearance of the recoveries it does not appear as if conditions at Hell's Gate might have caused these low recoveries, it will be recalled that several recaptures were made by the tagging crews below Hell's Gate of tags affixed during this period (see Figure 4). Here again, the unfinished left bank fishway may have been responsible for these low recoveries.

During the greater part of September the number of sockeye that could be caught at either bank of the river was so small that the per cent recoveries fluctuated greatly from 0 to 100 per cent. Toward the last of the month when the Adams River run of sockeye was moving up the river, the number increased so that larger catches were made. These were practically all precocious "jack" sockeye (3 years old) which normally would be returning to spawn in 1946. The charts show that the per cent recovery of those tagged on the left bank increased toward the end of the season, while the recovery of those tagged on the right bank decreased. This results, probably, from the difference in ability of the sockeye to pass the Gate on the two banks of the river at water levels around 15 feet and lower. It was shown by the tag recaptures of 1946 (Figure 5) that sockeye had some difficulty at these levels, and it will be shown later by the catch per hour above and below Hell's Gate that the difficulty exists on the right bank.

Tag recoveries below Hell's Gate in 1945 were fewer than for any previous year that tagging was done at the Gate (Figure 11).

1946

The per cent tag recoveries for 1946 are shown in Figure 12. The returns from tagging at both banks show similar results. No indication of the recovery pattern found during former block water levels can be found in the recoveries from above or below the Gate. It is significant that this was the first year that both fishways were complete. A comparison of the 1946 recoveries with those made in any of the years of tagging between 1938 and 1942 gives convincing evidence of the greater ease of passage of sockeye between the 26-foot and 40-foot water level.

There were few sockeye passing Hell's Gate between September 17 and 22, but after that date large numbers of sockeye of the huge Adams River run began their migration past the Gate. Recoveries of fish tagged on both banks appear to be normal until after October 10 when the per cent recovery above the Gate decreased toward the end of the season. This correlates with the recapture data presented in Figures 5 and 11 where it was shown that water levels below 15 feet appear to block the migrating sockeye.

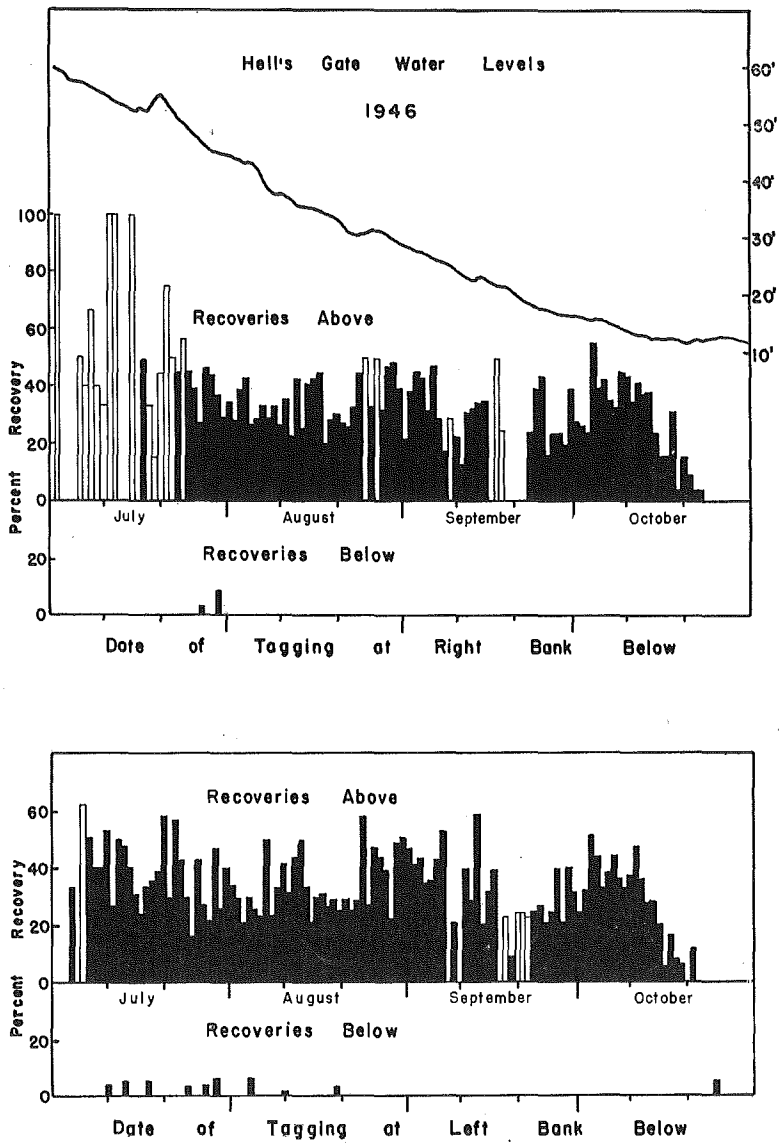

FIGURE 12. Percentage of tags recovered above and below Hell's Gate of those affixed daily at each bank of the river below Hell's Gate, 1946. (Returns for days when fewer than ten fish were tagged are shown in open bars).

1947

In this year clear celluloid tags were used at Hell's Gate instead of the customary white ones. These are difficult to see on the fish, and so tend to prevent the Indians from fishing selectively for tags. Because of this the tag recoveries could be used more accurately for estimating the Indian catch of sockeye and the size of sockeye populations migrating by Hell's Gate. As would be expected, the percentage of tags recovered was much lower than when the more visible white tags were used. The recoveries for 1947 are shown in Figure 13.

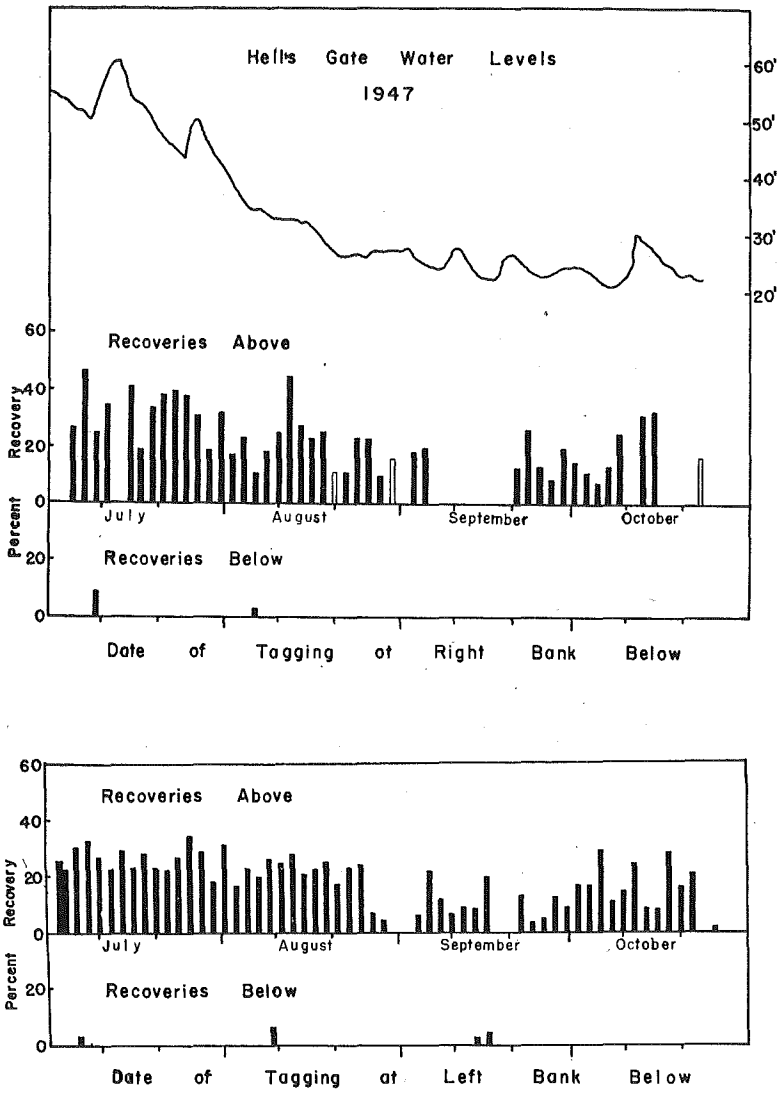

FIGURE 13. Percentage of tags recovered above and below Hell's Gate of those affixed daily at each bank of the river below Hell's Gate, 1947. (Returns for days when fewer than ten fish were tagged are shown in open bars).

The recoveries above Hell's Gate of tags put on at the left bank were fairly uniform until August 25. After that date they were erratic until the end of the season. The recoveries of tags affixed on the right bank fluctuated widely. Tagging was carried out every other day on each bank. There were many days on both banks when fish were tagged and no recoveries were made either above or below (Figure 13). Evidence will be given later to show that sockeye were able to pass the Gate at these times, and so no explanation for the paucity of recoveries can be found at this time other than inability to recover the transparent tags.

In 1947 the tag recoveries below Hell's Gate were the smallest for any of the years of tagging. The number returned by commercial fishermen and Indians

fishing non-selectively for food where the tag is not seen until after the fish is caught, was also smaller than for similar recoveries in any other year. This demonstrates that the low recovery was not altogether a result of using clear tags which are difficult to see in the water.

The type of analysis used in this section is not satisfactory for showing short periods of difficult water levels. Short block periods are not detected because if the sockeye are only delayed a few days and then are able to get through the Gate, the difficult period will not be apparent from the graph. This method is effective in showing long periods of blockade conditions where a certain proportion of tagged fish that are delayed the longest can not pass even though easy water stages later prevail. No such long periods of difficulty are shown in Figures 9, 10, and 11 for the years 1945, 1946, and 1947. Apparently the recoveries in these years were influenced more by factors other than water levels at Hell's Gate such as the number of fish examined on the spawning ground, etc. *This is good evidence that the long block periods which occurred each year before installation of the fishways have been eliminated.*

Table III lists the number of tags affixed below Hell's Gate, the number of tags recovered at places below Hell's Gate, and number of days of block water levels that prevailed at Hell's Gate each year in July, August, September and October. Gauge levels below 26 feet and at 40 feet and 50 feet were considered passable.

It is apparent from this table that all the years are not comparable. More fish were tagged during some years than others, and there were more block water levels during some seasons than others. The number of recoveries downstream was also not the same even when approximately the same number of days of block water levels prevailed. Many of these variations are the result of varying sizes of the different runs which were blocked each year. For instance, in 1941 it was part of the large Chilko run and the Adams River run, which migrates late in the season, that were blocked. The blockaded fish eventually dropped downstream and some entered the small tributaries draining into the Fraser. They were in such large numbers that it was profitable for Indians and also Commission observers to spend much time in the recovery of tags. In 1944 there were almost as many days of block water levels as in 1941, and the same runs had difficulty in passing Hell's Gate. In this year, however, the open period was more favorable to the Chilko run, and it was the small Adams River run of only a few thousand fish that was blocked. The small number of these sockeye which entered the tributary streams apparently did not attract the attention of the Indian fishermen, for even though the same percentage of tags may have been present, the total number would be fewer, and it would not be worthwhile for the Indians to spend the time looking for them. As has already been mentioned, the 1944 runs were also helped by the temporary fishway and the brailer. *Making allowances for all the factors which could affect the recovery of tags below the Gate, it can be seen by a comparison with the other years that the recoveries below the Gate were much smaller in 1945, 1946, and 1947 than before the installation of the fishways.*

TABLE III

Number of Tags Recovered* Below Hell's Gate Each Year Compared to Number Tagged and Number of Days When Passage Was Blocked

	Year	Number Tagged Below Hell's Gate	Number of Tags Recovered Below	Number of Days of Block Water Levels
Before Fishways	1939	4,344	612	92
	1940	5,194	161	90
	1941	12,023	2,671	115
	1942	6,847	195	57
	1943	6,491	250	70
	1944	4,460	111	103
After Fishways	1945	4,044	11	56
	1946	6,730	13	67
	1947	3,163	6	67

Tag Recoveries, Hell's Gate to Lillooet

In Bulletin No. 1 (pages 121 and 132), it was shown that if the recaptures of tags at Bridge River Rapids on the Fraser River (76 miles above Hell's Gate) were plotted with the date of tagging as the ordinate and date of recovery as the abscissa, the period of block water level would be illustrated by few or no recoveries in a triangular area on the chart. These blank areas resulted from the fact that even though sockeye were tagged every day, few or none passed the Gate until a passable water level occurred. When the water level dropped below 26 feet a "wave" of sockeye containing fish tagged many days previously would progress up the river. The majority of the recoveries made of these tagged fish would all be on the same few days after the Gate opened, regardless of what day they were tagged. Hence, the blank triangular area would have many points plotted a few days to the right of its right limb from all the days of tagging during the block. Recoveries in large numbers were usually made at Bridge River Rapids beginning 3 days after the Gate opened.

Charts of the date of tagging and date of recovery were plotted for the tags recovered during the years 1943 to 1947. Because it was determined that certain water levels made Bridge River Rapids difficult for sockeye to negotiate, the recoveries for these years were plotted using all recoveries between Hell's Gate and the Lillooet Bridge (70 miles above Hell's Gate), so that the influence of Bridge River Rapids would not affect the tag returns. These are shown in Figures 14 to 18. On these charts the date of tagging is shown along the left hand margin and the date of recovery along the bottom edge. The heavy diagonal line shows where a tag recovered the same day it was affixed was plotted. Those recovered several days after tagging are plotted in the appropriate place to the right of the line. The light dashed line is located 10 days to the right of the date of tagging and can be

*See footnote, page 11.

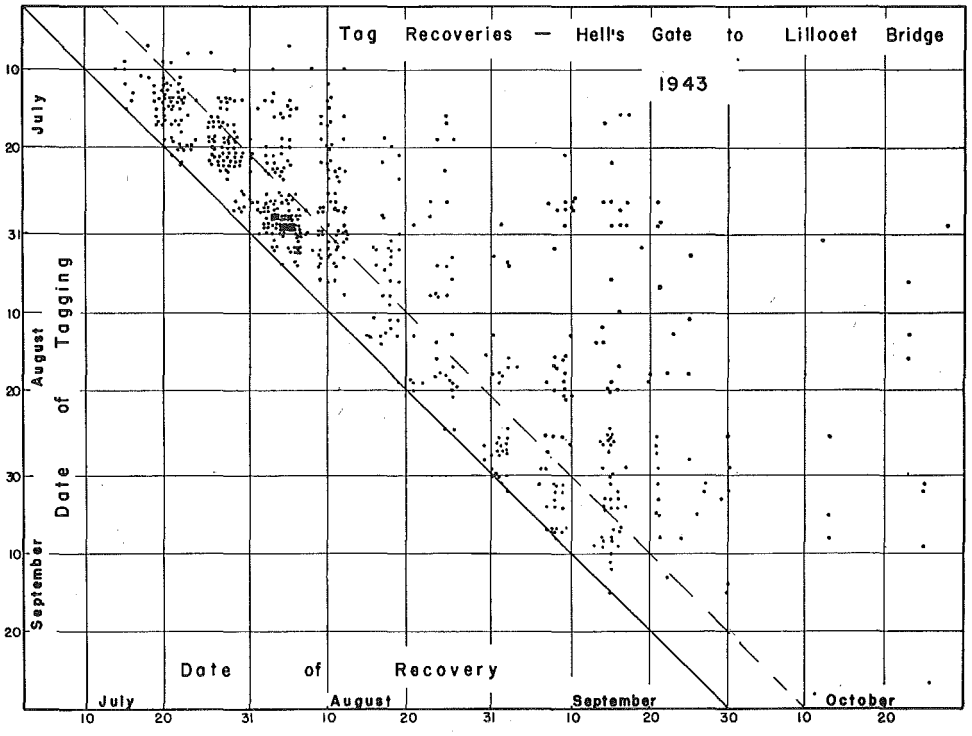

FIGURE 14. Tag recoveries between Hell's Gate and Lillooet Bridge, showing date of tagging and date of recovery, 1943.

used as a reference point. All tags recovered 10 days after tagging would fall on this line. All the charts show that there are certain days each week when few or no tags are recovered. These days are Friday, Saturday, and Sunday when it was illegal for the Indians to fish.

None of the charts shows distinct block levels as did similar charts for earlier years of tagging. For almost any day of tagging, recoveries were made above the Gate a few days later. From some days of tagging, however, and especially in 1943 and 1944, recoveries were not made of some tags until 40 to 70 days after tagging. Also, on many recovery days, tagged fish were caught which had been tagged only a few days before, and some which had been tagged a long time previously. For example, in Figure 14 for the 1943 recoveries, many tags were recovered on September 15. One of these was tagged on the same day, another 3 days before on September 12, others were tagged a few days before this, and 5 were recovered that were tagged August 26 which was 20 days after tagging. On this same recovery day, one was captured that was tagged on July 22. This is 55 days after tagging. Hence, the recoveries on September 15 were of tags affixed from 0 to 55 days before. Inasmuch as tag returns from all years of tagging have shown that the majority of Fraser River sockeye reach their spawning grounds in less than 30 days after tagging at Hell's Gate, regardless of the distance they must travel, it would appear from these recoveries that many have been delayed too long to reach their spawning grounds wherever they may be, and can be considered as mortalities.

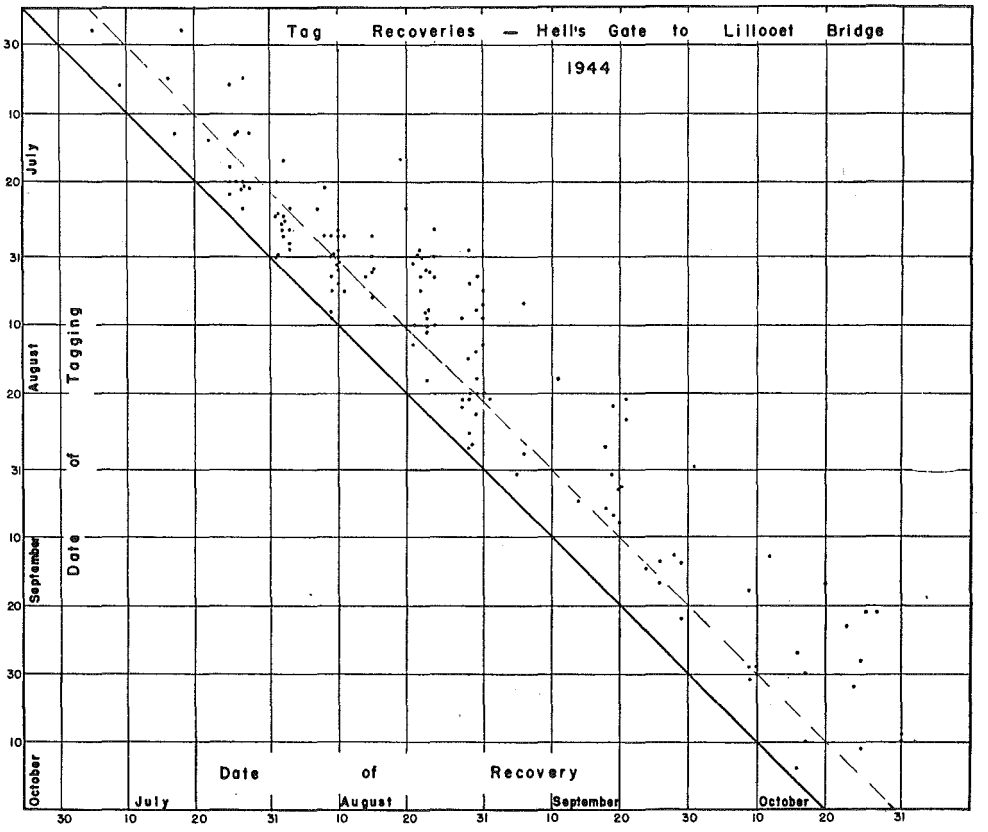

FIGURE 15. Tag recoveries between Hell's Gate and Lillooet Bridge, showing date of tagging and date of recovery, 1944.

In order to determine if some difficulties still exist at Hell's Gate which could be remedied, the graphs should be examined critically.

It will be seen in Figure 16 (1945) that between tagging dates July 5 and 20 a few fish were delayed longer than 10 days before recovery at points above Hell's Gate. These tagging dates coincide closely with the dates that sockeye were tagged below the Gate and recaptured below by the tagging crew (Figure 4). Another period in which some recoveries above the Gate were delayed is that between tagging date August 10 and 19 (Figure 16). Here again the recapture data below the Gate (Figure 4) show that fish tagged between those dates were delayed—some for long periods of time. Inasmuch as the left bank fishway was not completed in 1945, the tag delays are perhaps explainable on that basis. Those in 1946 and 1947 should be viewed more critically to determine if short difficult periods still exist.

The 1946 recoveries from Hell's Gate to Lillooet (Figure 17) show a delayed recovery period starting on tagging date July 2 and lasting until July 11. This same delay is shown in the recaptures below the Gate (Figure 5). The next period of delay shown in Figure 17 is that occurring from tagging date July 17 to August 10. This delay period is represented again in the recapture chart (Figure 5) by a group

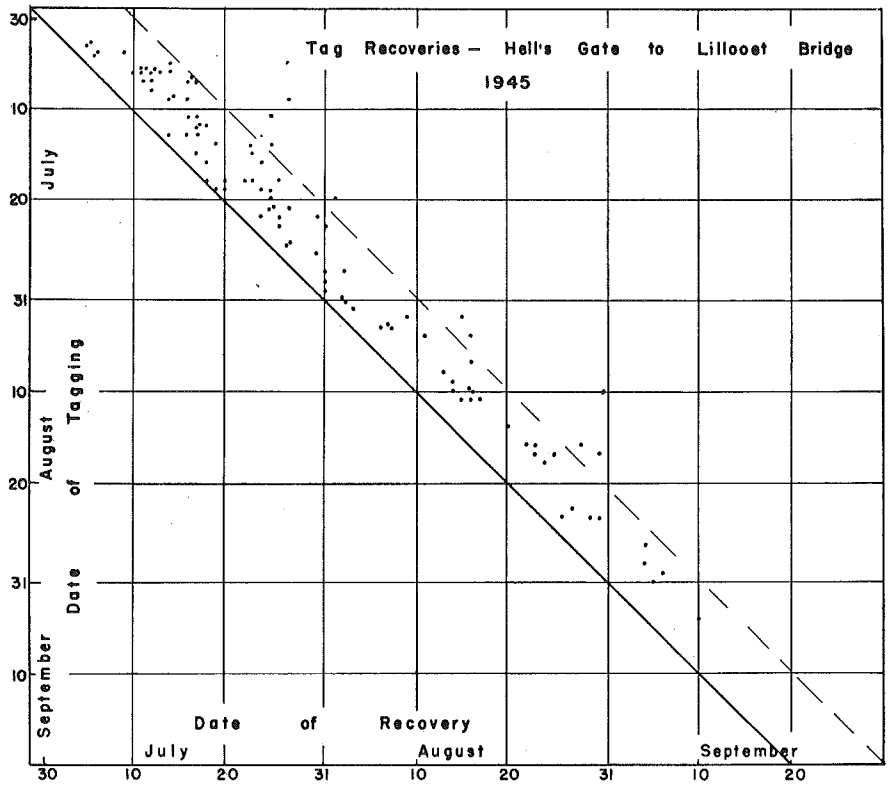

FIGURE 16. Tag recoveries between Hell's Gate and Lillooet Bridge, showing date of tagging and date of recovery, 1945.

of tagged fish recaptured below the Gate during this period. A few tags which took longer than 10 days to reach the Lillooet Bridge were recovered throughout the balance of the season, but these were too few in number to correlate with the recaptures. The numerous recaptures shown in Figure 5 made below the Gate late in the season were of Adams River sockeye. These turned into the Thompson River at Lytton, and so the delayed recoveries above the Gate are not shown in Figure 17.

The first delayed recoveries in 1947, shown in Figure 18, were two sockeye tagged on July 3, and recovered 11 and 12 days later. The next delayed sockeye were tagged July 10 and 11, and recovered as late as August 10. These may be the same group of fish delayed below the Gate and recaptured below at the first of the season as shown in Figure 6. On the next two days, July 12 and 13, no sockeye were tagged which were recaptured below the Gate (Figure 6) or delayed in recovery above (Figure 18). Another group of delayed recoveries was made between July 14 and 19. This corresponds to the time when a group of sockeye was tagged and later recaptured below the Gate as shown in Figure 6. It will be seen also that on recovery date July 24, many tags were recovered that had been affixed up to nine days before. In addition, on recovery dates July 28, 29, and 30 (July 25 to 27 was the Indian fishery week-end closed period) a heavy concentration of tags was recovered from fish that were tagged as early as July 10. This,

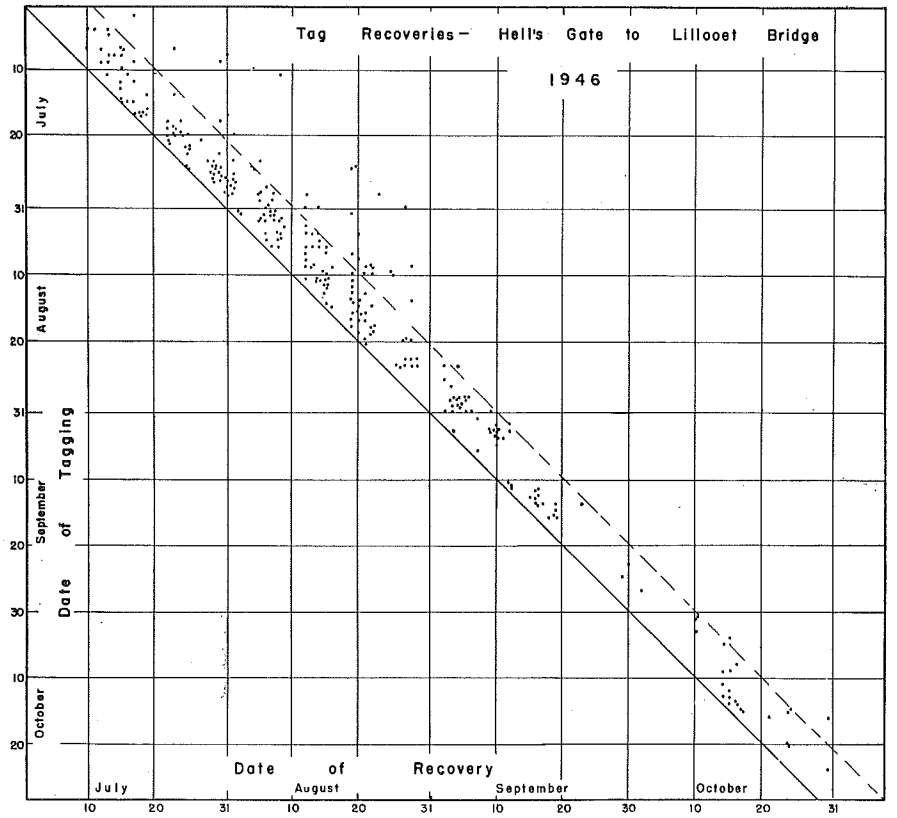

FIGURE 17. Tag recoveries between Hell's Gate and Lillooet Bridge, showing date of tagging and date of recovery, 1946.

on a small scale, is the type of recovery pattern found at Bridge River Rapids during the earlier tagging work at Hell's Gate (Thompson 1945, p. 132) after fish blocked at the Gate were released by changing water levels. No sockeye tagged after July 15 was recovered above the Gate until July 23 or 24. During this period the water rose suddenly to 60 feet (Table VI, p. 75). Recoveries above the Gate of these tags were not made until the water level dropped again to below 54 feet where the fishways operate.

It can be seen from a comparison of graphs before and after the installation of the fishways that sockeye at Hell's Gate were delayed much less since 1945, but that a few seem to be having some difficulty at certain times, especially at water levels above the operating level of the present fishways.

Tag Recoveries at Up-River Areas

It has been shown that during a year when long periods of block water levels prevailed at Hell's Gate during the sockeye migration some portions of the sockeye runs were lost completely (Figure 8). In a year of short block water levels, a percentage of the sockeye delayed the longest was not able to pass the Gate and died below, while the number which did pass the Gate increased as the length of

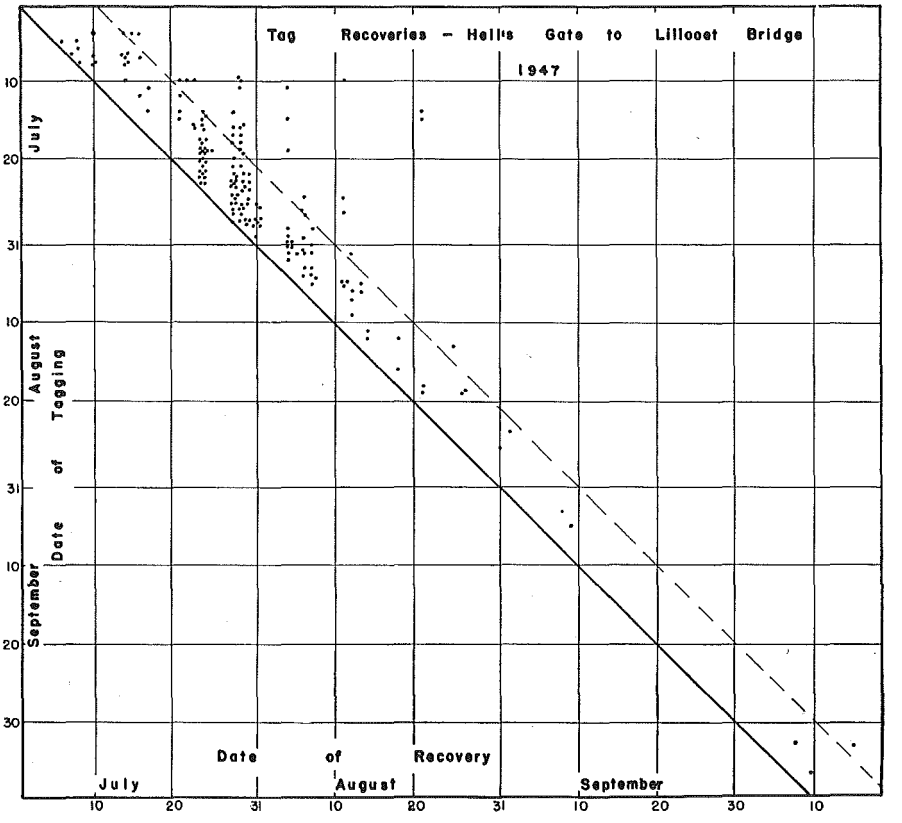

FIGURE 18. Tag recoveries between Hell's Gate and Lillooet Bridge, showing date of tagging and date of recovery, 1947.

time of delay decreased as shown in Figure 7. Those that did get through, however, must have been in all stages of physical condition. They would range from those blocked the longest and only barely able to pass the Gate to those vigorous fish which arrived at the Gate just before the blockade period ended. All the sockeye passing the Gate would then not have an equal chance to reach their spawning grounds. Some of those delayed the longest and consequently weaker and in a more advanced state of sexual maturity would probably not be able to reach the spawning grounds which are several hundred miles above Hell's Gate. Some of these fish weakened by block conditions at Hell's Gate are undoubtedly responsible for the recoveries of tags which had been out long periods of time between Hell's Gate and Lillooet as shown in Figure 14.

Where it has been possible to check the exact migration rates to the spawning ground, very few fish delayed long periods of time have been found, and since construction of the fishways at Hell's Gate the migration rate or number of days to reach these spawning grounds has changed but little in comparison to the recoveries in the Fraser Canyon. Unfortunately, there are only two recovery areas near the spawning grounds where tagged sockeye were recovered as soon as they arrived. These were at the Stuart weir and the Bowron weir. These counting fences are just below the spawning grounds, and all tags were recovered from the

fish just before they reached the redds. On the other spawning grounds of the Fraser River system, there was no way of determining how long the tagged fish were present before the tags were recovered, and so they could not be used to determine migration rates. There are, however, Indian recoveries in several areas near some of the spawning areas and the number of days taken to reach these places is of interest in comparison to the recoveries in the Fraser River Canyon both before and after the fishway construction.

The recoveries in each area are of tags that have taken varying lengths of time to reach that area. In order to show this clearly, the maximum and minimum time are given, and also the 1st, 5th, and 9th deciles of frequencies of time have been calculated to the nearest day for the recovery areas used. The maximum and minimum time represent the extremes of migration time, and usually are represented by only one tag. In this respect they are less reliable than the deciles in giving a true picture of the migration time of the main part of the run. Table IV shows these data for the recoveries at several areas above Hell's Gate. The recoveries at the Stuart weir and Stuart Lake are from the early Stuart run. Those from Fraser Lake are practically all from the Stellako run, those at Bowron weir from the Bowron run only, while the recoveries at Farwell Canyon and Siwash Bridge are from the Chilko run.

It can be seen from a study of Table IV that the difference between the maximum and minimum migration time from recoveries near the spawning grounds as shown by those recovered at the Stuart and Bowron weirs was always less than 22 days, and the recoveries since 1945 have not materially changed the deciles of recovery time from the years before installation of the fishways.

The recoveries in the other areas shown in Table IV which are located farther from the spawning grounds give a wider range of migration time in some cases, but except for the maximum number of days taken to reach the Fraser Lake area in 1943 and the Farwell Canyon in 1944, there is little difference in time required for migration before and after installation of the fishways.

The tag recoveries in the Fraser River Canyon areas, however, show a great difference in recovery time since 1945. Table V, which gives the maximum, minimum and 1st, 5th, and 9th deciles, illustrates this for the Lytton to Lillooet area for each year that tagging has been done at Hell's Gate. The greatest difference before and after the fishways were installed is found in the slowest half of the migrants. As shown in Table V, in the years before 1945 the 9th decile of migration time to this area has varied from 28 to 40 days while in 1945, 1946, and 1947, the time ranged only between 13 to 16 days. A similar difference exists on the Fraser River in the other recovery areas between Hell's Gate and Alkali Creek. To illustrate this graphically, Figure 19 has been prepared showing the combined recoveries from each area in the years 1941, 1942, and 1943 with the 1st, 5th and 9th deciles plotted according to the distance these areas are located above Hell's Gate. The maximum and minimum time is shown for each area also. *The long range of migration time to the Canyon recovery areas stands out clearly and is in sharp contrast to the migration time at the Bowron and Stuart weirs.* It is apparent that long-delayed sockeye do not reach these spawning grounds.

TABLE IV

Minimum, Maximum, and 1, 5, and 9 Deciles of Frequencies of Days Between Tagging at Hell's Gate and Recoveries at Several Places Above Hell's Gate

Recovery Area	*Year*	*No. Recovered*	*Days after Tagging**					*Distance Above Hell's Gate*
				Deciles				
			Min.	1	5	9	*Max.*	
Stuart weir	1941	20	21	22	26	31	35	543 miles
	1942	13	20	20	22	28	28	
	1945	79	17	20	23	29	35	
	1946	24	17	19	22	25	32	
Stuart Lake	1941	7	20	20	30	34	46	490 miles
	1942	9	15	15	16	23	27	
	1943	19	17	18	20	22	26	
	1945	142	15	16	18	24	36	
	1946	56	15	17	20	25	38	
	1947	12	14	14	18	24	32	
Fraser Lake	1939	15	20	22	30	44	47	477 miles
	1941	6	21	21	22	23	35	
	1942	26	20	20	23	36	45	
	1943	84	18	22	31	41	59	
	1944	21	21	24	29	36	40	
	1945	44	16	20	27	35	41	
	1946	88	13	20	23	32	39	
	1947	8	22	22	24	27	30	
Bowron weir	1943	55	20	21	25	28	41	531 miles
	1944	10	25	25	28	35	41	
	1945	21	18	20	25	26	33	
	1946	49	17	19	21	25	27	
	1947	76	15	18	20	23	28	
Farwell	1940	10	12	12	14	20	22	173 miles
	1941	5	8	8	11	28	28	
	1944	85	4	9	16	29	60	
	1945	22	9	10	14	21	27	
	1946	26	4	9	12	16	18	
Siwash Bridge and Keighley Holes	1940	24	14	14	18	26	40	242 miles
	1941	12	11	11	14	20	22	
	1944	71	9	11	19	32	37	
	1945	15	10	17	19	24	27	

*Includes day of tagging and day of recovery. Subtract one day to calculate miles per day.

TABLE V

Minimum, Maximum, and 1, 5, and 9 Deciles of Frequencies of Days Between Tagging at Hell's Gate and Recovery Between Lytton and Lillooet

Year	No. Recovered	Days after Tagging Deciles Min.	1	5	9	Max.
1938	59	1	3	14	40	69
1939	131	1	6	11	27	62
1940	178	3	7	14	30	65
1941	91	1	4	10	30	69
1942	280	4	6	12	28	63
1943	512	1	4	11	36	91
1944	80	4	6	13	34	55
1945	117	1	4	7	16	46
1946	122	1	4	7	14	35
1947	107	1	4	7	13	40

Since it is not known definitely how long a sockeye can be delayed at Hell's Gate and still progress upstream when passable levels occur, it is difficult to determine a time beyond which a delayed sockeye can not reach its spawning ground. The time probably varies with the individual fish as well as with the various races which spawn in the Fraser River. It has been shown by Thompson (1945, p. 144), however, that for the races of sockeye blocked at Hell's Gate in 1941, only those delayed less than 12 days progressed upstream during the open period of September 1, 2, and 3. As a further means of determining this maximum period, all the recaptures made below the Gate from 1938 to 1947 were checked as to their subsequent recovery location. *No sockeye which was delayed longer than* 14 *days when recaptured below the Gate by the tagging crew and then liberated was ever recovered on its spawning ground above Hell's Gate.*

From Table IV and Figure 19 it is possible to estimate the time that the sockeye of some races can be delayed at Hell's Gate and still reach the spawning ground. For instance, in Figure 19 it can be seen that the sockeye taking the longest time to reach the Stuart weir (not Stuart Lake) in the years 1941 to 1943 was 35 days from Hell's Gate. There is no way of knowing the shortest time possible for a sockeye to reach the Stuart weir. The best estimate of this time is the number of days taken by the fastest fish to reach this place during these years which was 20 days, as shown in Figure 19. Now if no fish took longer than 35 days, while the fastest fish made it in 20, it seems reasonable to believe that a sockeye delayed at Hell's Gate for more than 15 days (35 days minus 20 days) could not be expected to reach the Stuart weir. Line "a" has been placed on Figure 1 extending from 15 days at Hell's Gate to 35 days at the Stuart weir. This line shows the best available estimate with the present data of the maximum time a Stuart Lake sockeye can take to reach any recovery area along its route of migration and still be considered as having a chance to reach its spawning ground. These calculations

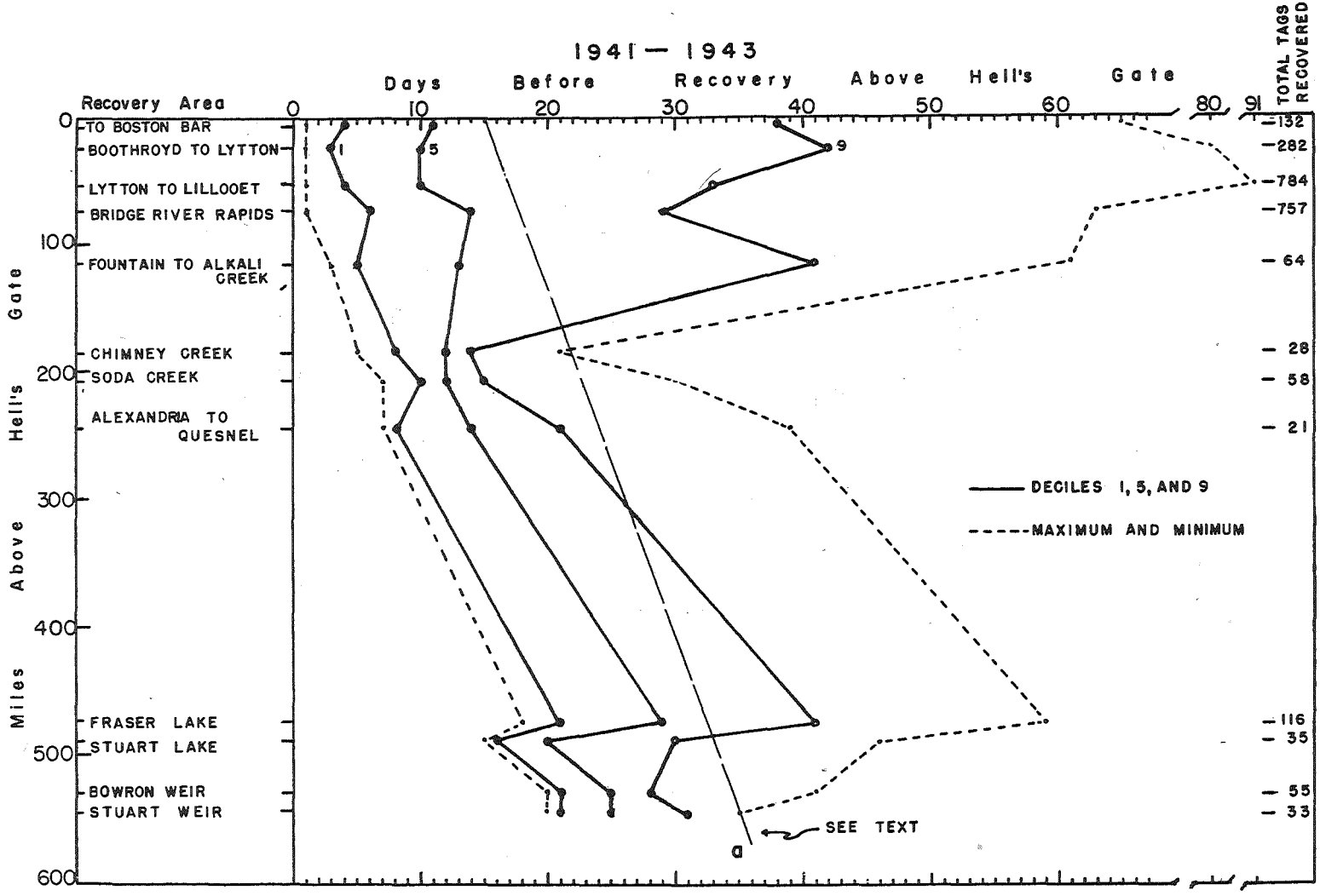

FIGURE 19. Minimum, maximum, and 1, 5, and 9 deciles of frequencies of days between tagging at Hell's Gate and recoveries at several places above Hell's Gate for the combined years 1941-1943.

are based on the slowest fish and the fastest fish reaching the Stuart weir and so are not typical of the bulk of the sockeye of the Stuart race. A figure obtained by eliminating the unusual individuals might be more reliable for the main part of the run. If the 9th decile is used for the average of the slowest Stuart sockeye as shown in Figure 19, and the 1st decile for the average of the fastest, then the longest period an average Stuart sockeye can be delayed at Hell's Gate and still reach its spawning ground is 10 days (31 days minus 21 days). In this case line "a", showing the longest time a Stuart sockeye can be delayed en route, should be moved 5 days to the left.

The recoveries made in Stuart Lake are of interest because they are from the same race of sockeye as those at the Stuart weir, but the tags are recovered about 50 miles before the weir is reached. As shown in Figure 19, the minimum time and the 1st and 5th deciles are each five days earlier in time than at the Stuart weir. The 9th decile, however, is only one day earlier, showing more slow-migrating sockeye recovered at Stuart Lake than at the weir. The slowest tag recovery at Stuart Lake was out 46 days as compared to only 35 days at the weir. The slowest of the fish to reach Stuart Lake do not reach the counting fence at the spawning grounds, and a mortality occurs between the two places. This is substantiated by the fact that Commission observers have often found dead, unspawned, but otherwise apparently uninjured sockeye between Stuart Lake and the weir.

The combined Bowron weir recoveries for 1941, 1942, and 1943 are shown in Figure 19 next above those at the Stuart weir. The minimum number of days for a sockeye to reach this place was 20 days, while the maximum time was 41 days. Calculated from these figures, the longest time a sockeye could be delayed and still reach the Bowron weir is 21 days. The Bowron spawning grounds average approximately 12 miles above the weir. It is probable, in view of the mortality shown between Stuart Lake and the Stuart weir, that some mortality also occurred between the Bowron weir and the spawning grounds. If the 1st and 9th decile of the Bowron weir recoveries are used to calculate the number of days a sockeye could be delayed and still reach the spawning ground, a figure of only 8 days is obtained (28 days minus 20 days). Line "a" as shown in Figure 19 should then extend from 8 days at Hell's Gate to 28 days at Bowron weir for this race. Any sockeye of the Bowron run delayed en route to the spawning ground so that it was out a longer time than this line "a" at any recovery area, would theoretically not be able to reach the Bowron weir or the spawning grounds.

The recoveries at Fraser Lake were practically all from the Stellako race of sockeye. These fish migrate and spawn at a later date than do either the Stuart or Bowron races of sockeye, and apparently they migrate at a slower rate of speed, for in proportion to the distance above Hell's Gate, the 1st, 5th, and 9th deciles and the maximum of time taken to reach Fraser Lake is greater than that for the corresponding time at Stuart and Bowron. This is true before the fishways were constructed, as well as after, as shown in Table IV.

The Fraser Lake recoveries are made several miles below the Stellako spawning grounds, and it is not known what mortality occurs between the two places. It can be seen in Table IV, however, that the recoveries at Fraser Lake, as shown in Figure 19, were influenced heavily by the 1943 recoveries. The recoveries of

the other years before 1945 are more similar to those made in 1945, 1946, and 1947, and so the mortalities, while present, may not have been excessive in most years. Excluding the 1943 recoveries at Fraser Lake, and using the maximum and minimum time as shown for each year in Table IV to calculate the longest time a Stellako sockeye could be delayed at Hell's Gate and still reach the spawning grounds, figures from 8 to 29 days are obtained or an average for all years (excluding 1943) of 22 days. Using the 1st decile and the 9th decile as representative of an average sockeye as done for the two previous recovery areas and including the 1943 recoveries, an average of 13 days is obtained. In either case the calculated period of delay which the Stellako race of sockeye can endure at Hell's Gate and still reach Fraser Lake is only a few days longer than for Stuart and Bowron fish. In view of the mortality shown between Stuart Lake and Stuart weir, the period of delay which the Stellako sockeye can endure and still reach the spawning ground in the river above Fraser Lake may not be any greater than that shown for Stuart and Bowron sockeye.

If, for the purpose of comparison, 15 days is considered as being the average maximum time a sockeye can be delayed at Hell's Gate and still reach the spawning grounds, and line "a", as shown in Figure 19, as the maximum time a sockeye can take in reaching various points along its migration route, then all sockeye recovered to the right of this line can be considered as mortalities as far as reaching the spawning grounds is concerned. Then for the combined years 1941 to 1943, between 30 per cent and 40 per cent of the tagged sockeye caught between Hell's Gate and Alkali Creek could not be expected to reach the spawning grounds, for line "a" lies between the 6th and 7th decile position. This average line "a" would be a minimum mortality for the blocked sockeye since the calculations are based on time-out-until-recovery of sockeye tagged during all water levels at Hell's Gate.

It is probable, in view of the individuality of each race of sockeye that spawns above Hell's Gate, that a line "a" for each race would be necessary to calculate the actual mortality suffered by the sockeye between Hell's Gate and the spawning grounds as a result of block conditions. It is possible also, that a straight line relationship does not occur in the sockeye migration up the river, in which case line "a" should curve accordingly. Circumstantial evidence from the observed abundance of fish of large runs at various points up the river, and also from a limited amount of tagging at Soda Creek indicates, however, that the migration rate from Hell's Gate to the spawning areas is fairly uniform.

In addition, the only completely reliable tag returns, as far as recovery date is concerned, are those from the two counting fences. The returns from the other areas were received from Indian fishermen who may not have given the correct recovery date of each tag they returned. This would affect the deciles of recovery one way or the other depending upon whether the Indians reported the tags recovered earlier or later than the actual recovery dates. Because of these varying factors, Figure 19 can be used only as an indication that a sizeable percentage of sockeye, at least of some races, may have been lost between Hell's Gate and the spawning grounds. A comparison with similar recoveries for the same cycle years to show the difference in mortality after installation of the Hell's Gate fishways should be valid, however, because the same races of sockeye are involved and the

possible errors in recovery dates of tags returned by the Indians should be similar since the same method of tag collection was used in each case.

The tag recoveries for the next cycle years after those shown in Figure 19 are similarly plotted in Figure 20 for the combined years of 1945, 1946, and 1947. The number of days to recovery in the Canyon areas is the most striking difference in the tag recoveries since the fishways were installed at Hell's Gate. Line "a" in Figure 20 is identical in position to line "a" in Figure 19. As can be seen, in most recovery areas it falls to the right of the 9th decile so that a loss of less than 10 per cent is indicated. Part of this loss may represent the natural mortality that occurs at all times during the life cycle of living organisms. It may also be considered as tagging mortality, but part of it also results from extreme high and low difficult water level periods which will be discussed later. Engineering plans for future work at Hell's Gate to correct the high and low level periods of difficulty may eliminate at least part of the small loss shown in Figure 20.

Line "a" in both Figures 19 and 20 may not represent the true average maximum migration time for those sockeye that reach their spawning grounds. It can be seen, however, that the same difference in mortality rates before and after fishway construction would be shown if line "a" is shifted to the right or left within reasonable limits.

An interesting feature of both Figures 19 and 20 is the recoveries at Chimney Creek. No sockeye out long periods of time were taken at this station in any year. An examination of the recovery dates of the tags recovered at this point disclosed that most of the fishing was done in July, while at the other fishing places on the Fraser River the recoveries were made throughout the entire migration period. Figure 14, giving the recoveries between Hell's Gate and Lillooet Bridge shows, however, that there were many delayed fish during the month of July in that year. Apparently none of the delayed fish reached Chimney Creek before fishing was discontinued, or it is also possible that those sockeye delayed the longest were too weak to reach the Chimney Creek area and died before getting that far up the river.

The recoveries shown in Figures 19 and 20 include the recoveries from all the main races of sockeye which spawn above Hell's Gate except those from the Thompson River and the Chilko River districts. Table IV lists the recoveries at Farwell Canyon and Siwash Bridge and Keighley Holes on the Chilcotin River system which enters the Fraser just below Chimney Creek. These recoveries were all from the Chilko River race. They were not included in Figures 19 and 20 because they conflicted in distance with the Chimney Creek and Alexandria to Quesnel area on the Fraser River. It can be seen that except for the maximum time taken for sockeye to reach Farwell Canyon in 1944 and the Siwash Bridge to Keighley Holes area in 1940, the migration time has changed but little since construction of the fishways. Most of the mortality in the Fraser Canyon as shown in Figure 19, evidently occurred before the Chilko sockeye reached Farwell Canyon.

In the Thompson district, practically all the tag recoveries were made on the spawning grounds. These could not be used for determining time of migration because it was not known how long they had been on the spawning grounds before they were taken. In 1942, however, on Adams River, which is the most important spawning stream in the Thompson district, a determined effort was made, both by

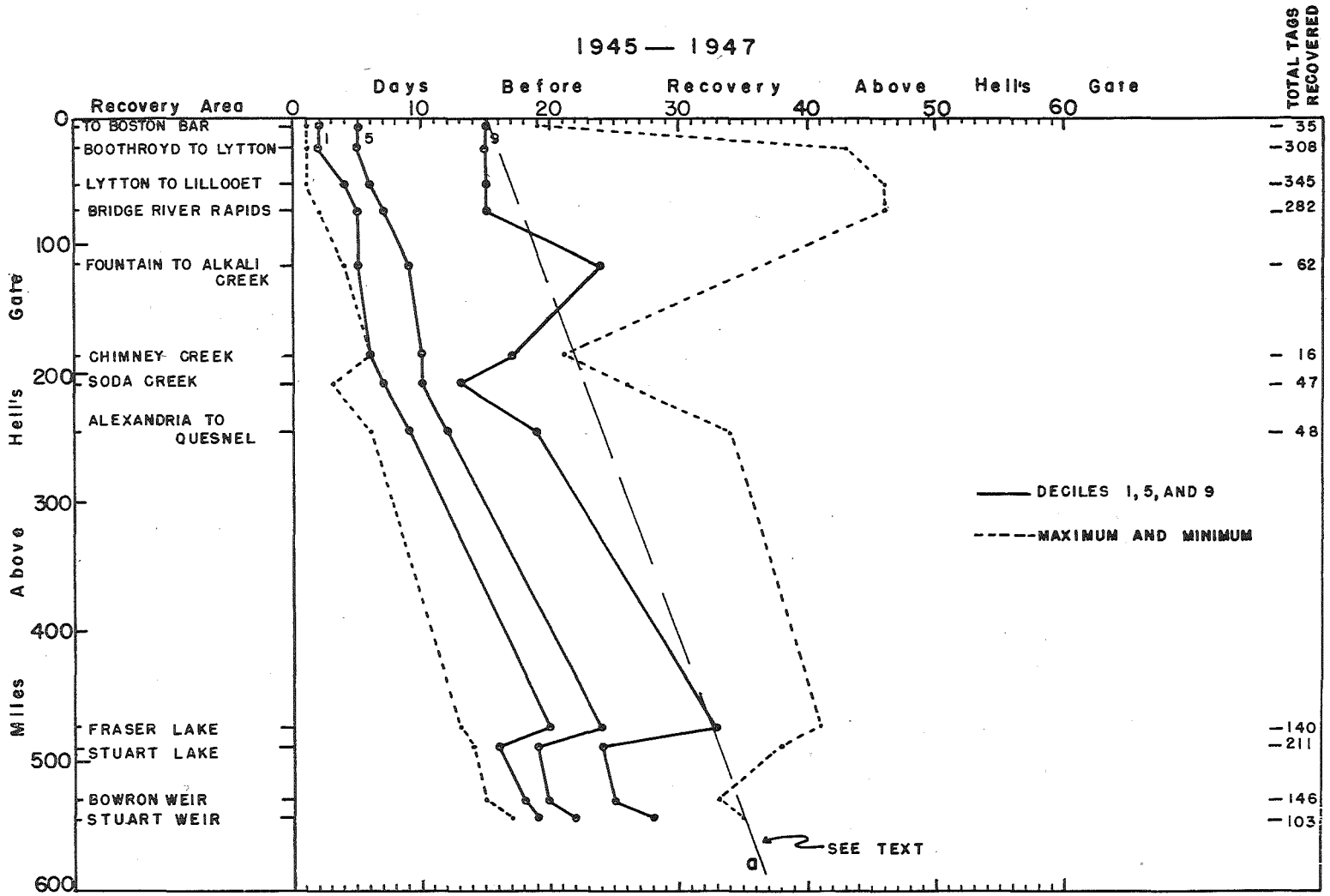

FIGURE 20. Minimum, maximum, and 1, 5, and 9 deciles of frequencies of days between tagging at Hell's Gate and recoveries at several places above Hell's Gate for the combined years 1945-1947.

the Indian fishermen and Commission observers, to recover the tags as soon after arrival as possible. Undoubtedly, not all tags were recovered as soon as they arrived, but the recoveries as shown by Thompson (1945, p. 46) do not show enough slow-migrating sockeye in this race to account for the delayed recoveries between Hell's Gate and Lytton. Since the Thompson district sockeye turn into the Thompson at Lytton, none of the recoveries taken above this point in the Fraser were Thompson River fish.

This accounts for all the major races of sockeye spawning above Hell's Gate. Now, if 15 days is accepted as an average maximum time a sockeye can be delayed at Hell's Gate and still reach its spawning ground, then 30 per cent to 40 per cent of those passing were not able to reach their spawning grounds. Since 1945 when the fishways were constructed the loss, on the same basis, has been reduced to less than 10 per cent. If the period of delay which an average sockeye can endure at the Gate and still reach the spawning ground differs within reasonable limits from the 15 days shown in Figures 19 and 20, the lower mortalities after construction of the fishways are still apparent. In either case the mortalities after construction of the fishways are 20 per cent to 30 per cent less than before construction. Thompson (1945, p. 171) has already shown that before the fishways were installed half or more of all sockeye delayed below Hell's Gate during certain periods of block water levels did not pass upstream after the water had reached passable levels. The total mortality suffered by certain races as a result of difficult water levels at Hell's Gate could therefore have been 70 per cent to 80 per cent of the total run reaching Hell's Gate. That this calculated loss is not exaggerated is indicated by the per cent increase in escapement to some spawning areas above Hell's Gate since construction of the fishways in 1945.

Net Marked Sockeye

During the tagging operations at Hell's Gate a record was kept of all injuries found on the fish tagged. More net marks were found than any other injury. These marks, it was thought, were caused by the nets of the commercial fishermen near the mouth of the river, and marked fish were ones that had been caught in the gill nets, but had subsequently escaped.

The percentage of net marks in each day's catch at Hell's Gate fluctuated from day to day, but no correlation could be found with the percentage of net marks and certain days of the week until 1945, after the installation of the fishways. During July and almost all of August in 1945, the percentage of net-marked sockeye fluctuated so that a low percentage of net-marked fish was caught on one or two days of each week. This usually occurred on Thursday or Friday, and a higher per cent of net marks was found on the other days. This is shown in Figure 21. On this chart, and all others illustrating the percentage of net-marked sockeye, the dates shown fall on Friday.

As can be seen in Figure 21, the percentage of net-marked sockeye rises and falls each week. The "peaks" occur between the Fridays of each week and the "troughs" usually fall on Friday. This fluctuation in the percentage of net-marked fish is undoubtedly caused by the week-end closure of the commercial fishery at the mouth of the river. The lag of 5 or 6 days from the closed week-end to Friday

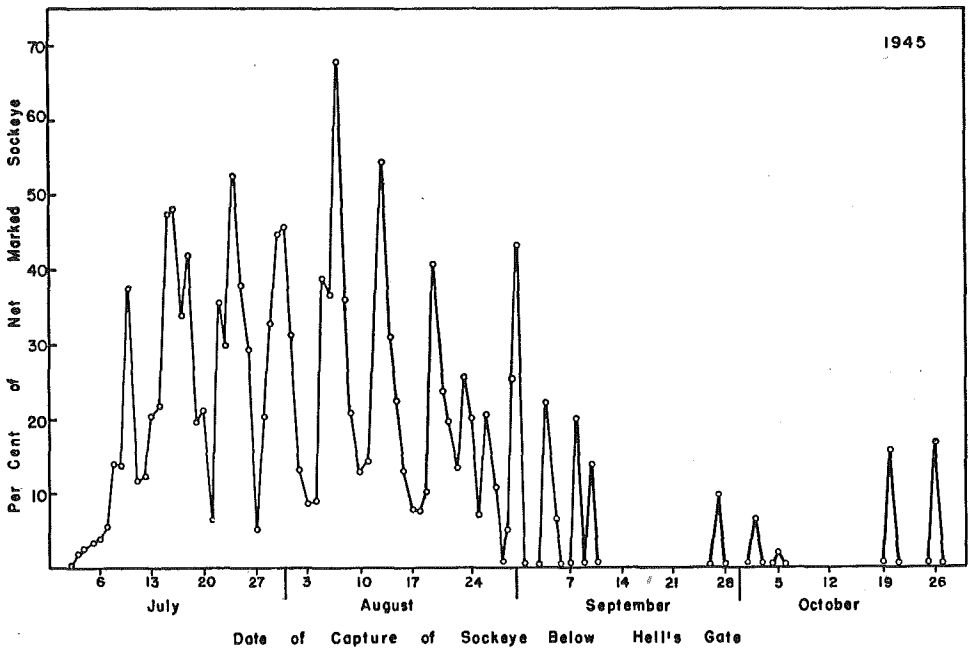

FIGURE 21. Percentage of net-marked sockeye in daily catch below Hell's Gate, 1945.

or Saturday is the length of time it takes the fish to migrate from the mouth of the river to Hell's Gate.

After August 24 this correlation does not exist. At this time only the last migrants of the Chilko, Stellako, and late Stuart runs were migrating by Hell's Gate, and it is possible that the late stragglers of these runs migrate at various rates and obscured the effect of the closed week-end in the commercial fishery. During most of September and October, the Adams River run, which this year was composed of 96.8 per cent small "jack" sockeye (I.P.S.F.C. Annual Report, 1945) was migrating up the river. These fish were probably too small to be affected much by the commercial gear operating at the mouth of the river. The lack of net-marked fish during September and October verifies this.

Graphs of the percentage of net marks recorded each day have been prepared for the years 1943 and 1944. These are shown in Figures 22 and 23. As can be seen, there is no correlation between net marks and any day of the week during these years except, possibly, during the last of September and October in 1943 when the water levels at Hell's Gate were not at a block stage. *At all other times during these seasons, those fish caught below the Gate each day must have been an accumulation of blocked fish which had arrived at various times and did not represent those arriving each day.* No correlation could be expected.

In 1946 the Commission began the regulation of the commercial fishery. In addition to the regular weekly closed periods, sockeye nets were permitted in the river from August 8 to September 25 only; at other times, subject to weekly closures, larger gill nets of 8-inch mesh which were used for spring salmon could be employed. These caught few sockeye. The percentage of net-marked fish

caught at the Gate reflected the results of these restrictions, and is shown in Figure 24. At the start of the season, a few net-marked fish were recorded which presumably had been caught and then had escaped from the 8-inch mesh. Fishing for sockeye with smaller nets started on August 8. Six days later a large percentage of net marks was found in the Hell's Gate catch. The commercial fishery was closed for the week-end the day after it opened, and fishing began again the following Monday, August 12. Each Friday thereafter, until the sockeye season was closed, a low percentage of net-marked sockeye was recorded as compared with the high percentage which existed while the fishery was in operation. The commercial sockeye fishery was closed September 25, and the percentage of net marks dropped accordingly. During the balance of the season only a few net-marked fish were found.

In 1947 the commercial fishery for sockeye with small nets was from September 8 to the end of the season. Figure 25 shows that few net-marked sockeye were found at Hell's Gate until late in the season. The first "peak" in net marks after the season opened was on September 16, but this was small. The closed week-end of September 13 and 14 in the commercial fishery shows up as a total lack of net marks on September 19 at Hell's Gate. The net marks then increase, but on the next Friday, September 26, there is again a low point. During October the correlation is not good. The next low point occurs on Sunday, October 5, the next on Saturday the 11th, then on Friday, October 17, again on the 19th and then on the 25th. It has been shown in an earlier report (MacKay, Howard and Killick) that the late sockeye runs of the Fraser tend to delay at the mouth of the river. It is probable that this delay tends to mix the marked and unmarked sockeye more than usual so that late in the season the effect of a few net marks as a result of the closed week-ends does not correlate well with any particular day at Hell's Gate.

The fact that a correlation exists during July, August, and September between the per cent of net-marked sockeye at Hell's Gate and the commercial fishery dates since the fishways have been constructed, while before there was no correlation, is good evidence that the new fishways have eliminated the delays which occurred each year at Hell's Gate.

Catch per Hour at Hell's Gate

During the first few years of tagging at Hell's Gate much experimenting was done to determine the best fishing methods. Also, many changes were made in fishing locations to determine the best places to fish as the water levels changed. With the experience gained during that time the best fishing locations became known, and the methods became standardized so that comparable catches per hour could be made.

Early comparisons of the catch per hour above the Gate with that made below were not regarded seriously, for except at certain times few fish were captured at the fishing stations above the Gate. Below the Gate the river bank is rough, forming many back eddies which make good fishing locations. Above the Gate the shore tends to be smooth and good fishing locations are hard to find. It was thought that the poor catches resulted from inefficient fishing locations rather than lack of fish.

However, as the tagging work began to show the effect that certain water levels had on the ability of sockeye to get through the Gate, it became apparent that

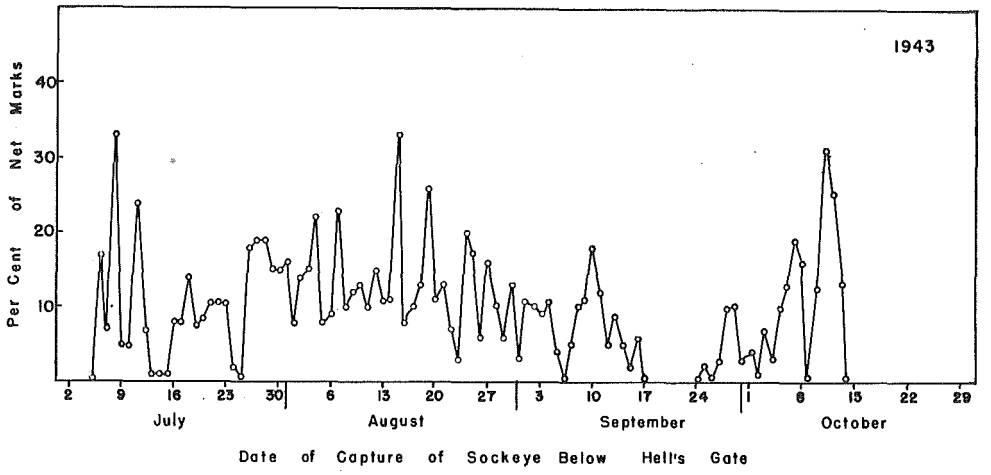

FIGURE 22. Percentage of net-marked sockeye in daily catch below Hell's Gate, 1943.

although the fishing stations above the Gate were not usually as efficient as those below, the catches of sockeye above the Gate seemed to be correlated with these levels. It was thought that this index might prove valuable to illustrate difficult water stages, and so starting with 1942 an accurate record was kept of the time that was spent by the tagging crew while fishing at each location. From this the catch per hour was determined.

The catch per hour at both banks for each season since 1942 is presented graphically in Figures 26 to 37, inclusive. The open squares along the date line indicate that the tagging crew fished that day at that location, but no catches were made. In addition to the catch per hour, the corresponding water levels at Hell's Gate are illustrated. Beginning with 1943 the dates of migration at Hell's Gate of each run of sockeye are shown.

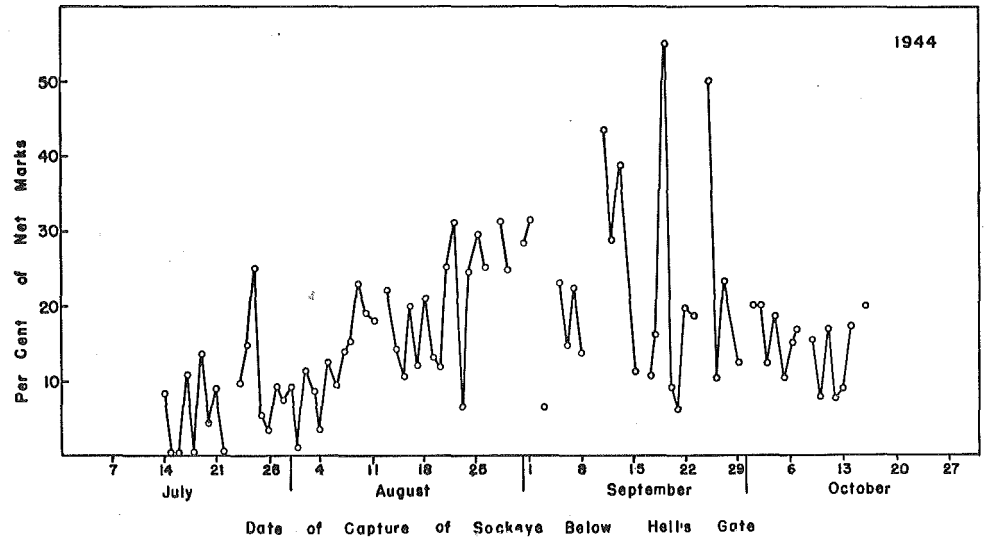

FIGURE 23. Percentage of net-marked sockeye in daily catch below Hell's Gate. 1944.

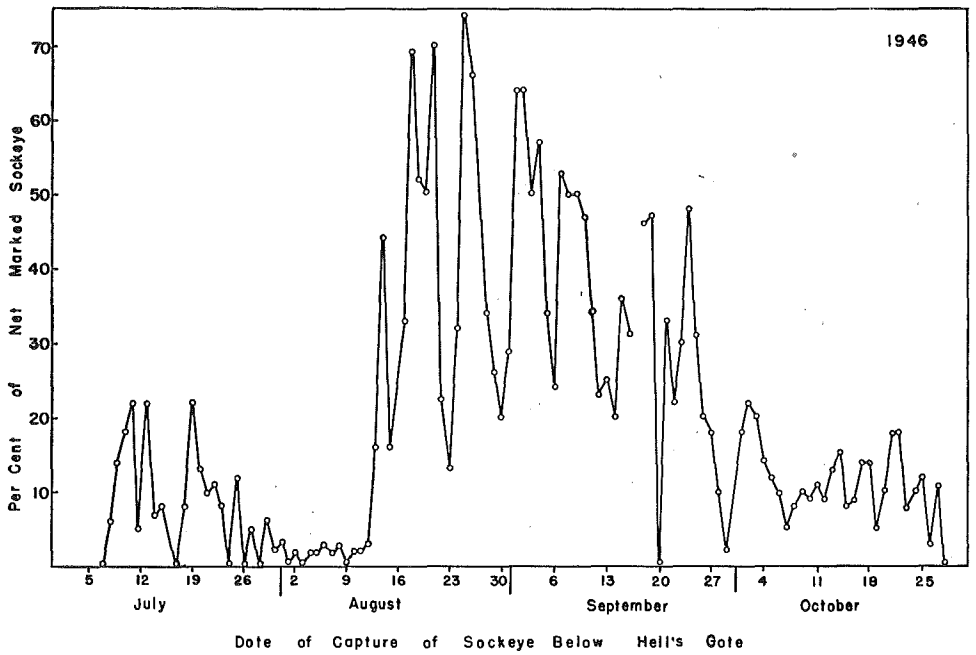

FIGURE 24. Percentage of net-marked sockeye in daily catch below Hell's Gate, 1946.

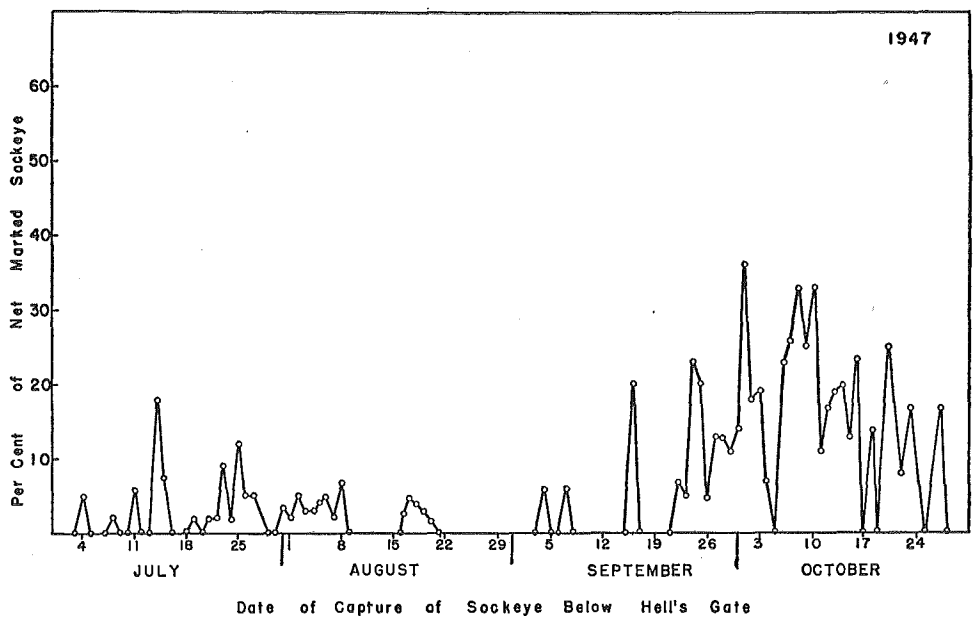

FIGURE 25. Percentage of net-marked sockeye in daily catch below Hell's Gate, 1947.

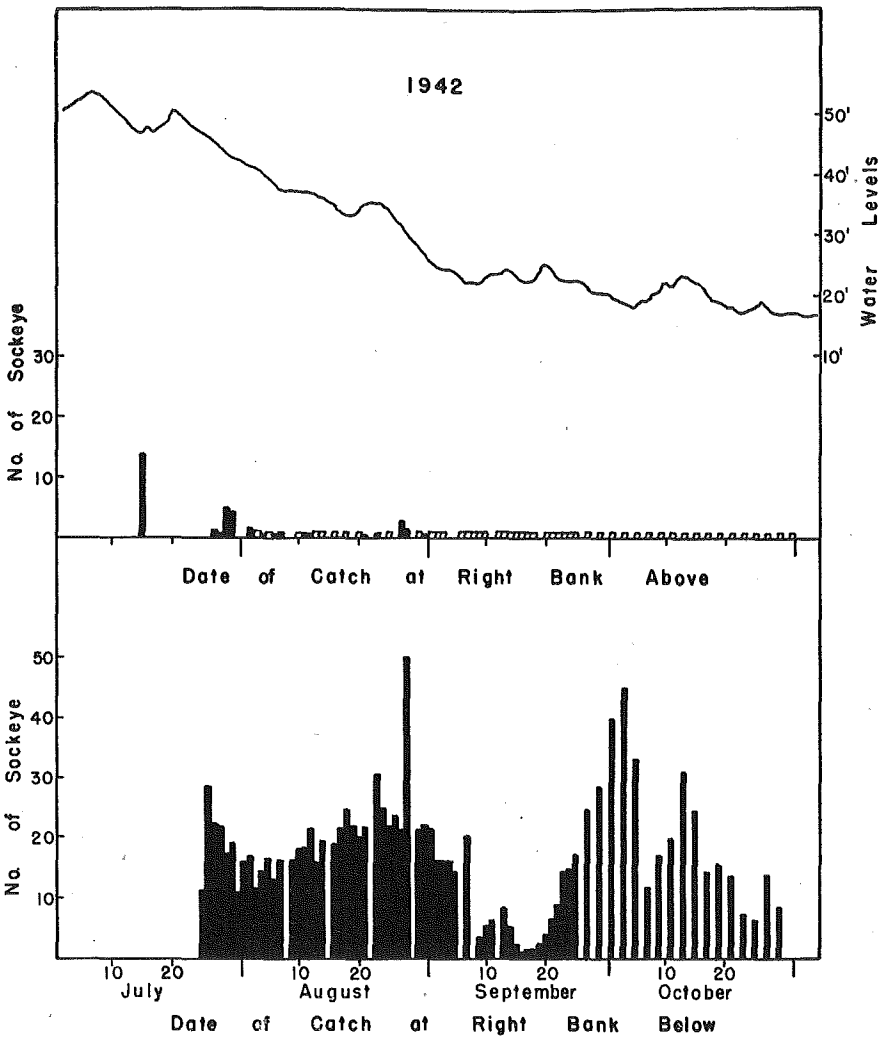

FIGURE 26. Catch per hour at Right Bank stations, Hell's Gate, 1942. (Open squares indicate that fishing was done but no catch was made).

1942

No tagging work had been done on the right bank of the river until 1942 because of the difficulty in crossing the river. A cable crossing (later replaced by a foot bridge) was installed by the 25th of July, 1942. Since that time operations have been carried out on both banks of the river.

As shown in the lower graph of Figure 26, fishing for sockeye began at the Right Bank Below stations on July 25. Fair catches were made until the first part of September when they dropped to a low level. After September 20 the catches increased again, fluctuated somewhat, and then dropped as the last of the migrants passed the Gate. The catches above the Gate at this bank, Figure 26, upper graph, were poor throughout the season, except on July 15 at a water level of 48 feet. On that date, a tagging crew walked up the right bank of the river from the

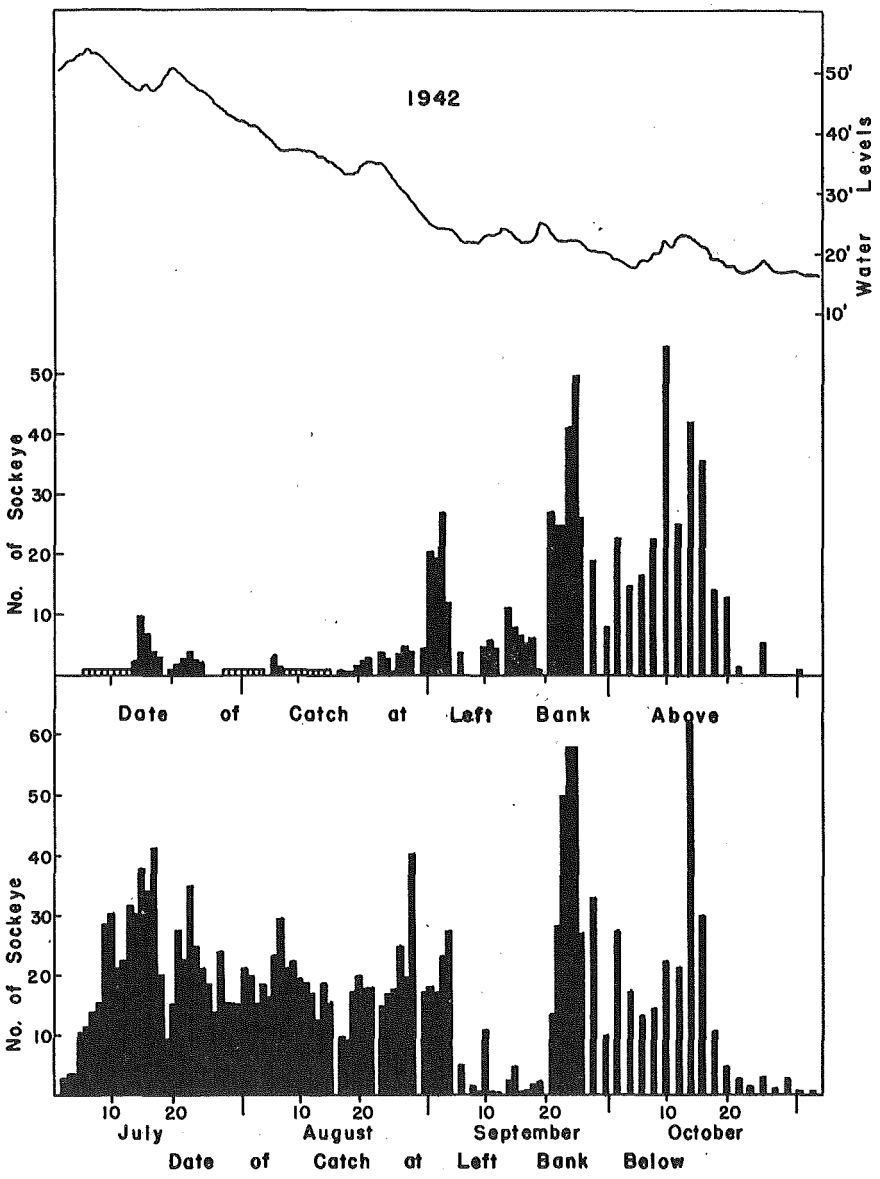

FIGURE 27. Catch per hour at Left Bank stations, Hell's Gate, 1942. (Open squares indicate that fishing was done but no catch was made).

Alexandra bridge (approximately 7 miles below Hell's Gate) to check the fishing conditions on that side of the river. Regular fishing was not attempted until after the cable crossing was installed. The next catches above the Gate from July 27 to 30, at water levels from 46 feet to 43 feet, were poor compared to the abundance of sockeye below the Gate at this time. Fish were caught occasionally after this date, but they were scarce. On August 27 and 28, at water levels of 31 feet and 30 feet, the catch per hour increased slightly, and a catch was made on August 31. After this date not a single sockeye could be caught on this bank although fishing

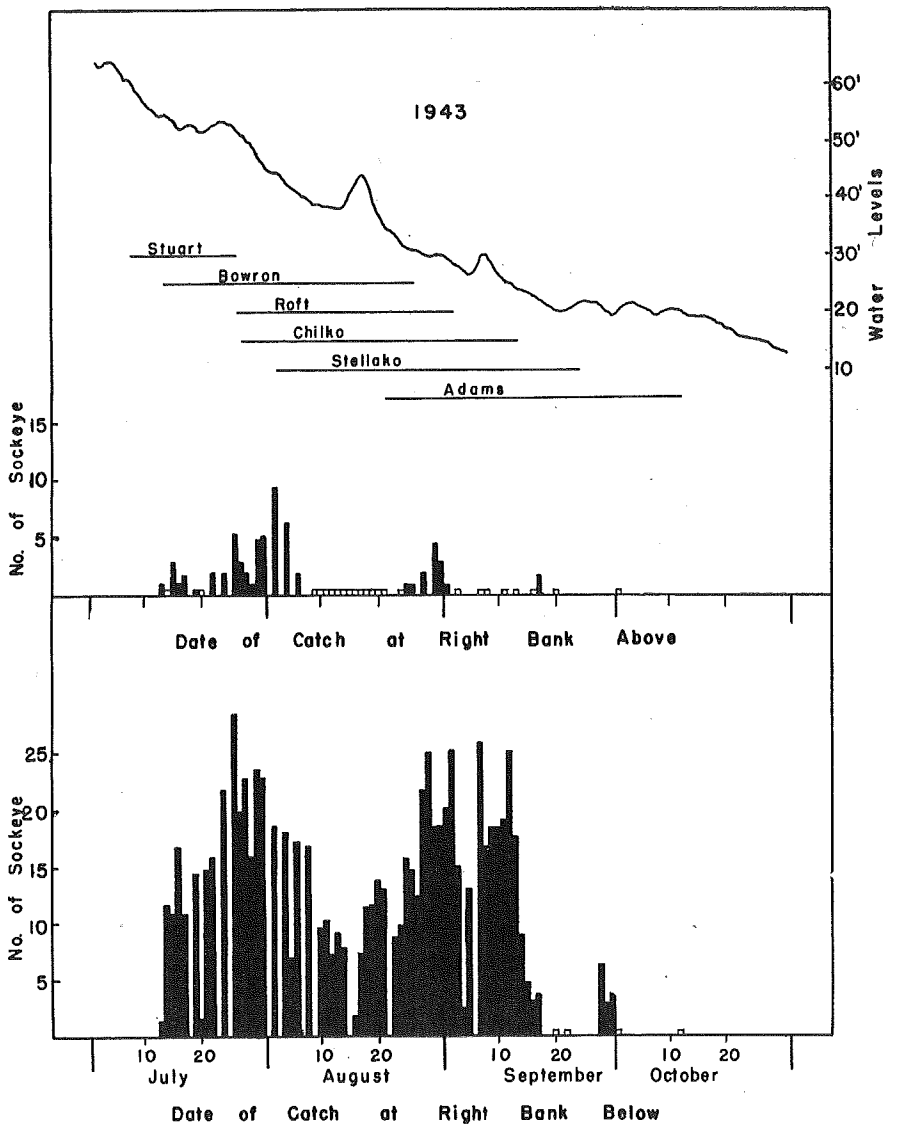

FIGURE 28. Catch per hour at Right Bank stations, Hell's Gate, 1943. (Open squares indicate that fishing was done but no catch was made).

was systematically carried out the balance of the season. *The contrast between the catches above and below the Gate on the right bank is very striking and significant.*

The catches per hour above and below the Gate on the left bank are shown in Figure 27. Fishing commenced on July 2 below the Gate. The catches were small, but gradually increased to a peak on July 17, and then dropped again on July 19. After this the catches on the left bank continued to fluctuate, but indicate approximately the same abundance of sockeye as do those on the right bank. Fishing above the Gate on the left bank began on July 6, but no sockeye were caught until July 14. The water levels during this period dropped from 54 feet to 48 feet. The

catches made the next few days, from July 14 to 25, were small compared to those made below the Gate at this time. Water levels between 48 feet and 51 feet prevailed on these dates. No fish were caught above the Gate when fishing was done between July 29 and August 4. A few sockeye were caught on August 6 and 7 at water levels of 38 feet and 37 feet, respectively. No fish were caught again until August 17. Small catches continued to be made, but when the water level dropped below 26 feet on September 1, the catch per hour above the Gate increased until it equalled the catch made below. The balance of the season the water levels fluctuated between 17 feet and 24 feet, and the catches made above continued to be similar to those made below the Gate.

The catch per hour at the Left Bank Above station illustrates the same block conditions in 1942 as those determined from the tagging data. The catch per hour shows that sockeye migrated past the Gate with ease at levels below 26 feet, but that at all levels above they had difficulty. It also shows that some sockeye could get through at levels near 50 feet, but the catch per hour on this bank does not show much passage at levels near 40 feet. The catch per hour above the Gate on the right bank shows difficult water levels all through the season, but the catches made during July suggest that some sockeye were able to get through the Gate on this bank at water levels between 42 feet and 48 feet.

1943

The catch per hour at the right bank stations below and above Hell's Gate for 1943 are presented in Figure 28. As can be seen, sockeye were first caught below the Gate on this bank on July 13. The abundance of sockeye below the Gate increased rapidly to a peak on July 26, dropped to a low point around August 16, increased again when the Adams River run commenced at the Gate, then fell to a low level on September 17. Little fishing was done on this bank during the balance of the season, but small catches were made the last 3 days of September.

The catches above the Gate on the right bank show that small numbers of sockeye were getting through at the start of the season at a water level of 55 feet. The number getting through increased as the water level reached 45 feet on August 2, but dropped off on August 6 when the level was 41.5 feet. After that date catches were poor above the Gate for the balance of the season when fishing was attempted. Small numbers of fish were caught between August 25 and September 1 when water levels were between 32 feet and 30 feet. A few fish also were caught on September 17 at a water level of 23.2 feet.

The catch per hour for 1943 on the left bank (Figure 29) shows that sockeye were first caught below on July 5. The catches reached a peak on August 3, and with some variations dropped to a low level on September 18. Soon after this the main bulk of the Adams River run arrived, and the catch per hour increased again, reaching a peak on October 4, and then fell as the last of the migrants reached Hell's Gate. The catches above the Gate on this bank were very poor at the high water levels. A fair catch, however, was made on August 9 at a water level of 39.5 feet and a few sockeye continued to be caught above the Gate until August 14 at water levels just below 40 feet. It is interesting to note that the catch per hour decreased below the Gate at this time, indicating that enough blocked fish may have

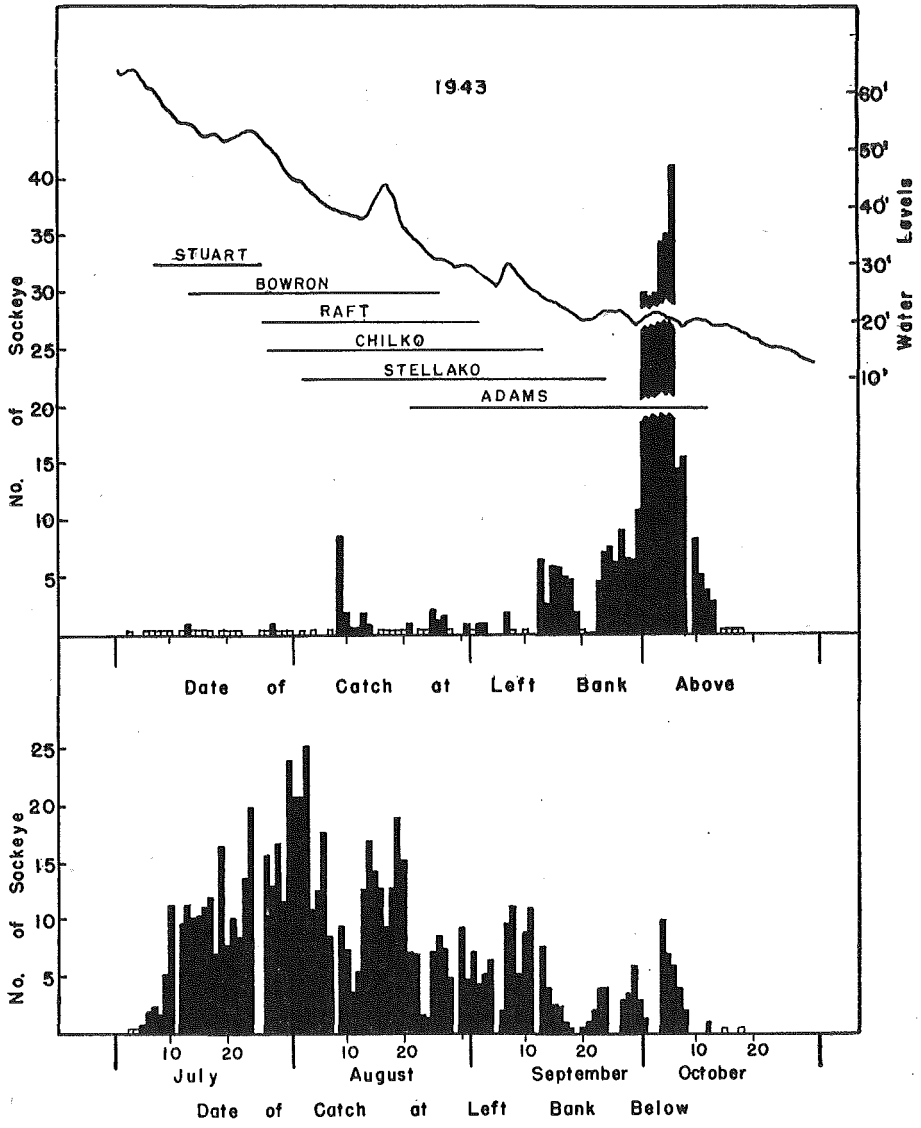

FIGURE 29. Catch per hour at Left Bank stations, Hell's Gate, 1943. (Open squares indicate that fishing was done but no catch was made).

migrated through to reduce the catch per hour there. As previously shown in Figure 1, the recaptures made below the Gate by the tagging crews show that the tagged blocked fish disappeared during this same period. It is possible that many fish crossed the river from the right to the left bank below the Gate and passed at that time, for the abundance also dropped off around August 10 on the right bank. The recaptures (Figure 2) show a slight shift to the right at this time, but not so definitely as for the recaptures made on the left bank where passage apparently was easiest.

Small catches of sockeye continued to be made above the Gate on the left bank

until September 13. These fish were probably using the temporary fishway. It is thought that as a result of this assistance the catch per hour on the left bank below between August 20 and about September 14 is much lower than on the right bank.

On September 12 the water level dropped below 26 feet, and the catches above the Gate on the left bank were about in the same abundance as below the Gate. When the bulk of the Adams River run reached the Gate, much larger catches were made above the Gate than below. Higher catches on the left bank have usually been made above the Gate than below at water levels below 24 feet. A shallow riffle of fast water forms a short distance above the Gate at this level which forces the fish to swim between narrow passages where they are more easily caught.

1944

The catch per hour below and above the Gate on the right bank for 1944 is presented in Figure 30. Fishing was not done consistently above the Gate during the season. A few fish were caught on July 23 and 25 at water levels around 38 feet, but the only days shown when sockeye could pass easily on the right bank, as illustrated by the catches above the Gate, were August 14 at a water level of 41.6 feet, and from August 18 to 23 at water levels from 42.4 feet to 36.6 feet. A few fish were also caught above from August 29 to September 13 when water levels fluctuated between 33.5 feet and 27.6 feet, but these were few compared to the abundance below the Gate. None was captured above the Gate after September 13 on the right bank when fishing was attempted even though fish were present below in fair numbers.

The catch per hour above and below Hell's Gate in 1944 on the left bank is shown in Figure 31. The first catches were made below the Gate on June 27. These continued in small numbers until the Chilko run arrived. The Chilko run was large this year, and the catch per hour increased reaching a peak on August 18, and then dropped to a low level until the end of the season.

The catches above the Gate show that a few fish got through on July 12, 16, and 19 at water levels of 37.2 feet, 37.0 feet, and 38.0 feet, respectively. Fishing was resumed on August 2 and 4 at water levels of 36.6 feet and 33.8 feet and a few sockeye were caught. None was caught on August 5, 6, and 9, however, at water levels of 32.8 feet, 32.0 feet, and 31.8 feet, even though sockeye were abundant below the Gate at this time. On August 10, 11, and 12, when the water levels were near 32 feet, fairly good catches were made. The variation in the ability of the sockeye to pass the Gate on this bank at the same or similar water levels was probably the result of changes made in the stop-logs in the temporary fishway. When water levels changed rapidly, the stop-logs had to be lowered or raised accordingly, and it sometimes took a day or two to get the ladder operating properly after the water level changed. On August 13 the water started rising rapidly and reached a peak on August 16. On August 19 at a water level of 39.5 feet, a comparatively good catch of sockeye was made above the Gate. When the water dropped into the difficult levels, however, the catches dropped off again, but gradually increased as the water dropped to the 32-foot level where, according

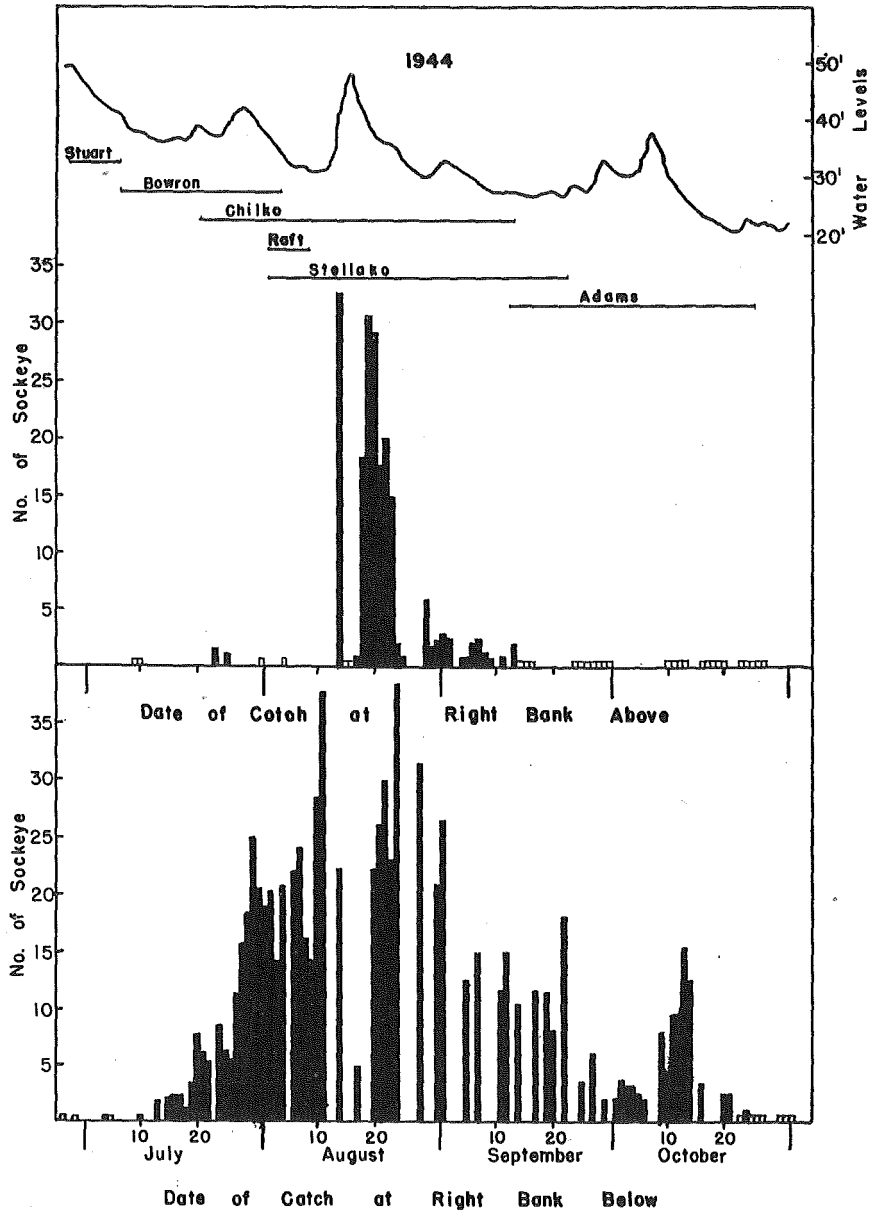

FIGURE 30. Catch per hour at Right Bank stations, Hell's Gate, 1944. (Open squares indicate that fishing was done but no catch was made).

to visual counts, the temporary ladder worked most efficiently. During September the catches above were small, as were those below. When the water level rose suddenly on September 28, the catches above dropped off until October 11 when the level was similar to that before the rise. The water level fell below 26 feet on October 14 and two days later the catch per hour above showed fair numbers of fish were getting through. These gradually diminished as the last of the sockeye were migrating through the Gate.

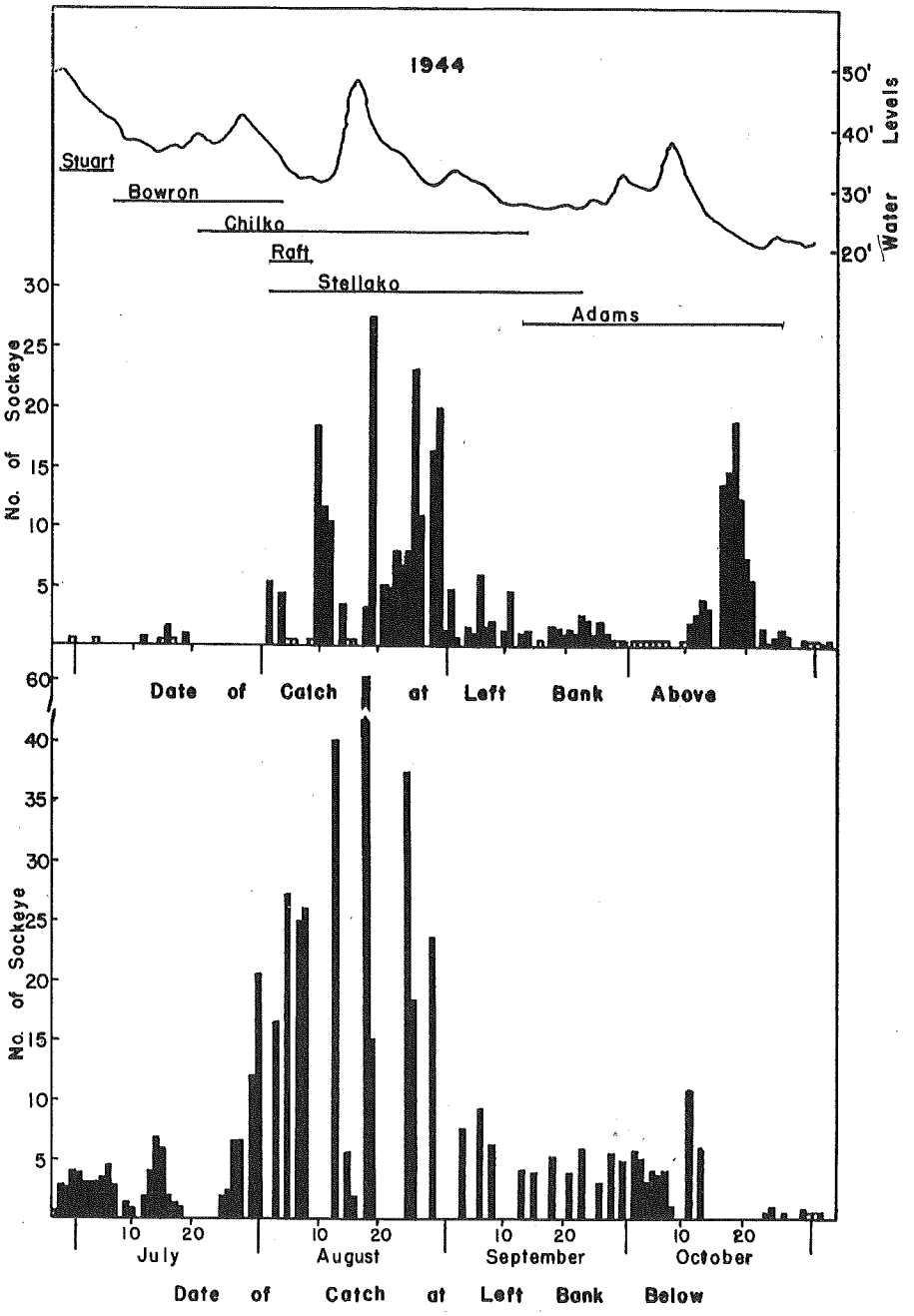

FIGURE 31. Catch per hour at Left Bank stations, Hell's Gate, 1944. (Open squares indicate that fishing was done but no catch was made).

1945

The catch per hour graphs of the fishing in 1945 after installation of the fishways show a much different pattern than in previous years. The catch per hour below the Gate fluctuated greatly with "peaks" occurring every 6 or 7 days during

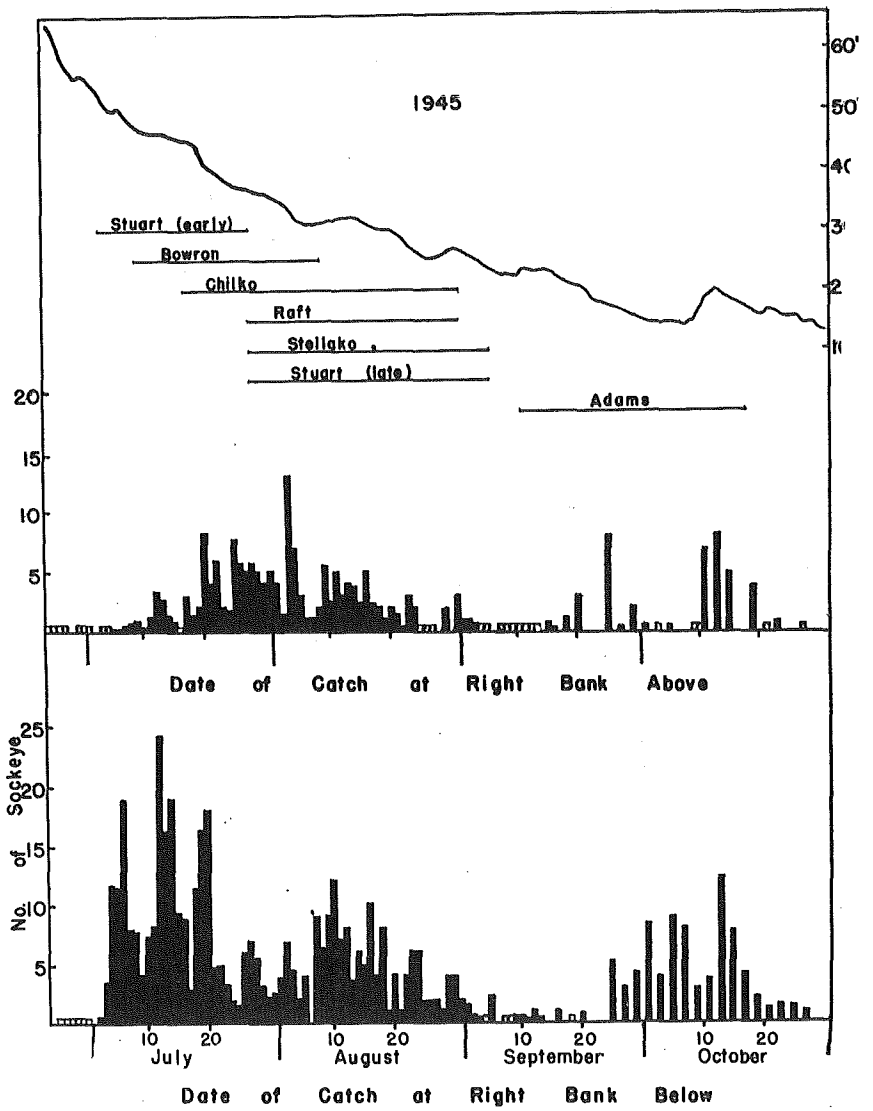

FIGURE 32. Catch per hour at Right Bank stations, Hell's Gate, 1945. (Open squares indicate that fishing was done but no catch was made).

July and August (Figures 32 and 33). These "peaks" occur on practically identical dates for the catches on each side of the river and occurred either on Thursday or Friday of each week. They are undoubtedly the result of the 3-day week-end closure of the commercial fishery near the mouth of the river. The five or six-day difference between the closure period and the "peak" catches at the Gate represent the migration time from the lower reaches of the river to Hell's Gate. As would be expected, these "peaks" and "troughs" in July and August are inverse to those of the percentage of net marks in the catch at Hell's Gate as shown in Figure 21.

This was the first time that the week-end closure of the fishery had had any noticeable effect on the catch per hour by the tagging crew at the Gate. In other

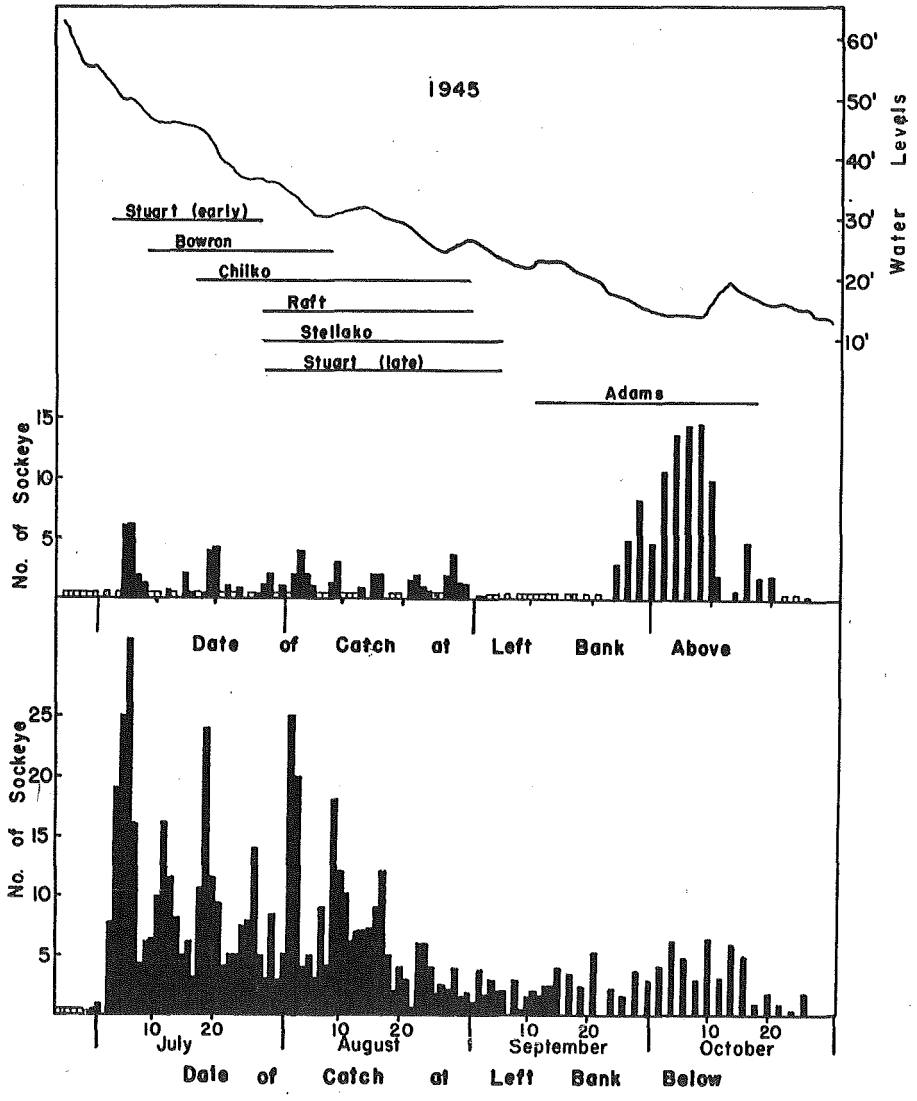

FIGURE 33. Catch per hour at Left Bank stations, Hell's Gate, 1945. (Open squares indicate that fishing was done but no catch was made).

years of tagging, the accumulation of blocked fish below the Gate must have been such that the extra escapement as a result of the closed period had not been noticed in the catch per hour. Instead, the catch per hour gradually increased below the Gate as the blocked fish accumulated. This has been illustrated in the catch per hour graphs of Figures 26 to 31 for the catches below the Gate in 1943 and 1944.

Sockeye were few in number during September 1945, but as the Adams River run began moving past the Gate, the catch per hour increased. As pointed out in the discussion of net-marked sockeye, the run to the Adams this year was almost 97 per cent "jacks" or small 3-year old fish which evidently were too small to be

affected by the commercial catch near the mouth of the Fraser. The fluctuations in catch per hour did not occur as they did in the early part of the season.

Although a tagging crew started fishing June 6 below the Gate, no sockeye were caught until June 29 on the left bank, and July 2 on the right. The catch per hour on the right bank (Figure 32) increased to a "peak" on July 6. The catch per hour above the Gate does not show this "peak", but merely indicates some sockeye were passing. The catch per hour above the Gate increased after July 10, and after July 20 until the end of August the catch above the Gate corresponded roughly to that made below. After August the catches above the Gate, when fishing was done, were similar to those below except for the period from October 1 to 10 when the water level dropped to between 15 feet and 14.2 feet. At these levels sockeye apparently could not pass on this bank. When the water level rose again to 18 feet on October 11, the catch above was nearly equal to that below.

The catch per hour above the Gate on the left bank (Figure 33) does not show nearly the abundance during July and August that is indicated by the catch below the Gate. No catches were made above the Gate from September 3 to 21, and it was not until the water level dropped to 18 feet on September 24 that catches were made again above the Gate. Previously, the sockeye easily negotiated the Hell's Gate reach on this bank at levels below 26 feet. It is possible that the partially completed fishway temporarily changed conditions so that the fish could not pass at levels between 18 feet and 26 feet on this bank. After September 24, the sockeye had easy passage on the left bank as indicated by the greatly increased catch above while that below increased only slightly.

1946

The left and right bank fishways were both completed by the season of 1946 so that this year's tagging presented the first opportunity to check on the efficiency of the new structures in their final form. As previously stated, the water levels of this year were very extreme. At the start of the season, sockeye were tagged at water levels higher than those usually prevailing at this time, and at the end of the season the water levels dropped lower than at any other time that tagging had been done at the Gate. Hence, this year's tagging also offered the opportunity to study conditions at the Gate during these unusual water levels.

A graph of the catch per hour above and below Hell's Gate on the right bank is presented in Figure 34. All the sockeye runs of this year were small except for the Adams River run at the end of the season. The first sockeye were caught below the Gate on the right bank on July 2 when the water level was 59.0 feet. None was caught above the Gate until July 17 and 18 when the water level dropped to 52 feet. When the river rose again to 54 feet no catches were made, but as the water level again lowered, catches above the Gate were made each day. The catches above the Gate from around the last of July to October 1 approximately reflected the abundance below Hell's Gate, and it can be surmised that sockeye passed Hell's Gate during this time without difficulty. On the first of October, however, the water level dropped to 16.6 feet, and continued dropping until on October 3 the level was 15.6 feet. During these 3 days, the catch per hour above the Gate dropped, and after October 2 no sockeye were caught above the Gate the balance

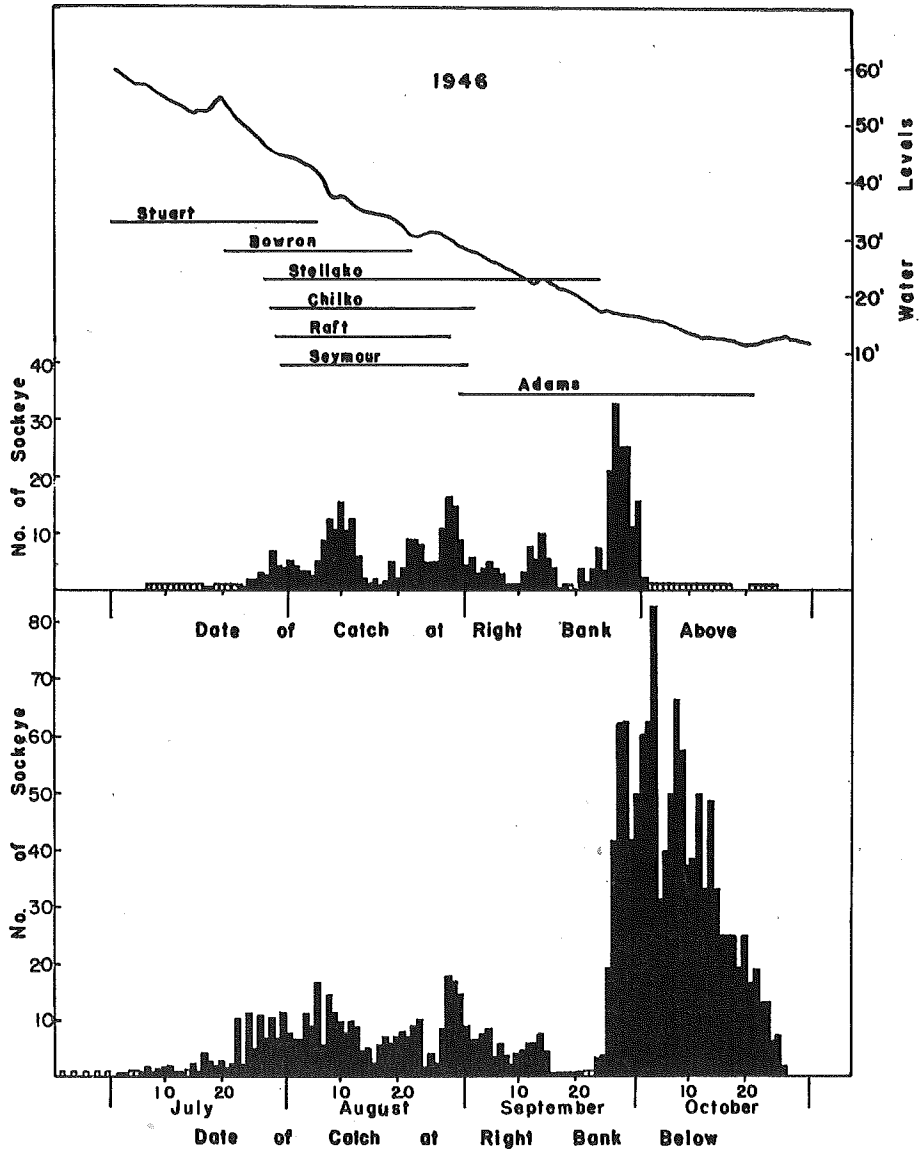

FIGURE 34. Catch per hour at Right Bank stations, Hell's Gate, 1946. (Open squares indicate that fishing was done but no catch was made).

of the season, even though the abundance below the Gate during this time, as shown in Figure 34, was large. It would seem from this, and also from the lack of catch above the Gate during the period October 1 to 10 in 1945 (Figure 32), that sockeye can not ascend the river on the right bank at levels around 15 feet and lower. It would appear also that at water levels above 52 feet sockeye had difficulty in passing the Gate.

The catches on the left bank for 1946 are shown in Figure 35. The first sockeye was caught below the Gate on July 1, but catches were not made regularly

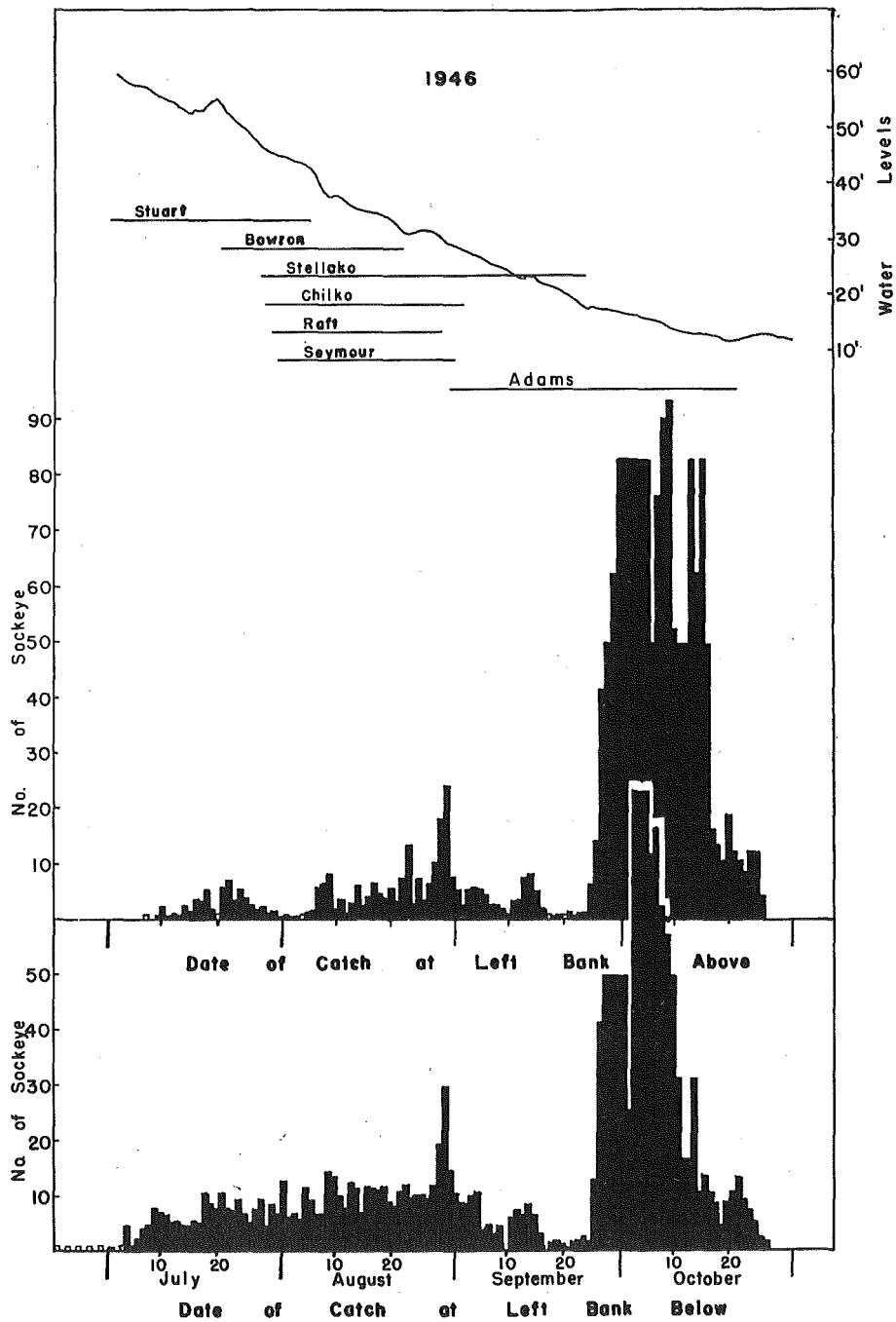

FIGURE 35. Catch per hour at Left Bank stations, Hell's Gate, 1946. (Open squares indicate that fishing was done but no catch was made).

until July 4. Fishing was not begun above the Gate on this bank until July 7, and on July 9 the first sockeye was caught. The catches above the Gate for the whole season reflected, in general, the same abundance as shown below. Two exceptions

occur, however—one about July 12 at water levels around 53 feet and above, and the other for a period centering around August 1. While it is possible that sockeye had difficulty in getting through the Gate during these periods, the catch per hour below the Gate does not indicate that sockeye were accumulating as a result of block conditions. The tag recoveries from Hell's Gate to Lillooet showed, however, that a few sockeye were delayed somewhat during these periods, and so some difficulty may still occur. At the end of the season greater catches were made above the Gate than below, as previously explained.

The "peaks" and "troughs", such as noticed in the catch per hour figures of 1945, are not found in the catch per hour figures of 1946. This is partly the result of the sockeye fishery regulations imposed upon the commercial fishery in 1946. Fishing in the Fraser River with gill nets of less than 8-inch stretched mesh was prohibited until August 8 and after September 25. These large nets caught very few sockeye and would not affect the number of sockeye caught at the Gate. Between August 8 and September 25, the only "peak" shown by the catches below the Gate was that on August 29 for the right bank and August 30 for the left bank. The other closed week-ends during this period apparently did not affect the catches at the Gate. No reason for this is known, for it has already been shown that the per cent net marks fluctuated during this period which indicates the fish caught for tagging were affected by the commercial fishery.

1947

The catch per hour graphs are presented in Figures 36 and 37. These show that sockeye were first caught on the Right Bank Below station on July 5, and catches continued to be made in varying amounts throughout the season. The catches above the Gate were poor until July 26. During this period the water levels were high. Catches were made on July 14 when the water level dropped to 50.5 feet. The water level rose again, and the next catch was made on July 22 when the water dropped to 54 feet. The water level continued to drop and after July 26, the catches above the Gate were similar to those made below for the balance of the season. Low water levels (below 16 feet) which blocked fish on the right bank in 1945 and 1946 did not occur this year.

The catch per hour on the left bank for 1947 is shown in Figure 37. The first catch was made below the Gate at the start of fishing on July 3, and catches made during the whole season were similar to those made on the right bank below. The catches above the Gate commenced with the first day of fishing on July 5. They continued to be made until July 17 when the water level suddenly rose to 59.8 feet. No catches were made above on the left bank after this until July 25 when the water level dropped to 50.5 feet. During the balance of the season, the catch per hour above the Gate reflected the abundance as shown by the catch per hour below the Gate, and hence easy passage is indicated.

The commercial fishery regulations for this year prohibited the use of sockeye nets until September 8. Again as in 1946, the closed week-ends after this date do not show up in the catch per hour as they did during July and August, 1945.

As has been shown, the catch per hour reflects the easy and difficult water levels at the Gate, and correlates closely with conditions determined by the tagging

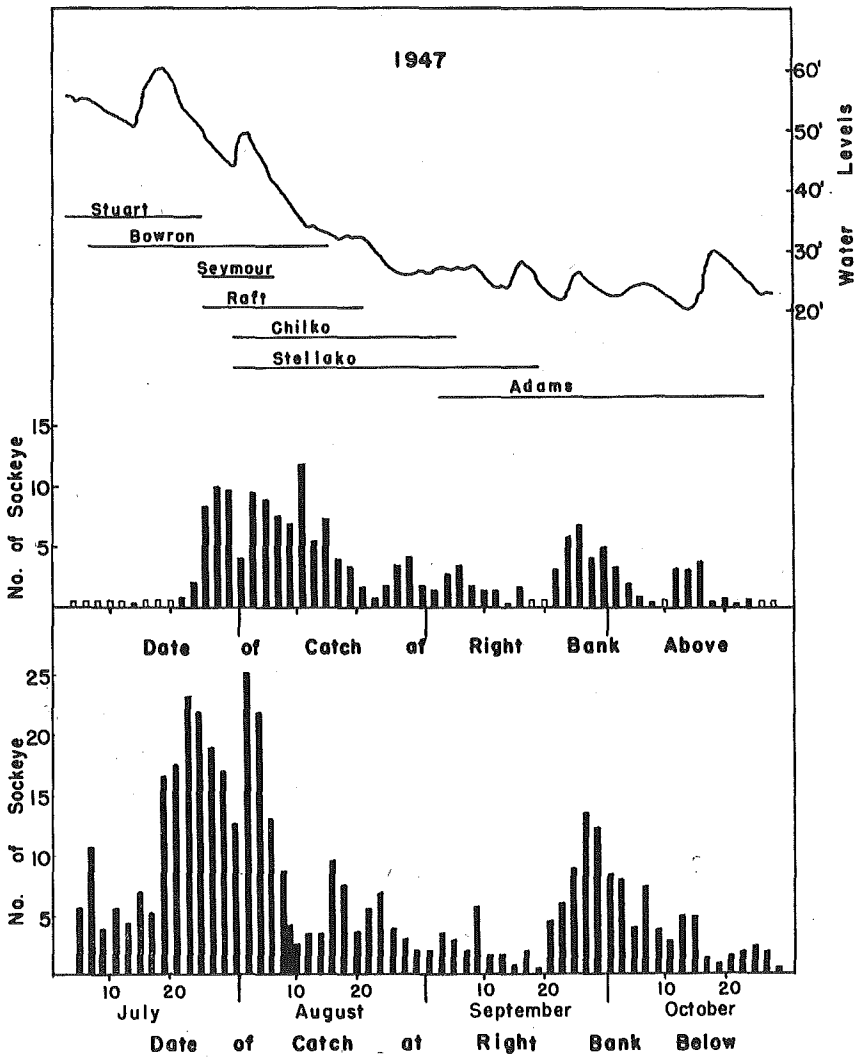

FIGURE 36. Catch per hour at Right Bank stations, Hell's Gate, 1947. (Open squares indicate that fishing was done but no catch was made).

results. At water levels from around 52 feet down to 15 feet on the right bank, and to at least 12 feet on the left, sockeye now pass the Gate, and can in most cases be caught as easily above the Gate as below. *This stands in sharp contrast to the few or no sockeye which could be caught during block levels above the Gate before installation of the fishways, as shown in Figures 26 to 31, inclusive.*

It is important that the catch per hour index illustrates the same conditions at the Gate as does the tagging work. It has been suggested that the tagged fish may not react in the same manner as the bulk of the sockeye population at Hell's Gate. For instance, if only a small percentage of the sockeye migrating by Hell's Gate were blocked each day—the bulk of the run passing upstream immediately—the tagging would be confined chiefly to these few blocked fish; hence, the block

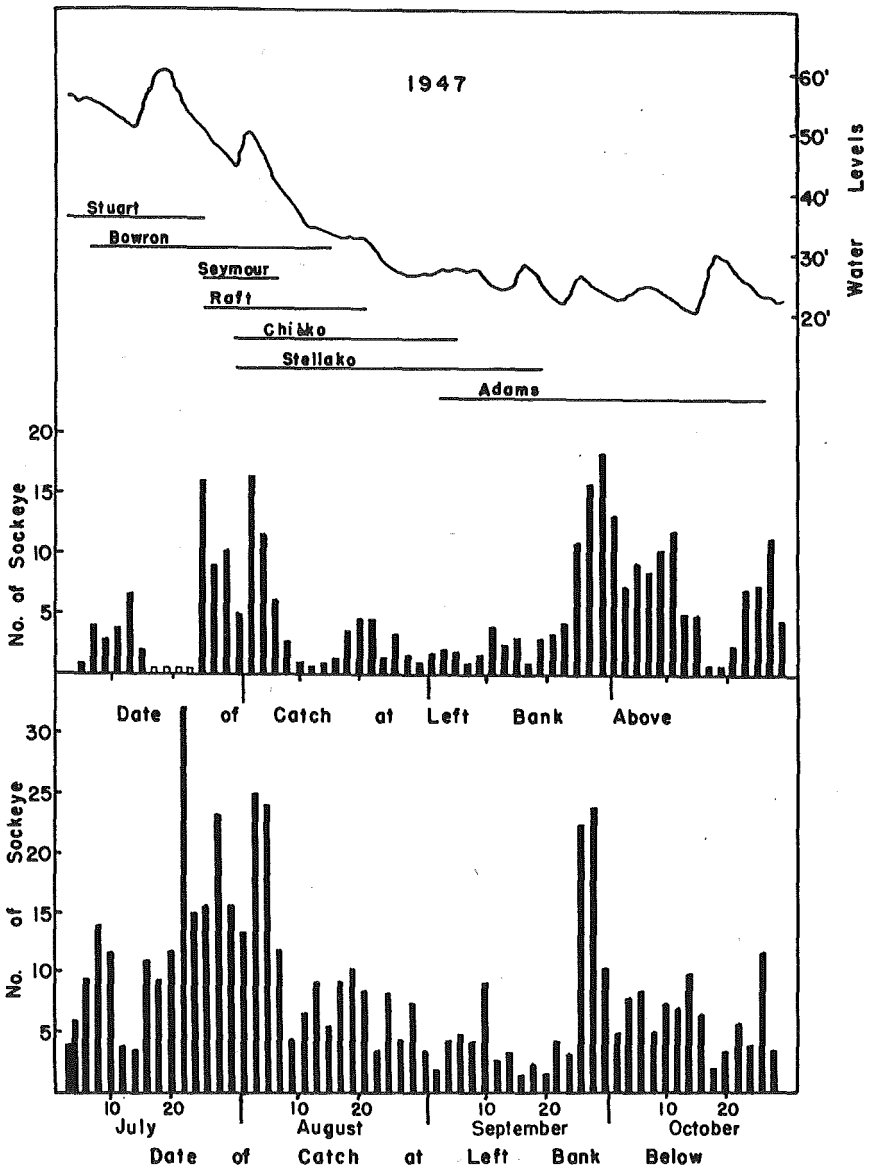

FIGURE 37. Catch per hour at Left Bank stations, Hell's Gate, 1947. (Open squares indicate that fishing was done but no catch was made).

conditions as depicted by the tagging would apply only to a small fraction of sockeye and not to the main part of the runs.

If this hypothesis were true, the catch per hour above the Gate would then have shown comparatively good catches at all water levels when sockeye were migrating, *before* the fishways were installed as well as after installation. The fact that few or no sockeye could be caught above the Gate during block water levels (even though large numbers were present below) before construction of the

fishways, while after construction the catches above Hell's Gate almost equalled or at least varied in a manner similar to those made below, is evidence enough to disprove this theory.

Spawning Ground Surveys

Spawning ground surveys on the Fraser River have been carried out for many years by the Provincial and Dominion Fisheries Departments. These observations usually were not quantitative, instead comparisons were made each year with the year before or with the run four years earlier by stating that it was "larger", "smaller", or a "failure". Starting with 1938 the Commission has endeavored to obtain numerical estimates of the spawning populations by standardized methods so that reasonably accurate comparisons can be made between the various runs of each cycle.

The failure of some runs to reproduce themselves, as indicated by the returns to the spawning ground four years later, was noticed early in the Commission's work. The most noticeable failure was the 1941 Adams River run which was blocked at the Gate by adverse water levels. Also, in 1940 the escapement to Raft River was 11,400. This dropped to 1,082 in 1944 when difficult water levels prevailed at the Gate at the time of this run's passage. There are many other records in the Provincial and Dominion Fishery Reports of the failure of certain runs to return to the spawning grounds.

The failure of the 1941 Adams River run received more attention and publicity than any of the others, for it was apparently the first run of large size to suffer severe mortalities at Hell's Gate since the obstructions of 1913 and 1914. The runs spawning above the Gate were reduced greatly after those years (Babcock, 1924, p. I 41) and the few fish seen below the Gate did not cause much concern. The 1941 cycle of the Adams run, however, which migrates by Hell's Gate in September and October had met favorable water levels since 1925 (Thompson, 1945, p. 162), and in 1929 the run was estimated to have been between 30,000 and 40,000 (Motherwell, 1930). In 1933 it was said to have been larger than 1929 (Motherwell, 1934), and in 1937 it was listed as similar to 1933 (Motherwell, 1938), but in 1941 the difficult water levels prevailed into September and October. Large numbers of sockeye were blocked below the Gate and filled, for miles below, the small canyon streams not having native sockeye runs. This was conclusive evidence that at certain water levels sockeye had great difficulty passing the Gate. The escapement to Adams River that year was estimated at only 50 sockeye.

Other runs spawning above the Gate had also been suffering mortalities as shown by the tagging results in Bulletin No. 1. Direct evidence of this was seen in 1944 when a counting fence was installed in the Bowron River to enumerate the population spawning in that area. The daily weir counts that year illustrated very conclusively how the block water levels, as ascertained by the tagging work, directly affected the sockeye reaching the spawning grounds. These daily weir counts (smoothed by a moving average of 3's) are shown in Figure 38. Also plotted on this graph are the water levels at Hell's Gate at the time the Bowron run migrated by Hell's Gate. This time was determined from the number of days it took the tagged fish to reach the Bowron weir from the Gate. In 1944 the time averaged 29 days.

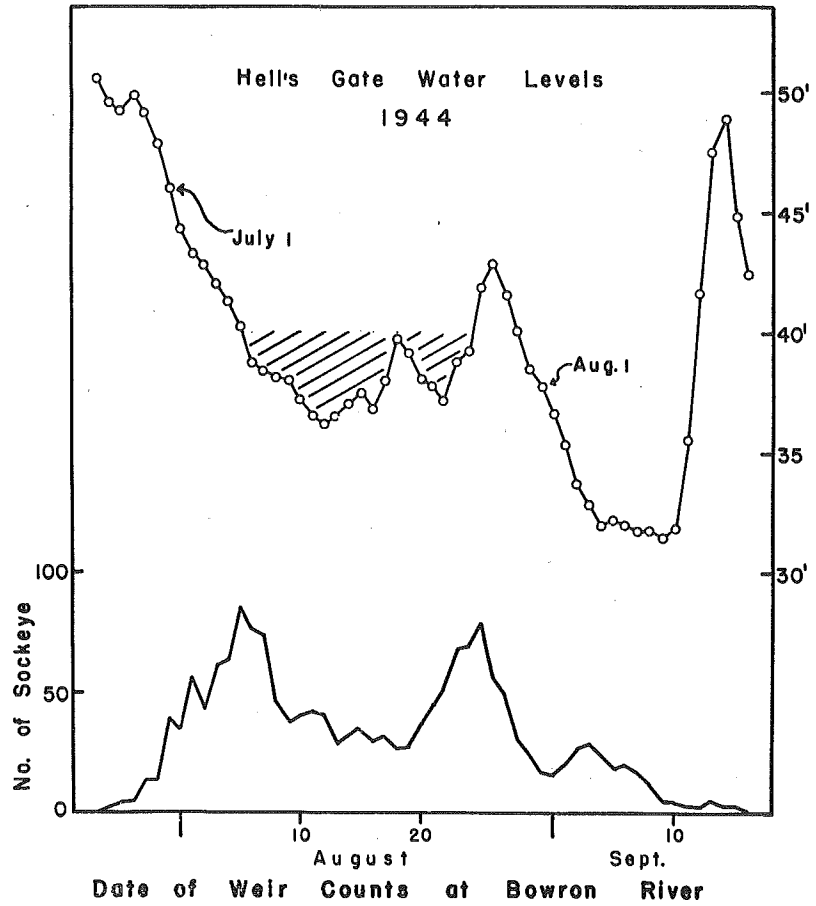

FIGURE 38. Bowron River daily weir counts compared with Hell's Gate water levels at time Bowron run migrated by Hell's Gate, 1944. (Daily weir counts smoothed by a moving average of 3's).

It will be seen in Figure 38 that the daily weir counts form a bi-modal curve with "peaks" on August 5 and 25. A depressed period occurs between these peaks which matches the period that the Hell's Gate water levels were below 40 feet, or the known block levels. When the water level at Hell's Gate rose above 40 feet on July 27 the weir counts 29 days later increased. Four days later the river again dropped into the block stage. The weir counts dropped during this period, also, but inasmuch as the end of the run would be going by the Gate at this time, the run would have been on the decline anyway. It is interesting to note, however, that a slight increase in the weir count is shown at a time corresponding to the date the water level dropped to near 32 feet. The temporary ladder was most efficient at that level and may have helped the sockeye of this run to some extent at that time.

This same effect of block water levels had been noticed in a general way at other spawning areas and in the Indian catches at several locations, and also in the weir counts at Bowron in 1943, and Kynoch and Forfar Creeks in 1941. The 1944 weir counts, however, exhibit the effect of the block levels more clearly than

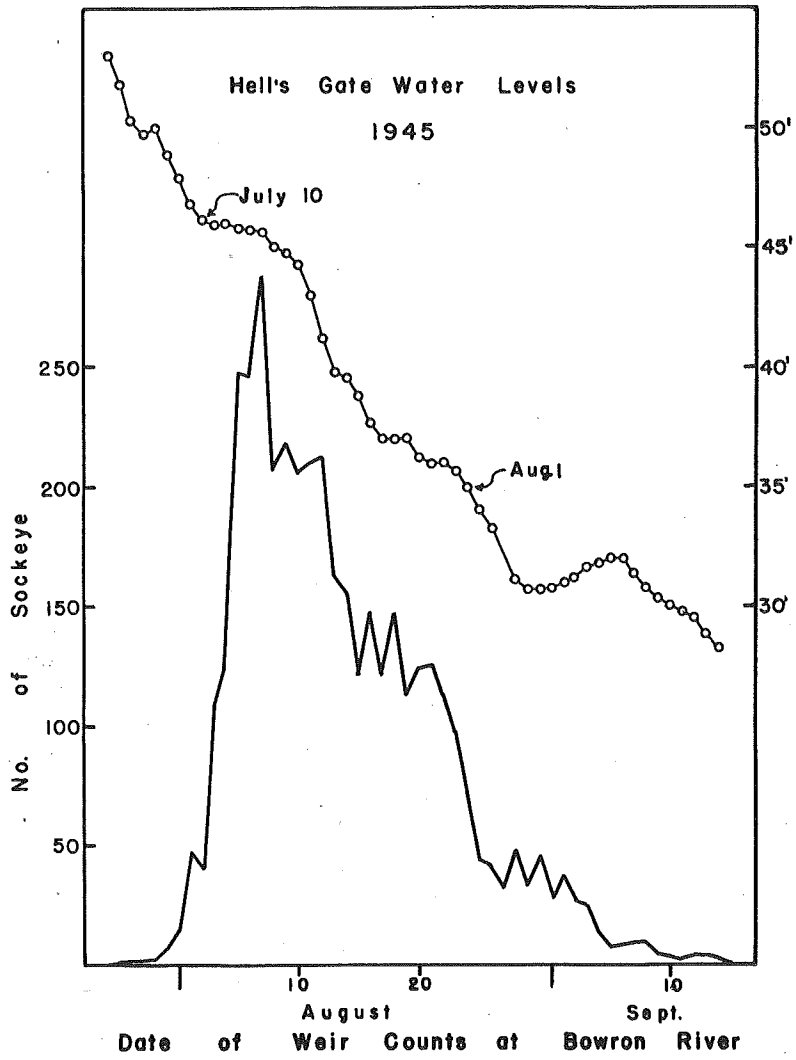

FIGURE 39. Bowron River daily weir counts compared with Hell's Gate water levels at time Bowron run migrated by Hell's Gate, 1945. (Daily weir counts smoothed by a moving average of 3's).

before because they occurred in the middle of the run with easier levels before and after.

In order to compare the Bowron weir counts of 1944 with those made when block conditions had been corrected at the Gate, the weir counts at Bowron for 1945 are presented in Figure 39. In this chart the daily weir counts (smoothed by 3's) are shown along with the Hell's Gate water levels at the time the run migrated past there. In that year the tagged sockeye averaged only 23 days instead of 29 days from Hell's Gate to the Bowron weir. As shown, the weir counts form a single-moded curve skewed sharply to the left. This type of curve has also occurred at the other counting fences when sockeye were not blocked. The Bowron run of 1945 *increased* 241 per cent over that of the parent year 1941. In contrast

to this, the 1944 run showed a *decrease* of 62 per cent as compared with the parent year 1940. The mortality which the 1944 Bowron run suffered as a result of the block water levels can be seen by comparing Figure 38 with Figure 39.

The number of sockeye reaching some of the spawning areas above Hell's Gate since 1945 is shown in Table VI. Also included is the size of each run in the parent year. The races shown have all been at a low production level in the cycles shown since the general depletion of these runs between 1911 and 1914.

The Adams River run of 1946 is not listed because it was shown in Bulletin I, page 162, that this run has found favorable water levels at Hell's Gate since 1926. As a consequence, it is the only run that spawns above Hell's Gate known to have rebuilt itself to its former abundance since the sockeye populations spawning above Hell's Gate were depleted during and following railroad construction in the Canyon. The regulations of the commercial fishery in 1946 were designed to concentrate the entire fishery as much as possible on this run. The escapement in 1942 was estimated to be 1,967,553 while that of 1946 was estimated to be 1,835,000. It is probable that this decrease is a normal fluctuation of a large run at the peak of its production capacity.

The escapement of sockeye to the Chilcotin watershed in 1941 and 1945 is also not listed in Table VI. The size of the run in 1941 was calculated from tagging below Farwell Canyon on the Chilcotin River through which the sockeye must migrate to reach their spawning grounds. It is now known that at certain water levels a serious loss of sockeye occurs at this place (Atkinson) so that the actual escapement reaching the spawning grounds was less than that computed from the tagging below Farwell Canyon. It has been estimated that the escapement in 1945 was only 68 per cent of that in 1941 (I.P.S.F.C. Ann. Rept. 1945, p. 16). Fishways are now being installed in Farwell Canyon to alleviate the loss at that point.

All other runs spawning above Hell's Gate have increased in number since the Hell's Gate fishways were installed. Both the early run to Stuart Lake, as well as the late run (which is of negligible size except in the 1941-1945 cycle) increased in 1945. A total of over 50,000 sockeye spawned in that area, which is the largest run reported in the district for many years, and was the largest that many residents of that district could remember having seen. The 1946 early Stuart run did not increase as much as did the other two years. In 1946 the Hell's Gate water levels were unusually high at the time that run migrates, and a large part of the run had to attempt passage at Hell's Gate at levels above which the fishway operated (see Figure 34). The Bowron River runs have increased each year since installation of the fishways. The 1947 run was the largest ever reported spawning there. The Horsefly River, one of the main spawning streams of the great Quesnel system, which in early years supported runs of millions of fish, has been depleted to such an extent that there is now a run only in the 1941-1945 cycle. The run of 1945 was approximately 3 times larger than that of 1941. The Chilko run has been of fair size for several years in the 1940 and 1941 cycles. In the other two cycles the runs have been comparatively small, but they improved in 1946 and 1947. The Raft River runs showed remarkable improvement in 1945 and 1946, and doubled in size from 1943 to 1947. The Stellako River has had good increases in

its spawning population each year since 1945, and gives promise, especially in the 1946 cycle, of becoming one of the first of the depleted areas to be of value to the commercial fishery. As has already been mentioned, the Adams River run has been good in the 1942 cycle since 1926, and has improved since then. The runs of the other 3 cycles which have not found continuous favorable water levels at Hell's Gate have been smaller, but the run of 1945 showed a remarkable increase, as did that of 1947 also.

TABLE VI

Sockeye Escapement to Some Spawning Areas Above Hell's Gate Since Installation of the Fishways, Compared to Previous Cycle

	1941	**1945**
Stuart (early)	6,306	26,341
Stuart (late)	5,400	24,507
Bowron	1,199	4,094
Horsefly	1,050	3,000
Raft	250	3,300
Stellako	5,230	20,826
Adams	50	1,064*
	1942	**1946**
Stuart (early)	8,006	9,554
Bowron	1,826	6,951
Chilko	34,109	58,638
Raft	450	3,000
Stellako	48,064	245,172
	1943	**1947**
Stuart (early)	3,007	14,618
Bowron	6,215	23,997
Chilko	13,546	55,000
Raft	4,000	8,202
Stellako	9,142	56,704
Adams	10,000	185,000

In direct contrast to the increased spawning escapement found above the Gate since installation of the fishways, there was a paucity of sockeye found in the Canyon streams below Hell's Gate. These creeks, principally Spuzzum, Emory, American Bar, and Yale, are turbulent, fast-flowing, and are not typical sockeye spawning streams. Each year, since at least 1913, sockeye have been found spawning in these creeks. The time of runs, however, was quite erratic and many sockeye entering these creeks during investigation by the Commission were found to have died unspawned. In recent years it was suspected, and later the Hell's Gate tagging proved, that many of these fish were sockeye which could not get

*This figure does not include the 3-year old sockeye. Total escapement was 58,000.

through the Gate, and which had become weakened, dropped downstream, and entered the creeks flowing into the main river. Not a single sockeye has been reported by either Commission observers or Dominion Fisheries Inspectors as being seen in the Canyon streams between Hope and Hell's Gate since construction of the fishways, whereas before, sockeye were found in some or all of them every year. The one possible exception was a few sockeye reported* spawning in a tributary to Kawkawa Lake, near Hope, in November, 1947. It is not known if a natural run of sockeye occurs in this system or not, but inasmuch as these fish were reported to be splendid specimens which spawned naturally, and as there were no blockade water levels after September 10 in that year, it does not seem likely that these were weakened sockeye which were unable to negotiate the Hell's Gate reach. The general over-all improvement in the escapement to the spawning areas above Hell's Gate since 1945 is the first to be found since the decline of the runs following railroad construction in the Fraser River Canyon between 1911 and 1914. Many improvements in individual runs have been recorded from time to time in Dominion and Provincial Fishery Reports, but in most cases the next cycle runs have been listed as "poor" or "failures". The improvement in 1945 can be attributed to the help of the Hell's Gate fishways. In 1946 and 1947, regulation of the commercial fishery has also helped. In view of these improvements there is every reason to expect that these up-river runs will again be of value to the commercial fishery in all cycles.

*Weekly Report, Dominion Fishery Inspector Barker.

TABLE VII

Hell's Gate Water Levels

Dates	1943				1944				1945			
	July	*Aug.*	*Sept.*	*Oct.*	*July*	*Aug.*	*Sept.*	*Oct.*	*July*	*Aug.*	*Sept.*	*Oct.*
1	64.0	45.5	30.0	20.5	46.0	37.8	33.5	31.0	54.6	35.0	26.0	15.0
2	63.5	45.0	29.2	22.0	44.3	36.6	33.0	30.6	53.0	34.0	25.8	14.6
3	64.5	44.0	28.4	22.2	43.3	35.2	32.0	30.3	51.8	33.2	25.0	14.2
4	64.0	43.0	27.7	22.5	42.7	33.8	31.8	30.4	50.2	32.2	24.6	14.5
5	63.0	42.0	27.0	21.5	42.0	32.8	31.0	31.7	49.8	31.0	23.8	14.6
6	61.5	41.5	26.7	21.3	41.3	32.0	30.8	35.9	50.0	30.6	23.4	14.8
7	61.0	40.5	31.0	20.5	40.2	32.2	30.0	38.7	48.8	30.7	22.6	14.5
8	59.5	39.7	31.0	20.0	38.8	32.0	29.0	37.4	47.8	30.7	22.6	14.4
9	58.0	39.5	29.3	20.8	38.4	31.8	28.0	35.6	46.7	31.0	22.6	14.3
10	57.0	39.5	27.7	21.0	38.2	31.8	27.6	32.0	46.2	31.2	22.0	16.0
11	56.0	39.0	26.5	20.8	38.0	31.5	27.6	29.8	46.0	31.7	23.6	18.6
12	55.5	38.7	25.5	20.5	37.2	31.8	28.0	28.0	46.0	31.8	23.5	18.8
13	55.0	38.2	25.2	20.0	36.5	35.5	27.6	26.9	45.8	32.0	23.0	20.0
14	55.0	39.0	24.7	19.8	36.2	41.6	27.6	25.6	45.7	32.0	23.1	19.0
15	53.5	41.7	23.7	20.0	36.5	47.5	27.1	24.8	45.6	31.4	23.1	18.2
16	52.5	42.2	23.5	20.0	37.0	48.7	26.8	24.0	45.0	30.9	22.8	17.8
17	53.0	45.2	23.2	20.0	37.5	44.9	27.0	23.2	44.8	30.2	22.0	17.6
18	53.5	43.5	22.7	19.0	36.7	42.4	27.2	23.0	44.3	30.0	21.0	17.0
19	52.5	40.0	22.0	18.0	38.0	39.5	28.0	22.0	43.0	29.8	20.6	16.5
20	52.0	37.5	21.0	17.6	39.8	37.8	28.0	21.5	41.2	29.5	20.5	16.0
21	52.5	35.7	20.9	17.2	39.2	36.8	27.1	20.8	39.7	28.8	20.2	16.8
22	53.0	35.2	21.0	17.0	38.0	36.6	26.9	20.6	39.6	28.2	19.0	16.8
23	54.0	33.8	21.5	16.8	37.7	36.5	28.5	20.8	38.8	27.8	18.0	16.2
24	54.0	32.5	22.2	16.4	37.2	35.2	29.0	23.0	37.6	26.8	18.0	15.4
25	53.5	32.0	22.8	16.0	38.8	33.6	28.4	22.2	37.0	25.2	17.4	15.2
26	52.5	31.7	22.0	15.6	39.2	31.8	27.8	22.0	37.0	25.0	17.2	16.4
27	51.5	31.2	22.2	15.4	41.8	31.0	28.5	22.2	37.0	25.0	16.5	14.3
28	50.5	30.7	21.0	14.6	42.8	30.5	31.0	22.0	36.2	25.2	16.1	14.5
29	49.0	30.5	20.2	14.0	41.5	30.2	33.4	21.2	36.0	25.6	15.5	14.0
30	47.5	30.5	20.0	14.0	40.0	31.2	32.5	20.8	36.0	26.8	15.2	13.6
31	46.5	30.5	.....	13.5	38.4	32.0	.....	22.0	35.6	26.6	.....	13.0

TABLE VII (*Continued*)

Hell's Gate Water Levels

	1946				1947			
Dates	*July*	*Aug.*	*Sept.*	*Oct.*	*July*	*Aug.*	*Sept.*	*Oct.*
1	59.8	44.5	28.6	16.6	56.0	49.0	26.5	23.0
2	59.0	44.0	28.2	16.2	56.2	51.0	27.2	22.6
3	58.5	43.4	27.6	15.6	56.0	48.5	27.4	22.8
4	57.5	42.6	27.2	15.4	55.5	45.5	27.1	24.0
5	57.0	43.0	27.0	15.4	55.3	44.0	27.6	24.4
6	57.3	42.0	26.0	15.2	55.5	43.0	27.8	25.0
7	56.8	40.0	26.0	15.0	55.0	41.8	27.5	24.6
8	56.0	38.0	25.6	14.6	54.0	40.0	28.2	24.6
9	55.2	37.0	25.0	14.4	54.0	38.0	28.2	23.6
10	54.8	38.0	24.2	13.8	53.6	36.4	27.0	23.0
11	54.0	37.6	23.5	13.4	52.8	35.0	25.0	21.8
12	53.8	36.5	23.0	13.0	52.0	34.8	24.5	21.0
13	53.0	35.6	22.4	13.0	52.0	35.0	24.2	20.2
14	52.6	35.2	23.0	12.8	50.5	34.0	24.3	20.8
15	52.0	35.0	23.2	12.6	52.0	33.5	24.0	21.2
16	52.6	35.0	22.0	12.6	56.7	33.0	29.0	26.0
17	52.0	34.5	21.8	12.5	59.8	32.8	28.3	31.0
18	52.2	34.0	21.6	12.2	60.0	32.8	28.3	29.8
19	54.0	34.0	21.2	12.0	61.0	33.0	25.2	29.6
20	55.0	33.5	20.5	11.8	60.0	32.4	23.5	28.0
21	53.6	32.0	19.6	11.8	56.0	32.6	22.8	27.0
22	52.0	31.0	19.0	12.0	54.0	32.0	22.2	25.8
23	50.5	30.0	18.4	12.0	53.0	31.0	22.0	25.2
24	49.8	30.2	17.8	12.2	52.4	29.4	22.8	23.6
25	49.0	30.8	17.8	12.4	50.5	28.4	26.0	23.0
26	48.2	31.0	17.6	12.8	49.0	27.6	27.4	23.4
27	47.0	31.0	17.2	12.8	47.6	27.0	26.4	23.0
28	45.8	31.0	16.8	12.8	46.8	26.4	25.0	22.5
29	45.0	30.2	16.8	12.8	45.4	26.6	24.0	23.0
30	44.6	29.8	16.6	12.4	44.0	26.6	23.4	.....
31	44.6	29.0	.....	12.0	43.5	27.0	.....	.....

SUMMARY AND CONCLUSIONS

A tagging program has been carried out at Hell's Gate each year since 1938. The results of the tagging work between 1938 and 1942 proved that sockeye were blocked each year at Hell's Gate by certain water levels, and that heavy mortalities were suffered during those periods. Fishways were constructed on each bank of the river during the winter of 1944-1945 to alleviate this condition. They were designed to operate from water levels between 23 feet and 54 feet. The left bank fishway was not completed until the spring of 1946. The tagging work was continued at Hell's Gate after 1942 to obtain additional data, and after 1945 to check on the efficiency of the new fishways.

The tagging results of 1943 and 1944 were similar to those of the tagging between 1938 and 1942 and illustrated the same difficult water levels as did the earlier tagging. The catch per hour of sockeye above the Gate in the years between 1942 and 1944 showed that sockeye had difficulty in negotiating the Hell's Gate reach on the right bank at all levels, but that they could pass most easily at levels near 40 feet and 50 feet. The catch per hour on the left bank during 1942 showed easy passage at water levels below 26 feet, but difficult passage at all other levels prevailing that season. Some sockeye passed at levels above 26 feet, particularly near the 50-foot levels, but these were few compared to the number present below the Gate. Passage on the left bank in 1943 and 1944 was made easier by the installation of a temporary fishway, but this did not operate efficiently, and the catches above the Gate were erratic as water levels changed.

After installation of the permanent fishways in 1945 and their completion in 1946, the tagging results revealed much easier passage than before. The number of tags recaptured below the Gate by the tagging crew was only a fraction of those previously caught. Furthermore, only a few of these were out long periods of time. Before the installation of the fishways from 75 to 304 tagged fish which were out more than 3 days were recaptured each season. After 1945 there were less than 15 each season, excluding those made at unusually low water levels in 1946.

The percentage of each day's tagged fish recovered above Hell's Gate also changed after installation of the fishways. Instead of the block water level pattern which had always shown up in the per cent recoveries from 1938 to 1944, the percentage recoveries fluctuated daily and were apparently more influenced by factors other than water levels. The numbers of delayed tagged fish recovered above Hell's Gate were also materially reduced. After installation of the fishways the mortality rate between Hell's Gate and the spawning grounds was reduced approximately 20 per cent to 30 per cent.

The percentage of net-marked sockeye in the daily catch at Hell's Gate after 1945 clearly illustrated the effect that the commercial fishery near the mouth of the river had on the run. A low percentage of net-marked sockeye was caught, usually on Thursday or Friday, as a result of the previous closed week-end, while during the balance of the week a high percentage was caught. The per cent of net-marked sockeye in the daily catch at Hell's Gate before installation of the

fishways did not show the weekly fluctuations as these were obscured by the accumulation of blocked fish below the Gate.

The catch per hour above Hell's Gate after installation of the fishways showed that many more fish were getting through than before. After the left bank fishway was completed in the spring of 1946, the catch per hour above the Gate indicated almost the same abundance of sockeye above as below during the levels for which the fishways were designed to operate. One exception is at water levels between approximately 52 feet and 54 feet. The fishways were designed to operate up to levels of 54 feet, but it has been found that the heavy surge in the river made the fishways ineffective at the upper levels. Methods of overcoming this difficulty are being studied.

With the additional tagging done during the past few years at levels above which the fishways operate, it was found that sockeye had difficulty up to at least the 61-foot level on both banks of the river. This is shown in the catch per hour above the Gate on both banks of the river between July 15 and 24 in 1947. It is also illustrated by the increase in the number of recaptures below the Gate at this time, and by the delayed recoveries above the Gate of fish which were tagged between those dates. The same difficulty at high water levels was found in 1946, but inasmuch as this occurred at the start of the season when few fish were present, it is not so clearly shown.

Lower water levels occurred in 1945 and 1946, at a time when sockeye were migrating in fair numbers, than at any other season that tagging was done. It was found that sockeye could not ascend the river on the right bank at water levels below 16 feet. This is illustrated in the catch per hour on the right bank in 1945, and even more clearly in 1946 when a greater number of fish were present at low levels. This low level block was also clearly denoted in the recaptures below the Gate in 1946.

The Engineering Division of the Commission has completed plans for additional fishways at Hell's Gate which, when constructed, should allow passage of sockeye at these extreme water levels.

The tagging analyses have demonstrated that sockeye can now negotiate the Hell's Gate reach between the 26-foot and 52-foot levels as easily as at the non-block water levels. As a result of this assistance and the additional help provided by the regulations imposed on the commercial fishery in 1946 and 1947, there has been a general over-all improvement in the numbers of sockeye reaching the spawning areas above Hell's Gate. The fishways have proven to be successful.

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In an investigation of this scope the material and data used have necessarily been collected and recorded by the entire staff of the Commission to whom the writer wishes to express his appreciation.

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BIBLIOGRAPHY

Atkinson, C. E.

1946. The effect of Farwell Canyon on the migration of sockeye salmon on the Chilcotin River. Manuscript. International Pacific Salmon Fisheries Commission.

Babcock, J. P.

1915. Spawning beds of the Fraser River. British Columbia, Province of. Commissioner of Fisheries. Report, 1914, p. S 16-17.

———

1916. Spawning beds of the Fraser River. British Columbia, Province of. Commissioner of Fisheries. Report, 1915, p. S 16.

———

1925. Spawning beds of the Fraser River. British Columbia, Province of. Commissioner of Fisheries. Report, 1924, p. I 41.

International Pacific Salmon Fisheries Commission 1941-1947 Annual Reports, 1943-1948.

MacKay, D. C. G., G. V. Howard, and S. R. Killick.

1944. Sockeye salmon tagging at Sooke and Johnstone Strait. International Pacific Salmon Fisheries Commission. Annual Report, 1943, p. 30.

McHugh, J.

1915. Report on the work of removal of obstructions to the ascent of salmon on the Fraser River at Hell's Gate, Scuzzy Rapids, China Bar and White's Creek during the year 1914, and early portion of year 1915. Canada. Naval Service, Department of. Fisheries Branch. Annual Report, v. 48, 1914/1915, p. 263-275.

Motherwell, J. A.

1930. Annual report of chief supervisor of fisheries . . . western division (British Columbia) 1929. Canada. Dept. of Marine and Fisheries. Fisheries Branch. Annual Report, v. 63, 1929/1930, p. 113.

———

1934. Annual report of chief supervisor of fisheries . . . western division (British Columbia) 1933. Canada. Dept. of Fisheries. Annual Report, v. 4, 1933/1934, p. 74.

———

1938. Annual report of chief supervisor of fisheries . . . western division (British Columbia) 1937. Canada. Dept. of Fisheries. Annual Report, v. 8, 1937/1938, p. 75.

Thompson, W. F.

1943. Report on the investigations of the International Pacific Salmon Fisheries Commission on the Fraser River Sockeye. International Pacific Salmon Fisheries Commission. Annual Report, 1941, p. 6.

———

1945. Effect of the obstruction at Hell's Gate on the sockeye salmon of the Fraser River. International Pacific Salmon Fisheries Commission. Bulletin No. I.

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

BULLETIN III

PART II

Variations In Flow Patterns At Hell's Gate And Their Relationships To The Migration of Sockeye Salmon

by

R. I. JACKSON

NEW WESTMINSTER, B. C.
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VARIATIONS IN FLOW PATTERNS AT HELL'S GATE AND THEIR RELATIONSHIPS TO THE MIGRATION OF SOCKEYE SALMON

By R. I. JACKSON

I. INTRODUCTION

Since 1913 the passage or non-passage of upstream-migrant adult sockeye salmon through the reach of the Fraser River known as Hell's Gate has been almost continually studied and discussed. Sockeye salmon (*Oncorhynchus nerka* Walbaum) enroute to the spawning grounds of the Shuswap, Chilko, Stellako, Quesnel, Stuart and various other watersheds must pass through Hell's Gate. These river basins produced the great runs of the past and are producing large and increasing runs at present.

When their progress to the spawning grounds was delayed or prevented at the Gate the sockeye spawning escapements and catches declined markedly.[1] It has been established that sockeye races were able to pass the Gate with varying success each year and that the degree of success or failure of passage could be correlated with the occurrence of certain water levels at the Gate.[2] The times at which block levels prevailed varied each year because of the natural variations in river flow. Because the various sockeye races arrive at the Gate at nearly the same date each year, a race might meet blocked conditions in one year and passable levels the following year. Thus Hell's Gate had a sporadic effect on the various races, which was analyzed in 1945.[3] At that time the results of several years of biological studies were presented to show that Hell's Gate was wholly or partially closed to the passage of sockeye between gauge heights of 26 to 50 feet inclusive.[4] G. B. Talbot has shown in Part I of this bulletin the effect of the Hell's Gate fishways in alleviating the difficulty of passage.

The purpose of this report is to present the available data concerning the *physical* characteristics of the river at Hell's Gate. It is a truism that if Hell's Gate varied in passability for runs of the same race of salmon arriving there at the same date in different years, then variations in flow characteristics for the varying stages encountered in the different years must determine passability or impassability. It is also true that the physical condition of a particular race in various years could affect its ability to pass the Gate, but such variations have not been detected except for the late straggling fish forming a minor portion of each

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[1] See Babcock, J.P. "The Spawning Beds of the Fraser". Report of the Commissioner of Fisheries, 1914. Province of British Columbia, pp. N16-N20. Victoria, 1915.
See also Thompson, W. F. "Effect of the Obstruction at Hell's Gate on the Sockeye Salmon of the Fraser River." Inter. Pac. Sal. Fish. Comm., Bull. No. 1, New Westminster, B. C., 1945.
See also Talbot, G. B. "A Biological Study of the Effectiveness of the Hell's Gate Fishways" Inter. Pac. Sal. Fish. Comm. Bulletin No. 3, Part I, New Westminster, B. C., 1950.

[2] Thompson, W. F. *op cit.* Talbot, G. B. *op cit.*

[3] Thompson, W. F. *op. cit.*

[4] Portions of the various runs were able to pass at all stages but the numbers passing during the block stages were not sufficient to maintain stocks at commercial levels.

normal run. Therefore, detailed examinations of the river were made before fishway construction was undertaken to see if the biological data regarding block stages could be correlated with observed variations in flow pattern. The results of these examinations will follow.

ACKNOWLEDGMENTS

The author wishes to acknowledge the valuable criticism and guidance of M. C. Bell, Chief Engineer, and L. A. Royal, Chief Biologist of the Salmon Commission. Sincere appreciation is due to the many men on the staff of the Commission who have aided in the collection of the data used in this report. E. S. Pretious, Professor of Civil Engineering at the University of British Columbia, read and criticized the report in manuscript. His assistance is gratefully acknowledged.

FIGURE 1. Hell's Gate, Fraser River in 1947. Lower Gauge 54. Left bank fishway awash.

II. HISTORY OF HELL'S GATE

A general impression of Hell's Gate may be obtained from a study of Figures 1 and 2. Figure 1 is a photograph of the Gate in 1947, the deck of the left bank fishway is shown. Figure 2 is a site map illustrating some of the salient features of the area.

The history of Hell's Gate may be divided into several periods, during which various physical changes occurred. These periods are discussed below.

Pre-1885

Before 1885 the Fraser River at Hell's Gate was in what must be regarded as a completely natural state. There are no data available concerning the physical characteristics of the reach, nor any usable information regarding the movements of sockeye through the area. Neither the Canadian Pacific Railway nor the Canadian Northern Railway (later to become the Canadian National) had been constructed. Since the commercial fishery in this period was only beginning, the catches fail to indicate the success of escapement and reproduction.

1885-1912

This period begins with the construction of the Canadian Pacific Railway past Hell's Gate along the right (west) bank of the river and ends just before construction of the Canadian Northern Railway began on the left (east) bank of the river. Figure 13 is a photograph taken during this period. As far as can be determined, the construction of the C.P. R. in 1885 had no effect on the river flow at Hell's Gate. Changes in flow through the Gate that might conceivably have resulted from dumping of waste rock a considerable distance above or below the area have not been recorded. However, since flow characteristics were not measured either in this period or prior to 1885, no direct comparison can be made.

Location of Indian fishing stations at the Gate since recorded history began for the area indicates that sockeye and other species of salmon passing through the Gate have always been forced to migrate in narrow bands along the banks. Only when the fish migrate in such marginal zones can they be taken by the Indian dip-nets. Runs of the "big years" 1897, 1901, 1905, etc., have been rumored to have congregated densely in the eddies below the Gate.[5] Such concentrations of fish might readily result from crowding in the passable margins of the reach. For example, if 10,000 fish per hour was the maximum number that could pass a certain point at a certain river stage and if 15,000 fish per hour were arriving, then there would be an accumulation of fish below the Gate. Fish would accumulate below the Gate until the number arriving per hour was substantially less than the number that could pass per hour, or until the river changed in stage and allowed an increased rate of passage. It seems logical that any stretch of fast rough water would cause short delays to the peaks of runs as large as those of the big years.

It is generally agreed, however, that before 1913 Hell's Gate was passable for salmon.

[5] See Babcock, J. P. "The Spawning Beds of the Fraser" in Rept. of the Commissioner of Fisheries for 1913. Province of British Columbia, pp. R22-R24, Victoria, 1914.

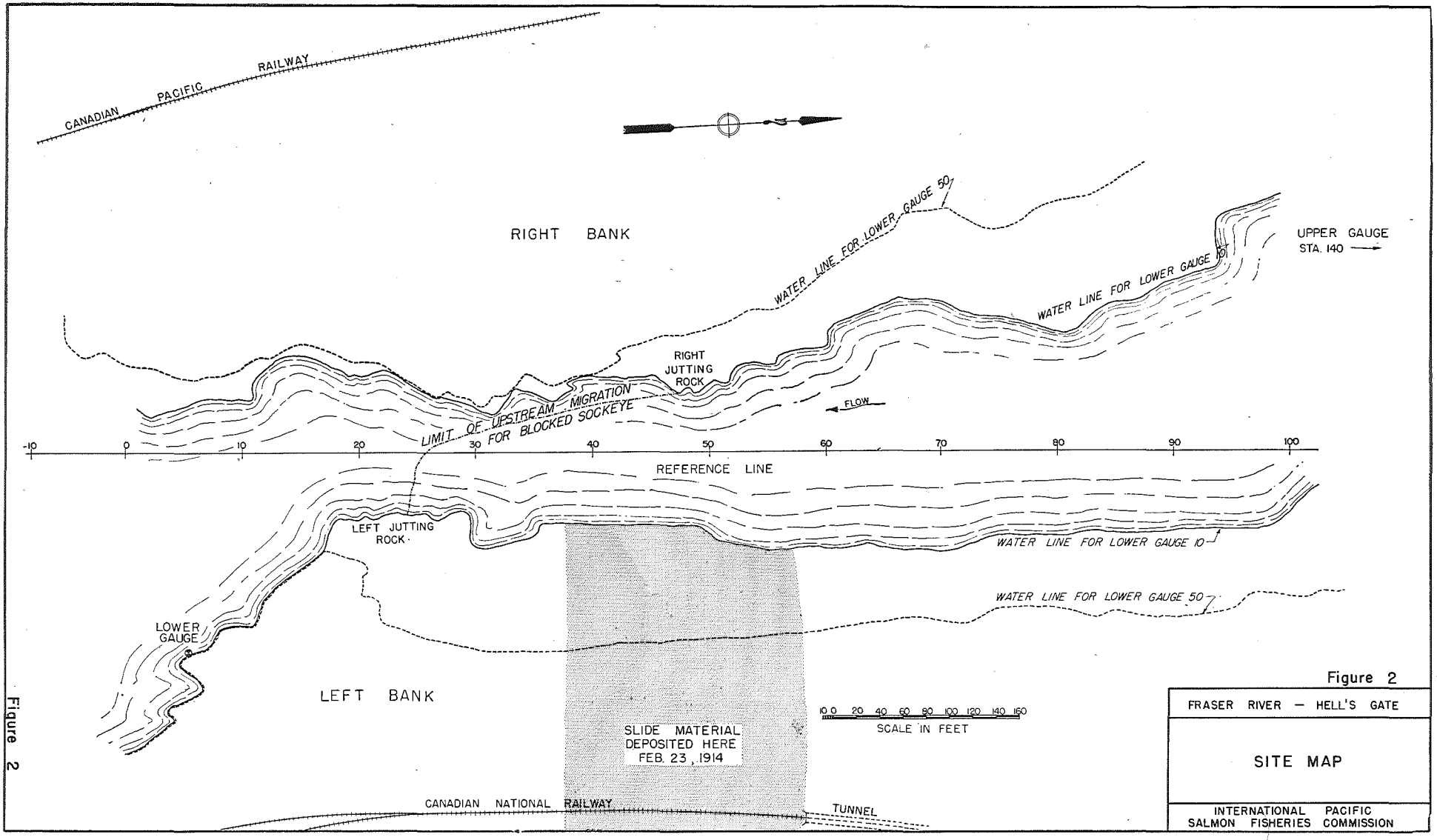

Figure 2

Figure 2

FRASER RIVER — HELL'S GATE

SITE MAP

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

1912-1913

During the winter of 1912-1913 the Canadian Northern Railway excavated a roadbed through the Fraser River Canyon occupying the left (east) bank at Hell's Gate. During the construction of the railway roadbed waste rock from excavations was dumped into the river at many points, causing flow conditions extremely unfavorable for the migration of salmon. In 1913 a spectacular climax was reached when the huge run of sockeye was almost completely blocked at Hell's Gate. This catastrophe to the species and the measures taken to alleviate it have been widely discussed.[6]

There is no record of delay in passage of the 1912 run of sockeye through Hell's Gate. Babcock[7] states that the first rock from Canadian Northern excavation was dumped into the river channel at Hell's Gate in the winter of 1912-1913. The reports of the Provincial Fisheries Department do not mention Hell's Gate until 1913. Then, in his preliminary discussion of the blockade at Hell's Gate, Babcock states:

> "At three points in the Canyon (Hell's Gate, Scuzzy Rapids, China Bar) the force of the water is such that the ascending salmon are called upon to exert all their strength and skill to make the ascent. At these points the water is so swift that at all stages only a limited number can pass at a time because in very swift water ascending salmon always hug the shore closely in order to make headway.
>
> *"In the years of a big run the major portion of the salmon have always been delayed at the points indicated but have eventually all reached the slower waters above and thence passed on to the lake sections of the river's watershed."*[8] (Italics ours).

In July, 1913, the first fish of the great sockeye run were noted at Hell's Gate. A "considerable number" of fish passed through the Canyon in July, but for weeks at a time in August and September the falling water at Hell's Gate and Scuzzy Rapids made ascent more difficult and few sockeye passed above Scuzzy Rapids, so far as could be ascertained.[9]

Sockeye had in the past been able to pass through Hell's Gate by swimming through a large eddy moving upstream along the right bank. The effect of the railway excavation upon the path of migration of the sockeye has been graphically described by Babcock as follows:

> "Previously to the construction of the Canadian Northern Railway a bay of some considerable extent existed on the left bank immediately above the Gate. Here such fish as succeeded in passing on that side found shelter. That bay has now been filled with immense masses of granite, and but little space remains in which salmon can maintain themselves. The filling of this bay has also greatly altered the currents through the Gate. Formerly the waters from the left bank were forced across toward the right bank, so that along that bank, and close to it, a back-eddy was formed, which enabled the fish attempting to pass on that side to reach the smoother water above. In

[6] See Babcock, J. P. *op. cit.* 1913, 1914, 1915. Also see Napier, G. P. "Report on the Obstructed Condition of the Fraser River at Scuzzy Rapids, China Bar, Hell's Gate and White's Creek." Rept. of the Commissioner of Fisheries, 1913. Province of British Columbia. pp. R39-R42. Victoria, 1914.

[7] Babcock, J. P. *op. cit.* 1913.

[8] Babcock, J. P. *op. cit.* p. 21, 1913.

[9] Babcock, J. P. *op. cit.* p. 21, 1913.

former years the main portion of the ascending fish passed through on the right side. Now (1913) the currents have been so changed that no fish were seen passing through, although many thousands were constantly attempting to do so. No sockeye were observed in the eddies immediately above. Limited as was the space above the left wall of the Gate, it was filled with sockeye struggling to maintain their position. Many of those which had passed through the Gate and gained shelter immediately above, on attempting further ascent were swept into the channel and downstream. That countless thousands were successful in passing was evidenced by the number noted in the river between the Gate and Scuzzy Rapids. After watching for some hours their efforts to ascend at Hell's Gate, it became apparent that the number passing was limited to those which could find resting places in the pockets and eddies just above the Gate, and that those attempting the passage largely exceeded the capacity of the passage-way."[10]

Sockeye salmon congregated in all the eddies and creeks for ten miles below Hell's Gate in "incredible numbers" during July, August and September, 1913. On September 27, 1913, arrangements were completed to attempt to alleviate the blockade.

A total of 2,000 cubic yards of rock was excavated at four sites—China Bar, Scuzzy Rapids, Hell's Gate, and White's Creek. For the most part the rock was apparently barred or blasted out of the way, to provide easier or alternate passage around the observed points of obstruction. When it is recalled that Thompson[11] and Talbot[12] have shown that no tagged sockeye delayed over 15 days at Hell's Gate has *ever* appeared on a spawning ground above the Gate it becomes apparent that the run of sockeye in July, August and part of September, 1913, must have been largely destroyed.

Thus a filling in of the river's left bank and part of the bottom with very large pieces of detached rock so changed the channel at Hell's Gate that it became almost completely impassable. It has been indicated that passage through Hell's Gate had in some years been delayed, particularly in the years of the big run. But in 1913 the sockeye of the Fraser River suffered a catastrophe from which they have not yet recovered.

The work of assisting sockeye around the points of obstruction in 1913 was in charge of G. P. Napier, Assistant Public Works Engineer for the Province of British Columbia. In his report[13] on the Canyon obstructions in 1913, Mr. Napier shows on a sketch plan of Hell's Gate that the fall of the river along the face of the dumped rock on the left bank was 5.0 feet. This was the obstructed zone. The right bank had become impassable because the river was now greatly increased in both turbulence and head along that side. The center was impassable because of the high velocities resulting from the increased head through the constricted channel. The left bank was impassable because of high velocities, turbulence, and concentration of head loss around the huge rocks in the dumped mass.

Since the head or fall through the now-impassable zone was 5.0 feet, it follows that the head through the reach before the masses of rock were dumped must have

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[10] B. C. Fisheries Dept. Report, 1913, p. R22.
[11] Thompson, W. F. *op. cit.*, 1945.
[12] Talbot, G. B. *op. cit.*, 1950.
[13] Napier, G. P. *op. cit.*

been appreciably less than five feet. There is, unfortunately, no record of the head through Hell's Gate prior to 1913. Beginning on page 118 more is said about flow conditions prior to 1913.

1914-1915

At 10 p.m. on February 23, 1914, the already impassable channel at Hell's Gate was further obstructed by the collapse of a huge rock cliff through which the Canadian Northern Railway had driven a cut and tunnel.[14] An estimated 100,000 cubic yards of massive granite rocks now filled the eddy existing immediately above the left bank bedrock outcrop which formed Hell's Gate. The channel was narrowed to 75 feet and the river was partially dammed, so that it had a fall of 15 feet in a length of 75 feet along the face of the slide. Large overhangs on the cliffs 300 feet above river level threatened to detach themselves at any moment.

At the time of this slide discussions had been underway regarding means of restoring the channel so that the blockade of 1913 would not be repeated. It was decided to attempt to remove enough rock to restore the channel to its natural condition, as it existed before 1913.

The work of excavation began on March 24 or 25, 1914. It had been decided that the smaller rocks would be dumped into the river, to be carried away by the currents. Close check would be kept on the flow patterns of the reach to make certain that no bad effects resulted. In addition excavated rock was to be placed on a bench high above the river on the right bank. Some of the rocks were of great size, measuring more than 100 cubic yards in volume. Excavation was carried on through the spring of 1914 until the rising river forced cessation of the work.

During the summer and fall of 1914 it was necessary to assist sockeye past Hell's Gate. In the summer, as the water dropped, it was necessary to assist sockeye along the toe of the slide by shifting and breaking rocks to provide a passable water margin.

Efforts to restore the channel continued during the winter of 1914-1915. Some sub-aqueous blasting was carried out in the channel where the large masses of slide material had been deposited. Each blast was accompanied by a reduction in head through the reach. By March 9, 1915, all work at Hell's Gate was concluded. McHugh[15] estimated that 60,000 cubic yards had been removed from the slide at Hell's Gate. Of this amount about 40,000 cubic yards were dumped in the river to be carried away by the currents, and 20,000 cubic yards were removed from the channel and piled on the right bank. In summarizing the work at Hell's Gate, McHugh made the following statement:

> "The result of blasting in the channel was mainly shown in the decrease in the height of the total fall. From 15 feet the fall had been reduced to 9 feet, this being only 4 feet greater than the fall as measured before the slide occurred. This 9 feet, furthermore, was distributed evenly along 350 feet

[14] Excellent descriptions of the slide at Hell's Gate and its removal may be found in the reports by J. P. Babcock and J. McHugh in the Report of the Commissioner of Fisheries, 1914. Province of British Columbia, Victoria, 1915.

[15] McHugh, J. "Report on the Work of Removal of Obstructions to the Ascent of Salmon on the Fraser River at Hell's Gate, Scuzzy Rapids, China Bar and White's Creek during the Year 1914 and the Early Portion of the Year 1915." 48th Ann. Rept., Fisheries Branch, Dept. Naval Service, Canada. 1914-15. Ottawa, 1915.

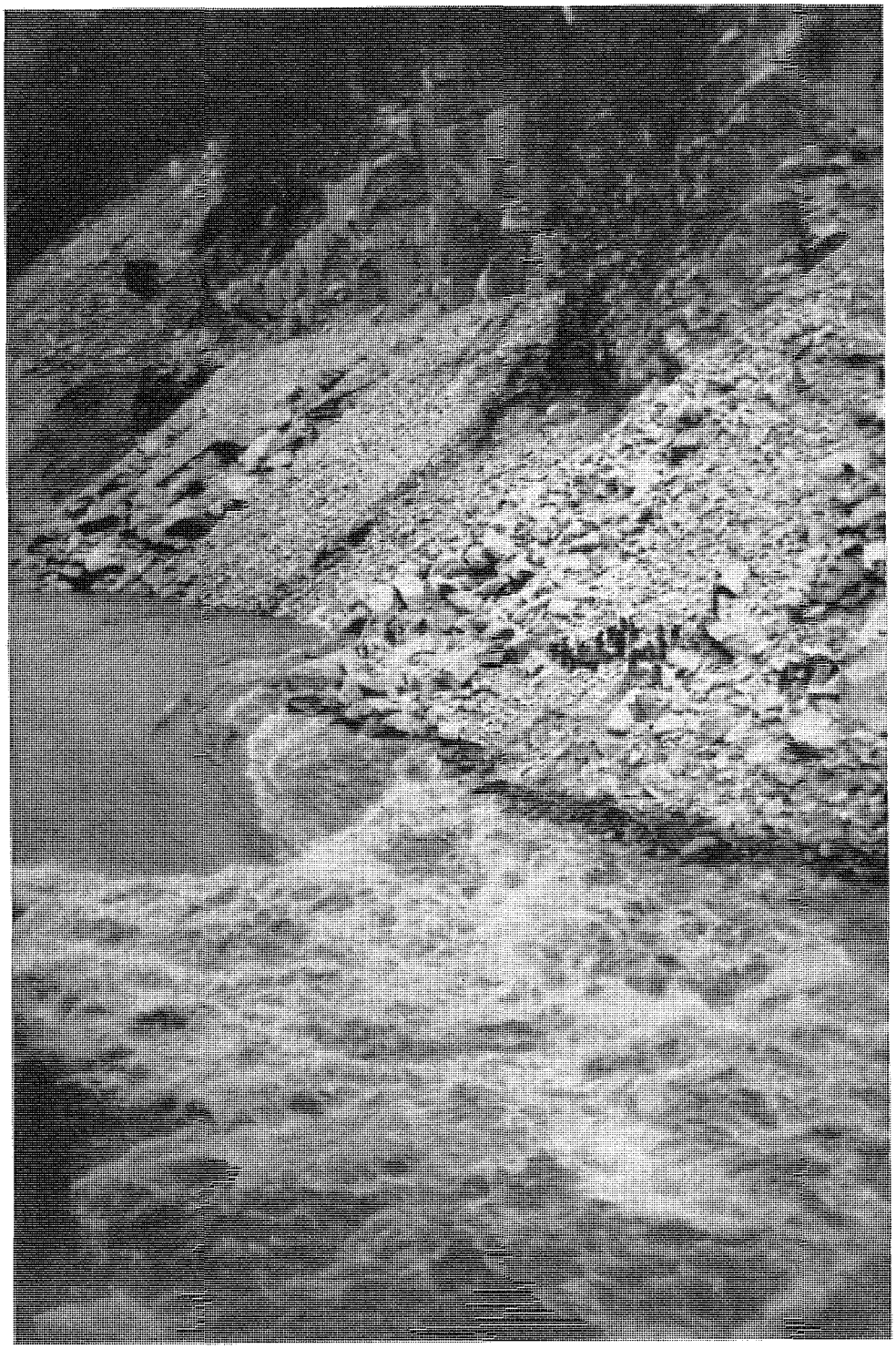

FIGURE 3. Hell's Gate on April 23, 1914. Men working on the left bank to remove slide material. Head 15 feet.

of the river. The average surface current velocity at this time measured between four and five miles per hour and it was felt that everything possible under the circumstances had been done, having due regard to the danger of further material possibly sliding into the river".[16]

Thus Hell's Gate went through a rapid succession of changes in the space of a few years; changes whose effects on the sockeye runs were of great significance for many years to come.

1915-1941

After completion of the excavation at Hell's Gate in March, 1915, there were no further man-made changes at Hell's Gate for twenty-six years. Comparison of Figures 16 and 17, however, indicates that the level benches formed in 1915 along the left bank slide face had been completely filled in with rock which gradually came down from the embankment and cliff above.

We are interested here in the physical conditions at Hell's Gate; statements by various men will illustrate such conditions, as well as their effects on the runs.

John McHugh was resident engineer for the Fisheries Branch, Department of the Naval Service, Canada. He had been in charge of removal of slide material at Hell's Gate in the winters of 1913-1914 and 1914-1915. When reporting on the work done McHugh expressed himself as follows:

". . . Observations made by the special fishery guardian at this point (Hell's Gate) during the run of 1915 showed undoubtedly that the work was successfully performed. Personally, however, I am not assured that salmon can pass as freely up the river as they did prior to the time when railroad construction on the Canadian Northern Railway was commenced. Up to this time no difficulties had been experienced on the Fraser River, and in consequence it was never considered necessary in the interests of conservation to keep close watch on the movement of salmon through the Canyon. In view, however, of the troubles which have since occurred, it often appears to me regrettable that some data concerning the flow of the river at Hell's Gate, and the action of the salmon in passing through before the trouble occurred should never have been obtained. Had such information been available a comparison of the conditions of today with those of the past would have shown just how the run today is affected. At certain stages of the water, salmon are now undoubtedly delayed in their passage up the river. That they get through eventually, however, is certain, but whether the greater delay and the greater physical exertion which is now undoubtedly required to get through has any effect upon the parent salmon, only the future can tell. Under these circumstances, then, only constant inspection and close observation of the salmon when passing through this place, together with the results which appear in the spawning grounds above, can decide for us the measure of success of this work. . . . In a recent report I have suggested that it may be yet necessary to do further work here. Such work, however, should not be performed until the data collected are sufficiently great to warrant the laying down of a further scheme of improvement. Suggestions should then be submitted to a board of engineers for consideration and approval or amendment, and then dealt with in the speediest manner possible. . . ."[17]

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[16] McHugh, J. *op. cit.*, p. 274.

[17] McHugh, J. "Report of the Departments Resident Engineer." p. 267. Forty-ninth Annual Rept., Fisheries Branch, Dept. of the Naval Service. 1915-16. p. 266. Ottawa, 1916.

Thus we see a doubt left in the mind of the man who had been in direct charge of the excavation of slide material at Hell's Gate. The observations of the passage of salmon and the study of the runs on the spawning grounds which McHugh suggested remained as problems to be studied by the Salmon Commission many years later.

For a few years Hell's Gate appears to have been forgotten, except for brief mention in the annual reports of the Fisheries Branch. It was apparent that the runs of sockeye to streams above Hell's Gate were greatly depleted while runs to streams below sustained themselves.

In 1926 the "board of engineers" of which McHugh had spoken ten years before was formed. Extensive hydraulic studies were made at Hell's Gate, a stage-discharge curve was determined, contours of the bed and banks were plotted, velocity measurements were taken, and the drop through the reach was recorded by means of gauges established above and below the Gate. Hearings were held at which evidence was sought regarding the passage of sockeye and other species through the Gate.

The final report[18] of the board may be summarized as follows:

1. Gauge readings indicate that the fall of the river through Hell's Gate varies from 8 to 10 feet at all stages.
2. As the river stage increases the fall moves downstream and concentrates near what is now called the Left Jutting Rock. (See Figure 2).
3. Maximum velocity was 17.3 feet per second at the metering section for a lower gauge height of 53 feet. Higher velocities prevailed immediately below the metering section.
4. The local fishery observer believes salmon pass satisfactorily when the stage exceeds 48 feet on the lower gauge, hence stream velocity is not the governing factor in regulating migration.
5. The opinion was formed that the Gate had always been an obstacle to salmon at certain river stages.
6. The greatest hindrance is caused by excessive turbulence. Turbulence is greatest at gauges 15 to 40 feet, lower gauge. It is within this range that salmon appear to experience greatest difficulty.
7. Hydraulic investigations indicate that enlargement of the cross section through the existing channel would not necessarily reduce velocity because of the exceedingly high coefficient of roughness of the present channel, but would reduce the turbulence.
8. To reduce velocities through the reach it would be necessary to consider channel improvements of considerable magnitude for some distance both above and below Hell's Gate.
9. The board of engineers did not decide whether or not salmon were delayed or blocked at the Gate. If, however, the Department of Marine and Fisheries decided that conditions at the Gate should be ameliorated the following proposals were made:

[18] "Final Report of the Engineers Enquiring Into Fraser River Conditions at Hell's Gate. 1926-28." Prepared for W. A. Found, Deputy Minister of Fisheries, Dept. of Marine and Fisheries, Ottawa. Mimeographed. Vancouver, B. C. July 27, 1928.

A. Eight thousand five hundred cubic yards of material should be excavated on the left bank between the 10 and 50-foot contours (datum: lower gauge) through a length of 145 feet in the slide material above the Gate.

B. Following the left bank excavation the "upper control" (see Right Jutting Rock, Figure 2) should be excavated between the —5 and 50-foot contours for a distance along the stream of 150 feet. Approximately 10,300 cubic yards of rock were involved in this plan.

C. A fishway should be built through what is now called the Right Jutting Rock, the fishway to be approximately 175 feet long and to function to a lower gauge height of 20 feet.

These proposals were not carried out; the board of engineers having no data on the movements of the salmon through Hell's Gate, were unable to determine whether or not Hell's Gate was a point of difficulty or blockade.

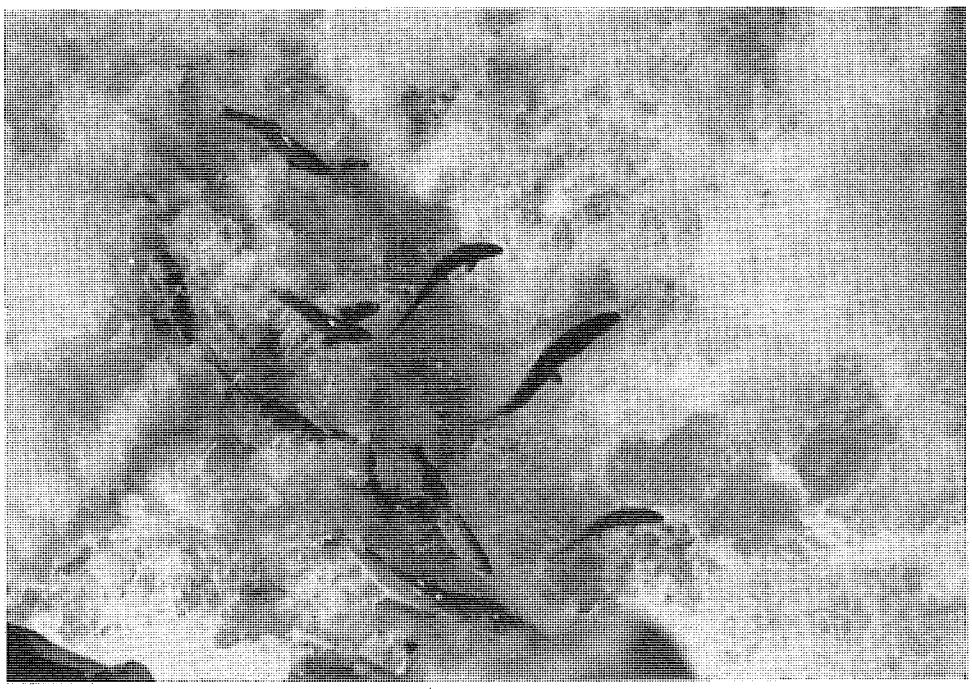

FIGURE 4. Sockeye jumping at the Left Jutting Rock, Hell's Gate, during block stage. Note the violent turbulence. September 1, 1941.

From 1928 until 1945 Hell's Gate continued to influence the movement of sockeye to the upper tributaries of the Fraser River.[19] No physical changes were recorded after 1915. In 1938 the Salmon Commission began its biological studies of the movement of salmon through Hell's Gate and in 1941 began physical studies of the flow and topography in this vicinity. The biological studies[20] proved the

[19] Thompson, W. F. *op. cit.*

[20] See the Annual Reports of the International Pacific Salmon Fisheries Commission, 1937 to 1948. Also W. F. Thompson, Bulletin No. 1, "Effect of the Obstruction of Hell's Gate on the Sockeye Salmon of the Fraser River." In. Pac. Sal. Fish. Comm. New Westminster, 1945.

existence of a damaging blockade to the migration of sockeye at certain stages of flow. The engineering investigation provided correlated data which will be analyzed later in this report. Fishway construction at Hell's Gate began in 1942, with the construction of a small temporary fishway on the left bank. In 1944 the construction of permanent fishways began; the right bank main fishway was completed for the 1945 runs, as was a functioning portion of the principal left bank fishway. The two main structures were entirely completed by early 1946. It had been determined for reasons which will be discussed later, that no change should be made in the flow characteristics through the reach. The fishways were designed and installed in a manner which left the natural flow through the Gate substantially unchanged.

III. A DESCRIPTION OF HELL'S GATE

Hell's Gate is perhaps the most pronounced constriction in the narrow mountain pass known as the Fraser River Canyon, which extends from the towns of Yale to Lytton, a distance of about 50 miles.

The bedrock forming both walls of Hell's Gate is almost entirely fresh, massive medium-grained granodiorite, broken by many prominent joints. It is cut by many seams of white, fine-grained aplite, a slightly harder variety of the granodiorite. A dike of fine-grained, greenish gray andesite crosses diagonally through the Gate in a southwest direction, appearing in the Canadian National Railway tunnel on the left bank and on the right bank below the Gate. It varies in width from about 18 inches to about 8 feet and the dike is nearly vertical.

The right bank at Hell's Gate consists of bedrock, as described above, for the entire distance over which the migration of sockeye was affected. On the left bank the bedrock appeared at the surface only at the Left Jutting Rock and at the base of the Canadian National Railway tunnel; the intervening several hundred feet of bank being covered with large granodiorite boulders from both ancient and recent slides. The bedrock is heavily jointed along three sets of planes, as follows: vertical northeast joints; vertical northwest joints; and flat joints, nearly horizontal. Thus the granodiorite is divided into irregular but dominantly rectangular blocks.[21]

The following description of Hell's Gate applies specifically to the period from 1938 to the present, and to a considerable extent to the period from 1915 to 1938. The head or drop through the reach was stated to be 9 feet at the conclusion of the slide removal in 1915; it varied between 8 and 10 feet when measured by the Dominion Water Power and Reclamation Service during 1927 and 1928, and the drops measured by the Salmon Commission in 1941, 1942, and 1943 varied between 8 and 10 feet depending on stage. The fact that surface drop through the Gate remained substantially the same through this period (1915-present) indicates that over-all hydraulic conditions were unchanged.

The stage or height of the river at Hell's Gate is measured on a vertical staff gauge (known as the "lower gauge") painted on the face of a bedrock cliff on the left bank about 200 feet below Hell's Gate. The datum or zero of the gauge is 224.03 feet above mean sea level. Daily gauge levels from 1912 to 1948 are shown in Figure 5. The term "Hell's Gate" strictly means the point of constriction formed by the Left Jutting Rock, but is also used to designate the entire reach. Extreme variations in stage recorded to date have been a minimum level of —3 feet, lower gauge on January 8, 1916, and a maximum level of 108 feet, lower gauge, on May 31, 1948. Minimum discharge was 12,000 cfs. on January 8, 1916, maximum discharge 536,000 cfs. on May 31, 1948, mean discharge for the period 1912 to 1942 was 93,300 cfs. Discharge records are computed from the records taken at Hope, 29 miles downstream, by the Dominion Water and Power Bureau.

The following calculations will illustrate in a general sense why Hell's Gate is an obstacle to the upstream passage of sockeye. At lower gauge 25 feet the

[21] This brief description of the geology of Hell's Gate is summarized from: Gunning, H. C. "Preliminary Examination of the Geology of Hell's Gate Salmon Project." Unpublished manuscript, Vancouver, B. C., April 26, 1944.

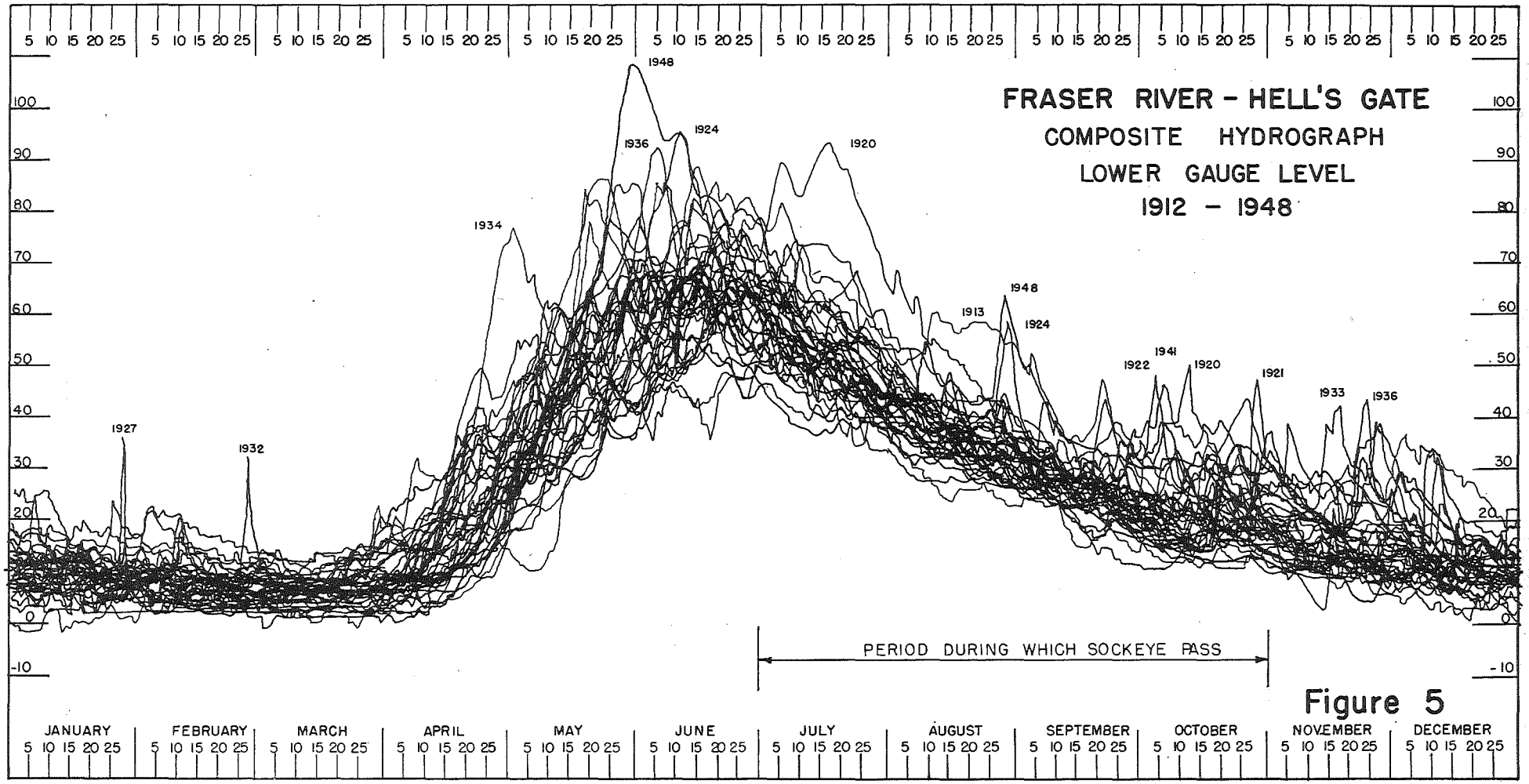
FRASER RIVER - HELL'S GATE
COMPOSITE HYDROGRAPH
LOWER GAUGE LEVEL
1912 - 1948
1948
1936
1924
1920
1934
1927
1932
1913
1922
1941
1921
1933
PERIOD DURING WHICH SOCKEYE PASS
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

Figure 5

discharge through the Gate is 75,000 cfs.[22] Using 8.8 feet as the head through the reach we find that approximately 75,000 horsepower is dissipated in the form of turbulence over a lineal distance of about 750 feet. Although the water leaves the reach with appreciable velocity and turbulence, so does it enter the reach at even higher velocity. Thus energy of approach and energy at exit are considered compensative and are disregarded. It should be understood that the energy which is available at Hell's Gate is consumed by friction due to turbulence. The friction is developed in the water itself, as internal friction between particles. Since the end product of friction is heat, the entire amount of energy consumed at Hell's Gate is converted to heat.[23] However, the violent boils, eddies, surges, upwellings, and standing waves are the visible signs of the consumption of energy, and it is these physical disturbances of the water which cause the average condition at Hell's Gate to be impassable to sockeye.

In Tables No. I and II the energy dissipation and the average velocity through the smallest cross-section in the reach for various gauge heights are shown. These data serve to indicate the fact that the average flow condition through Hell's Gate is not favorable for the passage of sockeye. The forces exerted by rapidly moving water are surprisingly large. A thin plate 12 inches square immersed normal to the direction of motion requires a force of 253 pounds to hold it motionless in water flowing with a velocity of 15 feet per second.[24]

The smallest cross section at Hell's Gate for each river stage is not necessarily the "control"[25] in the hydraulic sense. The great roughness of the banks may reduce the effective area of another cross section to a value below that of the sections used.

TABLE I

Lower Gauge Height, Discharge, Static Head Loss, and Total Energy Dissipated at Hell's Gate

Lower Gauge	*Discharge Cu. Ft./Sec.*	*Head Feet*	*Total Horse Power*
10	30,000	9.1	31,000
25	75,000	8.8	75,000
35	103,000	8.6	101,000
40	138,000	8.5	133,000
50	195,000	8.8	195,000
60	260,000	10.0	295,000

[22] Stage-discharge data is from Webb, C. E., "Second Interim Report on Hydraulic Investigations Carried Out by Dominion Water Power and Reclamation Service on Fraser River at Hells Gate." Unpublished manuscript. Plate IV, Vancouver, B. C. February 22, 1928.

[23] Although the total amount of energy converted to heat at Hell's Gate is very large it may readily be calculated that the rise in water temperature is only 0.011° F. when the discharge is 75,000 cfs. and the total energy dissipation is 75,000 horsepower. Even this slight rise in temperature is reduced by losses to the atmosphere and the channel.

[24] Russell, G. E. *Hydraulics.* 5th ed. New York, Holt, 1947.

[25] A control section is any constriction of channel, free to discharge its maximum possible flow for any given upstream depth. Thus any constriction in a channel which backs up the water and creates a surface drop forms a control.

TABLE II

Average Velocity of Flow Through the Smallest Cross Section at Hell's Gate For Various River Stages

Lower Gauge	*Discharge Cu. Ft./Sec.*	*Area of Smallest Cross Sec. Sq. Ft.*	*Location of Section, Reference Sta. No.*	*Average Velocity Ft./Sec.*
10	30,000	2,328	51.5	12.9
25	75,000	5,568	46.5	13.5
35	103,000	7,832	46.5	13.2
40	138,000	9,124	46.5	15.1
50	195,000	11,812	46.5	16.5
60	260,000	14,820	46.5	17.5

The control at Hell's Gate shifts with river stage. At stages below 25 feet lower gauge it lies at approximately station 48 to 50 on the reference line. At stages above 25 feet the control has shifted abruptly downstream to station 24 on the reference line. At the highest stages the control section is in the vicinity of station 18 on the left bank. On the right bank for stages above 40 feet the control is not well defined, and the river does not show any abrupt transition. The water surface profiles, Figures 8 and 11, show how the control section shifts downstream with rising stage.

Surface flow at Hell's Gate is best illustrated by the many photographs to be found in this and other reports on the subject. At stages below 25 feet the drop takes place in the vicinity of the Right Jutting Rock. The midstream surface flow is always relatively smooth and of high velocity. It forms a "V" with point downstream, with tips touching the banks, and with extreme surges and turbulence along the banks and below the point. The midstream smooth flow carries downstream the farthest before it is distorted by the eddies and intercepting flow set up by the banks.

As the stage increases the smooth, high velocity mid-stream flow reaches farther downstream. At gauge 25 and above it actually impinges its point on the Left Jutting Rock. This gives rise to a marked change in the manner of flow around the rock. The measurement of this shift in control and its significance will be discussed later in this report.

The flow pattern at Hell's Gate is by no means stable. There are tremendous surges, boils, eddies, and vortices which form and disappear constantly. The surge at the Left Jutting Rock has a range of two to four feet vertically, even at low stages. At high stages, particularly along the right bank, the surges are of great height and extent. Such unstable conditions make migration of all fish difficult at any stage, since it is hard for them to maintain equilibrium and direction.

It is true in any control section that rising stages will cause a greater head or drop through the control than will the same discharge on a falling river. This is because the river channel below the control must be filled to bring the head loss

to its normal value again. During the period in which the channel below the control is filling, the drop through the control is greater than usual.

Though the foregoing is true of Hell's Gate, it has not been possible to show a clear-cut variation in head due to rising or falling discharge at the same stage. The fluctuations due to surge, inability to read the staff gauges with sufficient precision, and other factors have prevented determination of the variations. It was felt that understanding of the changes in head due to a rising or falling river might aid in explaining the passage and non-passage of sockeye. But, although the phenomenon is always present, its duration and extent cannot be evaluated here.

The high velocities prevailing on the surface at Hell's Gate are considered to be impassable for sockeye except where such velocities are reduced by the roughness of the banks. The average mid-stream surface velocities through Hell's Gate are shown in Table 3. These values are the average of numerous float measurements made down the center of the stream in the last 200 feet before the smooth rapid mid-stream flow dissolves into violent turbulence. They were measured between stations 27.85 and 47.85 along the Reference Line, as shown in Figure 2. All measurements were made in 1942, before any fishways were constructed.

TABLE 3

Midstream Surface Velocities at Hell's Gate

Lower Gauge	37.5	38.5	39.5	41	50	54	56	58	62
Average mid-stream surface velocity ft. per sec.	22.2	21.7	20.4	23.4	17.7	17.4	22.3	16.5	18.4

Unfortunately, data for the lower stages are lacking. It appears from visual observations, however, that the mid-stream velocities are of about the same order of magnitude for all stages above 14 feet, lower gauge. The effects of such velocities on the success or failure of sockeye passage are discussed in Section IV of this report.

IV. PHYSICAL CRITERIA OF BLOCKING

W. F. Thompson[26] and G. B. Talbot[27] in their respective studies of the passage of sockeye salmon through Hell's Gate before and after construction of the fishways demonstrated in many ways the duration and magnitude of the blockade. Among the measures of blocking were the following:

1. It was shown that the index values of success of each year's run in reproducing itself have since 1920 varied inversely with the number of days that passage was blocked at Hell's Gate during September and October of each year.
2. It was shown that sockeye tagged below Hell's Gate were recaptured below the Gate during periods of water levels between 25 and 50 feet, lower gauge; and that sockeye tagged below at other water levels were recaptured on the spawning grounds above. After construction of the fishways recaptures below Hell's Gate of tags applied below decreased markedly indicating no blockade between the levels of 25 to 50 feet.
3. After the completion of the fishways the proportion of net-marked sockeye caught below the Gate varied directly with the weekly opening and closing of the commercial gill net fishery. Prior to construction of the fishways, the proportions of net-marked sockeye from day to day did not vary in accordance with the openings and closings of the fishery, since the net-marked fish merged with the accumulation of blocked fish.
4. The catch per hour of sockeye above Hell's Gate when compared with the catch per hour below increased greatly after installation of the fishways.
5. Counts of daily arrivals of sockeye at the Bowron River weir, above Hell's Gate, showed a break in migration in 1944 corresponding to a block stage at Hell's Gate. Arrivals at the same weir in 1945 after fishway construction did not show this bi-modality, although formerly-blocked levels prevailed at the Gate.
6. Escapements to up-river spawning areas have increased greatly since 1945.
7. The intermittent runs of sockeye which formerly appeared in streams below Hell's Gate have not appeared since the fishways were constructed. This indicates that such runs were composed of blocked fish, which strayed into these unsuitable streams.

The directly-observed manifestations of blocking supplement the above criteria. During block periods sockeye are seen in numbers on the surfaces of the eddies below the Gate, in contrast to their scarcity above. There are constant attempts by numbers of sockeye to jump over or through the heavy high-velocity downpours of water around the Left and Right Jutting Rocks. (See Figure 4). Large numbers of sockeye, especially in 1941 when the blocked run was very large, were observed failing to cross from below the Right Jutting Rock to the eddy above

[26] Thompson, W. F. *op. cit.*
[27] Talbot, G. B. *op. cit.*

the Left Jutting Rock. The high mid-stream velocities, exceeding 20 feet per second, swept the sockeye down through the Gate once again. Sockeye with their noses eroded away almost back to the eye sockets by contact with the banks illustrated the difficulty of maintaining equilibrium in the turbulent water.

There is almost no information available on the swimming ability of sockeye or other salmon. Terminal velocity which a sockeye can reach or maintain may be modified by the following considerations: sex, physical condition, distance to be covered, turbulence, temperature of the water, psychological factors, etc. These are briefly discussed below.

It seems probable that there might be a slight difference in swimming ability between the average female and the average male sockeye, since their weights and body proportions vary somewhat. No measurements of such differences have been made.

Swimming ability must vary with physical condition, especially as the sockeye approach sexual maturity, and also as vigor declines because of long or difficult migrations. Various races and segments of races would thus be expected to have varying abilities and endurance upon arrival at Hell's Gate.

Swimming velocity must decline as distance to be covered increases. Peak velocity could only be maintained over relatively short distances. The velocity which could be maintained over a distance of 5 feet must surely exceed that which could be averaged over a distance of 200 feet. In this instance we are also without numerical data.

It would be expected that the maximum rate of consumption of energy by a cold-blooded organism would vary with the temperature to which it is subjected. Above or below some optimum temperature it is expected that the swimming ability of the sockeye would decline.

Turbulence serves to deflect a swimming fish from its course, causing it to expend energy to resist up-wellings, eddies, entrapped air, vortices, etc. In the violent turbulence at the foot of the Left Jutting Rock at Hell's Gate it has frequently been observed that sockeye are jumping in all directions at once. The tremendous surges and boils apparently cause the migrant sockeye to lose their sense of direction, or else throw them off their proper course. Turbulence thus makes it impossible for a salmon to make effective use of all its swimming power; most, if not all of its energy may be utilized simply to maintain position and direction at the foot of a high velocity obstacle. When turbulence exists in the high velocity areas, as it does at Hell's Gate, the difficulty is further enhanced.

"Psychological factors" is used to indicate the desire of a sockeye to pass upstream. It has often been observed that a salmon, having nearly overcome a fall or section of fast water, will turn and drop back—giving up when the difficulty had already been surmounted. In the same manner a sockeye may fail to pass through a physically passable fishway if a trailing rope, the odor of a man, or some other disturbing factor is present. Experiments on the swimming ability of fish must take account of the urge or motivation of the fish both in nature and in the experimental environment. Simply expressed—it is not known at what point a sockeye becomes discouraged, changes its mind, and turns back to hunt for a new route.

The physical causes of failure of sockeye to pass Hell's Gate are: 1. Excessive velocity, and 2. Excessive turbulence. Velocity can be measured directly, by use of floats or a current meter, or indirectly by measurement of slopes, cross sections, and computation of the average velocity. Computed velocities are inaccurate in channels as rough as that at Hell's Gate. Turbulence cannot be measured in any manner that can be related to the passage of sockeye. Turbulence is a constantly changing state; the water surges and boils, then may momentarily calm, only to roar back again. Huge volumes of air are entrapped and the entire river is a seething, swirling, heaving mass. Even long and heavy logs are drawn vertically downward in the area immediately below the Left Jutting Rock.

Midstream velocity and the distance over which it prevails has been measured on the surface at Hell's Gate. The summarized results are shown in Table 3. Water flowing at such velocities over this distance is considered impassable for sockeye for the following reasons:

1. Sockeye have repeatedly been observed failing to pass upstream through this high velocity mid-stream area. No successful attempts have been seen.
2. In 1943 a flume 650 feet long, 23 inches wide and 20 inches deep was used to convey salmon from below Hell's Gate to quiet water above. Spring salmon could and did turn in the flume and swim upstream against the current. Sockeye almost without exception were unable (or possibly unwilling) to do so. Velocity in the flume varied from 12.5 to 14.5 feet per second, which is substantially less than the 20 to 23 feet per second velocities measured at block stages.
3. To jump 4 feet vertically a sockeye would have to leave the water with a vertical velocity component of 16 feet per second, neglecting air resistance. Observations indicate that sockeye at Hell's Gate cannot jump higher than 4 feet. A 5-foot jump would require a vertical swimming velocity of 18 feet per second at the instant the fish left the water.
4. Velocity cross-sections measured by the Dominion Water Power and Reclamation Service in 1927 showed that high mid-stream velocities persist nearly to the bottom of the channel at Hell's Gate. However, since the sockeye migrate at or very near the water surface they cannot be assumed to travel along the bottom of the very deep channel.
5. Entry into the smooth high-velocity zone can only be accomplished by successfully passing through the extremely turbulent margins (see Figures 4 and 12). This is obviously difficult and unusual.

The result of the impassability of the smooth-flow area at Hell's Gate is that sockeye must pass the obstacle, if they pass at all, on the surface along one or both banks of the reach. Here the velocity is retarded by the roughness of the banks and the turbulence varies so that passage is conceivable. The area used for passage is a narrow shallow zone, extending three feet, more or less, from the banks; varying in width and depth with flow and bank conditions. In measuring flow conditions along the margins of the channel much use has been made of the water-surface profile.

The water-surface profiles, as originally plotted, show the position in plan and the average elevation of points along the water lines on the banks, for various gauge heights. The elevation view is called a "profile"; it shows points on the water surface in correct elevation (mean of the high and low surges) and the true slope of the water surface between points. If the profiles are all projected to a common plane to aid in making comparisons of profiles taken at various stages, the slopes are no longer shown correctly, since the distances between points may be foreshortened while the elevations remain correct. However, when the banks are nearly parallel to the projection plane the error is usually small and, further, the correct slope may be noted on the projected slopes. Profiles used in this report have been projected to a vertical plane containing the Reference Line as shown in Figure 2. The plane passes down the center of the river, roughly parallel to the banks. True slopes and true slope distances are noted at all critical points. The profile, then, is a graphic presentation of the path that a sockeye must follow to pass Hell's Gate. Each profile represents a separate survey, made by stadia transit, of the water surface for the stage shown. When profiles taken at various stages are projected to the same plane and compared, differences in marginal flow conditions may be readily seen. Profiles on the two banks are not the same because of the great variations in bank roughness, nor does either bank profile illustrate the mid-stream profile, which cannot readily be measured.

In the following section of this report the passability or blocking of Hell's Gate, as determined by biological data, is related to the physical flow patterns at various stages.

V. FLOW PATTERNS AND THE PASSAGE OF SOCKEYE

Tagging of sockeye salmon at Hell's Gate has been carried on and the results analyzed for ten years, 1938-47, inclusive. The results of the analysis have been summarized in the Annual Reports of the Commission for the various years and presented in detail by Thompson[28] and Talbot.[29] The tagging data, after analysis, answer the following questions for any particular river stage at which sufficient tagging has been possible.

1. Is the reach passable?
2. Is the reach impassable?
3. Is the reach partially passable, i.e., passable to a limited number of sockeye per hour, or passable to the more vigorous swimmers?
4. Is it passable, or impassable, or partially passable on one or both banks?

The degree of passability, as has been pointed out, varies with the ability of the fish as well as with flow characteristics. However, the data year after year have shown that certain river stages always result in an accumulation of blocked fish, that other stages are almost completely passable, and that there are also stages which are partially passable. For convenience the evidence concerning the degree of passability of various stages published by the Commission to date will be summarized here.

LOWER GAUGE 0 TO 10 FEET.

During the Commission's existence there has never been a run of sockeye at Hell's Gate during river stages between 0 and 10 feet. The flow characteristics in this range can be compared with those at higher stages at which sockeye are present and the probable passability estimated.

LOWER GAUGE 10 TO 25 FEET.

The right bank was blocked in 1946 at stages from 17 to 11.8 feet, (the right bank fishway ceases operating at lower gauge 16) as shown by an increase in recaptures of tagged sockeye. The left bank has always been passable in this range. Late season nearly mature sockeye were unable to pass the Gate in 1939 and 1940 until the water level dropped to 22 feet.

LOWER GAUGE 25 TO 40 FEET.

In each year the Commission has made investigations at Hell's Gate, from 1938 until the fishways began to function in 1945, there has been abundant evidence of a block in migration at all stages between 25 and 40 feet. The blockade was effective on both sides of the river and continuous throughout the range both on rising and falling stages. Examination of the composite hydrograph (Figure 5) will show that the 40-25 period usually occurs at a time when the runs to the Fraser River watershed above Lytton should be passing the Gate.

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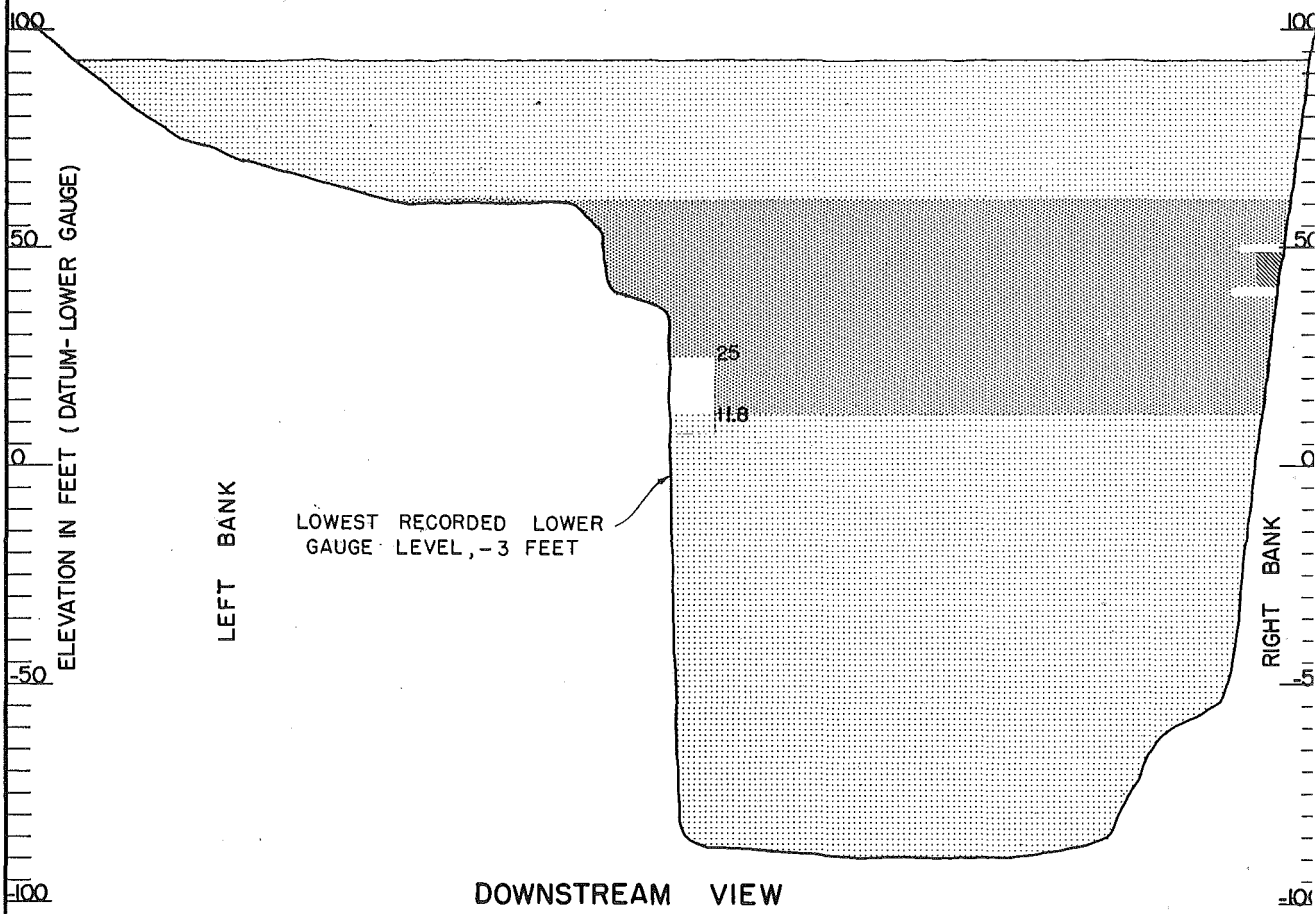
[28] Thompson, W. F. *op. cit.*
[29] Talbot, G. B. *op. cit.*



FRASER RIVER - HELL'S GATE

CROSS SECTION AT REFERENCE LINE STATION 20

SHOWS DIAGRAMMATICALLY THE PASSABLE AND BLOCKED ZONES

STAGES FOR WHICH THE COMMISSION HAS CONCLUSIVE BIOLOGICAL DATA
MAXIMUM OF 61 FEET TO MINIMUM OF 11.8 FEET ON LOWER GAUGE

STAGES AT WHICH SOCKEYE WERE PRESENT FROM 1912 TO 1948
MAXIMUM OF 93 FEET TO MINIMUM OF 8 FEET ON LOWER GAUGE

PASSABLE ZONES SHOWN THUS
BLOCKED ZONE SHOWN THUS
DIFFICULT ZONE SHOWN THUS
STAGES WITHOUT BIOLOGICAL DATA

Figure 6

LOWER GAUGE 40 TO 50 FEET.

This range of water levels was passable at both its upper and lower limits. That is, the evidence from tagging results indicates that passage was possible through the reach in the vicinity of the 40-foot and 50-foot levels, with a somewhat more difficult condition at intermediate levels. The passage at 40 and 50 is assigned to the right bank by analysis of the tagging data. It appears that the pattern of flow in the river is at a critical condition throughout this range, and that head variation due to rising or falling stage, variation in condition of the sockeye and other factors may make the difference between passage and non-passage.

LOWER GAUGE ABOVE 50 FEET.

Sockeye are not present in abundance every year at Hell's Gate at stages above 50 feet. However, tagging data available indicate that stages from 50 to 61 feet are difficult for sockeye, with recaptures of tagged fish below the Gate indicating failure to pass. The water surface profiles, which will be discussed later, are useful in making estimates of the passability of a stage at which sockeye are only occasionally present.

A cross-section of the channel at Hell's Gate is shown in Figure 6. The cross-section illustrates the conditions for passage of sockeye through the reach before construction of any fishways, showing passable, blocked and difficult-passage areas. These are relative terms, since there is always some passage at even the "blocked" stages and some difficulty at the "passable" stages. The widths of the zones shown as passable are not to scale. Visual observations show that the passable area is a narrow band not more than three or four feet wide, measured out from the banks. It can readily be seen that the passable areas at the Gate represent a very small proportion of the total cross section.

RIGHT BANK PROFILES

The projected water surface profiles for the right bank are shown on Figure 7. The biological data, already discussed, have shown that passage is blocked on the right bank from 11.8 to 40 feet, lower gauge, that at stages 40 and 50 there are passable flow conditions, that at stages between 40 and 50 there is a partial passage, and that at stages from 50 to 61 feet passage is again blocked. Examination of Figure 7 shows immediately that the profiles for stages 35.7 and below are much steeper than those for stages 39.7 and above. Note that for stages below 39.7 the steep fall in the river surface is always in the vicinity of reference station 50, which is opposite the center of the Right Jutting Rock. The minimum slope shown for the drop around the Right Jutting Rock during blocked stages is 0.23 (6.5 feet vertically in 28.4 feet horizontally) for gauge 35.7. The average maximum slope of the water surface around the Right Jutting Rock as shown in the seven profiles taken below gauge 39.7 is 0.63. In each case the slope used is the maximum found on each profile. The minimum vertical fall found in the right bank profiles below gauge 39.7 at their critical points is 6 feet and the maximum vertical fall is 9.5 feet.

The biological data indicate that the right bank is passable at gauge 40. The profile taken at gauge 39.7 has a maximum slope of 0.04, far less than even the

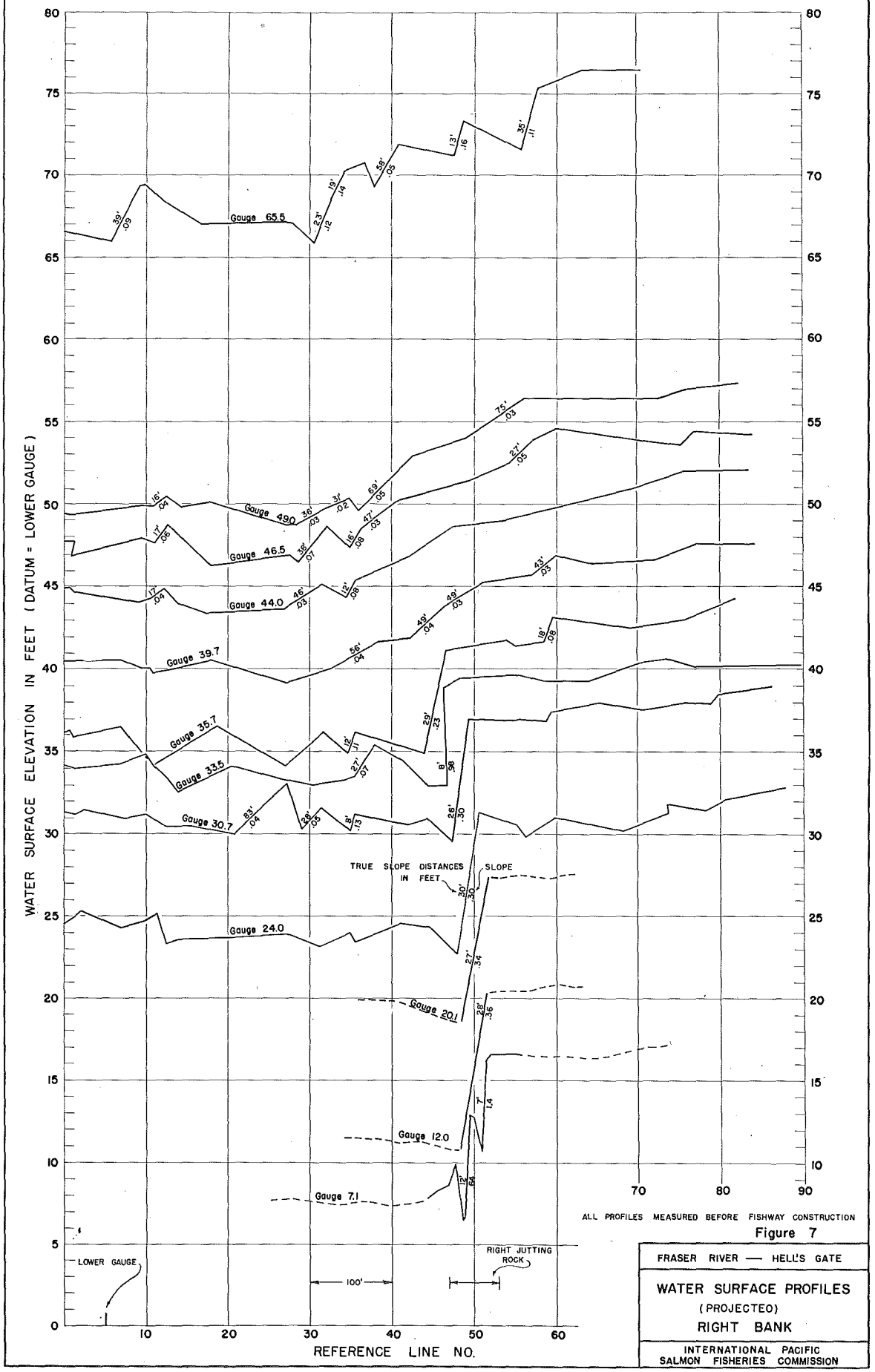


Figure 7

FRASER RIVER — HELL'S GATE

WATER SURFACE PROFILES
(PROJECTED)
RIGHT BANK

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

minimum critical slope of 0.23 found in the profiles at obstructed stages. Profiles at gauges 44.0 and 46.5 have a maximum slope of 0.08. This may be considered slightly less favorable for passage than the maximum slopes of 0.04 at gauge 39.7 and 0.05 at gauge 49.0, but the differences do not appear to be conclusive. The results of the biological data indicate that the right bank is passable in the vicinity of gauge 50. The profile taken at gauge 49.0 shows a maximum slope of 0.05. As stated, the minimum value of the critical slope at any blocked-stage profile was 0.23 at gauge 35.7, the average value of the critical slopes for the blocked stages was 0.42. These values are judged to be significantly higher than the 0.05 critical slope at gauge 49.0. (Table 4, page 116, tabulates all maximum slopes.)

Conclusions reached from the tagging experiments, catch-per-hour records, etc., show a blockade condition on both banks at levels from 50 to 61 feet. Above gauge 61 no data are available, since sockeye have not been present in numbers sufficient for conclusive experiments at stages above 61 feet during the Commission's existence. The profile taken at gauge 65.6 shows a maximum slope of 0.16 over a slope distance of 13 feet and two connected slopes of 0.12 and 0.14 over distances of 23 and 19 feet, respectively. These slope values are 50 per cent to 100 per cent higher than the maximum slope of 0.08 measured during the 40 to 50-foot stages. The increased turbulence along the rough bedrock outcrops on the right bank increases the difficulty of passage at higher stages and adds weight to the conclusion that gauge 65.5 is a blocked stage.

On page 116, Table 4 contains a tabulation of maximum slope for each profile on both sides of the channel. Unfortunately, no profiles are available for stages between 49.0 and 65.5 on the right bank. For illustrative purposes, Figures 8 and 9 show the flow around the Right Jutting Rock at passable and blocked stages, respectively. The table below summarizes the critical slope data for all profiles on the right bank for which conclusive biological data are available.

Stages	*Smallest Maximum Slope*	*Largest Maximum Slope*	*Average Maximum Slope*
Blocked—12.0 to 35.7	0.23	0.98	0.42
Passable—39.7 to 49.0	0.04	0.08	0.06

The velocity of flowing water increases with increased slope of the free surface, and the turbulence resulting from dissipation of energy at the foot of the slope also increases with increasing slope. *Thus the water surface slopes found at stages* 35.7 *to* 12.0 *indicate that conditions for the passage of sockeye were far more difficult than at stages* 39.7 *to* 49.0. *It is apparent that the conclusions drawn from the biological studies of passage of sockeye on the right bank at Hell's Gate are corroborated by the physical data concerning flow patterns, as would be expected.*

It would seem valid to extend the above conclusions to the right bank profiles at gauge 7.1 and 65.5 as shown on Figure 7 and to decide that those stages are blocked on that side, even though biological evidence has not yet been obtainable.

FIGURE 8. Hell's Gate. The Right Jutting Rock at Gauge 50. Note the smoother flow than at the stage shown in Fig. 9, and less pronounced fall. Date of photograph May 25, 1942.

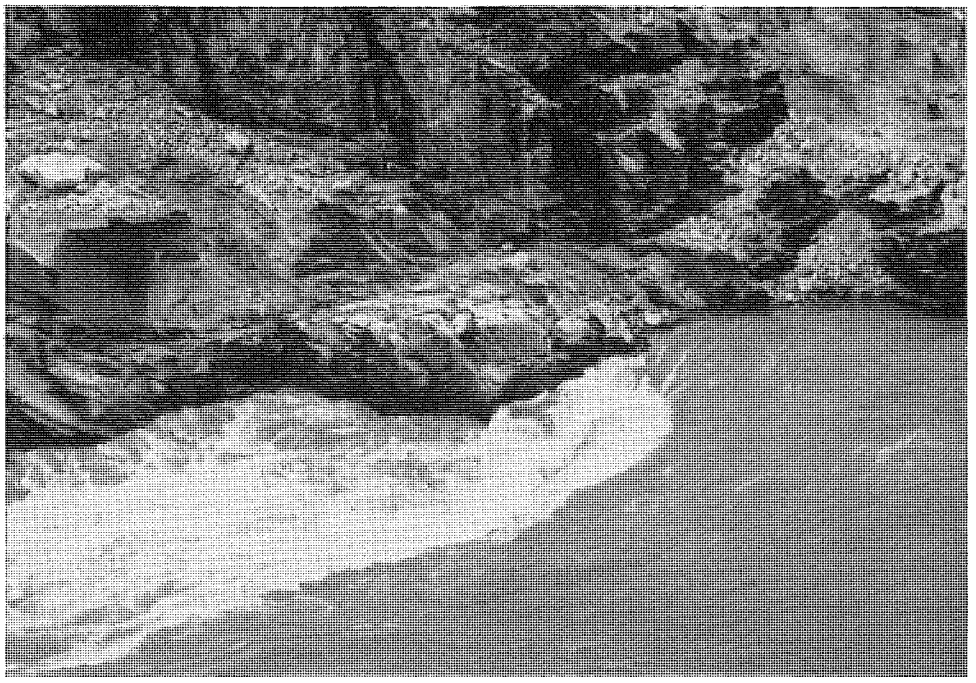


FIGURE 9. Hell's Gate. The Right Jutting Rock at a blocked stage, Gauge 26.9. Note the more pronounced drop over the rock than at the passable stage shown in Fig. 8. Date of photograph October 13, 1944.

LEFT BANK PROFILES

It has been concluded from biological data that the left bank at Hell's Gate is passable to sockeye salmon at gauge heights between 11.8 and 25 feet. Further, that it is blocked at stages from 25 to 61 feet. The left bank appears to be passable at stages below 11 feet lower gauge and blocked at stages above 61 feet, but insufficient biological data are available at these stages.

Before proceeding with a discussion of the left bank profiles it is necessary to note the physical nature of the bank itself. From reference station 0 and below to approximately station 30 on the reference line the left bank is composed entirely of bedrock. Thus the bank is very steep and relatively smooth; the roughnesses consist largely of indentations, benches, overhangs, etc. From station 30 upstream to station 90 and indefinitely beyond, the left bank is composed of broken granite rock which for the most part has been excavated from the railway cut above or is left from the major slide of 1914 and the lesser slides of subsequent years. The right bank, on the other hand, is bedrock from station 0 to 70. On the left bank the abundance of broken rock along the slide surface upstream from station 30 results in steep water surface gradients which are, however, quite passable because the slopes are broken by so many protruding rocks. It is impossible to show in a profile to a small scale the number of changes in slope that actually occur along this broken-rock face. However, the broken slopes, the reduction of velocity because of shallow depths, and the abundance of resting places along the bank make conditions for sockeye migration much more acceptable than those along bedrock faces.

The first profiles to be discussed on the left bank (Figure 10) are the seven covering the stages from 5.6 to 25.0, inclusive. Note that the steepest slopes in this group are a value of 0.14 at gauge 25.0 and a value of 0.23 at gauge 5.6. These two slopes occur between reference line stations 50 and 60, well up into the broken rock bank, where passage is assisted by the surface roughness of the channel. Furthermore, stages as low as 5.6 have never occurred while sockeye were present in the 37 years of record, 1912-48, inclusive. (See Figure 5). Also the slope of 0.14 at gauge 25.0 occurs at a Reference Line station where the slope is 0.04 at gauge 23.0 and 0.07 at gauge 26.5 so it is evidently a transitory phenomenon.

The true point of block on the left bank has been established at the Left Jutting Rock, between Reference Line stations 18 and 26. At gauge 25.0 the slope at the Left Jutting Rock is 0.06 over a distance of 26 feet. At gauge 23.0 the slope of the water surface at the same point has decreased to 0.05 over a distance of 25 feet. And at all stages below 23.0 the slope and consequent drop around the Left Jutting Rock are negligible. In fact, at the lower stages there is a back eddy extending upstream past the Left Jutting Rock. Control of the reach has obviously shifted upstream to a cross-section in the vicinity of Reference Line station 60.

The conclusion reached in the Commission's biological studies of sockeye passage at Hell's Gate was that the left bank was obstructed at all stages above 25 feet prior to construction of the fishways. Note the rapid transition in the pattern of flow around the Left Jutting Rock when the stage changes from 25.0 to 26.5[30] (Figure 10). The slope changes from 0.06 over 26 feet at gauge 25.0 to

[30] The river level at Hell's Gate occasionally changes 6 feet in 24 hours, so the transition from a blocked level to a passable one, or vice versa, *may* occur very suddenly.

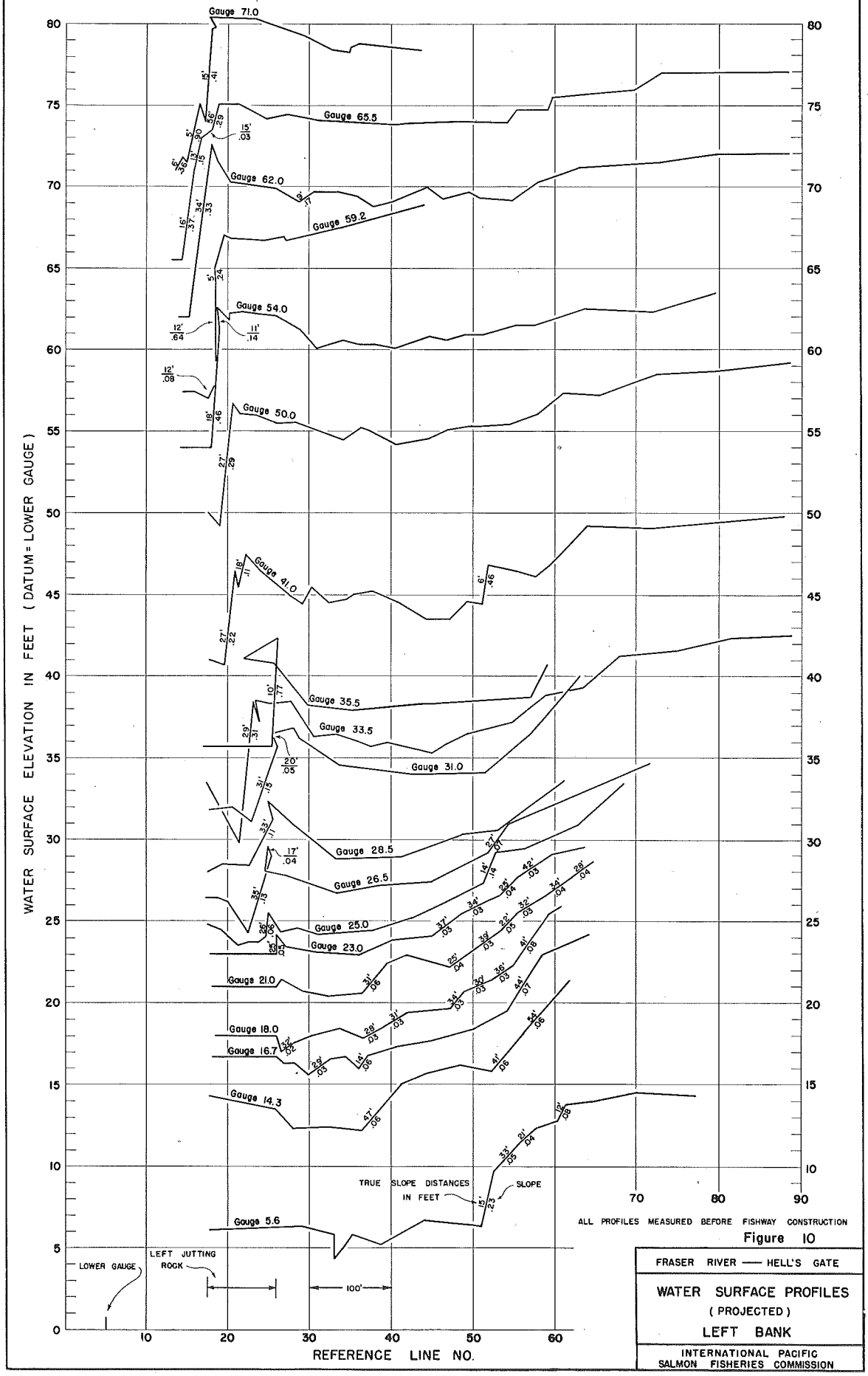


Figure 10

FRASER RIVER — HELL'S GATE

WATER SURFACE PROFILES
(PROJECTED)
LEFT BANK

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

0.13 over 35 feet at gauge 26.5. The drop or fall has increased from less than 2 feet at gauge 25.0 to 5 feet at gauge 26.5. The slope value 0.06 is of the same magnitude as the maximum value of 0.08 which occurs at the passable stages on the right bank. (Gauge 40 to 50).

Twelve profiles are shown in the blocked stages, covering lower gauge levels between 26.5 feet and 71.0 feet, inclusive.[31] The smallest value of maximum slope on any profile in this blocked group is 0.11 at gauge 28.5, representing a change in elevation of about 3.15 feet in a slope distance of 33 feet. The value 0.11 is nearly twice the maximum slope of 0.06 found around the Left Jutting Rock at passable stages. If a comparison between slopes around the Left Jutting Rock is made for passable and blocked stages for which conclusive biological data are available, the following results occur:

Stages	*Smallest Maximum Slope*	*Largest Maximum Slope*	*Average Maximum Slope*
Passable—14.3 to 25.0	0	0.06	0.02
Blocked—26.5 to 62.0	0.11	0.77	0.34

Figures 11 and 12 illustrate the change in flow patterns around the Left Jutting Rock as the passable condition becomes impassable.

Perhaps more could be said about the significance of these water surface profiles. It would be possible to theorize about the increase of turbulence as a result of increased slopes, about the relationship of velocity to slope, and other hydraulic relationships. But such hydraulic factors have little, if any, value in extremely rough river sections such as that occupied by the Fraser at Hell's Gate. The largest maximum slope at any passable stage on either bank is 0.08, the smallest maximum slope at any impassable stage is 0.11. The average of all maximum slopes at stages designated as *blocked* by the biologists is about **0.37**. The average of all maximum slopes at stages designated as *passable* by the biologists is less than **0.04.** *The relationship between passability and slope found here corroborates without exception the conclusions reached by the biological studies of the passage of sockeye at Hell's Gate.* Even the very steepest, most effective energy-dissipating fishways known to have been tested are not recommended for slopes exceeding 25 per cent.[32] It would appear specious to argue that under uncontrolled natural conditions sockeye salmon could be expected to surmount long reaches of water at average slopes of 37 per cent (0.37).

[31] Strictly speaking, there are no biological data to show that fish are blocked on the left bank above gauge 61. However, the left bank profiles at gauges 62.0, 65.5 and 71.0 (Figure 10) show surface drops so long and steep that they are obviously impassable. Visual observations confirm this conclusion.

[32] McLeod, A. M. and Paul Nemenyi "An Investigation of Fishways". Bull. 24. University of Iowa Studies in Engineering, 1939-40.

TABLE 4

SLOPE-PASSABILITY RELATIONSHIP. A tabulation of the maximum[33] water surface slope around the Left and Right Jutting Rocks for each profile shown on Figures 7 and 10. The relationship of each maximum slope to the conclusion from biological data regarding passage or non-passage of sockeye salmon is shown.

LEFT BANK			RIGHT BANK		
Lower Gauge	*Max. Slope*	*Biological Conclusion*	*Lower Gauge*	*Max. Slope*	*Biological Conclusion*
5.6	0	No data			
			7.1	1.40	No data
			12.0	.36	Blocked
14.3	0	Passable			
16.7	0	"			
18.0	0	"			
			20.1	.34	"
21.0	0	"			
23.0	.05	"	24.0	.30	"
25.0	.06	"			
26.5	.13	Blocked			
28.5	.11	"			
			30.7	.30	"
31.0	.15	"			
33.5	.31	"	33.5	.98	"
35.5	.77	"	35.7	.23	"
			39.7	.04	Passable
41.0	.22	"			
			44.0	.08	"
			46.5	.08	"
			49.0	.05	"
50.0	.29	"			
54.0	.46	"			
59.2	.64	"			
62.0	.33	Data insufficient			
65.5	.37	" "	65.5	.13[34]	Data insufficient
71.0	.41	" "			

[33] As previously explained, the maximum slope values shown on the left bank profiles at gauge heights 5.6 to 23.0, inclusive, are upstream along the broken rock bank of the river rather than at the Left Jutting Rock, where the block actually occurred.

[34] The slope value 0.16 is the true maximum on this profile, but since it covers a slope distance of only 13 feet, an average value of 0.13 is shown for a total distance of 46 feet between reference stations 30 to 34.

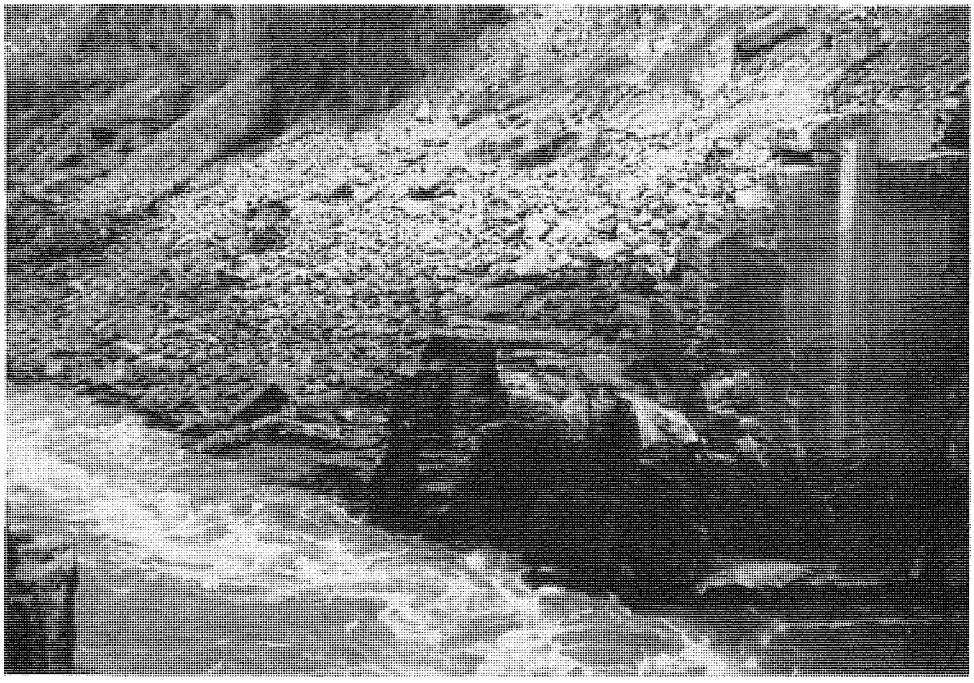


FIGURE 11. The Left Jutting Rock at Gauge 5. Note the flat passable flow along the face of the solid rock. Date of photograph March 26, 1942.

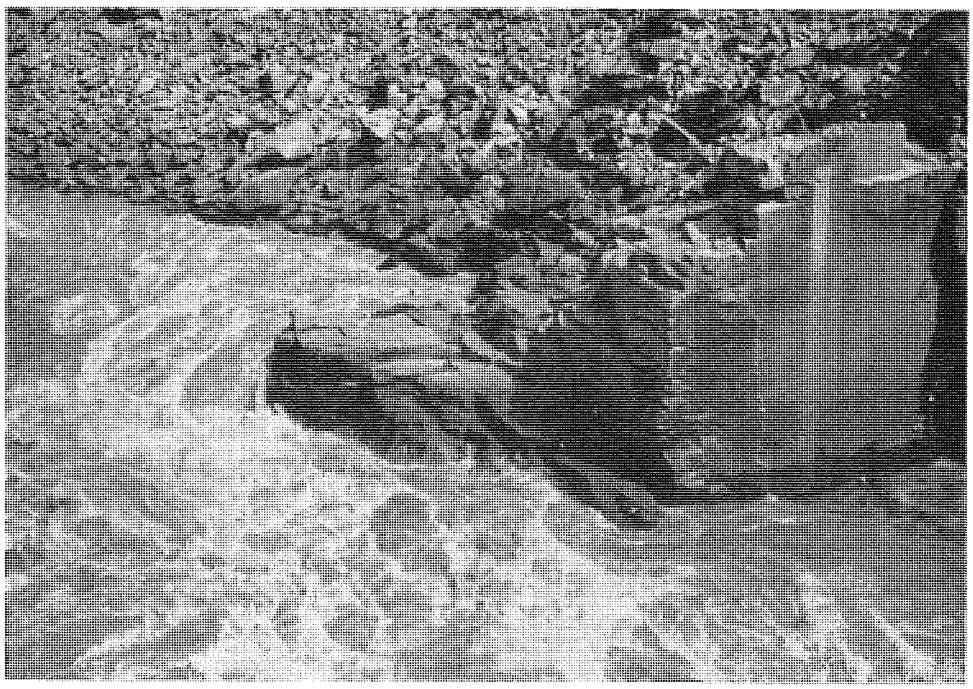


FIGURE 12. The Left Jutting Rock at Gauge 30. Note the steep drop in water surface around the upstream corner of the Rock at this blocked stage. Compare with Figure 11.

VI. THE PASSAGE OF SOCKEYE BEFORE AND AFTER 1913

It had been hoped that a newly-developed technique in photogrammetry could be applied to the problem of determining the profile of the water surface through Hell's Gate prior to the construction of the Canadian Northern Railway in 1912-13. In this process elevations may be determined by analysis of a single oblique photograph, provided that the positions of two intersecting horizontal lines and of several paired points of known elevation can be located in the photograph. However, the deep snow cover of the winter of 1949-50 has made it temporarily impossible to obtain the required field data. Since the same outcrops, faults, and other solid rock features that were present before 1913 (see Figure 13) are still visible today, it is expected that this method of determining water surface elevations will be applied in the near future to the best pre-1913 photographs available.

There remain both circumstantial and direct evidence concerning differences in flow conditions at the Gate before and after 1913. Figures 13 and 14 are of Hell's Gate at the same stage, lower gauge 30. Figure 13 shows Hell's Gate after 1885 when the C.P.R. was constructed, but before 1912, when C.N.R. construction began. The exact date of the photograph is unknown. However, the C.P.R. grade may be seen on the left side of the photograph and there is obviously no railroad on the left bank (right side of the photograph).[35] The road shown on the left bank is the old Cariboo Road, leading to the gold fields of the interior. The river stage was established by careful comparison with more recent photographs at various known stages. *Note the marked difference in surface flow conditions along the right bank in the two photographs.* The early photograph shows a relatively smooth unbroken water surface, with most of the turbulence existing in the eddy along the left bank. Figure 14, taken from approximately the same viewpoint at the same stage, in 1941, shows clearly that there is marked turbulence along the right bank. This seems to indicate that additional large volumes of water have been displaced by the left bank slide and thrust over and upward to impinge heavily on the rough right bank, where the high velocity flow is reduced by turbulence.

J. P. Babcock, in a statement already quoted on page 91 of this report, has said that the main passage for sockeye prior to 1913 was through the eddy moving upstream along the right bank. This eddy was destroyed by the construction of the Canadian Northern Railway and the subsequent slide. These two photographs, and other similar pairs not shown, illustrate plainly that the quiet flow along the right bank was replaced by excessive turbulence, eddying, and other disturbances characteristic of dissipation of large amounts of energy.

It has already been shown (pages 91 and 92) that the fall or water-surface drop at Hell's Gate was 5.0 feet when the big run in 1913 was destroyed. If the runs in the years before 1913 passed the Gate successfully then the static head through the reach must have been less than 5.0 feet or the head loss must have been distributed in a different manner. It is possible that the filling in of the left bank in 1913 only concentrated the static head loss in a short length of channel.

[35] "Left Bank" and "Right Bank" refer always to the position of stream banks when the observer is looking downstream. Hence in photographs or drawings in which the observer looks upstream, the "Left Bank" appears on the right side of the photograph, and vice versa.

FIGURE 13. Hell's Gate prior to the construction of the C.N.R. Note the smooth flow along the right bank (left side of photograph). Lower gauge 30 (estimated). Date of photograph unknown, but prior to 1912.

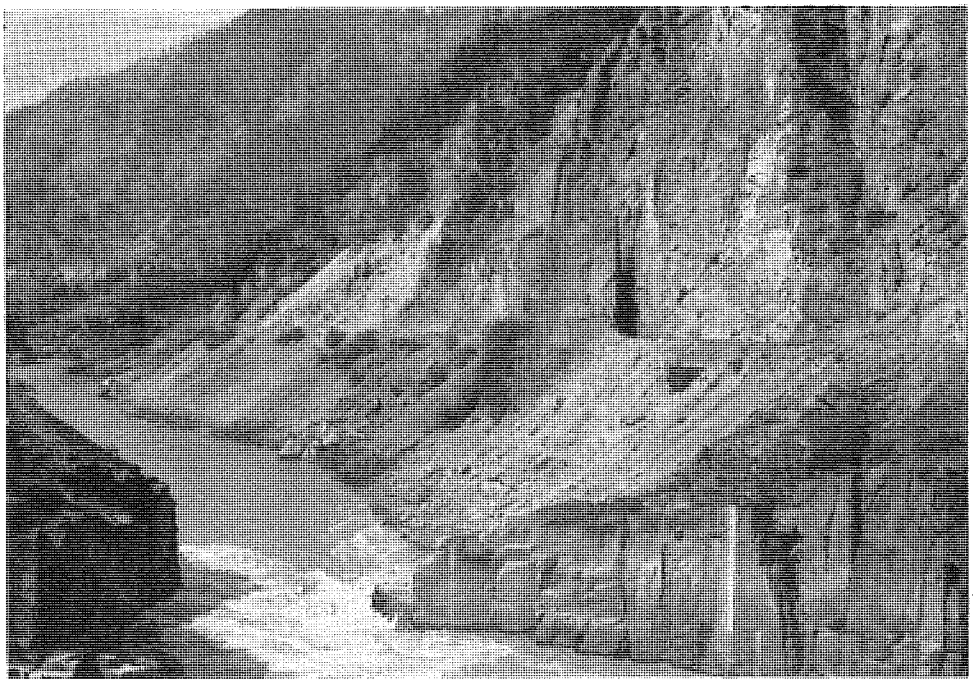


FIGURE 14. Hell's Gate on August 20, 1941. Lower gauge 30. Note the rough turbulent flow along the right bank. Comparison with Figure 13 shows that the smooth path for sockeye is no longer present.

After the slide in February, 1914, the drop through the Gate increased to 15 feet[36] in a horizontal distance of 75 feet along the left bank (see Figure 3). This was the situation that brought swift action. The 1913 spawning run above Hell's Gate had been all but exterminated and now the 1914 run faced a far worse situation. Work throughout 1914 and early 1915 resulted in reduction of the head from 15 feet in 75 feet horizontally to 9 feet in 350 horizontally.

Figure 15 is a photograph of the left bank and Left Jutting Rock at Hell's Gate at gauge 28 on October 13, 1913. At this time the blockade of the 1913 run was in full effect. Passage through the river margin along the foot of the loose rock was possible only when the rocks shown were rearranged to permit sockeye to pass (see page 91.) Figure 12 shows the Left Jutting Rock on August 20, 1941, at gauge 30. Comparison of these two photographs illustrates the increase in head loss around the Left Jutting Rock between 1913 and 1941 at comparable stages. The change must have been caused by rock entering the channel during the slide in 1914 and remaining there, or else being replaced by new slide material.

In line with the conclusion that the removal of slide material in 1914 and 1915 did not provide a permanent and stable channel for the passage of sockeye, consider the change in the left bank as shown in Figures 16 and 17. These photographs show plainly that the well-excavated berms left in 1915 had filled in and had been covered by additional rock from periodic small slides between 1915 and 1942. Such slides continue until the present day, as the steep, high, badly fractured cliff above the railway continues to release small and large fragments.

A summary of physical conditions at the Gate, as indicated by loss of static head through the reach, and the resultant passage or blocking of sockeye has been prepared as follows:

Pre-1913

Head through the reach unknown, but apparently 5.0 feet or less, drop well distributed along banks. Sockeye, so far as is known, passed freely through eddy on the right bank. Some evidence of congestion or delay in years of the big runs.

1913

Static head loss through the reach 5.0 feet along the loose rock on the left bank, horizontal length of the difficult zone unstated. Huge run of 1913 blocked at all river stages, except when temporary passageways were provided to allow limited numbers to pass.

1914-15

Static head loss through the reach increased to 15 feet in a horizontal distance of 75 feet along the left bank slide. Width of the river decreased to 75 feet. Removal of slide material, temporary passages, and flume and dipnet salvage assisted an unknown proportion of the 1914 sockeye run past the obstruction. By 1915 the head loss had been lowered to 9 feet along 350 feet horizontally on

[36] See p. 92 of this report for a description of this condition.

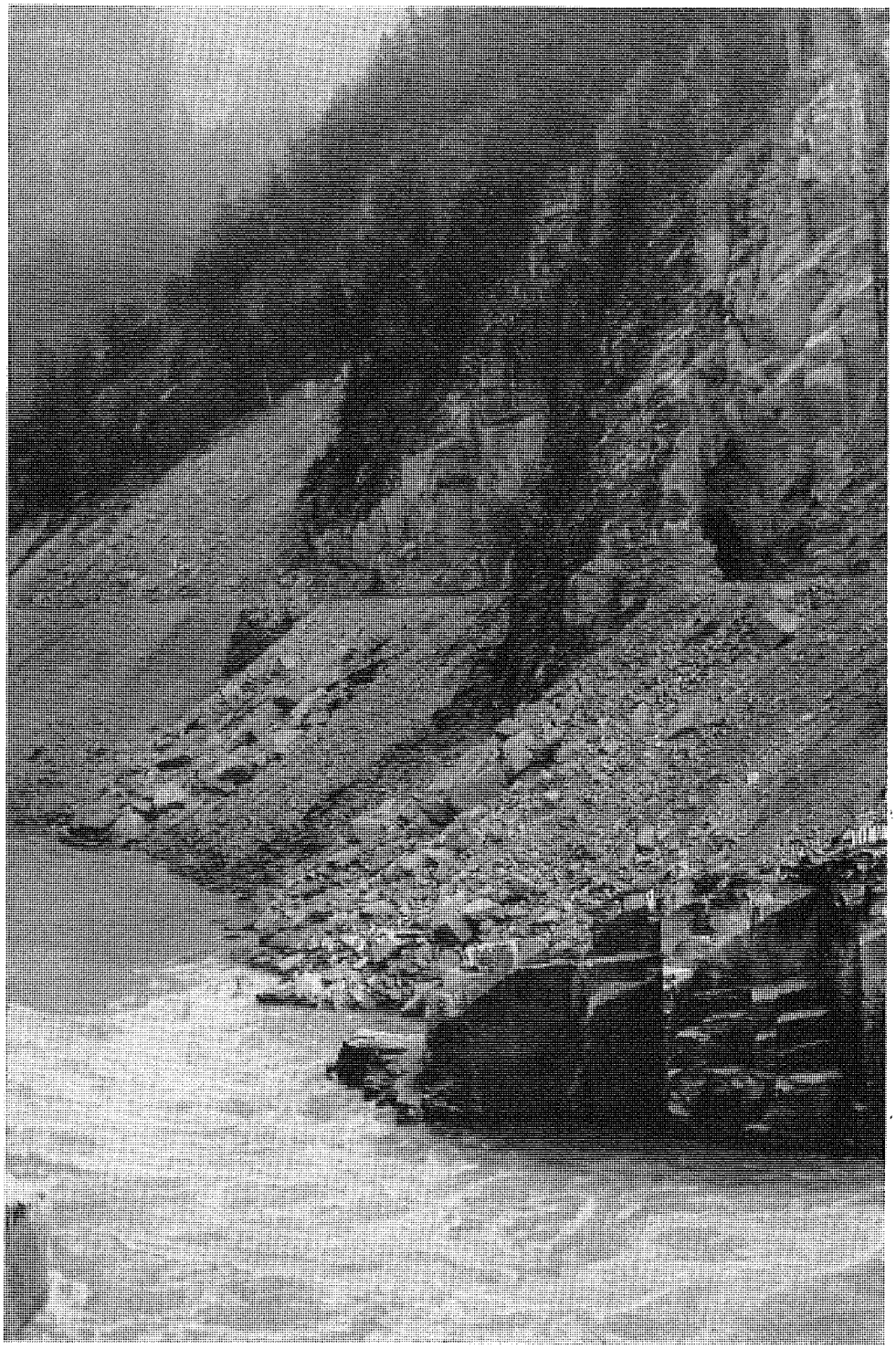


FIGURE 15. Hell's Gate on October 13, 1913, lower gauge 28 (estimated). Comparison of this photograph with Figure 12 shows that the drop in water surface around the Left Jutting Rock increased considerably between 1913 and 1941.

the left bank (stage not given) and the sockeye run of that year gave no visual evidence of being blocked.

1915-37

Head loss 9 feet in 350 horizontal at unknown stage at conclusion of the slide removal operations in March, 1915. Conditions for passage of sockeye declared suitable insofar as visual observations could be relied on. Discussion at intervals throughout this period as to passable stages, extent of delay, harmful effects on runs, necessity for further work. Board of Engineers measured physical factors in 1926-28. Gradual sloughing-in of loose rock on left bank throughout this period.

1938-44

Head through the reach still averaging about 8 to 9 feet. Position of drop varying with stage, shifting downstream at higher stages. Conditions for passage proved unfavorable at stages 25 to 61 on the left bank and from 61 to 50 feet and from 40 feet to 11.8 feet on the right bank.

1945-Present

Fishways installed on both banks to alleviate blockades of sockeye. Discussion of their size, range of operations and flow patterns follows in Section VII of this report.

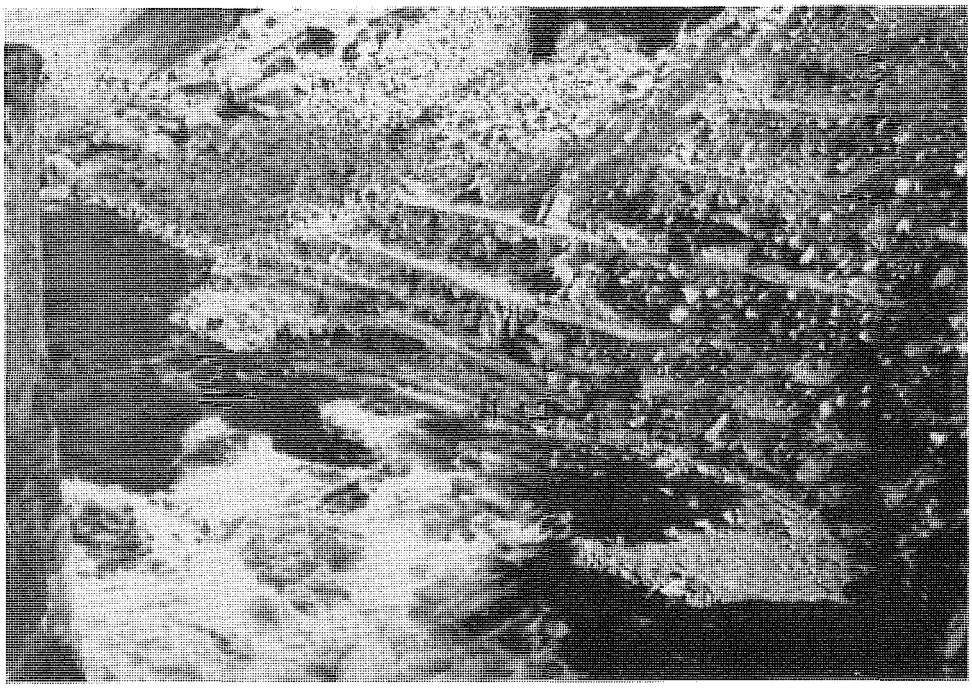


FIGURE 16. Hell's Gate during excavation of slide material in 1914. Note the well-excavated berms on the left bank. Compare with Figure 17 below.

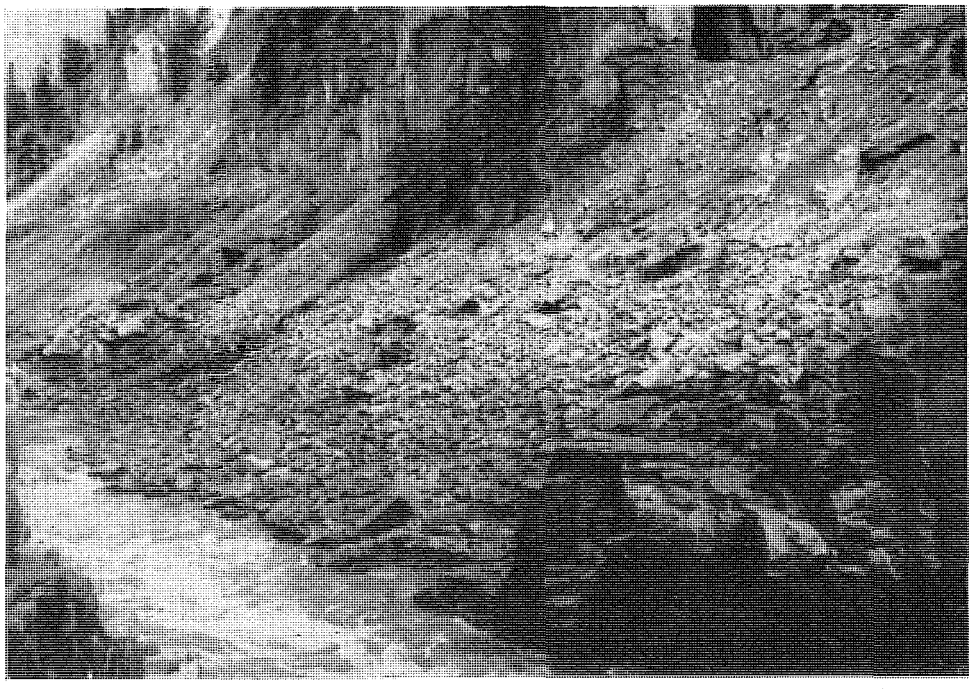


FIGURE 17. Hell's Gate on March 26, 1942, lower gauge 5. Compare with Figure 16 and note that the left bank has filled in with slide material again in the interval 1915-1942.

VII. THE HELL'S GATE FISHWAYS

It is frequently suggested that the blockade at Hell's Gate should have been remedied by changes in the banks and bottom of the channel rather than by construction of fishways. There were a number of reasons why fishways were preferred to channel alterations—the principal determining factors will be mentioned below.

First, model tests made by the Board of Engineers in 1927 and by the Salmon Commission in 1943 showed that the head loss through the Gate would be only slightly changed by removal of substantial volumes of material at the Left Jutting Rock and the Right Jutting Rock. The Board of Engineers' model, which was built to a small scale, was not operated at stages above lower gauge 35.7. It showed no measurable change in head loss or drop between the upper and lower gauges when either or both of the sections was removed. The Commission model, built to a larger scale, and exactingly verified, showed a decrease in drop of 2½ to 3 feet through the reach for stages 25 and 50 feet, lower gauge. But both the Board of Engineers and the Salmon Commission[37] noted that increased velocities due to reduction in bank roughness indicated that passage would be as difficult as ever. Also the change in general flow patterns made passage at other levels unpredictable.

Second, if the channel were altered there could be no certainty that the new conditions would be passable. It would be exceedingly difficult and expensive to make subaqueous excavation under rapidly flowing water with controlled results. Part of the excavation would of necessity be submerged at even the lowest winter stages.

Third, if channel corrections were made they would not, in all probability, be permanent or stable in nature. After all, the slide removal of 1914-15 did not provide a permanent solution for the difficulties of passage. There was always doubt as to its degree of effectiveness. Furthermore, the bank conditions left in 1915 did not maintain themselves; the excavated area filled in again, in part.

Fourth, reductions in the head loss through Hell's Gate by lowering the head water level would mean increases in slope and drop at some point or points upstream. If the drop at Hell's Gate were not reduced below the drop prevailing prior to 1913 it would appear that no harm would result from increased drops farther upstream. That is, these head losses had once occurred farther upstream; the slide and dumping at Hell's Gate raised the level there and drowned out the upstream surface drops; now the reduction in head at Hell's Gate would transfer these drops back to their original locations and the sockeye would pass as easily as they did before 1913. However, the drop through Hell's Gate prior to 1913 was not known for any river stage. And the construction of the Canadian Northern Railway in 1912-13 had not only resulted in dumping of rock at Hell's Gate, but in many other places immediately upstream. For this reason, passage of sockeye through areas above Hell's Gate could not be assured if the surface drop from Hell's Gate were to be added to the drops left by railway construction in the river reaches immediately above the Gate.

[37] Basic material for this section has been taken from:
Bell, M. C. "Report on the Engineering Investigation of Hell's Gate, Fraser River." I. P. S. F. C. Annual Report, 1944, pp. 15-22.
Webb, C. E. "Second Interim Report on Hydraulic Investigations Carried Out by Dominion Water Power and Reclamation Service on Fraser River at Hell's Gate." Blueprinted report, Vancouver, 1928.

Fifth, the cost of making careful channel studies for a considerable distance above Hell's Gate and the time required to make such studies were both prohibitive. The loss of even the smallest of the annual runs would far exceed in value the cost of suitable fishways. It was therefore necessary to proceed immediately with a permanent solution.

Sixth, the fishways could be so designed and constructed that they changed as little as possible the natural conditions in the reach. The head loss at various stages, the exact points of blockade, the velocities, and pattern of flow could be left substantially unchanged. Thus, there could be reasonable assurance that what was being done to assist sockeye at one stage and location would not cause a blockade at another stage or location.

When fishways were chosen as the best method for a rapid and permanent solution of the difficulties at Hell's Gate it was first necessary to fix the basic premises of the design. Sockeye had to be assisted at stages 25 to 40 feet and for some unknown range above gauge 40. They had to be lifted vertically between 8 and 9 feet. The maximum number of sockeye per week, day, hour, or minute could only be estimated for the years ahead when it is hoped that the big runs will be restored. However, the existing run to the Adams River in 1942 contained over two million sockeye. It was decided from tagging data that 10 per cent of this run might reach Hell's Gate in a single day. Of this two hundred thousand, 10 per cent or 20,000 fish might wish to pass in the peak hour of that day.

It was estimated by Dr. W. F. Thompson[38] that from 1,500,000 to 1,750,000 sockeye might be expected in a peak week in the future and that the maximum rate of arrival for passage at the Gate might exceed 500 sockeye per minute. These figures were in general agreement with those based on the Adams River run, and also agreed with figures from the Karluk River[39] when account was taken of difference in total size of the runs. The fishery exercises a marked effect on the runs at Hell's Gate. Huge numbers of sockeye may be released during the weekly closed season to arrive in bunched fashion at the Gate. It is important that these fish be passed without further delay.

The drop between pool levels in the fishway was set at from ten inches to one foot, varying with river stage. Daily fluctuations in river stage of 4 to 6 feet or more during freshet periods made it desirable to design fishways requiring no adjustment for change in depth of flow. Fishway design, particularly under such conditions, is far from an exact science and success or failure depends upon the experience and good judgment of the designers.

It was assumed that the pools would be six feet deep at the minimum stage for which fishways were required. The pools were designed to be 20 feet wide and 18 feet long. Thus at the lowest operating stage there would be 2160 cubic feet of water in each pool. Two cubic feet of water was allowed as a minimum for each sockeye, so each pool could contain 1080 sockeye at gauge 25. The key to the entire design assumption is the average time required for passage through the fishway, or through each pool. Data are very scarce on this point and of doubtful value in fishways of a new type. Five minutes per pool was allowed, or

[38] Thompson, W. F. Letter to Milo C. Bell, March 16, 1944.
[39] Interview of T. Barnaby by M. C. Bell, March 7, 1944.

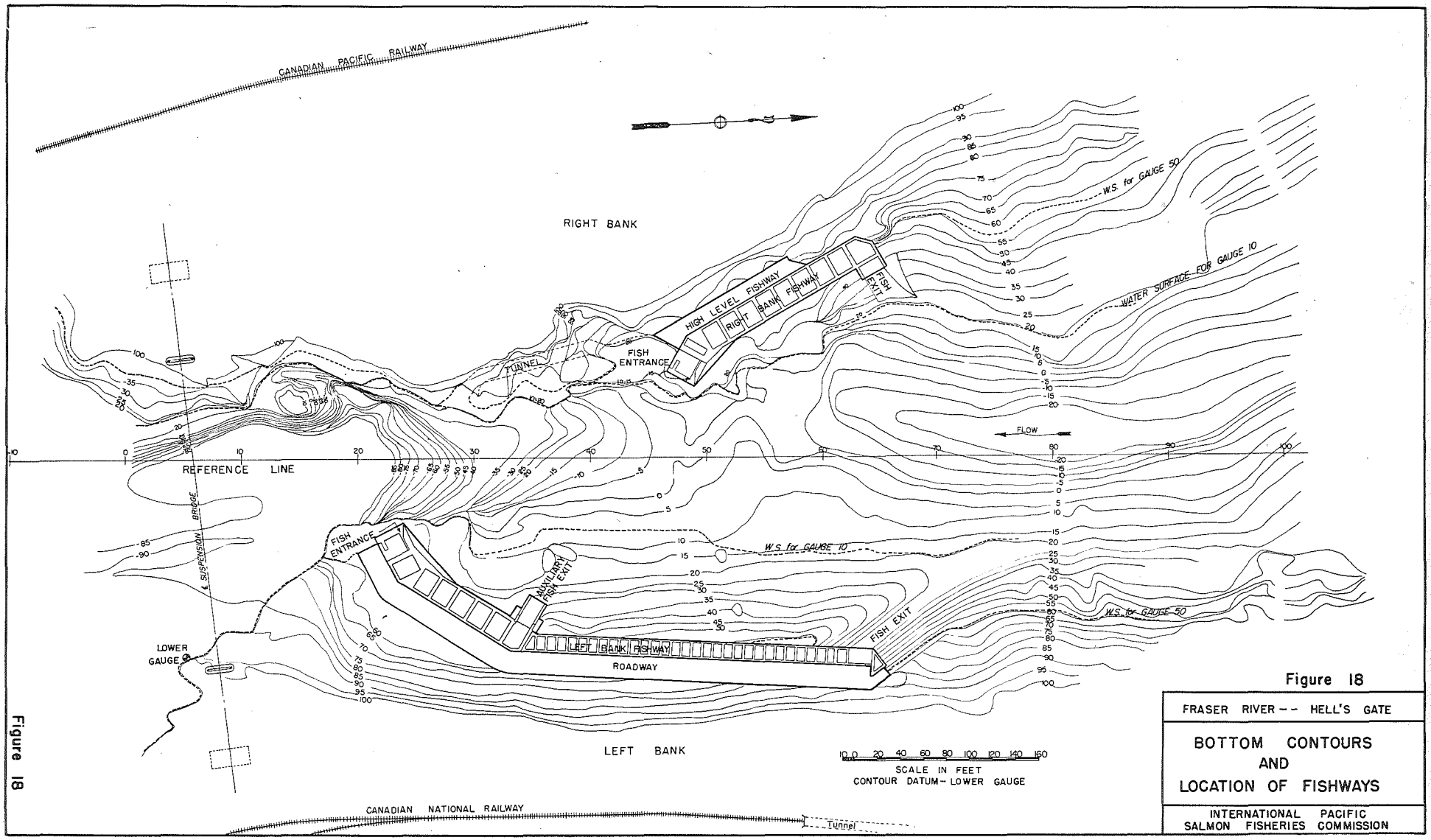


Figure 18

Figure 18

FRASER RIVER -- HELL'S GATE

BOTTOM CONTOURS AND LOCATION OF FISHWAYS

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

45 minutes for a 9-pool fishway. The average sockeye can swim about 25 miles per day in the Fraser Canyon. Swimming at the same rate through the 220-foot long right bank fishway a sockeye would require only 2.4 minutes to make the passage. Allowance of 45 minutes would seem to be ample.

The right bank fishway at design capacity at gauge 25 was thus expected to pass nearly 13,000 sockeye per hour. A similar capacity was expected in the left bank fishway, although it is slightly different structurally. The total capacity of the two fishways at gauge 25 was therefore approximately 26,000 sockeye per hour.

Passage between pools was also considered. The jet velocity between pools is approximately 8 feet per second. A sockeye 2½ feet long swimming at 12 feet per second would pass through the short jet in about 1 second. Since there are two jets in each of the two fishways the jet capacity for fish passing single file would be 240 fish per minute. However, each jet is two feet wide and six feet deep at minimum operating level, so the number passing per minute could be several times greater than 240 without any crowding whatsoever.

These figures are based on use of six feet of depth of the fishways only. As the stage increases above gauge 25 the volume of each pool increases as does the jet area available for passage between pools, consequently the capacity in fish per hour might be increased. It is not yet known at what depths sockeye will travel in the Hell's Gate fishways—some are known to pass through orifices submerged six feet in the Bonneville fishladders even though a surface path is available. The turbid water at Hell's Gate makes visual observations impossible at depths over six inches.

The finished Hell's Gate fishways have been described and illustrated in the various Annual Reports of the Salmon Commission, beginning in the report for 1944. Figure 18 shows the location of the finished structures on a contour map of the reach. The fish entrances are located at the exact points where upstream passage in the natural channels becomes impossible at block stages. The fish leave the fishway exits in quiet water and experience no difficulty in proceeding upstream.

Biological data show that sockeye pass in the right bank fishway from gauge 16, at which stage there is only about one foot of water over the floor of the fishway, to gauge 52 when water pouring through the deck gratings overtops the structure. The left bank fishway passes sockeye from gauge 19 to 52.

A high level fishway on the right bank aids passage on that side to gauge 70. A low level right bank fishway already designed will, when built, make uninterrupted passage possible on that side from gauge 10 to 70. A high level left bank fishway will allow uninterrupted passage on that side from gauge 19 to 70, (see footnote No. 31) with natural passage at all levels below lower gauge 25.

It was assumed that most sockeye use the fishways only during the daylight hours, as is the case with other fishways passing salmon. The hours of daylight vary with season, cloudiness and topography; it was assumed that 13 hours per day were used by sockeye migrating through the reach.

There are admittedly many unknowns and opportunities for argument in these assumptions. The proof lies in the biological data—to date no run, however large, has shown any delay at Hell's Gate for stages at which the fishways are operative. This is in marked contrast to the difficulties experienced in the years before their construction.

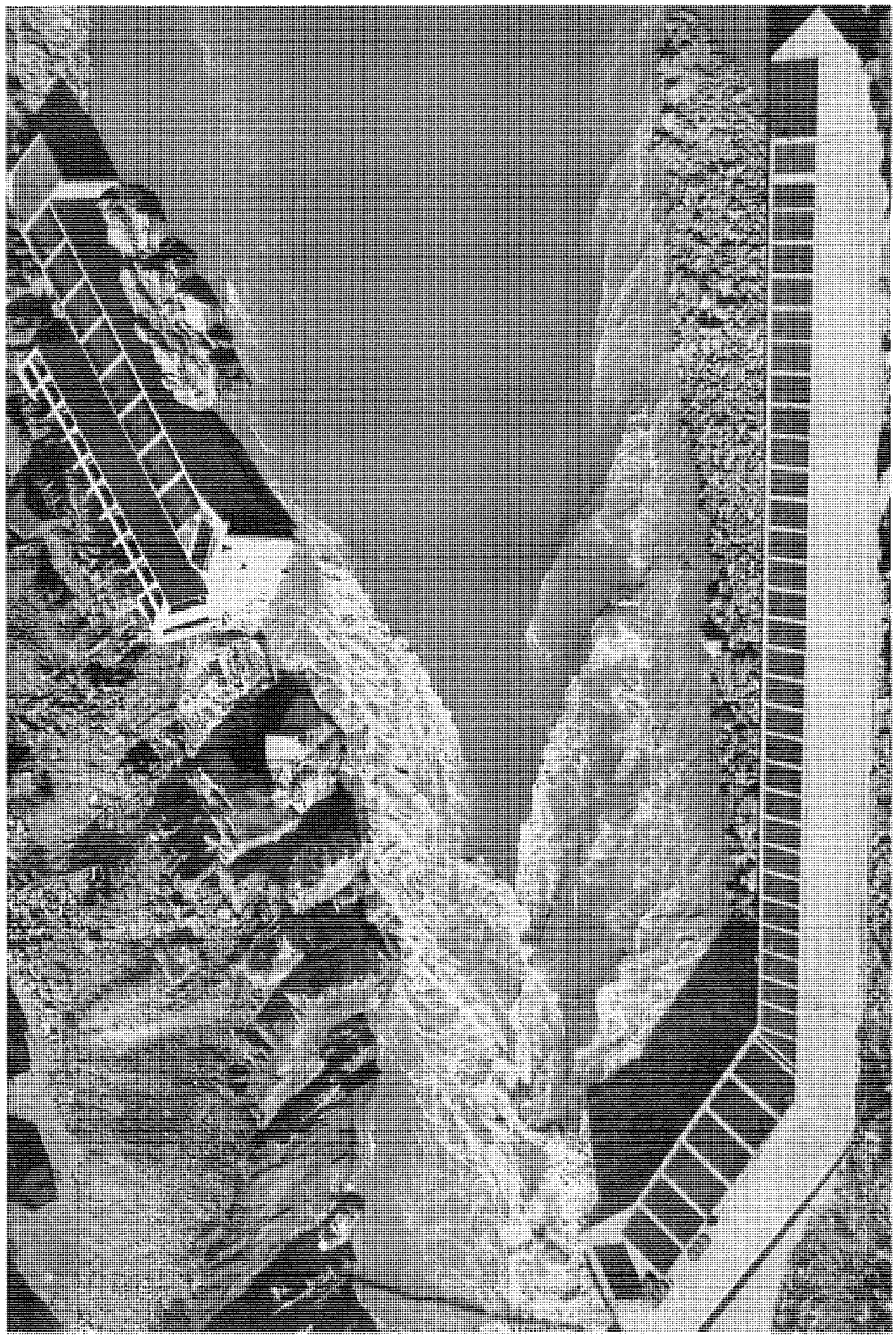


FIGURE 19. The Hell's Gate fishways and tunnel. Lower gauge 28.3. September 17, 1947.

VIII. SUMMARY AND CONCLUSIONS

The greatest known blockade of upstream migrant sockeye in the Fraser River at Hell's Gate occurred in 1913 when rock dumped on the left bank during construction of the Canadian Northern Railway caused the virtual destruction of the huge sockeye run of that year. The flow conditions which destroyed the run were relatively unmeasured; however, a drop of 5.0 feet along the left bank was recorded during the blockade.

The block condition of 1913 was aggravated by a slide on the left bank on February 23, 1914. An estimated 100,000 cubic yards of rock raised the upper pool level at the Gate to a level 15 feet above the lower pool level. Prompt action by the Dominion Department of Fisheries resulted in excavation of slide material which lowered the head to 9 feet through the reach and aided the 1914 run to pass, as well as subsequent runs.

After the slide of 1914 was removed no further action was taken at Hell's Gate for many years. In 1926 a Board of Engineers was organized by the Dominion Fisheries Department to study conditions for passage of sockeye at the Gate. They suggested removing certain portions of the banks if required, but did not wish to decide on the biological question of block or non-block to migration. No further work was done at the Gate and it remained as it was left in 1915 except for natural changes which were not recorded.

Biological studies of the movement of sockeye were begun by the Salmon Commission in the first year of its existence, 1938. Engineering studies began in 1941. It was established that sockeye were blocked at all stages above 25 feet on the left bank and at all stages below 40 feet on the right bank as well as at stages above 50 feet. The engineering studies showed that during the block stages the slope of the water surface increased markedly over the slopes prevailing at passable stages. *The average maximum slope was of the order of* 17 *times greater on the left bank and* 7 *times greater on the right bank during blocked stages than the average maximum slopes during passable stages.* The combination of turbulence and high velocities prevented movement of large portions of the runs at these stages.

The available evidence indicates that prior to 1913 the fall in water surface through Hell's Gate was less than 5.0 feet. During the blockade of the run of 1913 the fall through the Gate was measured at 5.0 feet. After the slide on February 23, 1914, the head through the reach was 15 feet. Removal of slide material reduced the drop to 9 feet in 1915. It varies between 8 and 10 feet today; the average drop is approximately 9 feet. Hell's Gate thus appears not to have been restored in 1914-15 to a condition identical with that before the slide. Photographs taken of the various conditions seem to substantiate this view.

Fishways proved to be the most satisfactory, predictable, and permanent answer to the blockade of sockeye at Hell's Gate. Reinforced concrete fishways of unique design which do not require adjustment for changing river stage were constructed in 1944-46. The design capacity of the fishway system is approximately 26,000 sockeye per daylight hour at the lowest block stage, 25 feet.