INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

BULLETIN VI

AN INVESTIGATION OF THE EFFECT OF BAKER DAM ON DOWNSTREAM-MIGRANT SALMON

BY

J. A. R. HAMILTON and F. J. ANDREW

PARTICIPATING ORGANIZATIONS

INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION
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INTERNATIONAL PACIFIC SALMON FISHERIES COMMISSION

APPOINTED UNDER A CONVENTION
BETWEEN CANADA AND THE UNITED STATES FOR THE
PROTECTION, PRESERVATION AND EXTENSION OF
THE SOCKEYE SALMON FISHERIES IN
THE FRASER RIVER SYSTEM

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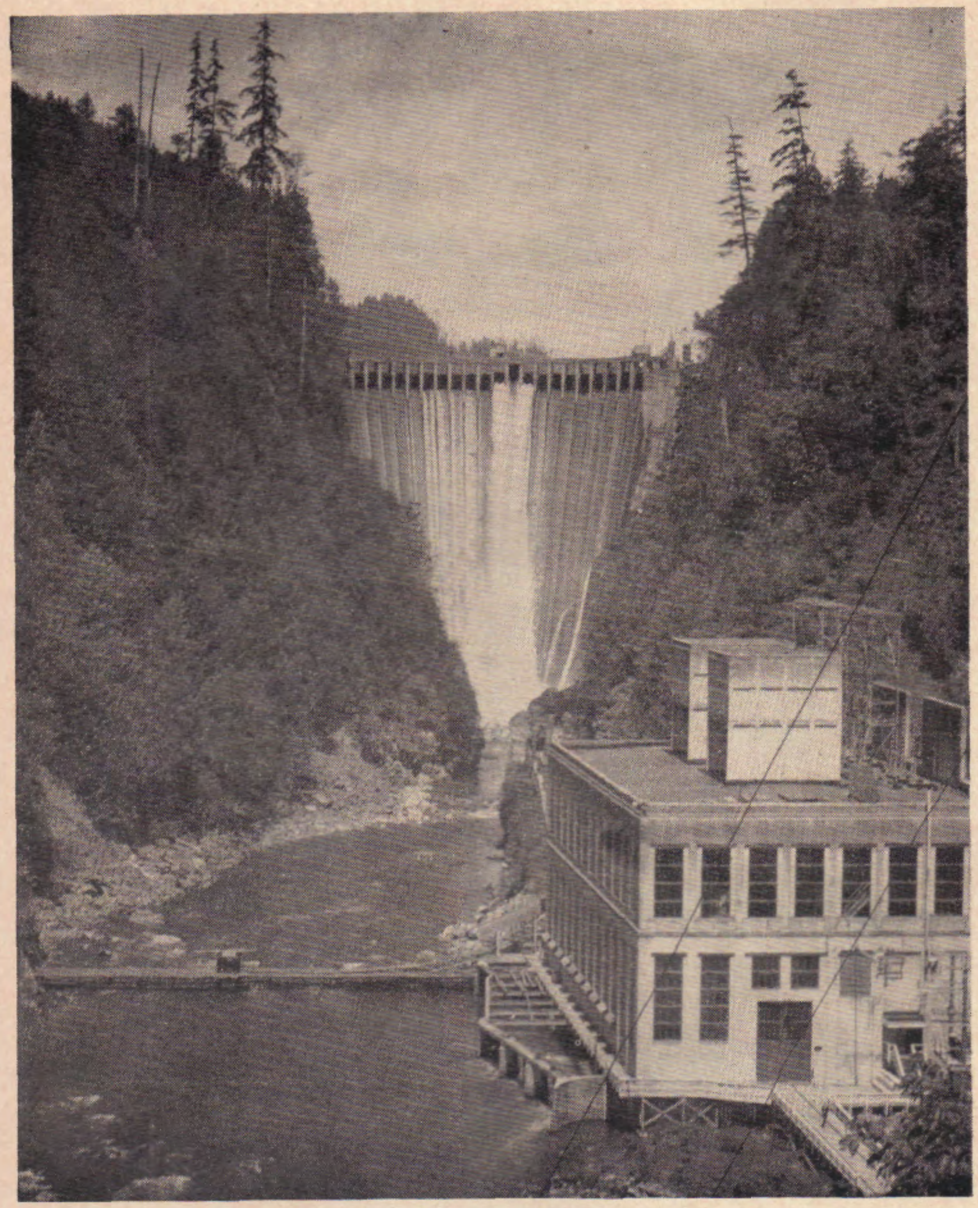

Baker Dam and Powerhouse showing one spillway gate fully open and two adjacent gates cracked one foot.

ABSTRACT

The effects of a hydroelectric plant and dam 250 feet high on the downstream migration of sockeye and coho salmon were investigated at Baker Dam in Western Washington. The migrating population was sampled with survival-type fyke nets in order to determine the pattern of migration from the reservoir, the effect of the spillway and the Francis-type turbines on survival, and the causes of mortality. It was found that over 95 per cent of the migrants leaving the reservoir used the surface spillway as their exit route and that less than 5 per cent left through the turbine intake, which was submerged 85 feet at full reservoir. It was concluded that 64 per cent of the native sockeye and 54 per cent of the native coho were killed in passing down the spillway when one spillway gate was open. The mortality rates in passing through the turbines were calculated to be 34 per cent for native sockeye and 28 per cent for native coho under full load conditions. These findings are supported by data showing that sockeye marked as downstream migrants and released over the spillway and through the turbines, upon return as adults had experienced a spillway mortality of 63 per cent and a turbine mortality of 37 per cent. Further confirmation of the effects of the structure is provided by the decline of 55 per cent in the sockeye run since the dam was constructed. Much of the injury and mortality to the yearling salmon was caused by abrasion on the spillway and pressure changes and cavitation in the spillway and turbines. It was concluded that a dam of this type has a very detrimental effect on the downstream migrants and that the spillway is responsible for the major part of the mortality.

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INTRODUCTION

The construction of dams on rivers through which salmon must migrate when enroute to or from their spawning areas has often resulted in the destruction of valuable fisheries resources. The lethal effect of dams which prevent the migration of adult salmon is obvious. Much has been done to ensure safe upstream passage of adult salmon at dams through construction of fish ladders, locks and mechanical collecting and hauling systems. However, relatively little is known about the less-obvious effect of dams on *downstream-migrant salmon*. While losses of downstream migrants at a dam may not be sufficient to cause extinction of a run, mortalities at this stage are important because they may destroy the economic value of the run.

In recent years evidence has indicated that mortalities occurring at one stage of the life history of sockeye salmon may be compensated for at a later stage. Data presented by Barnaby (1944), studying the sockeye salmon *(Oncorhynchus nerka)* populations in the Karluk River, show that, in general, poor seedings resulted in relatively large rates of return of adult salmon whereas large seedings produced relatively lower rates of return of adult salmon. More recently, Withler (1953) indicated that compensation was effective from the time of egg deposition to the time when the sockeye smolts migrated seaward from Babine Lake. He showed that with decreased numbers of spawners there was an increase in the survival rate to the smolt stage. However, it appears that compensation may not be effective beyond the time when the fish enter the sea. Although this has not been adequately demonstrated for sockeye, Neave (1953) indicates that such may be true for pink and chum salmon. He showed that compensation was effective from the time of egg deposition to the time of fry emergence but not for subsequent stages. The view that scarcity of numbers is not compensated for in the sea has also been supported for spring salmon *(O. tschawytscha)*, coho salmon *(O. kisutch)* and steelhead trout *(Salmo gairdnerii)* by Murphy and Shapovalov (1951). Since compensation is probably not effective after downstream-migrant sockeye leave a lake, it would seem that significant mortalities at dams could have a very limiting effect on production because the mortalities occur at a stage of the life cycle after which compensation is impossible.

Certain potential power sites in the Fraser River Basin, if developed, would create hazards to the survival of sockeye salmon. In order to supply factual information on the physical effects of dams on seaward-migrant salmon a program of research was initiated in 1950. It is the purpose of the present report to present data and conclusions from experiments relating to the seaward passage of salmon at Baker Dam, located on a tributary of the Skagit River in Western Washington. This hydroelectric development was selected as a site for the initial study because the Baker River system supports a native run of sockeye and coho salmon and because the structure is fairly typical of modern high-head plants. A comparable experimental site was not available on the Fraser River Watershed.

The experimental program was undertaken with the following specific objectives:

1. To determine the character of the downstream migration from the reservoir.
2. To evaluate the effect of the turbines and spillway on survival of the seaward migrants.
3. To isolate the cause or causes of any existing mortality.

The study was begun in 1950 with the assistance of the State of Washington Department of Fisheries. In 1952 the Department of Fisheries of Canada also assigned men to the project. The first year's study was principally of an exploratory nature to determine what methods might best be employed to accomplish the above objectives. These methods were put into practice in 1951 and were further developed in 1952. This report deals primarily with the findings of the 1951 and 1952 investigations.

DESCRIPTION OF THE HYDROELECTRIC INSTALLATION

Baker Dam was built in 1925 by the Puget Sound Power and Light Company on the Baker River one mile above its confluence with the Skagit River. The dam created a reservoir, Lake Shannon, nine and one-half miles long with an area of 2250 acres and a maximum depth of 240 feet. The hydroelectric plant produces a maximum of about 54,000 horsepower, operating at a head of 250 feet and a discharge of 2200 cubic feet per second. The dam which is of the arch type has a height of 285 feet above bedrock and is 360 feet long at deck level. The water for power generation is taken from the 85- to 107-foot levels below normal reservoir elevation and is carried to the power house in a conduit through solid rock. This conduit consists of a lined tunnel 22 feet in diameter, 1034 feet long, followed by a lined tunnel 16 feet in diameter and 111 feet long, and four penstocks each 8 feet in diameter and about 325 feet long. The powerhouse consists of two generators each of which has two Francis overhung (horizontal shaft) turbines revolving at 300 revolutions per minute and each discharging about 550 cubic feet per second. The operational layout is shown in the Frontispiece and in Figure 3.

The water for power generation is discharged from the turbines through four draft tubes the exits of which are located 12 feet below the normal water surface of the tailrace. The water ejected from the draft tubes is deflected to the surface making a very turbulent area within the immediate tailrace, and merges with the spillway discharge at the powerhouse which is approximately 1200 feet downstream from the dam.

The spill at Baker Dam is controlled by 23 vertical lift gates 9 feet 6 inches wide and 13 feet high. The two spillway gates located closest to the right bank are operated by remote control from the powerhouse. The operators of the dam were of the opinion that use of the remotely controlled gates during the period of downstream migration might be harmful to the fish, since these gates spill directly on a concrete-paved cliff. For this reason spilling during the migration period has been confined as much as possible to the central gates which discharge onto the spillway face. When spilling occurred during the period of downstream migration in 1951 and 1952 the surplus water was usually discharged through one or two gates. More gates were opened when necessary to accommodate increased run-off.

It has been the practice at this plant during the period of migration to raise one adjacent gate on each side of the fully open gate sufficiently to create an opening of approximately one foot. It was believed by the operators that this system of releasing excess water made passage of fish over the dam less hazardous. At full reservoir with one gate fully open and the adjacent gates cracked one foot the discharge is about 1850 cubic feet per second. The discharge with two gates open and adjacent gates cracked is 3370 cubic feet per second.

Water discharged over the crest of the dam through the central gates falls free of the dam face for approximately one-third of its descent and then strikes the curving slope of the dam, spreads out on the spillway face and enters the spillway pool at a very high velocity. The spillway pool, bordered by cliffs and large boulders, is approximately 170 feet in width, 270 feet long and 41 feet deep at its deepest point. The drop from the reservoir surface to the spillway pool is about 240 feet and the pool is extremely turbulent during spilling.

BAKER RIVER SALMON POPULATIONS

Sockeye *(Oncorhynchus nerka)* and coho *(O. kisutch)* are the principal species of salmon utilizing the areas above Baker Dam for reproduction and rearing. The sockeye salmon spawn in the upper Baker River, tributary to Baker Lake, which is located 18 miles upstream from the dam. The coho spawn in numerous tributaries to Lake Shannon and Baker Lake. The average annual run of sockeye to the spawning grounds over the past ten years has been about 3000 fish. The run of coho to the areas above the dam for the same period has amounted to about 10,000 fish annually (State of Washington Department of Fisheries Annual Report, 1953).

The adult salmon returning to the spawning grounds are trapped at a weir below Baker Dam and elevated about 250 feet to the reservoir in a small tank supported by a high-line cable. On reaching the reservoir the fish are transferred to floating live boxes which are towed up the lake a distance of several hundred yards. The fish are then released and allowed to resume their migration to the spawning grounds.

After incubation and approximately a year of residence in fresh water above the dam, the young sockeye and coho migrate seawards. Length measurements and scale studies have shown that a small portion of the migrating population of sockeye and coho in 1951 and 1952 consisted of fish that had remained in fresh water for more than one year before migrating. Unlike the adults, the young have no special facilities provided to assist them in their migration past the

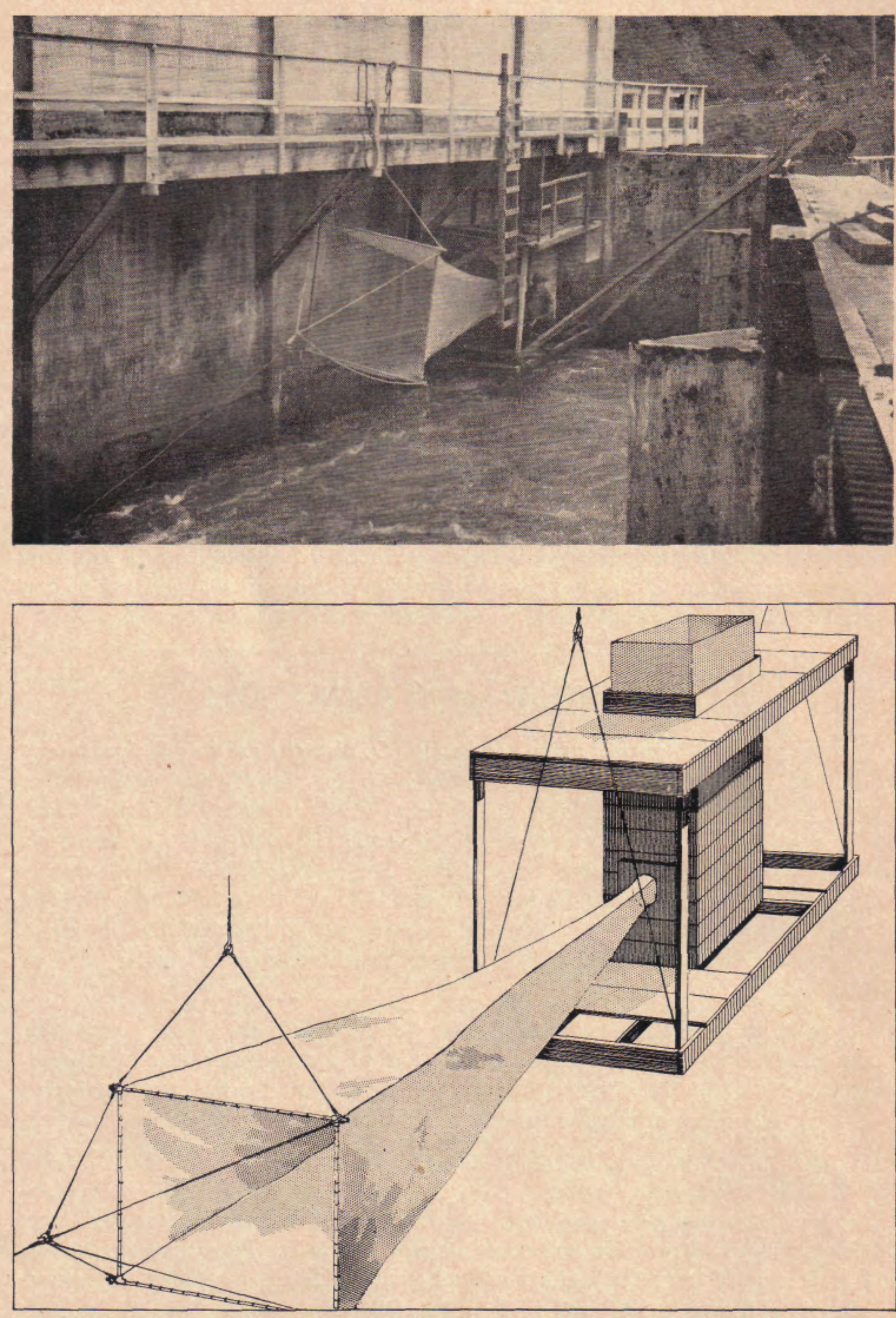


FIGURE 1. Tailrace survival gear.

obstruction. In order to reach the river below the dam they must pass through either the surface spillway exit or the subsurface tunnel exit.

METHODS OF INVESTIGATION

The principal method employed to fulfill the objectives of this investigation consisted of sampling the native sockeye and coho downstream-migrant populations with fyke net gears designed to capture and retain fish without causing any additional injury. The gears were located in the tailrace below the powerhouse and in the river below the spillway pool. The principal type of fishing gear consisted of a fyke net made from anchovy webbing of one-half-inch stretched mesh with a survival box attached. The nets used in 1951 and 1952 were of the same general design but differed in dimension. In 1951 the nets had a four-foot square opening and tapered to a 12-inch diameter exit in 12 feet of length. The nets in 1952 differed from the above only in the size of the entrance, which was five feet square. Each survival box was constructed in such a manner that the water in it was relatively free of turbulence thus allowing captured fish to be retained alive.

Three types of survival gear were required to fit the fishing conditions that prevailed. An attempt was made to design each gear so that it would operate in as high a velocity as possible. The type of gear employed in the tailrace in 1951 consisted of a fyke net connected directly to a survival box secured in a relatively quiet section of the tailrace. This gear was improved in 1952 by mounting the survival box on a weighted wooden frame as shown in Figure 1. Four cables were attached to the four corners of the frame and extended through overhead pulleys to winches. The entire gear could thus be elevated or lowered at will. The two remaining types of survival gear were developed for use in the river. The first of these gears was developed in 1951 and consisted of a net which was connected to a canvas hose 12 inches in diameter and 28 feet long which in turn was attached to a survival box located in a quiet back eddy in the river. Fish captured in the net in the fast flowing section of the stream were carried through the submerged canvas hose to the survival box where they were retained until examined. The second type of river survival gear was developed in 1952. This gear was a floating device, as shown in Figure 2. Two pontoons 20 feet long, 18 inches deep and 8 inches wide were spaced five feet apart to form a raft. Auxiliary pontoons provided extra buoyancy at the upstream end. Each pontoon raft supported a fyke net and survival box. The entrance of the net was immediately in front of the pontoons. From there the net extended back 12 feet and was attached to the live box located at the downstream end of the raft. Two one-ton winches were placed on the raft and a cable from each extended to an anchor on each bank. The gear supported two men and was readily maneuverable.

In addition to the survival gears described above, several of the fyke nets were used without live boxes attached. These nets killed or injured the captured fish and served for enumeration purposes only. Early in the development of survival gear in 1951 a fyke net made of wire screen was tried. This net had a four-by-four-foot entrance and tapered to a one-by-four-foot exit in seven feet of length. A wire screen collecting compartment was attached to the downstream end. This gear was cumbersome and injured the captured fish. Therefore it was not operated after 1951.

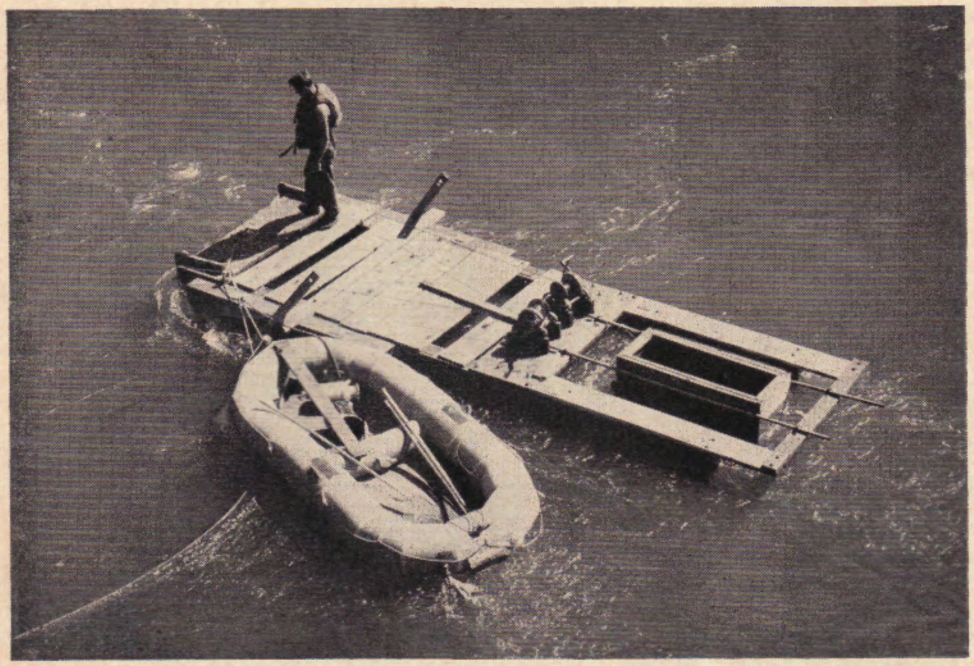
The locations of the various fishing gears are shown in Figure 3. The types of gear which operated at these sites in 1951 and 1952 are given in Table I. All gears associated with the tailrace are marked with the letter "T". Those gears located in the section of river between the dam and the confluence of the tailrace and spillway discharges are designated by the letter "S". Another gear was located in the river about 1000 feet below the confluence of the tailrace and spillway discharges and is referred to as net "ST".

Two separate stations were set up in the spillway section of the river as shown in Figures 3 and 4. Station S_1 was established in 1952 and was located approximately 100 feet below the lower end of the spillway pool. This station was used principally for auxiliary experiments. A pontoon survival gear could be operated at this site for only short periods of time because of high velocities and turbulence. Station S_2, located about 400 feet farther downstream was the principal fishing station in that section of the river above the tailrace. This site was selected because it had a wide range of velocities in which the gear could be operated. At this station the river is 16 feet deep at its deepest point with one spillway gate fully open. The gears were installed in their respective positions prior to the onset of the spring spill so that they would capture migrants when spilling commenced. They continued to operate until the migration became insignificant. In 1951 and 1952 the survival gears operated almost continuously for one gate of spill except for periods when repairs to the gears were necessary. Only in 1952 were survival gears operated for two gates of spill. When greater quantities of water were discharged over the crest of the dam the gears could not be operated.

The tailrace gears were located immediately downstream from the draft tubes. The depth of the tailrace at this point is about 18 feet. Because of the structural separation of the tailrace and the river, fish that passed over the spillway did not enter the tailrace fishing gears. In both 1951 and 1952 net T_b was installed early in the migration period while the survival gear T_a was installed at a later date. Fishing was carried on at the station throughout the major part of the migration, except for periods when there was no power generation.

The gear at Station ST was operated for auxiliary experiments only. Continuous fishing was not maintained at this station. All nets whether in the tailrace or in the river operated at the surface of the water and depending on the size of the net used, did not extend deeper than four or five feet.

For the purpose of evaluating the fishing efficiency of the gears, sockeye, coho and spring salmon marked by the excision of a fin or fins were released at the crest of the dam and into the tunnel. These fish were obtained from various sources. Native sockeye and coho were captured in the forebay. Hatchery coho, sockeye and spring salmon of suitable size were supplied by the Washington State



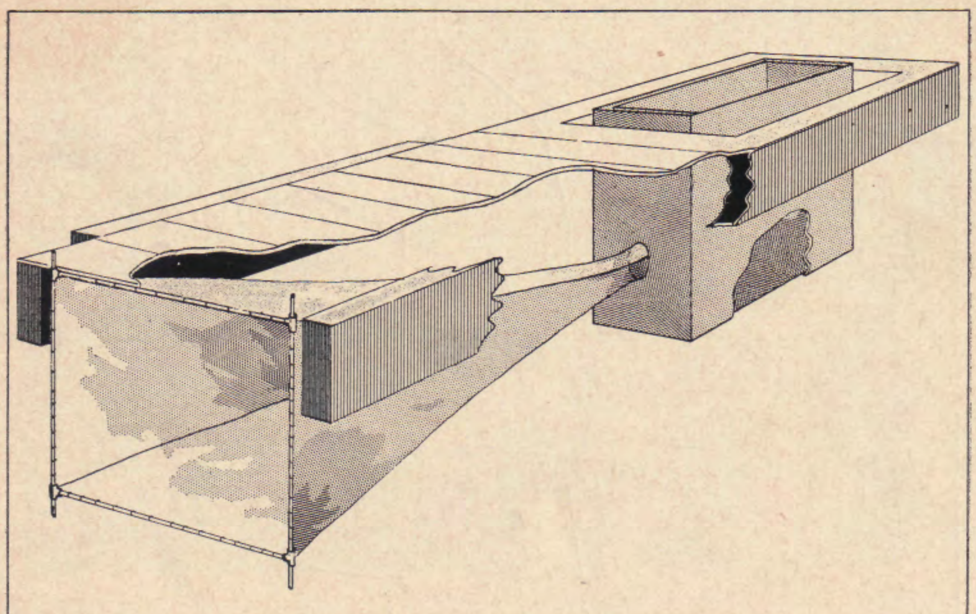


FIGURE 2. Pontoon-mounted fyke net and survival box used in the river.

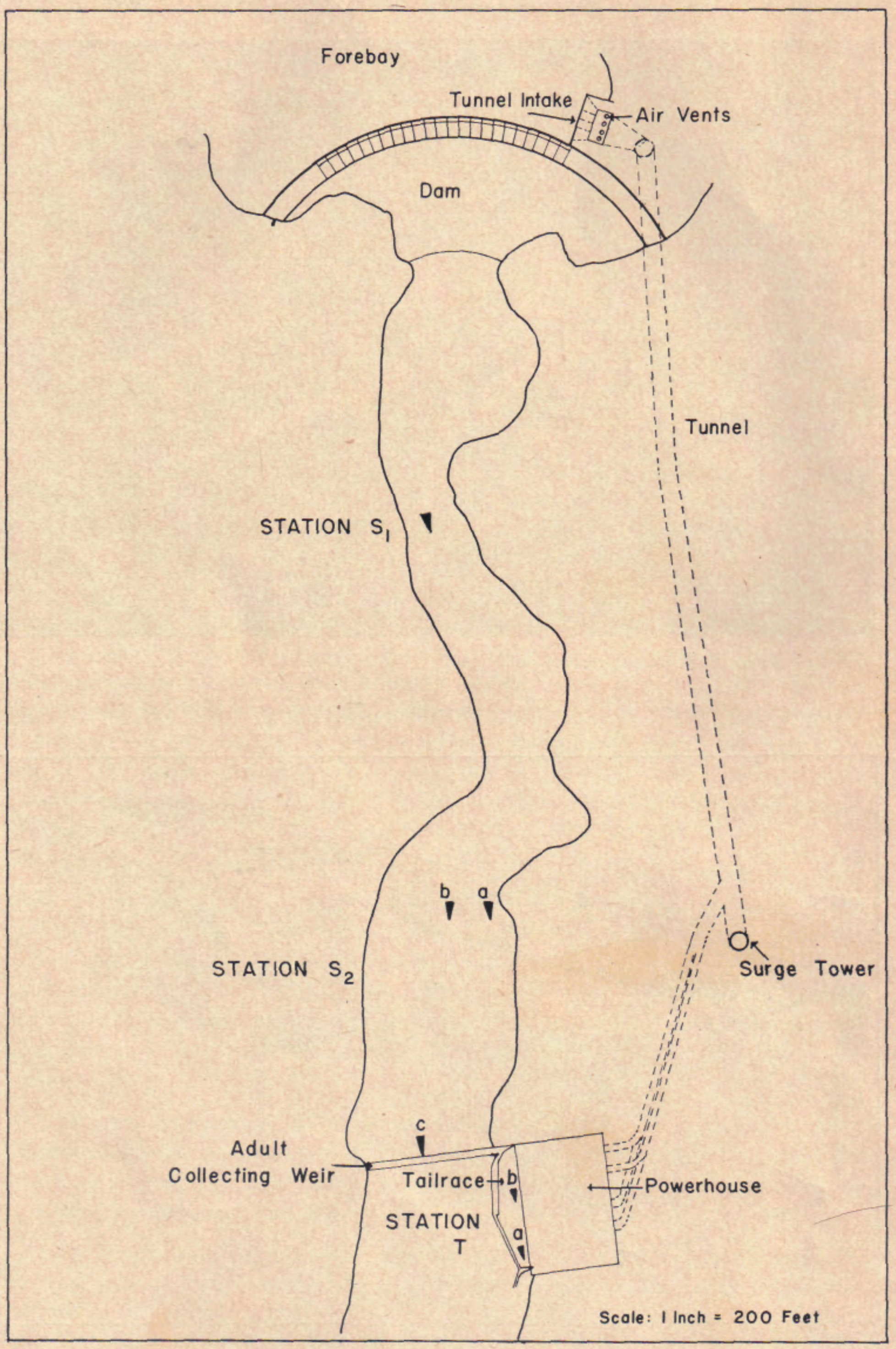


FIGURE 3. Location sketch of fishing gears operated below Baker Dam.

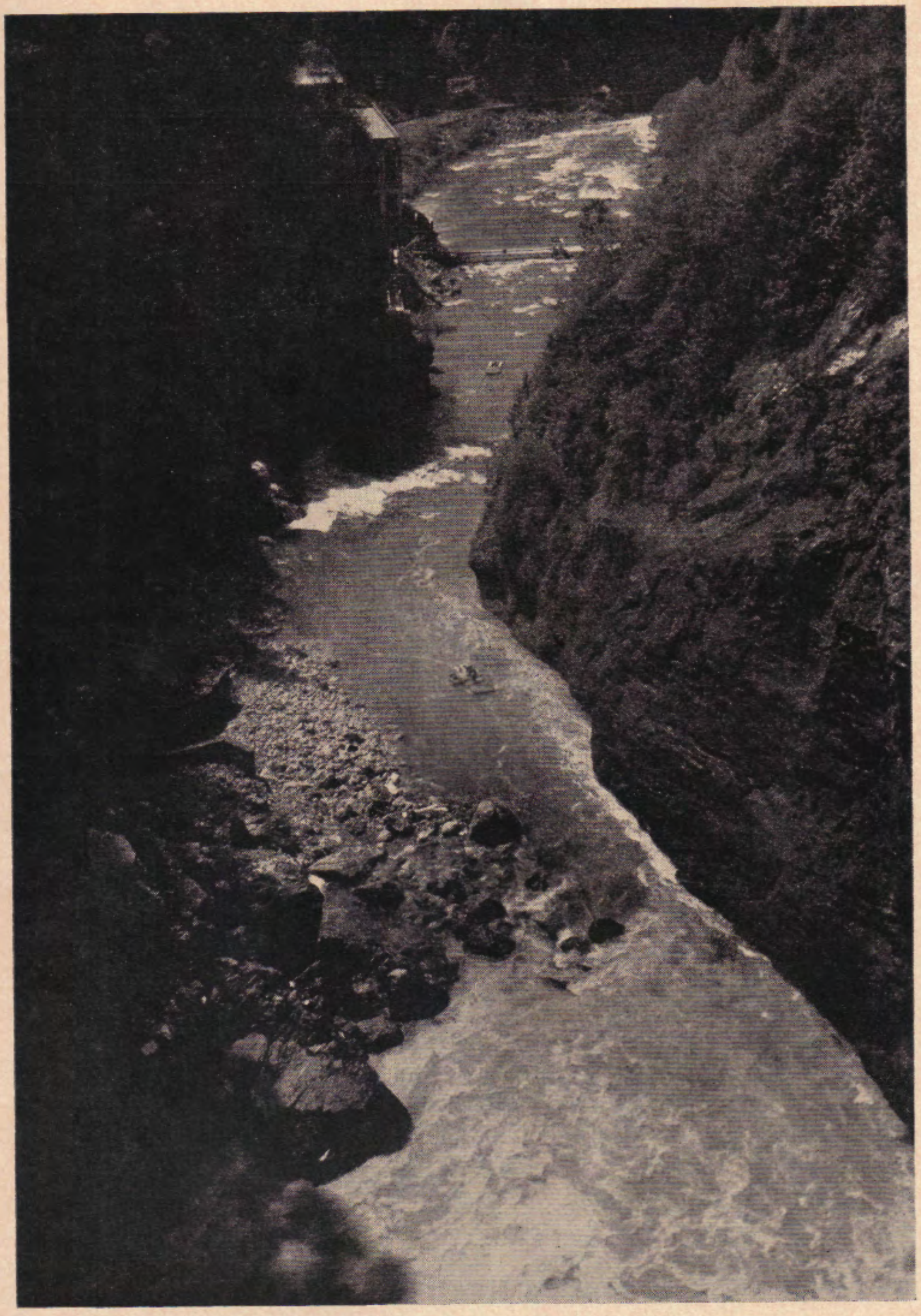


FIGURE 4. Spillway section of the Baker River looking downstream from the deck of the dam. Net S_1 is shown in the center of the photograph and S_{2b} 400 feet farther downstream.

TABLE I

Type and Number of Fishing Gears Operating in Each Fishing Station in 1951 and 1952

Year	*Station Number*	*Number of Gears*	*Gear Number*	*Type of Gear*
1951	T	2	T_a	Fyke net with survival box.
			T_b	Fyke net.
	S_2	3	S_{2a}	Fyke net with canvas hose to survival box.
			S_{2b}	Fyke net.
			S_{2c}	Wire fyke net.
1952	T	2	T_a	Fyke net with survival box.
			T_b	Fyke net.
	S_1	1	S_1	Pontoon gear with survival box.
	S_2	2	S_{2a}	Fyke net with canvas hose to survival box.
			S_{2b}	Pontoon gear with survival box.
	ST	1	ST	Pontoon gear with survival box.

Salmon Hatchery at Marblemount. Several thousand sockeye were obtained from Cultus Lake, tributary to the Fraser River.

A simple method for capturing the Baker River native sockeye and coho was devised. A basket-type net, as shown in Figure 5, approximately 20 feet long and 14 feet wide made of one-half-inch stretched mesh, spread by two-inch-square wooden cross members at each end and supported by floats along the two sides was lowered into the forebay at the face of the dam. The bottom of the net was submerged so that fish swimming along the face of the dam could pass over the net from either end. When a school of fish passed over the net it was raised quickly at each end, thus trapping the fish. The fish were removed from the net and placed in floating live boxes where they were held in active condition until marked and released.

Only active vigorous fish were used for live releases. Some marked fish were killed for release as dead fish over the spillway and into the tunnel to determine the relative availability of live fish and dead fish to the gears. In the 1951 study native coho, hatchery coho and native sockeye were used as dead releases. These fish were killed with formaldehyde before release. In 1952 hatchery coho and Cultus Lake sockeye were used for this purpose. These fish were killed immediately before release by throwing them forcefully onto a concrete floor. Fish killed with formaldehyde were rigid and quite unlike native

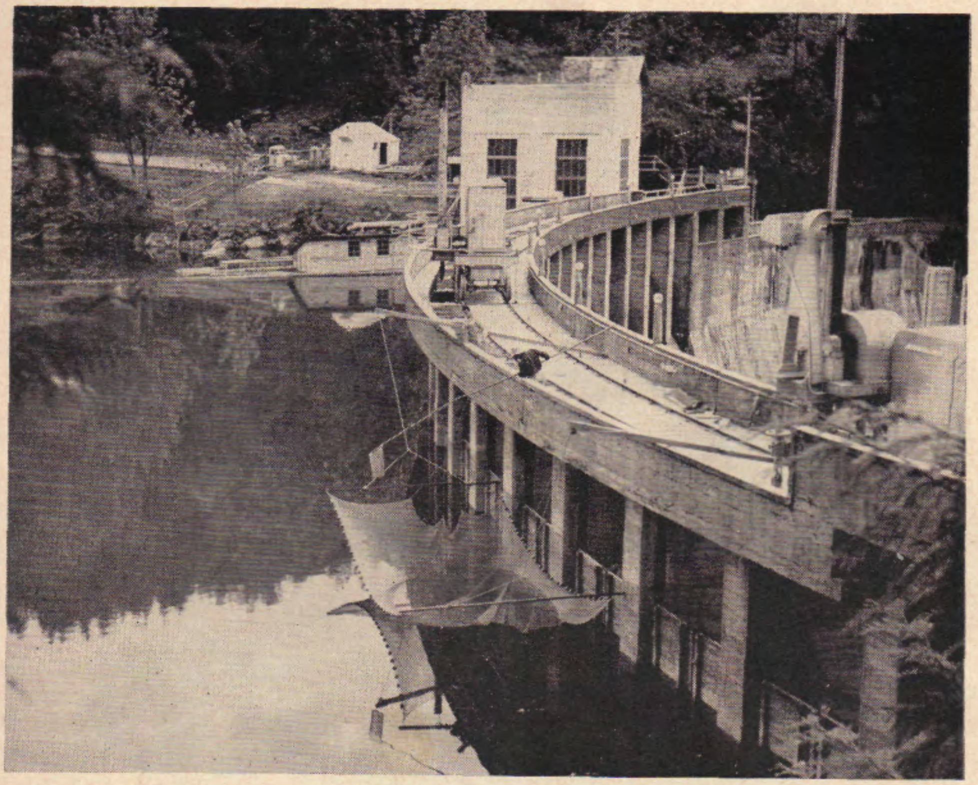


FIGURE 5. Basket-type net used for catching native sockeye and coho migrants in the forebay at Baker Dam.

fish that had been killed while passing over the dam whereas fish killed by the other method resembled those fish killed in descent over the dam.

Releasing over the crest of the dam was accomplished by lowering buckets containing marked fish to the water surface of the forebay far enough upstream from the open spillway gate so that the fish could orient themselves to the direction of the current before going over the spillway but close enough to the gate opening to ensure that no fish could swim upstream against the current and escape back into the reservoir (Figure 6). One hundred to two hundred fish were released at a time. Marked dead fish were released in the same manner and at the same time as the marked live releases.

Releasing fish into the tunnel 85 feet below the reservoir surface was a more difficult operation. Access to the tunnel was gained through one of the air vents which extend from the gate house floor to the top of the tunnel about 16 feet downstream from its entrance. The fish were released into the tunnel at a point where the velocity was approximately 4.5 feet per second.

Approximately 100 fish were released at a time into the tunnel in the following manner. A cloth approximately two feet in diameter was placed across the top of a two-gallon pail. The centre of the cloth was then pushed downward to the bottom of the pail while the outer margin of the cloth remained at the top of the pail, thus forming a bag. Fish and water were poured into the bag. The open end of the cloth bag was then closed up and cinched with a piece of fine thread. The bag containing the water and fish and weighted with a small bag of sand was removed from the pail. It was quickly lowered down the air vent on

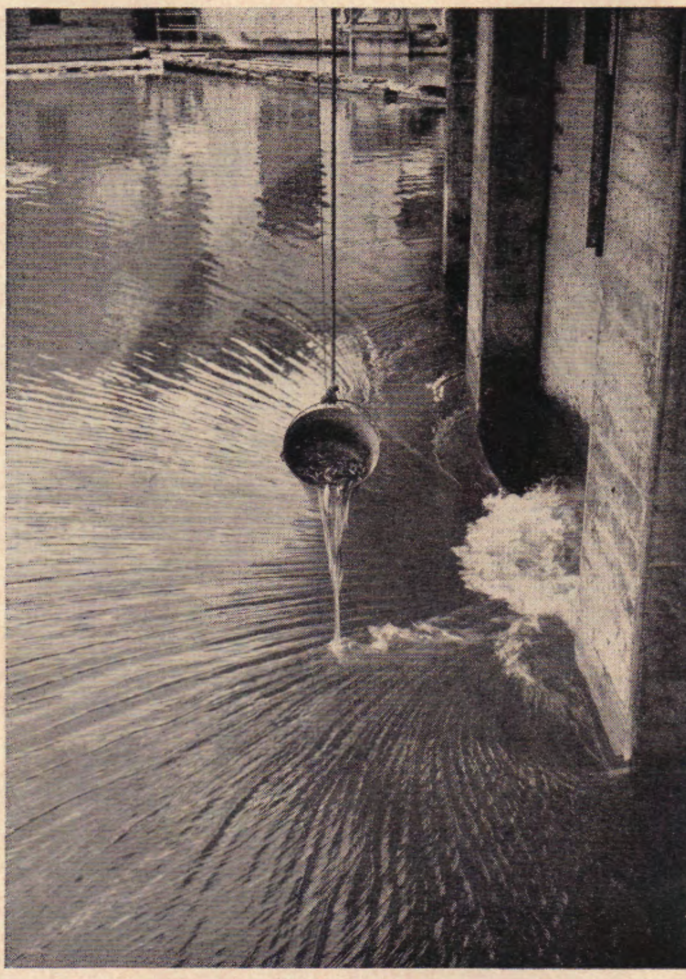


FIGURE 6. Releasing marked fish at an open spillway gate.

a rope until the tunnel was reached. When the current in the tunnel pulled the bag the lowering line was jerked sharply, breaking the thread which closed the bag of fish. A few moments later, after the fish had escaped, the sandbag and cloth were retrieved. Approximately 30 seconds elapsed between the time the fish were introduced into the bag and the time when they were released into the tunnel.

In addition to the principal method of investigation, two other methods were employed for measuring the mortalities incurred by downstream-migrant sockeye salmon passing over the spillway and through the turbines. The first of these consisted of comparing the relative returns of marked adult sockeye that were released as yearling migrants over the spillway, into the tunnel and in the river below the dam. The marked fish released into the river were unaffected by the spillway or turbines and therefore their rate of return served as a control with which the rates of return of the spillway and turbine releases could be compared. The second method involved a study of the size of the Baker River adult sockeye run before and after construction of the dam using records of the catches and escapements obtained from the State of Washington Department of Fisheries.

Several special tests pertinent to the general method of sampling the migrant population with fyke net gears were conducted. These will be described in detail in later sections of this report.

MIGRATION FROM THE RESERVOIR

Under natural conditions young salmon passing from lake to stream on their way to the sea utilize a shallow surface exit. This exit is constantly available as a means of migration from the lake. Baker Dam, on the other hand, presents a different set of conditions to young salmon migrating from the reservoir. Two exits are provided, the tunnel located 85 feet below normal reservoir elevation and the spillway openings located at the crest of the dam. The availability of either is dependent on the operation of the plant and on the level of the water in the reservoir as explained in the following paragraph.

During the month of April and part of May the plant operated daily from about 6 a.m. until 12 midnight. After May 4 in 1951 and May 12 in 1952 continuous plant operation was maintained until the termination of the investigation. Consequently, the tunnel exit was available for fish every day during the period of migration. The surface or spillway exit was not available every day throughout the period of migration. In 1951 the spillway gates were first opened on April 29. In 1952 no spilling occurred until May 13 because the reservoir level remained below the spillway crest. After the initial spilling the gates were closed at frequent intervals.

The character of the migration from the reservoir is governed by these artificial conditions, a subsurface exit located 85 feet below the lake surface which is available daily and a surface exit which is more variable in its time of availability. It will be shown that the reaction of the migrating fish to these artificial conditions has an important bearing on their survival.

Period and Character of the Migration

Observations of the migration from the reservoir were made as early as April 3, at which time no fish were seen in the forebay but downstream-migrant coho were found on the gratings at the top of the tunnel air vents. These fish must have been in the tunnel, since the only means of entry into the air vents was through the tunnel, and were presumably migrating from the reservoir. The earliest date that a net was set in the tailrace for the purpose of catching tunnel

TABLE II

Number of Native Sockeye and Coho Migrants Captured in Nets in the Tailrace in 1951

	SOCKEYE			COHO		
	Number of Fish Taken			*Number of Fish Taken*		
Date	*Net T_a*	*Net T_b*	*Total*	*Net T_a*	*Net T_b*	*Total*
April 14 - 18	–	0	0	–	0	0
19	–	0	0	–	1	1
20	0	0	0	0	2	2
21	0	0	0	0	0	0
22	0	0	0	1	1	2
23	0	0	0	0	1	1
24	0	0	0	2	0	2
25	0	0	0	2	0	2
26	0	0	0	1	0	1
27	1	0	1	2	0	2
28	0	0	0	8	1	9
29	1	0	1	4	0	4
30	2	–	2	2	–	2
May 1	0	–	0	3	–	3
2	1	–	1	3	–	3
3	1	–	1	1	–	1
4	2	0	2	2	0	2
5	5	0	5	3	0	3
6	0	0	0	1	0	1
7	3	0	3	2	0	2
8	0	0	0	0	1	1
9	0	1	1	0	0	0
10	10	3	13	1	3	4
11	–	–	–	–	–	–
12	2	1	3	2	2	4
13	0	0	0	0	0	0
14	1	0	1	2	0	2
15	6	0	6	1	0	1
16	7	0	7	7	0	7
17	0	0	0	1	1	2
18	2	3	5	0	0	0
19	4	4	8	0	0	0
20	6	1	7	3	4	7
21	1	1	2	1	1	2
22	2	0	2	1	0	1
23	0	–	0	0	–	0
24	1	1	2	0	0	0
25	1	0	1	0	1	1
26	1	0	1	9	3	12
27	1	0	1	0	0	0
28	3	0	3	6	0	6
29	3	0	3	5	3	8
30	12	1	13	20	3	23
31	5	1	6	16	6	22
June 1	3	0	3	11	3	14
2	9	0	9	12	2	14
3	10	1	11	23	2	25
4	15	2	17	25	6	31
5	1	1	2	0	1	1
6	4	0	4	3	3	6
7	1	0	1	1	1	2
Totals	127	21	148	187	52	239

NOTE: The symbol (–) denotes that a gear was not operated that day.

TABLE III

Number of Native Sockeye and Coho Migrants Captured in the Nets in the Tailrace in 1952

	SOCKEYE			COHO		
	Number of Fish Taken			Number of Fish Taken		
Date	Net T_a	Net T_b	Total	Net T_a	Net T_b	Total
April 10	–	0	0	–	0	0
11	–	0	0	–	1	1
12	–	0	0	–	4	4
13	–	0	0	–	6	6
14	–	0	0	–	8	8
15	–	0	0	–	8	8
16	–	0	0	–	5	5
17	–	0	0	–	6	6
18	–	0	0	–	3	3
19	–	0	0	–	0	0
20	–	0	0	–	2	2
21	–	0	0	–	8	8
22	–	0	0	–	3	3
23	–	0	0	–	0	0
24	1	0	1	7	4	11
25	0	0	0	5	5	10
26	0	0	0	0	0	0
27	–	1	1	–	6	6
28	1	0	1	0	2	2
29	1	0	1	13	0	13
30	1	0	1	13	4	17
May 1	0	0	0	5	3	8
2	1	0	1	0	0	0
3	3	0	3	1	0	1
4	2	0	2	7	0	7
5	1	0	1	4	3	7
6	0	0	0	3	0	3
7	0	1	1	3	0	3
8	0	0	0	1	0	1
9	3	1	4	8	2	10
10	1	0	1	2	0	2
11	0	–	0	0	–	0
12	0	–	0	1	–	1
13	3	–	3	8	–	8
14	8	–	8	5	–	5
15	2	–	2	9	–	9
16	–	–	–	–	–	–
17	1	–	1	1	–	1
18	0	–	0	1	–	1
19	4	–	4	2	–	2
20	1	–	1	2	–	2
21	2	–	2	1	–	1
22	0	–	0	4	–	4
23	2	–	2	1	–	1
24	1	–	1	2	–	2
25	0	–	0	3	–	3
26	1	–	1	0	–	0
27	0	–	0	1	–	1
28	0	–	0	2	–	2
29	0	–	0	0	–	0
30	0	–	0	0	–	0
31	1	–	1	1	–	1
June 1	–	–	–	–	–	–
2	1	–	1	5	–	5
3	2	–	2	1	–	1
Totals	44	3	47	122	83	205

NOTE: The symbol (–) denotes that a gear was not operated that day.

migrants was April 10 in 1952. This gear captured a coho migrant on April 11 (Table III). Coho were still migrating from the reservoir on June 18 in 1952 when the experiment was discontinued (Table V). The sockeye migration followed a very similar time pattern. The fyke net catches in the tailrace and in the river indicate that the migration started on April 27, 1951 and April 24, 1952 and was drawing to a close by the end of the study on June 18, 1952. The migration of sockeye was still in progress when the 1951 investigation was concluded on June 7.

The migration through the tunnel seemed to occur principally at night, as shown by the catches in the tailrace gears. Similarly when the timing was not altered by closed spillway gates the normal migration over the crest of the dam was principally at night. However, during periods of very sporadic spill the spillway gates were often closed during the night and opened during the day. On such occasions the day migration over the spillway was fairly heavy.

The sockeye and coho present in the surface layers of the forebay moved in schools varying in size from a few fish to several hundred. These schools usually contained both species. The movement of migrants in the immediate forebay seemed to take place primarily along the margins. This was particularly true during periods of bright sunshine. During the early morning or evening or on days of heavy overcast the fish were observed to be more evenly distributed throughout the surface of the forebay.

When the downstream migrants approached the spillway opening they behaved in a rather consistent manner. While approaching the spillway and yet still some distance from it they swam with the current in the direction of the opening. As the fish drew closer to the spillway and the velocities increased, they turned and commenced to swim against the current while being drawn towards the gate opening. On entering the opening the fish swam very vigorously but few fish were able to escape from the high velocities at this point.

Tunnel versus Spillway as a Migration Route

The relative number of native sockeye and coho migrants passing over the spillway and through the tunnel was determined from the fyke net catches at Station S_2 and Station T. The number of migrants captured in the gears at these locations are given in Tables II to V. In order to make a valid comparison between the catches in the two locations it was necessary to measure the fishing efficiency of each gear so that the catches in the tailrace and in the river below the spillway could be compared on a common basis. This was done by comparing the recoveries of marked sockeye and coho migrants released over the spillway and into the tunnel at frequent intervals throughout the investigation. Sufficient fish were not available for daily release. However, the releases were arranged in such a manner that wherever possible more than one was made for each discharge condition. In addition to native coho, hatchery fish of the same species were also employed in the tests thereby making possible twice as many tests with coho.

To determine if hatchery coho could be used to measure the fishing efficiency of the gears the numbers of native and hatchery coho taken in each fishing gear were compared and the differences were tested for significance by the method of Chi-square (Snedecor, 1940). Chi-square values corresponding to probabilities of less than 5 per cent were considered to be significant. Only Net T_a in 1952 showed a significant difference in the recoveries of native and hatchery coho. A Chi-square value of 8.01 with a corresponding P value of less than 1 per cent for one degree of freedom was obtained. Therefore, only native fish could be used in establishing the fishing rate of Net T_a. The differences in the number of native and hatchery fish recovered in all other nets were not significant. In determining the fishing rates of these gears, therefore, hatchery and native coho were combined.

TABLE IV

Number of Native Sockeye and Coho Migrants Captured in Nets in the River below the Spillway in 1951

		SOCKEYE				*COHO*				*Number of*
		Number of Fish Taken				*Number of Fish Taken*				*Gates*
Date		*Net S_{2a}*	*Net S_{2b}*	*Net S_{2c}*	*Total*	*Net S_{2a}*	*Net S_{2b}*	*Net S_{2c}*	*Total*	*Full Open*
May	5	5	–	1	6	6	–	1	7	1
	6	12	–	10	22	41	–	22	63	1
	7	–	–	–	–	–	–	–	–	1–2
	8	–	–	0	0	–	–	1	1	1
	9	46	–	52	98	36	–	50	86	1
	10	102	–	61	163	95	–	63	158	1–2
	11	–	–	–	–	–	–	–	–	2–5
	12	–	–	–	–	–	–	–	–	1–3
	13	30	–	34	64	25	–	20	45	1
	14	3	–	0	3	8	–	5	13	1
	15	48	–	34	82	37	–	26	63	1
	16	7	–	7	14	21	–	15	36	1
	17	32	–	27	59	76	–	48	124	1
	18	57	12	27	96	101	34	63	198	1
	19	43	174	15	232	82	231	37	350	1
	20	–	–	–	–	–	–	–	–	2
	21	3	37	52	92	13	107	82	202	1–2
	22	22	99	6	127	32	74	13	119	1–2
	23	–	23	9	32	–	80	70	150	2–3
	24	–	18	18	36	–	127	63	190	2–3
	25	7	43	5	55	80	480	58	618	1–3
	26	–	–	–	–	–	–	–	–	1
	27	12	48	9	69	130	533	40	703	1
	28	0	4	0	4	3	55	11	69	1
May 29-June 3		–	–	–	–	–	–	–	–	0
June	4	0	8	4	12	55	138	15	208	1
	5	11	39	4	54	121	333	21	475	1
	6	16	36	6	58	150	312	37	499	1
	7	4	–	0	4	30	–	22	52	1
Totals		460	541	381	1382	1142	2504	783	4429	

TABLE V

Number of Native Sockeye and Coho Migrants Captured in Nets in the River below the Spillway in 1952

	SOCKEYE			COHO			
	Number of Fish Taken			Number of Fish Taken			Number of Gates
Date	Net S_{2a}	Net S_{2b}	Total	Net S_{2a}	Net S_{2b}	Total	Full Open
May 13	136	–	136	178	–	178	2
14	339	–	339	355	–	355	1–2
15	367	–	367	503	–	503	1
16	83	80	163	258	138	396	1–2
17	39	31	70	206	108	314	2
18	–	–	–	–	–	–	3
19	8	15	23	20	31	51	2
20	9	6	15	29	28	57	2
21	1	20	21	11	38	49	1
22	29	27	56	118	59	177	1
23	33	15	48	126	85	211	1
24	22	37	59	158	190	348	1
25	16	30	46	169	164	333	1
26	17	0	17	275	23	298	1–2
27	10	2	12	162	122	284	1–2
28	6	1	7	152	12	164	2
29	3	6	9	124	89	213	1–2
30	6	4	10	68	122	190	1
31	4	0	4	41	62	103	1
June 1	–	–	–	–	–	–	0
2	3	–	3	121	–	121	1
3	11	–	11	102	–	102	1
4	–	–	–	–	–	–	1–6
5	–	–	–	–	–	–	3–6
6	0	–	0	3	–	3	1
7	3	3	6	15	25	40	1
8	4	1	5	58	37	95	1–2
9	–	–	–	–	–	–	2
10	1	0	1	14	15	29	1–2
11	0	0	0	15	57	72	1
12-16	–	–	–	–	–	–	0
17	1	5	6	88	110	198	1
18	3	1	4	82	174	256	1
Totals	1154	284	1438	3451	1689	5140	

The number of marked sockeye and coho available to the nets, the number of releases for each discharge condition and the mean percentage recovered in the various gears are given in Tables VI to IX. Net S_1, located upstream from the nets at Station S_2 was operated from June 7 to June 17 in 1952. A number of the marked test fish released during this period were caught by the upper net S_1 and consequently were not available to the lower nets at Station S_2. The number of fish available to the lower nets was obtained by subtracting the number of fish caught by the upper net from the total number released. It was necessary

TABLE VI

Number Recovered of Marked Native Sockeye Migrants Released Over the Spillway and Available to Nets at Station S_2 in 1951 and 1952

No. of Spillway Gates Open	Net S_{2a}				Net S_{2b}				Net S_{2c}			
	No. of Releases	No. Released	Recoveries* No.	Recoveries* %	No. of Releases	No. Released	Recoveries* No.	Recoveries* %	No. of Releases	No. Released	Recoveries* No.	Recoveries* %
1951												
One Gate	5	3003	50	1.67 ± .77	1	572	30	5.24	4	2971	27	.91 ± .17
Two Gates					1	305	2	0.66	1	303	2	0.66
1952												
One Gate	4	7638	211	2.76 ± .50	3	6221	207	3.33 ± 2.83				
Two Gates	1	1222	20	1.64	1	1222	32	2.62				

* Per cent recoveries include 95 per cent confidence intervals.

TABLE VII

Number Recovered of Marked Native and Hatchery Coho Migrants Released Over the Spillway and Available to the Nets at Station S_2 in 1951 and 1952

No. of Spillway Gates Open	Net S_{2a}				Net S_{2b}				Net S_{2c}			
	No. of Releases	No. Released	Recoveries* No.	Recoveries* %	No. of Releases	No. Released	Recoveries* No.	Recoveries* %	No. of Releases	No. Released	Recoveries* No.	Recoveries* %
1951												
One Gate												
Position 1	8	4210	60	1.43 ± .34	5	2372	154	6.49 ± .51	12	5126	41	0.80 ± .53
Position 2	3	1055	30	2.84 ± 1.29								
Two Gates					3	1594	40	2.51 ± 2.73	3	1554	13	0.84 ± 1.11
1952												
One Gate	10	13483	378	2.80 ± 0.67	7	10053	481	4.78 ± .81				
Two Gates	3	4920	186	3.78 ± 0.52	2	3918	151	3.85				

* Per cent recoveries include 95 per cent confidence intervals.

to follow this same procedure in 1951 for Net S_{2c} by deducting the catches of the two upper nets S_{2a} and S_{2b} from the number of fish released.

Toward the end of the study in 1951 the position of Net S_{2a} was changed. The effect of this change on the fishing efficiency of the gear was measured by the release of marked coho. As shown in Table VII the relocation of the net approximately doubled the recovery rate. No release of sockeye migrants was made with Net S_{2a} in its new position but the change in recovery of marked coho from one net position to the other is assumed to measure the relative change that would be expected for sockeye. In its original position Net S_{2a} caught an average of 1.67 per cent of the marked sockeye released over the spillway. Using the relationship established by the recovery of marked coho it was calculated that for sockeye the recovery rate of Net S_{2a} in its new position would be 3.32 per cent.

TABLE VIII

Number of Marked Native Sockeye Migrants Released into the Tunnel and Recovered in the Tailrace Nets in 1951 and 1952

	Net T_a				Net T_b			
Year	No. of Releases	No. Released	Recoveries No.	Recoveries %	No. of Releases	No. Released	Recoveries No.	Recoveries %
1951	9	2626	112	4.27	8	2574	53	2.06
1952	2	871	36	4.13	2	871	0	0

TABLE IX

Number of Marked Native and Hatchery Coho Migrants Released into the Tunnel and Recovered in the Tailrace Nets in 1951 and 1952

	Net T_a				Net T_b			
Year	No. of Releases	No. Released	Recoveries* No.	Recoveries* %	No. of Releases	No. Released	Recoveries* No.	Recoveries* %
1951	13	5670	202	3.56 ± 1.06	8	4635	84	1.81 ± .57
1952	3	2820	187	6.63 ± .69	3	2621	34	1.30 ± .10

* Per cent recoveries include calculated 95 per cent confidence intervals.

Where possible, a confidence interval was calculated for each mean percentage recovery. An analysis of the recoveries of marked fish by the method of Chi-square revealed that the rates of recovery in certain nets were not homogeneous. Therefore in determining the confidence intervals the following procedure was used.

Let u = mean percentage recovery. Then the 95 per cent confidence interval for u is $\bar{x} \pm \frac{St}{\sqrt{n}}$

where $\bar{x}$ = estimated mean percentage recovered

n = total number of observations

S^2 = variance

t = Students "t" (5 per cent confidence point with $n - 1$ degrees of freedom).

Shown in Tables VI, VII and IX are the 95 per cent confidence intervals for the mean recovery rates for nets operating during more than two releases. Confidence intervals could not be calculated for sockeye in 1951 in the tailrace nets because the nature of the recoveries showed that a number of the released fish did not move through the tunnel immediately after release. Since some sockeye were recovered as much as one week after the date of release and the releases were not spaced sufficiently far apart it was impossible to associate recoveries with specific releases. The coho for some unknown reason were not delayed in the tunnel to the same extent.

Having established the rate of fishing of each gear it is possible to compute the total number of fish migrating over the spillway or through the tunnel. This can be done very conveniently with the aid of the following equation.

$$N = \frac{nt}{S}$$

where N = estimated number of migrating fish

n = number of unmarked fish captured

S = number of marked fish captured

t = number of marked fish released

Knowing the appropriate fishing rate$\left(\frac{S}{t}\right)$, the numbers of fish passing over the spillway and through the tunnel each day were determined. Since neither the gears in the tailrace nor in the river operated for the same length of time each day, the daily migration has been expressed as the number of fish migrating per hour. When more than one gear was operating at a single station the number of fish migrating was determined from the catch of each net separately. These values were summed and the total divided by the total number of hours of fishing by all gears at the station to arrive at the number of fish migrating per hour. Since no marked sockeye were captured in Net T_b in 1952 the catches of unmarked native sockeye in this net could not be used to aid calculation of the rate of migration of native sockeye through the turbine. The computed numbers of fish passing over the spillway and through the tunnel per hour of fishing each day in 1951 and 1952 are plotted in Figures 7 to 10.

Both sockeye and coho migrants used the tunnel very sparingly in their migration when the reservoir was full or nearly full. The mass exodus of sockeye and coho migrants from the reservoir following the opening of the gates on

May 13 in 1952 indicated that the fish had accumulated in large numbers behind the dam (Figures 9 and 10). Yet despite this accumulation there was no apparent increase in the number of sockeye and coho using the tunnel during the period of spill closure.

In 1951 the reservoir remained full during the migration period, but in 1952 the reservoir level varied considerably in height (Figures 9 and 10). This resulted in a variation in the depth of water cover over the tunnel intake. On April 11 in 1952 the intake was only 44 feet below the lake surface. From this date onward the reservoir gradually filled but not until May 13 did it reach the full level at which time the tunnel was submerged 85 feet. This variation in the depth of the tunnel intake affected the number of coho migrants passing through the tunnel. Although the migration (Figure 10) had barely started during the period of low reservoir elevation more coho passed through the tunnel at this stage than at any time to follow. As the water cover over the tunnel increased, the number of fish using the tunnel gradually decreased. This is particularly significant when it is recognized that the coho population in the forebay was constantly building up. Despite the increase in the available fish the number using the tunnel decreased with increased water cover.

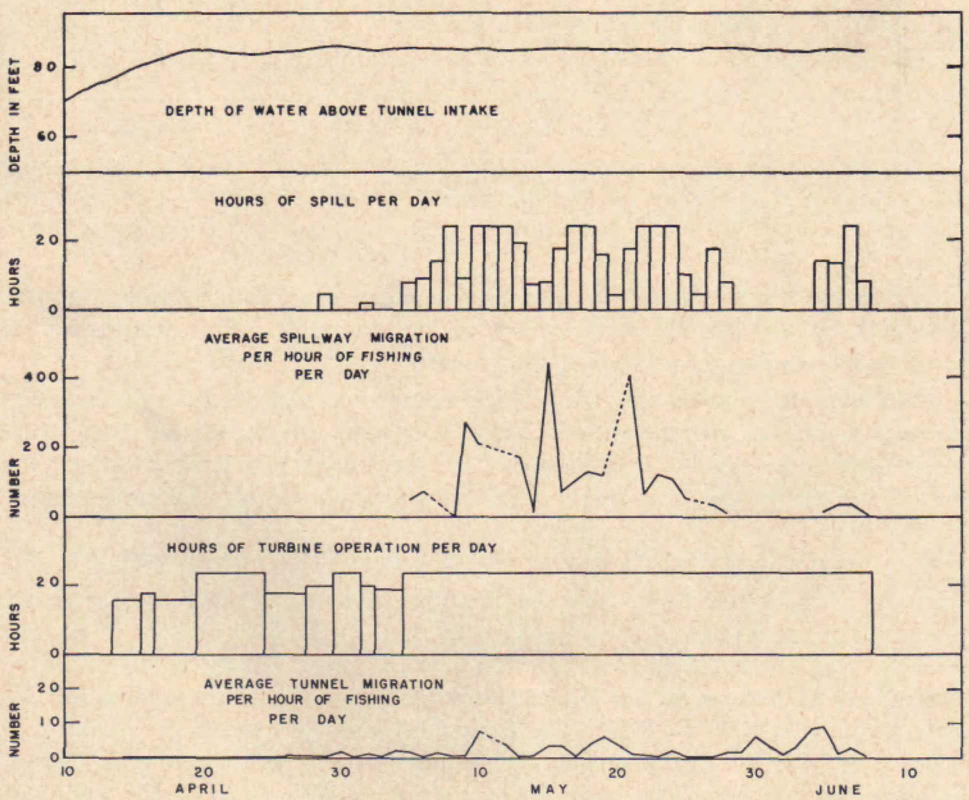


FIGURE 7. Calculated number of sockeye passing per hour over the spillway and through the turbines in 1951. Period of spill and plant operation also shown. Depth of tunnel intake shown in upper graph.

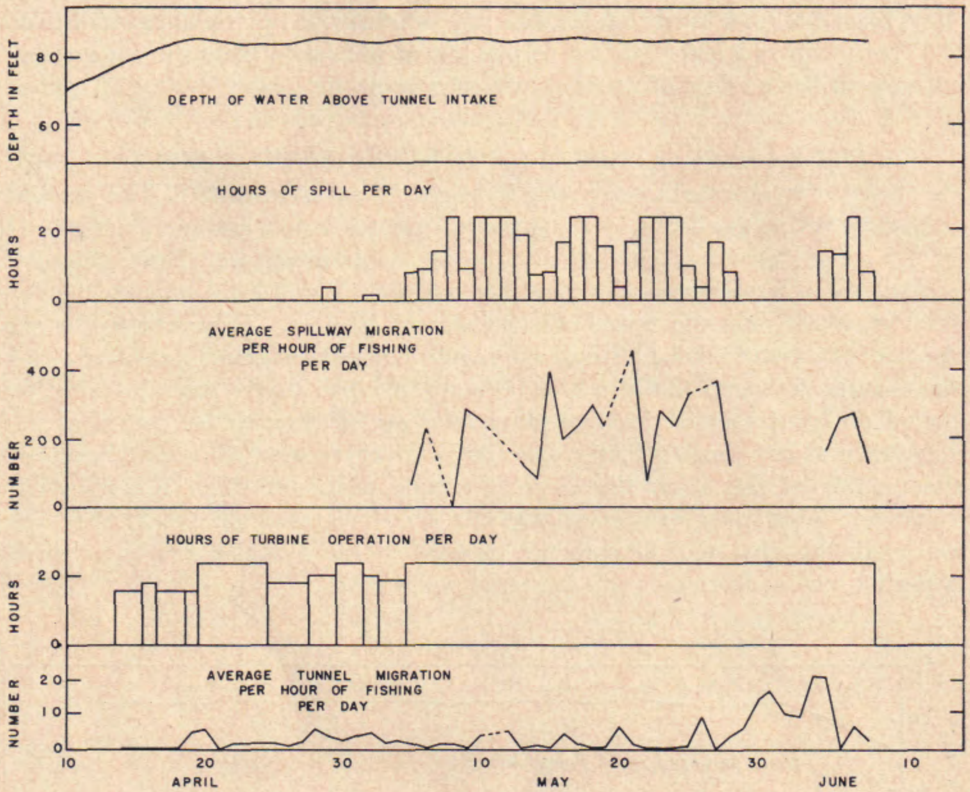


FIGURE 8. Calculated number of coho passing per hour over the spillway and through the turbines in 1951. Period of spill and plant operation also shown. Depth of tunnel intake shown in upper graph.

The use of the tunnel as a migration route may also be related to the temperature and thermal stratification of the reservoir. This relationship is discussed beginning on page 61 of this report.

In addition to calculating the relative numbers of sockeye and coho migrants using the spillway and tunnel exits on a daily basis an attempt has been made to determine the relative proportions of the total migrating stock that used the tunnel and the spillway exit during the entire migration period. The same formula $N = \left(\frac{nt}{S}\right)$, used above for calculating the number of fish migrating per hour each day, can be used here. Also the formula can be used to develop confidence limits for the estimates. For example, an estimate of the total number of sockeye passing over the spillway in 1952 when one gate was spilling is desired from the catches of sockeye in Net S_{2a}. The total catch of unmarked sockeye for one gate of spill was 679 in 1952. The fishing efficiency or percentage recovery of marked sockeye for that year was $2.76 \pm .50$ (Table VI). Knowing the fishing efficiency of the gear the catch (679) represents 2.26 $(2.76 - .50)$ and 3.26 $(2.76 + .50)$ per cent of the total migration during one gate spill. Therefore the confidence limits for this part of the total migration are:

$$\frac{679}{.0226} = 30{,}044, \quad \frac{679}{.0326} = 20{,}828$$

while the best estimate of the number migrating is: $\frac{679}{.0276} = 24{,}601.$

The numbers of sockeye and coho passing over the spillway when the gears were in operation in 1951 and 1952 were calculated in this manner from the total catches of unmarked native fish in Net S_{2a}. The calculated numbers of sockeye and coho passing through the tunnel in 1951 were based on the catches of Net T_a. In 1952 the first portion of the coho migration, April 11 to April 23, was enumerated from the catches of Net T_b while the number of fish in the remainder of the migration was calculated from the catch of Net T_a only. The rates at which fish were captured by the gears as furnished by the recovery of marked releases have been referred to previously and are presented in Tables VI to IX and in the text. The total number of fish taken during the entire fishing period by the gears are presented in Tables II to V. Confidence limits were not calculated

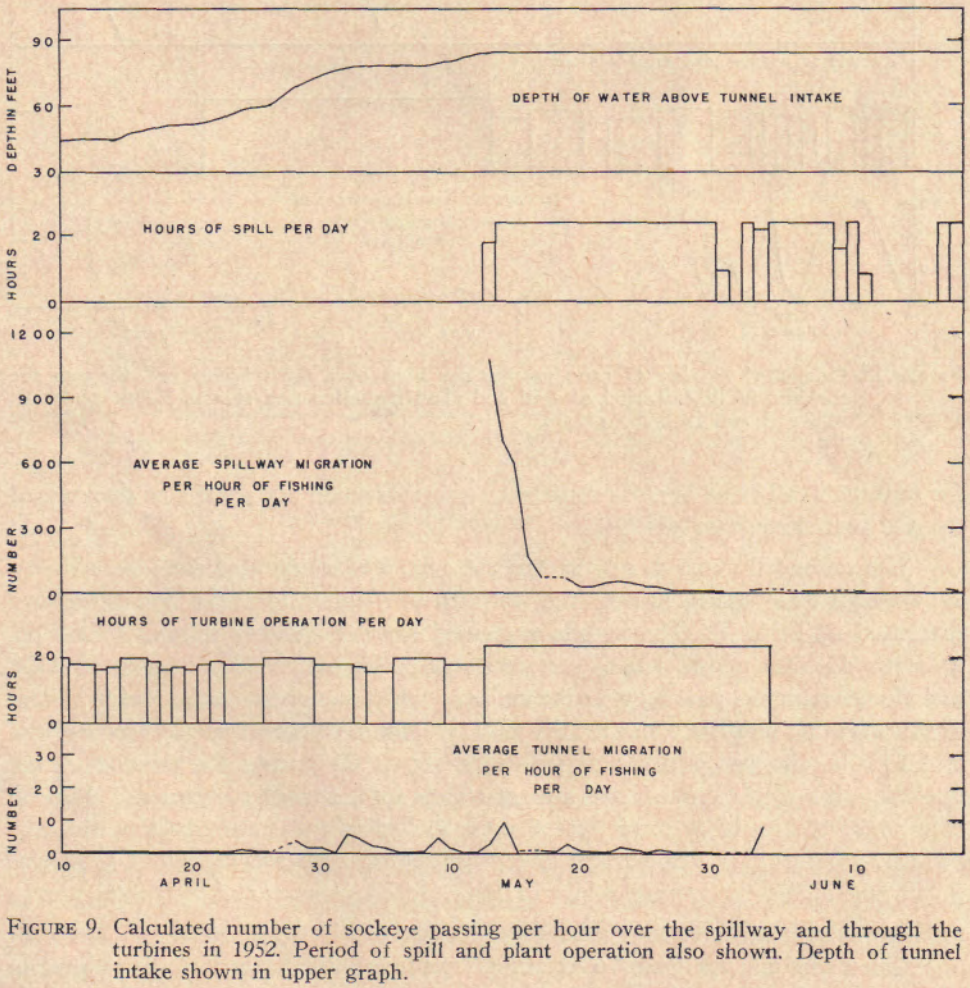


FIGURE 9. Calculated number of sockeye passing per hour over the spillway and through the turbines in 1952. Period of spill and plant operation also shown. Depth of tunnel intake shown in upper graph.

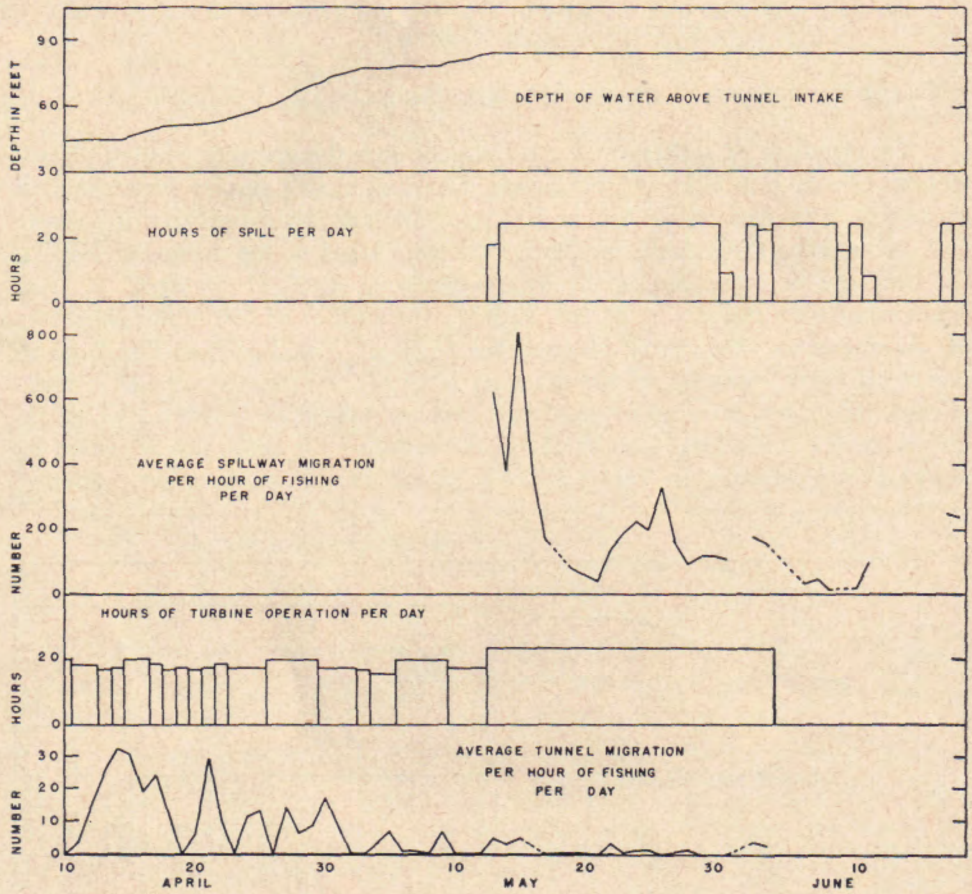


FIGURE 10. Calculated number of coho passing per hour over the spillway and through the turbines in 1952. Period of spill and plant operation also shown. Depth of tunnel intake shown in upper graph.

for sockeye in all cases because confidence intervals could not always be determined for the percentage recoveries.

The estimated numbers of sockeye and coho which migrated over the spillway or through the tunnel during the periods of fishing in 1951 and 1952 are presented in Table X. The figures presented for the spillway migration in 1951 are only for the period when one gate was spilling. Those presented in 1952 include the numbers passing over the spillway when one or two gates were spilling. When Net S_{2a} was in operation in 1951 it was estimated than 25,680 sockeye and 54,965 coho passed over the spillway. In 1952, during the periods of net operation for conditions of one and two gate spill, 53,560 sockeye and 113,700 coho were estimated to have passed over the spillway. In contrast to this the estimated number of sockeye and coho passing through the tunnel in 1951 was 2,970 and 5,250 respectively while in 1952, 1,070 sockeye and 5,990 coho were estimated to have passed through the tunnel.

Since the tailrace gears operated almost continously during the migration period the figures for the tunnel migration can be considered to be fairly representative of the actual number of fish passing through the tunnel during the period of migration. However, no measures of the numbers of fish passing over the spillway in 1951 when more than one gate was open or when more than two gates were open in 1952 were obtained. Therefore the estimates of spillway migration shown in Table X are lower than would be expected if the entire migrating population had been sampled. Nevertheless a comparison between the most probable estimates of the numbers of fish passing through the tunnel and over the spillway when the gears were operating in 1952 shows *that 98 per cent of the sockeye and 95 per cent of the coho migrating from the reservoir used the spillway exit.*

TABLE X

Calculated Number of Native Sockeye and Coho Passing Over the Spillway and Through the Tunnel During the Periods when the Nets were Fishing. 95 Per Cent Confidence Limits Also Shown

		COHO			*SOCKEYE*		
		Calculated	*Confidence Limits**		*Calculated*	*Confidence Limits**	
Year	*Exit*	*Number*	*Upper*	*Lower*	*Number*	*Upper*	*Lower*
1951	Spillway One Gate Position 1	54,965	1.31	.80	25,680	1.86	.68
	Tunnel	5,250	1.42	.77	2,970	—	—
1952	Spillway One Gate	86,430	1.31	.81	24,600	1.22	.85
	Two Gate	27,270	1.16	.88	28,960	—	—
	Total	113,700	1.28	.82	53,560	—	—
	Tunnel	5,990	1.19	.92	1,070	—	—

* Confidence limits expressed as a factor of the estimated number migrating.

Effect of Delay on Migration

The migration from Lake Shannon in 1951 and 1952 was governed by the availability of a surface exit which in turn was dependent on the reservoir elevation and the operation of the power plant. A temporary closure of the spillway exit compelled practically all of the fish to remain in the reservoir until this exit was again made available. An examination of the spillway records for Baker Dam from 1930 to 1952 revealed that there has been a considerable variation in the dates when the gates were first opened during the migration period. In most years spilling had started by late April; but in other years a surface exit was not available until as late as May 24.

If a delay in the spillway opening has any significant controlling effect on the number of downstream-migrant salmon that leave the reservoir then such an effect, all other things being equal, would be reflected in the annual number of adult salmon produced. Therefore a measure of the effect of delay could be obtained by comparing the number of adult fish that are produced each year with the date of initial spilling during their downstream migration. The Baker River race of sockeye salmon lends itself admirably to such a comparison. Usually in trying to determine the magnitude of the return of adult salmon the investigator is plagued by the problem of not knowing how many fish from a given race are taken by the commercial fishery because the catch is made up of several races which cannot be accurately segregated. But this does not pose a problem in the case of Baker River sockeye. The catch of sockeye at the mouth of the Skagit River and in Skagit Bay, which is the principal fishery, is of pure Baker River stock. The number of adult salmon escaping to the spawning grounds has been obtained each year since construction of the dam by the operators of the fish hauling device at the dam. The catch and escapement records have been furnished by the State of Washington Department of Fisheries. Records of spillway operation from 1930 to the present were supplied by the Puget Sound Power and Light Company.

In order to use the annual sockeye runs to measure the effect of the delay on the downstream migrants it is necessary to obtain a knowledge of the age composition of the Baker River race. Unfortunately, scale samples are not available for every year. However, from 608 individual scale samples obtained from Baker River sockeye in 1939 it was found that 82.3 per cent of the run was comprised of 4_2 fish (fish migrating to sea in their second year and maturing in their fourth year). The remainder of the run consisted of 5_2 fish (12.8 per cent) and 5_3 fish (4.9 per cent). This information was corroborated in 1940, 1941 and 1946 from scales obtained from fish that were tagged at the Sooke traps located on the south shore of Vancouver Island and subsequently recovered at Baker Dam or in Skagit Bay. In 1940 the age composition as determined from scales from 33 fish was 81.8 per cent 4_2 fish and 18.2 per cent 5_2 fish. The 4_2 fish again predominated in 1941 where 79.3 per cent of the sample of 29 fish were of the 4_2 age group. The remainder consisted of 5_2 fish. The age composition of the Baker River race as determined from 88 fish tagged at Sooke and recovered enroute to their spawning ground in 1946 was 85 per cent 4_2 fish, 12.6 per cent 5_2 fish and 2.4 per cent 5_3 fish. On the basis of this information it has been assumed that Baker River sockeye mature primarily in their fourth year.

Since both the size of the spawning stock and the size of the resulting adult return are variable it was necessary to determine the success of return from year to year in terms of rate of production. The annual rate of production is defined as

$$\frac{\text{Number of adults produced}}{\text{Number of spawners producing the adults}}$$

It was not possible to use the catch and escapement data for every year since 1930, because the escapements in certain years were subject to considerable delay below the dam which could influence the rates of production. To successfully pass the adult sockeye over the dam without causing undue delay and injury, the fish must be captured at a weir below the dam which depends on a moderate amount of spill for its operation. When spilling is discontinued the trap ceases to operate and while a secondary trap at the head of the tailrace accommodates a portion of the available fish each day the majority of the fish accumulate below the weir. With regular spill the upstream migration occurs undelayed from late June until about the middle of August but in those years in which there is little or no spill the migration is extended into late September or early October. Because of the possible ill effects of such delay on reproduction the runs of 1944 to 1946, 1948 and 1949 were disregarded.

As previously stated the period of downstream migration extended from about April 24 to June 18 and the peak of migration occurred on approximately May 15, 1952. The annual rates of production with relation to the dates of spillway opening are presented in Figure 11. The rates of production for those runs which were not delayed by the spillway opening (gates opened on April 20) varied from 1.96 to 4.24. In contrast to this the rates of production for the runs 1937, 1943 and 1950 which had been delayed during their downstream migration until at least May 15 were 6.9, 0.49 and 0.64 respectively.

The major exception in 1937 and the marked variation in production rates for those groups of fish which were undelayed by spillway opening have indicated that the declining trend shown in Figure 11 may not be the result of delay in spillway opening but may be due to some other completely unrelated factor. Annual variations in spillway mortality can probably be discounted as a major cause of the declining trend shown in the figure if only for the reason that it is unlikely that spillway mortality would be more pronounced on years of delayed spillway opening than on years of early spillway opening.

There is, however, another variable that must be considered. As already mentioned, data furnished by Barnaby (1944) show that an inverse relationship exists between the number of spawners and the rate of production of sockeye salmon in Karluk River. It can be demonstrated that this is also true for Baker River sockeye. Shown in Figure 12 are the annual rates of production of Baker River sockeye plotted against the size of the spawning stock. The low rates of production of 0.49 and 0.64 for the years 1943 and 1950 are directly related to the large spawning populations, 5,775 fish and 4,892 fish, whereas the high production rate of 6.9 in 1937 is related to the small spawning population of 660 fish in 1933. The same relationship of declining production with increase in the size of the spawning stock exists in that group of runs which were not delayed or only briefly delayed by a closed spillway exit during the seaward migration. The declining trend in this group is represented by the curves which were fitted to the points by the method of least squares. It was necessary to apply two curves because as shown in Figure 12 and again in Figure 13 four runs in this group reproduced at an exceptionally high rate and do not appear to be directly related to the remainder. The rates of production of the undelayed runs establish a trend which is not affected by spillway closure. If the lower curve in Figure 12 is extended mathematically (dotted line) it can be seen that it falls very close to the low values for 1943 and 1950. It would seem therefore that the rates of return for these delayed runs are of that magnitude which would be expected for large runs and since these points fit the trend established by the undelayed or briefly delayed runs so closely, it would appear that delay in spillway opening during the downstream migration had no appreciable effect on

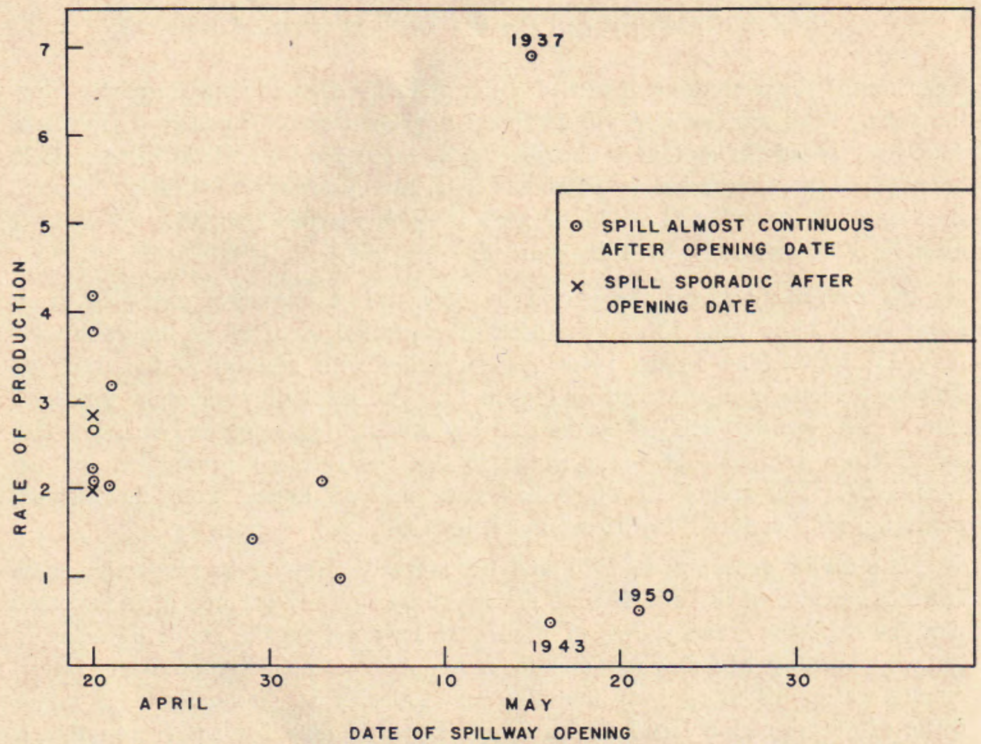


FIGURE 11. Rate of adult sockeye production in relation to date of spillway opening two years previous. April 20 selected as date for start of migration. Rate of production plotted by year in which adults returned, 1934-1943, 1947 and 1950-1953.

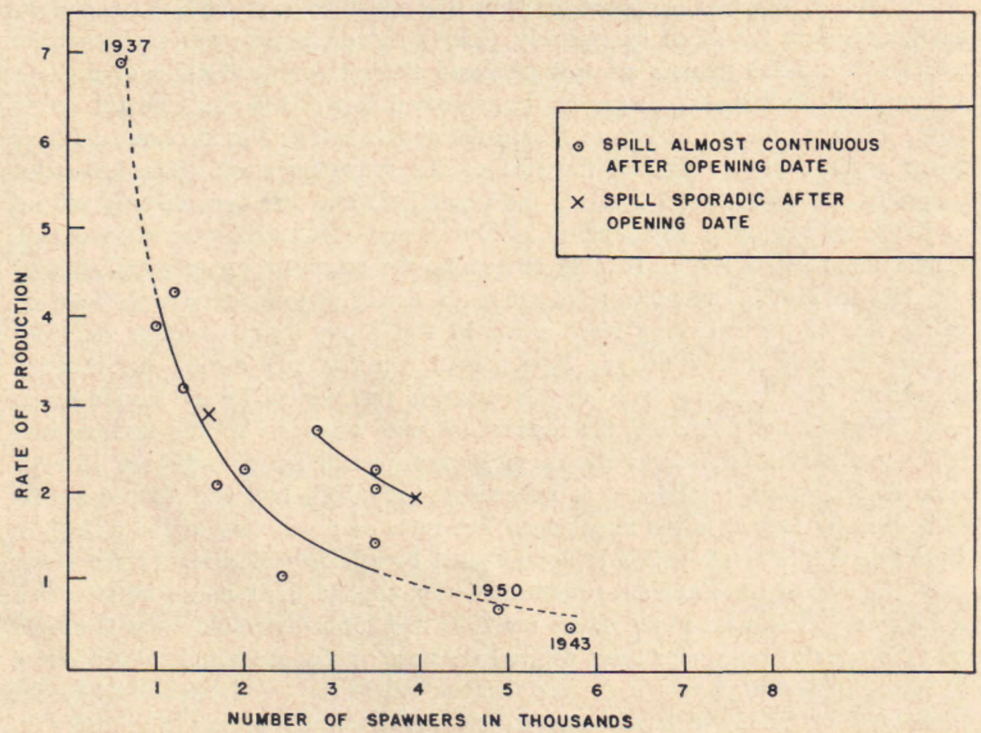


FIGURE 12. Rate of adult sockeye production with relation to size of Baker River spawning population. Rate of production plotted by year in which adults returned, 1934-1943, 1947 and 1950-1953.

the number of fish produced two years later. This is further demonstrated in Figure 13 which shows the relationship between the number of adult sockeye produced each year and the date of spillway opening during the downstream migration. It is apparent that while delay in spillway opening may have caused a slight decline in the size of the adult run it was not a major factor in regulating population size. It follows therefore, that these data do not demonstrate that delays during downstream migration reduced the number of effective migrants. Those which were delayed by tardy spill apparently migrated at the next opportunity when spill was provided.

This view is substantiated by the age compositions of the Baker River run which have been referred to earlier. It will be recalled that 4.9 per cent of the run in 1939 consisted of fish that had migrated to sea in their third year and matured in their fifth year. These fish would have migrated in 1936 had they gone to sea in their second year. An examination of the spillway records for 1936 shows that the gates were first opened on April 21 and that the run of this year was not delayed. In 1943 the timing of the sockeye migration was considerably impaired. In this year the spillway gates were closed from April 25 to May 3 and for a sixteen day period from May 5 to May 21 when the migration should have been at its peak. But this very appreciable delay did not produce

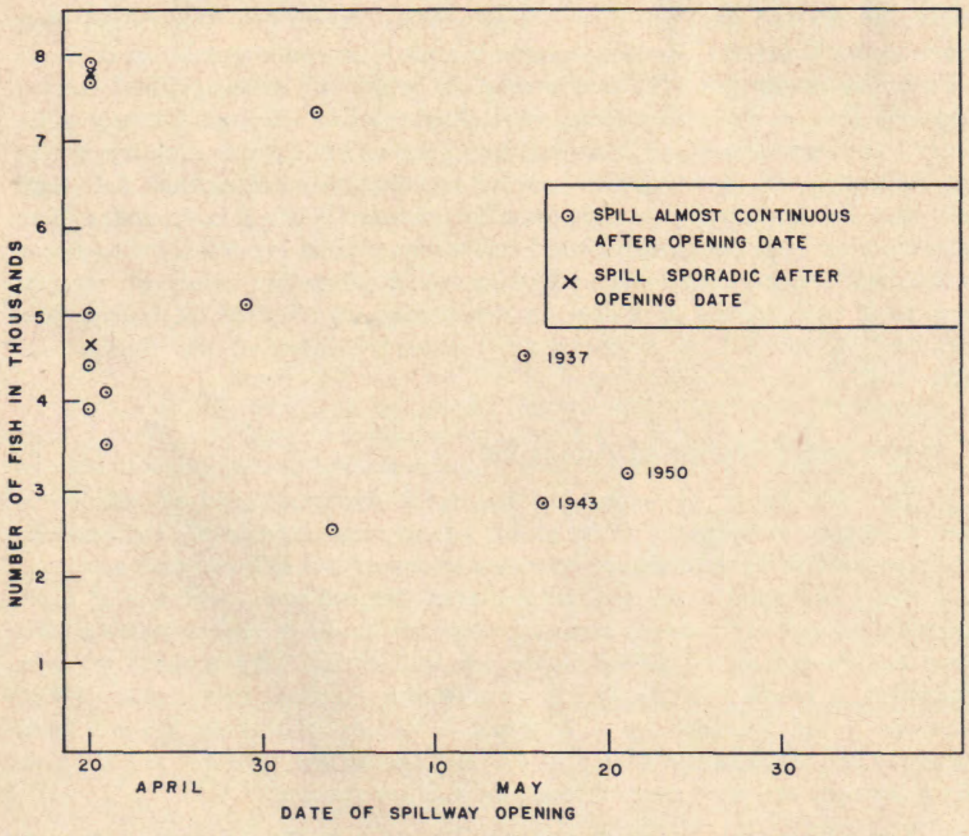


FIGURE 13. Number of adult salmon produced in relation to date of spillway opening two years previous, 1934-1943, 1947, 1950-1953.

an increase in the number of 5_3 fish three years later. Only 2.4 per cent of the run in 1946 was made up of 5_3 fish. The low proportion of 5_3 fish in the adult run in this latter instance, even though the run had experienced an appreciable delay during its seaward migration, indicates that delay in spillway opening causes very few of the sockeye migrants to remain in the lake system above the dam for an additional year. Although delays, longer or of different periodicity than those experienced by downstream-migrant sockeye salmon in this study might result in reductions in the production of adult salmon the conditions to date have apparently not caused any appreciable decrease in the size of the runs.

MORTALITIES CAUSED BY SPILLWAY AND TURBINES

Sampling Problems

In order to assess the effect of the spillway and the turbines on sockeye and coho seaward migrants it is essential that the samples of fish taken in the nets be representative of the stock of fish that emerges from the foot of the spillway and from the draft tubes. If the samples are not representative of the stocks of live and dead fish from which they are drawn then this failure must be recognized and the necessary corrections made before any use can be made of the fyke net catches. The catches may not be representative for the following reasons: the net may not capture or retain the active fish; the net may cause injury and mortality to the fish captured; further, while the net may not be at fault, the sample taken may not be representative because the fish were distributed in the stream in a non-random manner. Failure to recognize these possible sources of error and failure to make adjustments for any observed errors would result in inaccurate estimates of mortality. Therefore before any attempt was made to utilize the catch data for determining the effect of the spillway and turbines on survival of migrants the representativeness of the catches was examined.

Capture and Retention of Active Fish

The velocity requirements for successful operation of fyke nets were investigated by studying the ability of downstream migrants to swim and maintain their position in varying stream velocities at one of the spillway gate openings. As the water approached and passed over the spillway there was a rapid acceleration of flow. Velocity measurements were taken at various points in this flow and related to the ability of the fish to maintain their position or swim upstream. The fish had no difficulty in swimming upstream in velocities of 1.38 feet per second. In velocities of 2.00 to 2.28 feet per second the fish still made headway but in velocities of 4.2 to 4.5 feet per second they did not maintain their positions and were swept through the spillway opening.

The fishing gears in the river below the spillway and in the tailrace were located so that they fished in velocities approaching 4 feet per second. Frequent checks of the velocity conditions at the net entrances were made during the course of the study. Table XI gives the average of these velocity measurements.

TABLE XI

Average Velocities at Entrances of Survival Gears.

Net Number	Average Velocity Feet per Second	
	1951	1952
S_1		3.56
S_{2a}	3.85	3.87
S_{2b}		3.77
T_a	4.62	3.69

Even though the entrance velocities were in most cases less than 4 feet per second, evidence cited below indicates that they were sufficiently high to capture and retain the active fish. Since these fish were subjected to very rigorous and abnormal migration conditions as they passed from the reservoir, it is hardly likely that they could react as efficiently and as energetically as normal seaward migrants that had not been subjected to such conditions.

The active fish may elude the net because they are able to see it as they approach and, although not able to swim against the current, may be sufficiently agile to evade the net. To test whether the nets were fishing at a significantly higher rate at night, yearling hatchery spring salmon, larger than the Baker River native coho and sockeye, were released during daylight hours on three separate days and during darkness on two different nights. The net was set in the same position for day and night releases and each release was made with one gate spilling. The number of spring salmon recovered in Net S_{2a} is given in Table XII.

TABLE XII

Number of Hatchery Spring Salmon Released at Night and During the Day and Recovered in Net S_{2a} in 1951.

Date	Number Released	Recoveries Number	Recoveries Per Cent
	Day Releases and Recoveries		
June 4	517	11	2.13
5	705	16	2.27
6	601	20	3.33
Total	1823	47	2.58
	Night Releases and Recoveries		
June 4	1370	44	3.21
5	384	12	3.12
Total	1754	56	3.19

The data were examined for significance by the method of Chi-square. The total recoveries of night releases and day releases were compared. A Chi-square value of 1.21 with a corresponding P value greater than .20 for one degree of freedom was obtained. The difference in the rates of recovery of day releases and night releases was not significant. It may be concluded therefore that the nets capture fish during the day at the same rate as during the night.

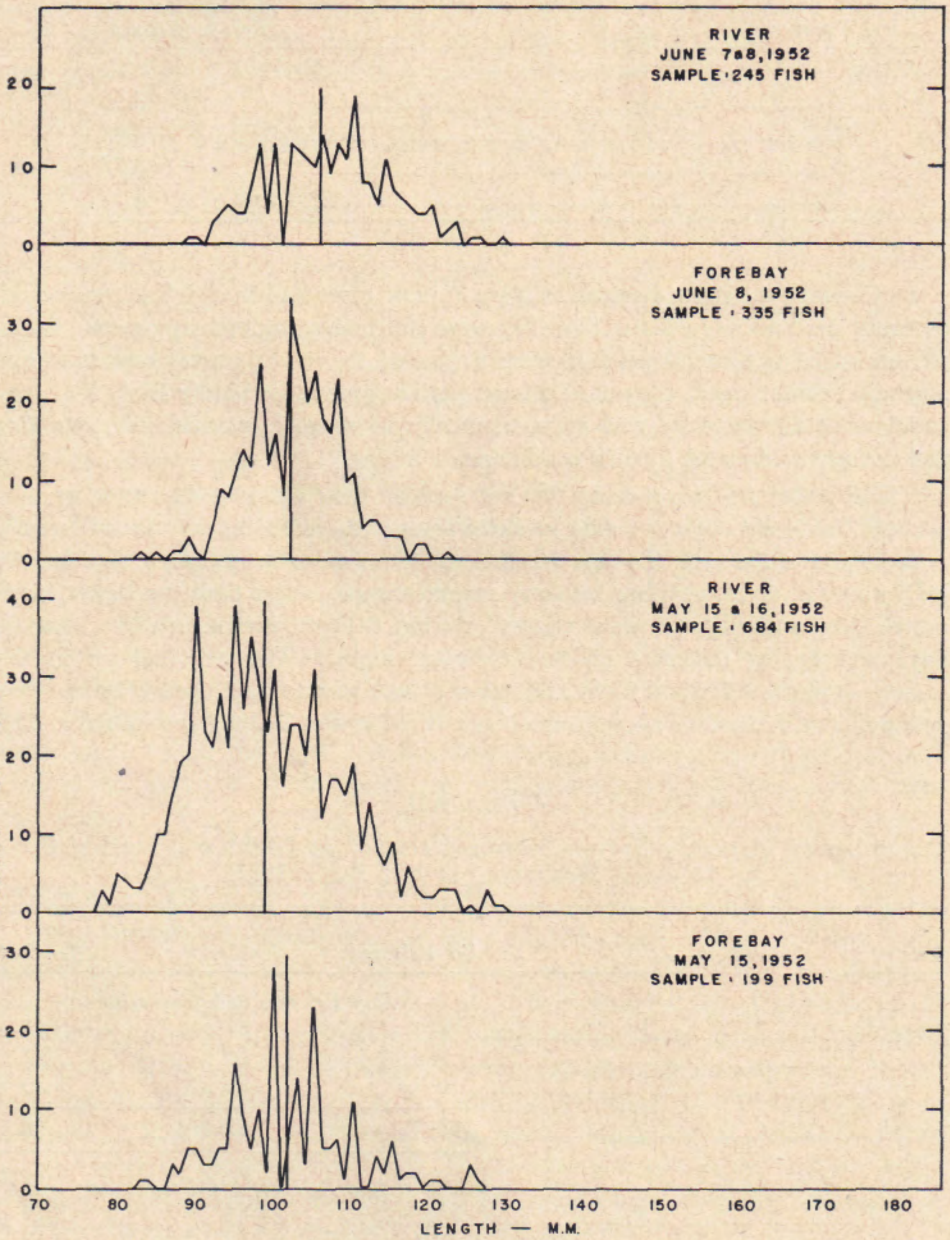


FIGURE 14. A comparison between the length of native coho captured in the forebay and the length of fish captured in the river below the spillway. Mean length shown as vertical bar.

If fish could evade the net or escape from it, it would seem logical that the larger migrants would be the principal escapers since they are the stronger, more vigorous fish. To determine if any particular size group of native sockeye or coho was more successful in resisting capture, samples of the migrating stock were obtained from the forebay and the length of these fish was measured from the tip of the snout to the fork of the tail. The lengths were compared with those of fish captured in the gears located below the spillway at Station S_2. Additional tests were made using hatchery spring salmon and coho salmon.

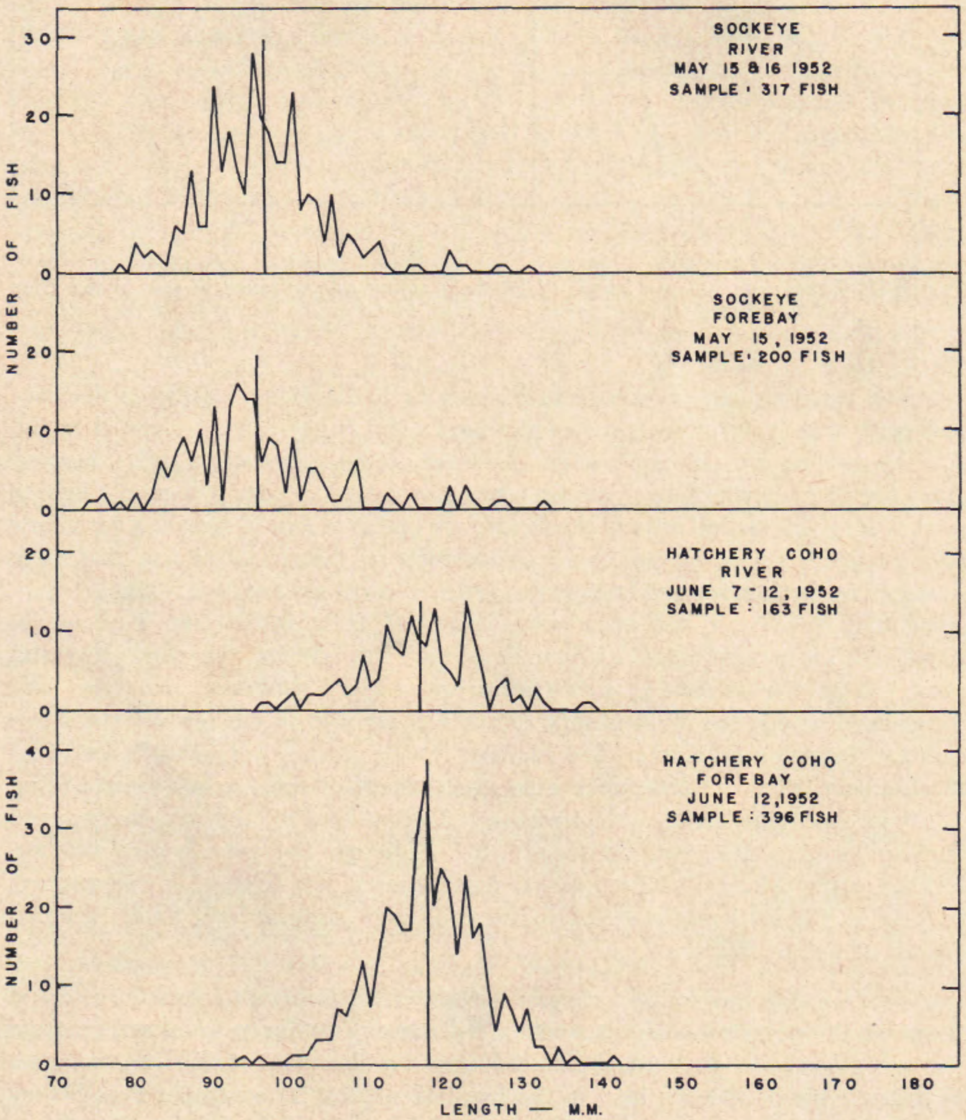


FIGURE 15. A comparison between the length of hatchery coho and native sockeye measured before release and the length of fish captured in the river below the spillway. Mean length shown as vertical bar.

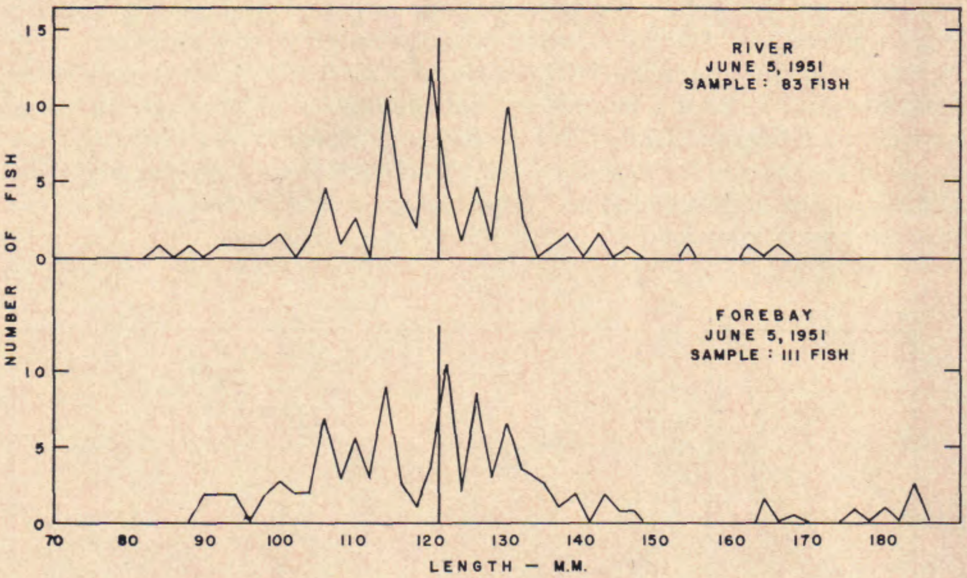


FIGURE 16. Comparison between length of hatchery spring salmon taken in nets in the river and fish measured before time of release. Mean length shown as vertical bar.

The resulting data, as shown in Figures 14 to 16, give no evidence that any particular size group of fish eluded the nets. The larger fish represented in the forebay samples are also represented in the net catches. The slight shifts, ranging from 0 to 4 millimeters, in the mean lengths of native sockeye and coho migrants as shown by the vertical bars in the figures are probably due to sampling variations and periodic changes in the length composition of the stocks of fish that were available in the forebay and to the nets, rather than to net selection. The hatchery coho used in the test had an average length of 117.5 millimeters whereas the native coho averaged only 102.0 millimeters. But despite the large size and presumed greater swimming ability of these hatchery fish there was very little difference between the mean lengths of the fish sampled in the forebay and those sampled from the fyke nets. The hatchery spring salmon were even larger than the hatchery coho just referred to, the mean length of the forebay sample being 121.0 millimeters. The length frequency distributions of the net catches and forebay samples are given in Figure 16. Although the very largest fish are lacking in the fyke net catches, this is not a serious loss because an insignificant portion of the total migration of native coho and sockeye from Lake Shannon consist of fish of this size.

In 1952, marked active sockeye and coho were introduced into the survival boxes of the gears to establish whether fish already captured could escape from the nets. None of the fish introduced into the live box of Net S_{2a} escaped. Similarly none of the fish held in the live box of Net T_a escaped although they were held for three and one-half hours. Forty per cent of the fish introduced into the live box of Net S_{2b} had escaped at the end of one hour. A second test conducted after this gear was relocated in higher velocities produced similar results. Therefore, the catches of native fish from this net could not be used for determining mortalities.

Effect of Gears on Survival of Fish

The survival gears were designed to retain the fish in the condition in which they entered the nets. To determine to what extent the gears affected the survival of the fish, marked vigorous members were brought down from the forebay and released immediately in front of each net and also into the live boxes. The fish were retained in the live boxes for one to four hours and then examined and their condition noted. The results of the tests conducted in 1952 are shown in Table XIII. The good fish were classed as such because they had been lightly scaled but possessed no other superficial injury and were active. Fish in excellent condition had no noticeable injury and were very vigorous. Net S_{2a} in the river and Net T_a in the tailrace captured and retained the fish in good condition. Net S_{2b} was quite injurious to the fish. A second test was conducted after changes had been made in the holding container of this net. Improved conditions resulted but some fish were still injured as they passed down the net to the holding box. As previously pointed out, catches from this net could not be used for computing spillway mortalities. Although no tests were conducted with Net S_1, fish taken by this net showed no evidence of stress or harmful effect of the gear.

TABLE XIII

Condition of Fish Introduced into Entrances of Nets and into the Live Boxes and Examined after One to Four Hours of Captivity—1952

			CONDITION OF FISH							
			Released in front of net				*Released into live box*			
Net No.	*Species*	*Hours Retained*	*Dead*	*Weak*	*Good*	*Excellent*	*Dead*	*Weak*	*Good*	*Excellent*
T_a	Coho	4 hours			15	10			2	23
S_{2a}	Coho	1 hour			1	14			4	26
S_{2b}	Coho	1½ hours	4	1	2	2		2	4	6
	Sockeye	1½ hours	4	2	1		2	3		1
S_{2b}	Coho	2 hours		2	1	8			1	16

Although every attempt was made to remove the fish from the live boxes at hourly intervals it was not always possible to adhere to such a rigid schedule. During the daylight hours when the catches were light or moderate the fish were removed from the survival boxes hourly but when the catches were large they were removed at less frequent intervals. Fish taken during the night in 1951 were not removed from the gears and examined until the following morning. Such fish could have been retained in the live boxes for as long a period as twelve hours depending on the time when the last examination was made on the preceding evening and when the fish entered the net. In 1952 extra crews were employed to operate the spillway gears at night. These night operations did not start until about one week after spilling had commenced but were continued thereafter for the major part of the fishing period.

Many of the native sockeye and coho in the catches were retained in the live boxes for greater periods of time than four hours, the maximum length of captivity in the special tests referred to above. Since it was desirable to use as large a portion of the available fyke net catch as possible for the final mortality

TABLE XIV

Mortalities of Fish for Various Periods of Retention in Live Boxes of Spillway and Tailrace Survival Nets

	Time of Retention in Hours											
Species	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12 or more*
					Net S_{2a}, 1951							
Coho												
Total Catch	282	232	55	47	25				41		66	335
No. Dead	40	43	7	16	9				34		27	121
% Dead	14	19	13	34	36				83		41	36
Sockeye												
Total Catch	111	74	16	9	4				6	40	8	153
No. Dead	42	22	2	4	3				4	11	7	74
% Dead	38	30	13	44	75				67	28	88	48
					Net S_{2a}, 1952							
Coho												
Total Catch	486	919	306	193	4	15	71			153	178	1120
No. Dead	68	121	51	19	1	2	7			23	25	326
% Dead	14	13	17	10	25	13	10			15	14	29
Sockeye												
Total Catch	185	316	34	50		12			8	201		337
No. Dead	38	95	11	5		3			5	83		243
% Dead	21	30	32	10		25			62	41		72
					Net S_1, 1952							
Coho												
Total Catch	55	64		37								53
No. Dead	17	16		10								29
% Dead	31	25		27								54
					Net T_a, 1951 and 1952							
Coho												
Total Catch	222	102	33	22	24	9	10	7	4	10	4	35
No. Dead	27	10	2	3	2	2	1	0	0	0	0	3
% Dead	12	9	6	14	8	22	10	0	0	0	0	9
Sockeye												
Total Catch	58	41	6	5	6	8	1	4	4	7	8	43
No. Dead	10	6	1	0	3	2	1	1	0	1	5	8
% Dead	17	15	17	0	50	20	50	25	0	14	63	19

estimates, the effect of the time of retention in the gears was examined. Shown in Table XIV are the numbers of dead fish that were removed from the gears after various periods of retention. Each percentage value denotes the proportion of dead fish in catches that were retained in the survival gears for different lengths of time. Data in Table XIV do not indicate any general increase in mortality of captured sockeye and coho retained for periods of one to three hours in Net S_{2a} in 1951. In 1952 sockeye migrants could be retained in this net for at least six hours before any definite increase in the mortalities was noted. Periods of retention of one to eleven hours in Net S_{2a} did not show a serious effect on native coho in 1952. The effect of retention in Net T_a was determined from the catches of marked sockeye and coho in 1951 and from marked and unmarked sockeye and coho in 1952. Although not shown in the table it appeared that the unmarked fish in 1951, the majority of which were retained in the net for ten hours or more, were harmfully affected by the gear. However, the mortalities to marked fish in 1951 and marked and unmarked fish in 1952 (Table XIV) appeared to be unaltered with respect to time of retention.

The apparent increase in the mortalities with increased time of retention may not be caused entirely by possible ill effects of the imprisonment. The increased mortality may be a reflection of the delayed effect of injuries sustained by the migrants while passing over the spillway or through the turbines or a combination of the effects of injuries and of the imprisonment. However, since the effects of retention cannot be divorced from the delayed effects of injuries, the estimates of spillway and turbine mortality must be based on those groups of fish showing no ill effects from retention.

Availability of Live and Dead Fish to the Nets

Observations made at various locations in the river below the dam showed that fish emerged from the spillway pool in various conditions. Some appeared to be active and quite unaffected by their journey over the dam, others swam in a very erratic manner or swam very weakly suggesting that they suffered from serious injury, while others were stunned or dead. If a true estimate of mortality is to be obtained from the fyke net catches these segments of the population must be equally available to the fishing gears. The numerical relationship of each segment in the catch must be the same as in the river immediately below the dam. Similarly, the tailrace catches must be representative of the fish that emerge from the draft tubes.

There was reason to believe that the dead fish were not as available as the live fish at the various fishing stations. The dead fish having lost their propelling and stabilizing ability tended to sink and although the gears were located as close as practicable to the draft tube exit and to the lower edge of the spillway pool, it was possible that the dead fish were not available in the surface layers where the nets were fishing.

In an effort to determine the relative availability of live and dead fish to the gears, marked live fish and marked dead fish were released over the spillway and into the tunnel and samples were recovered in the gears. The majority of the tests involving dead coho were conducted with hatchery fish. Migrants obtained from Cultus Lake served as the dead release for sockeye. Native fish were used very sparingly and then only to measure the relationship between recovery of marked dead native fish and marked dead hatchery fish.

Shown in Tables XV to XVII are the number of live and dead fish released and the number recovered in Nets S_1, S_{2a} and T_a in 1952. Since Net S_1 lies upstream from Net S_{2a}, the number of marked fish available to Net S_{2a} is obtained by subtracting the number of fish taken by Net S_1 from the total released. In each instance the nets in the river and the tailrace recovered a greater proportion of the live releases than of the dead releases. Obviously the dead fish were not as available to the nets as the live fish.

Not only were the marked dead fish less available than the marked live fish in the river, but also their availability varied with respect to the position of the nets. Net S_1, located approximately 400 feet upstream from Net S_{2a}, had a lower ratio of marked live to marked dead recovery rates than the lower gear. On the average about equal proportions of live releases were captured in the two nets but a considerably higher proportion of dead releases were recovered in Net S_1 than in the lower net, S_{2a}. The dead fish were therefore not as available to the lower net.

TABLE XV

Numbers of Marked Dead and Marked Live Native and Hatchery Coho and Sockeye Released Over the Spillway and Recovered in Net S_1 in 1952 During One-Gate Spill

	Dead Releases			*Live Releases*			
	No.	*Recoveries*		*No.*	*Recoveries*		*Ratio of*
Date	*Released*	*No.*	*%*	*Released*	*No.*	*%*	*Recovery Rates*
				Native Coho			
June 7	1,131	13	1.15	1,733	41	2.36	2.05:1
10	241	10	4.15	451	9	1.97	1 :2.10
Totals	1,372	23	1.68	2,184	50	2.28	1.35:1
				Hatchery Coho			
June 7	1,915	22	1.15	1,697	44	2.59	2.25:1
10	1,522	38	2.49	1,571	68	4.32	1.73:1
17	2,773	53	1.91	2,824	84	2.97	1.58:1
Totals	6,210	113	1.82	6,092	196	3.21	1.78:1
				Sockeye			
June 7	1,869	22	1.18	2,030	47	2.31	1.95:1
10	1,961	48	2.44	1,943	73	3.75	1.53:1
17	2,675	57	2.13	2,466	98	3.97	1.86:1
Totals	6,505	127	1.95	6,439	218	3.38	1.73:1

TABLE XVI

Number of Marked Dead and Marked Live Native and Hatchery Coho, and Sockeye Available After Release over the Spillway and Recovered in Net S_{2a} in 1952 during One-Gate Spill

	Dead Releases			*Live Releases*			
Date	*No. Available*	*Recoveries No.*	*%*	*No. Available*	*Recoveries No.*	*%*	*Ratio of Recovery Rates*
			Native Coho				
May 14	1,003	11	1.09	1,301	51	3.92	3.59:1
June 7	1,118	4	.36	1,692	47	2.77	7.69:1
10	231	3	1.24	442	7	1.58	1.27:1
Totals	2,358	18	.76	3,435	105	3.05	4.01:1
			Hatchery Coho				
May 15	884	13	1.47	1,073	20	1.86	1.26:1
23	2,002	4	.20	1,618	20	1.24	6.20:1
June 7	1,893	9	.48	1,653	37	2.23	4.64:1
10	1,484	8	.54	1,503	40	2.66	4.92:1
17	2,720	17	.62	2,740	117	4.27	6.87:1
Totals	8,983	51	.57	8,587	234	2.73	4.79:1
			Sockeye				
June 7	1,847	15	.81	1,983	46	2.31	2.85:1
10	1,913	18	.94	1,870	51	2.72	2.89:1
17	2,618	29	1.11	2,368	72	3.04	2.73:1
Totals	6,378	62	.97	6,221	169	2.71	2.79:1

TABLE XVII

Number of Marked Dead and Marked Live Hatchery Coho Released into the Tunnel and Recovered in Net T_a in 1952

	Dead Releases			*Live Releases*			
Date	*No. Released*	*Recoveries No.*	*%*	*No. Released*	*Recoveries No.*	*%*	*Ratio of Recovery Rates*
May 7	950	18	1.89	223	5	2.24	1.18:1
9	986	36	3.65	1,048	52	4.96	1.35:1
15	1,311	56	4.27	999	51	5.10	1.19:1
Totals	3,247	110	3.38	2,270	108	4.75	1.40:1

Further evidence of the lower availability of dead fish can be obtained by comparing the mortalities of unmarked fish taken from Net S_1 and Net S_{2a} from June 7 to June 17 (Table XVIII). These data show that there was a greater

TABLE XVIII

Mortality of Coho and Sockeye Taken in Net S_1 and S_{2a} in 1952

Net Number	Number of Dead Fish in Catch as Per Cent.	
	Unmarked Coho	Marked Sockeye
Net S_1	27.5	35.3
Net S_{2a}	12.8	20.3

proportion of dead fish in the upper net, indicating once again that the dead fish were more available at the upper station. It is quite apparent, therefore, that corrections for the disproportionate availability of live and dead fish must be applied before any reliable mortality estimate can be computed.

Availability of Fish Released Dead and Fish Released Alive but Killed in Passage

In testing the availability of dead and live fish to the nets two groups of marked fish were released; one group consisted of dead fish, the other group of live fish. The marked dead fish, of course, are recovered dead. However, the marked live fish may be recovered either dead or alive depending on how well they fared in passage through the turbines or over the spillway. Therefore from a given release of marked live and marked dead fish the catch in each net will consist of three differing categories, recoveries of dead releases, recoveries of live releases that are dead and recoveries of live releases that are alive at the time of recovery. In the future, in order to readily distinguish between the categories, the following terms will be used:

Dead-dead	Marked fish released dead and recovered dead.
Live-dead	Marked fish released alive but recovered dead in the nets.
Live	Marked fish released alive and recovered alive in the nets.

Although the samples obtained in the nets do not appear to be representative of the stocks of fish passing over the spillway or through the turbines, the recovery rates of marked dead and marked live fish serve as measures of the extent the samples fall short in this respect. However, before any valid correction can be made for loss of dead fish in computing mortalities it must be established that the dead-dead fish used in this study and the live-dead fish are equally available.

The method employed for testing the relative availability of live and dead fish consisted of fishing one gear several hundred feet downstream from a second gear. Marked live fish and marked dead fish were then released either into the tunnel or over the spillway, depending on where the test was being conducted, and the numbers of live-dead and dead-dead in both the upper gear and lower gear were compared. If the two groups were equally available any change in the abundance of one group from one location to the other would be reflected in the other group. That is, if fewer dead-dead were taken in the lower net than in the upper net, a proportionately smaller number of live-dead fish should also be taken.

The first test was conducted using Net T_a in the tailrace as the upper net and Net ST located below the confluence of the tailrace and spillway as the lower net. The results of this test using hatchery coho are presented in Table XIX. From these results it can be seen that both the dead-dead and live-dead were less available to the lower net than to the upper net. To determine if the numerical relationship between dead-dead and live-dead established at the upper net was maintained at the lower net the total values in Table XIX were tested by Chi-square. The number of dead-dead and live-dead involved in the tests were small, therefore it was necessary to employ the half correction factor (Snedecor, 1940). A Chi-square value of 0.205 was obtained which for 1 degree of freedom corresponded to a probability greater than 0.50 and was therefore not significant.

TABLE XIX

Recovery of Marked Dead-Dead and Marked Live-Dead Hatchery Coho in Tailrace (Net T_a) and in River Below Confluence of Tailrace and Spillway Discharge (Net ST)

	Number Captured In:				
	Net T_a		*Net ST*		*Net ST*
Date	*Marked Dead-Dead*	*Marked Live-Dead*	*Marked Dead-Dead*	*Marked Live-Dead*	*Theoretical Marked Live-Dead*
1952					
May 7	18	0	10	1	0
9	36	7	18	1	3.5
15	56	9	6	1	.96
Total	110	16	34	3	4.95

Since the numbers of dead fish involved in these tests were so small further tests were made using Net S_1 and Net S_{2a} where it was thought more dead fish would be available. The recovery of live-dead fish and dead-dead fish in Nets S_1 and S_{2a} are given in Table XX. These data indicate that dead-dead hatchery coho releases settled out faster or became less available than live-dead releases between Stations S_1 and S_{2a}. This is the opposite of what occurred between the Station T_a and Station ST for hatchery coho. Marked dead-dead sockeye were recovered at Station S_2 in quantities slightly higher than would be expected if they were equally as available as marked live-dead.

The changes in numerical relationship of dead-dead and live-dead of each experimental group between Nets S_1 and S_{2a} were examined for significance by Chi-square. A Chi-square value of 2.51 for hatchery coho was obtained. This was not significant ($.20 > P > .10$ for one degree of freedom). For native coho a Chi-square value of 2.28 was obtained which was also not significant (for one degree of freedom $.20 > P > .10$). The Chi-square value of .239 for sockeye was not significant ($.70 > P > .50$ for one degree of freedom). The overall results therefore show that there is neither significant nor consistent difference in the availability of dead-dead and live-dead fish.

Although the availability of live-dead and dead-dead could not be measured in the section of the river from the dam to the upper net it can be assumed that equal availability prevailed. It is reasonable to suspect that the very turbulent nature of the pool, the lower limit of which was only 100 feet upstream from the upper net, would preclude any differential settling out of live-dead and dead-dead fish and that the assumption of equal availability is probably true for the pool and the short section of the river above the net.

TABLE XX

Recovery of Marked Dead-Dead and Marked Live-Dead Fish at Station S_1 and Station S_{2a} in 1952

	Number Captured in:				
	Net S_1		*Net S_{2a}*		
Date	*Marked Dead-Dead*	*Marked Live-Dead*	*Marked Dead-Dead*	*Marked Live-Dead*	*Theoretical Marked Live-Dead*
			Hatchery Coho		
June 7	22	1	9	1	0.41
11	38	9	8	3	1.89
17	53	13	17	10	4.17
Totals	113	23	34	14	6.92
			Native Coho		
June 7	13	3	4	6	0.92
10	10	2	3	0	0.60
Totals	23	5	7	6	1.52
			Sockeye		
June 7	22	5	15	14	3.41
10	48	34	18	6	12.75
17	57	38	29	12	19.33
Totals	127	77	62	32	37.59

Comparison of the Recovery Rates of Releases of Marked Dead Sockeye, Marked Dead Native Coho and Marked Dead Hatchery Coho

Two releases of marked dead sockeye, marked dead native coho and marked dead hatchery coho were made over the spillway to compare the recovery rates of these three groups. The results of the two tests were combined and the differences in the rates of marked dead recovery in Nets S_1 and S_{2a} for each experimental group were examined statistically by the method of Chi-square. The results in Table XXI show that the differences in the recovery rates of the three groups were not significant. A Chi-square value of 4.35 with a corresponding P value greater than 0.10 for 2 degrees of freedom was obtained for the recovery rates of Net S_{2a}. The Chi-square value for the recovery rates of Net S_1 was 0.106 which corresponds to a P value greater than 0.90 for 2 degrees of freedom. It is possible therefore, if need be, to use any one of the groups; sockeye, native coho or hatchery coho, or the releases and recoveries of all three combined to determine the rate at which marked dead fish were captured by the nets in 1952.

Correction for Loss of Dead Fish

In order to determine the mortality of fish passing over the spillway and through the tunnel from samples taken in the various nets a correction must be applied to compensate for the disproportionate availability between live and dead fish in the river and tailrace. This may be accomplished by comparing the recovery rates of marked live fish and marked dead fish. However, the true recovery rate

TABLE XXI

Comparison Between the Recoveries of Releases of Marked Dead Native Coho, Marked Dead Hatchery Coho and Marked Dead Sockeye in Nets S_{2a} and S_1 in 1952

	Net S_{2a}	*Net S_1*
Sockeye		
Number Released	3,760	3,830
Number Recovered	33	70
Native Coho		
Number Released	1,349	1,372
Number Recovered	7	23
Hatchery Coho		
Number Released	3,377	3,437
Number Recovered	17	60
Chi-Square	4.35	.106
Degrees of Freedom	2	2
	$.20 > P > .10$ (Not significant)	$.95 > P > .90$ (Not significant)

of marked live fish is not known because an unknown number were killed while passing over the spillway or through the turbines and because dead fish are less available to the gears than live fish. Before a correction can be obtained the true recovery rate of the survivors must be computed and this recovery rate compared with the known recovery rate of marked fish released dead.

The rate of recovery of dead fish is known. It is determined from the recovery of marked dead fish released over the spillway and into the tunnel. Of a given number of fish released alive a certain number are recovered alive and a certain number are recovered dead. These two components of the marked live release are represented in the following formulæ:

$$\text{Fish recovered alive} = X\,(P)\,R = x \qquad (1)$$
$$\text{Fish recovered dead} = X\,(1 - P)\,r = x_1 \qquad (2)$$

Where X is the number of fish released alive

x is the number of live releases captured alive

x_1 is the number of live releases captured dead (live-dead)

P is the survival rate

R is the rate of recovery of live fish

r is the rate of recovery of dead fish (dead-dead)

From equation (2)

$$1 - P = \frac{x_1}{Xr}$$

and

$$P = 1 - \frac{x_1}{Xr}$$

Substituting for P in equation (1)

$$x = X\left(1 - \frac{x_1}{Xr}\right)R$$

and $$R = \frac{x}{X - \dfrac{x_1}{r}}$$

Having determined the true rate of recovery of live fish (R) it can then be compared with the known rate of recovery of dead fish (r). This will establish the relative availability of live and dead fish to the gears and the correction factor $\left(\frac{R}{r}\right)$ necessary to compensate for the lower availability of dead fish.

The correction factor necessary to compensate for disproportionate availability of dead coho to nets S_1 and S_{2a} in 1952 was determined from the releases and recoveries of marked native and hatchery coho during a one-gate spill. A correction factor for a two-gate spill condition could not be determined because insufficient fish were available for release. In 1951 marked native coho were employed to derive the correction for Net S_{2a} during a one-gate spill. The correction factors necessary to compensate for the lower availability of both dead native coho and dead native sockeye in the tailrace were obtained by comparing the recovery rate (r) of marked dead hatchery coho with the true rate of recovery (R) of marked live native coho and also with the recovery rate (R) of marked live native sockeye since no dead sockeye or native coho were available for release. Since it has been demonstrated (Table XXI) that there was no significant difference in the recovery rates of marked dead native sockeye, marked dead native coho and marked dead hatchery coho this procedure for obtaining the correction factor for loss of dead coho and sockeye in the tailrace seems sound. The rates of recovery of live and dead fish at different fishing stations and the correction factors necessary to compensate for the lower availability of dead fish are presented in Table XXII.

Delayed Effects of Injuries Caused by Spillway and Turbines

Although the fish may be alive at the time of removal from the net, later mortalities may ensue due to the delayed effects of injuries sustained in the journey through the turbines or over the spillway. To evaluate the delayed effects, holding experiments were conducted. In these experiments sockeye and coho migrants captured in the tailrace and river gears were carefully examined for injury and general vigour and classified as active or weak. They were placed with controls in holding boxes in the forebay (1951) and in hatchery-type troughs (1952). The sockeye being limited in numbers have been combined with the coho. The number of active and weak fish retained and the number dying in each of these categories are given in Table XXIII.

TABLE XXII

The Calculated True Rate of Recovery of Marked Live Fish and the Correction Factor Necessary to Compensate for Lower Availability of Dead Fish

Species	*No. of Live Fish Released*	*Recoveries of Live Fish Released* *Live*	*Dead*	*Rate of Recovery of Dead Releases Per Cent*	*Calculated True Rate of Recovery of Live Releases Per Cent*	*Correction Factor*
	X	x	x_1	r	R	$\frac{R}{r}$
			1951 Net S_{2a}			
Coho	2,609	35	7	0.69	2.19	3.17
			1952 Net S_{2a}			
Coho	12,022	317	22	0.61	3.76	6.17
Sockeye	6,221	137	32	0.97	4.68	4.82
			Net S_1			
Coho	8,276	217	29	1.79	3.26	1.82
			Net T_a			
Coho	2,820	167	19	3.38	7.39	2.18
Sockeye	871	29	7	3.38	4.36	1.28

Two estimates of delayed mortality are shown in Table XXIII for active and weak spillway fish. An attempt has been made to eliminate the adverse effect of confinement in the fishing gear and the effect of handling during the examination for injuries. The difference between the two percentage values for active and weak fish was arrived at as follows: In the group of 154 active fish which passed over the spillway, 52 individuals were classified as being in excellent condition. They possessed none of the characteristic injuries of spillway fish and were very active. If they were in any way harmfully affected it was not evident at the time they were examined. It was felt that the mortalities to these fish would

TABLE XXIII

Results of Holding Tests to Measure Delayed Mortalities of Live Native Sockeye and Native Coho Migrants After Passage Through the Tunnel and Over the Spillway

	Active	*Weak*	*Control*
		Tunnel—1951 Experiment	
Number Taken	52	0	50
Number Dead	4		0
Percentage Dead	7.7		0
		Spillway—1952 Experiment	
Number Taken	154	82	63
Number Dead	52	57	0
Percentage Dead	33.7	69.5	0
Adjusted Percentage Dead	18.3	54.1	0

serve as a measure of the delayed effect of the fishing gear as well as a measure of the effect of the handling during the examination which were not operative on the control fish. By the end of the experiment 8 or 15.4 per cent of this group had died suggesting that the mortalities to the remaining injured active and weak fish may have increased by this amount from factors other than those associated with passage over the spillway. Therefore the estimates of delayed mortality were adjusted as shown in Table XXIII. These adjusted figures will be used in the computation of spillway mortality rates.

The estimate of delayed tunnel mortality has only been supplied for active fish. Not enough weak fish were available at any single time to make a parallel test. However, for lack of an estimate of delayed mortality for this group the adjusted figure obtained for the spillway experiment will be employed in future computations of mortality rates. Any possible error in the calculation of delayed mortality is minimized by the fact that this type of mortality represents only approximately 20 per cent of the total mortality resulting from passage over the spillway or through the tunnel.

Indicated Spillway Mortalities

Spillway mortality estimates were determined from the catches of unmarked native sockeye and native coho which were captured in Net S_{2a} from May 5 to June 7 in 1951 and from May 13 to June 18 in 1952 and from the catch of fish taken in Net S_1 from June 7 to June 18 in 1952. In 1951 only fish retained in the gears for three hours or less were used in calculating the estimates. In 1952 the mortality estimates were determined from sockeye held in the gears for six hours or less and from coho held for eleven hours or less. Justification for these procedures has been derived from Table XIV.

As already pointed out the dead fish were less available to the nets than live fish. The corrections which were applied to compensate for lower availability of dead fish when one spillway gate was open are presented in Table XXII. No correction factor was obtained for sockeye in 1951 but as shown by the 1952 data (Table XXII) the correction factor for sockeye was 21.9 per cent lower than that obtained for coho. It was assumed therefore that the correction factor for sockeye in 1951 should likewise be 21.9 per cent lower than the 1951 coho correction factor (3.17) or 2.48. The corrections obtained for one-gate spill in 1952 were also applied for the two-gate spill condition. On the basis of information provided by the holding experiments 18.3 per cent of the active fish and 54.1 per cent of the weak fish were considered as potential mortalities.

The numbers of live and dead native sockeye and coho migrants captured in Net S_{2a} and Net S_1 and the estimated mortality rates of fish passing over the spillway in 1951 and 1952 are shown in Table XXIV. In 1952 during one-gate spill *62.1 per cent* of the sockeye migrants died. This is in close agreement with the mortality figure obtained for 1951 which was *64.9 per cent.* The average for the two years was *63.5 per cent.* In 1951 the estimated mortality to native coho passing over the spillway was *49.9 per cent* during periods of one-gate spill. Two estimates of coho mortality were obtained in 1952 for one-gate spill. The indicated mortality from the catch in Net S_{2a} was 59.9 per cent while that from the catch in Net S_1 was 56.5 per cent. These two gears operated in widely separated sections of the river. Also, the proportions of live to dead fish in each gear were quite different. Despite the difference in location of gears and the difference in the composition of the catches the mortalities, with the appropriate corrections applied, differed insignificantly. The close agreement in the mortality estimates obtained from these two separate gears tends to confirm the reliability of the method employed. The average mortality obtained from these two nets in 1952 was *58.2 per cent* and the average for the two years was *54.0 per cent.* Native coho which migrated over the spillway when two gates were open in 1952 suffered a mortality of 65.2 per cent. Sockeye migrating under the same conditions in 1952 had an estimated mortality rate of 82.2 per cent.

Indicated Turbine Mortalities

Since so few unmarked native sockeye and coho were taken in the tailrace survival gear (Net T_a) it was necessary to base the mortality estimates on both unmarked and marked native fish. The catches of marked fish in 1951 and marked

TABLE XXIV

Final Corrected Estimate of Mortality of Native Unmarked Sockeye and Coho Migrants Passing Over the Spillway During One- and Two-Gate Spill in 1951 and 1952

Spill Condition	*Species*	*Number Captured* *Active*	*Weak*	*Dead*	*Correction Factor*	*Final Estimated Mortality in Per Cent*
			1951 Net S_{2a}			
One Gate	Sockeye	120	15	66	2.48	64.9
	Coho	454	25	90	3.17	49.9
			1952 Net S_{2a}			
One Gate	Sockeye	235	73	60	4.82	62.1
	Coho	1175	245	203	6.17	59.9
Two Gate	Sockeye	111	26	92	4.82	82.2
	Coho	495	93	114	6.17	65.2
			Net S_1			
One Gate	Coho	87	26	43	1.82	56.5

and unmarked fish in 1952 have been combined to furnish an average mortality rate for the two years. Unmarked native sockeye and coho captured in 1951 have been excluded for reasons cited previously (page 39). No correction factors were established for the lower availability of dead sockeye and coho in 1951 so those obtained in 1952 were employed (Table XXII). Adjustments in the mortality estimates were made to allow for delayed effects of injuries. On the basis of the holding experiment 7.7 per cent of the active fish and 54.1 per cent of the weak fish were considered as potential mortalities.

The best estimate of turbine mortality rate for sockeye is *33.6 per cent* while for coho it is *28.3 per cent* (Table XXV). These values indicate that the Baker turbines are less harmful than the spillway to downstream migrants.

Mortality as Determined from the Return of Marked Adults

A measure of the effect of the spillway and turbines on the mortality of seaward migrating salmon may be determined from the number of adults returning from releases of known numbers of marked fish over the spillway and through the turbines. In determining mortality in this way each group must be recognizable at the adult stage. Furthermore, a control group unaffected by the spillway or turbines must be employed, the tunnel and spillway returns being compared with the return of this control group.

This method was employed by Holmes (unpublished manuscript) in determining the effect of Bonneville Dam on the survival of seaward migrating chinook salmon in the Columbia River. Over a period of several years chinook fingerlings were marked and released above the dam (test group) and below the dam (control group) and were recovered as adults in the commercial fishery.

TABLE XXV

Final Corrected Estimate of Mortality of Marked and Unmarked Native Sockeye and Coho Migrants Passing Through the Tunnel in 1951 and 1952. Data from Both Years Combined

Species	*Number Captured*			*Correction Factor*	*Final Estimated Mortality in Per Cent*
	Active	*Weak*	*Dead*		
Sockeye	136	17	38	1.28	33.6
Coho	407	25	50	2.18	28.3

The rates of recovery of the test and control groups served as a measure of the mortality incurred by the fingerlings in passing from the reservoir.

As already mentioned in the section entitled "Tunnel Versus Spillway as Migration Route" marked fish were released over the spillway and into the tunnel of Baker Dam in order to determine the fishing efficiency of the river and tailrace fyke net gears. With a view to using the adult return of these marked fish for mortality estimates, marked fish were also introduced into the river below the dam to serve as a control group.

The sockeye and coho marked and released in 1951 returned as adults in 1953 and 1952 respectively. A systematic check for all marked fish was maintained in the Skagit River and Skagit Bay fishery as well as at Baker Dam. Table XXVI shows the numbers of permanently marked sockeye and coho released over the spillway, into the tunnel and into the river. The catches of the fyke nets have been subtracted from each category since these catches were not returned to the river and hence could not be expected to return as adults. Also shown in the table are the numbers of marked adult sockeye and coho recovered from each group.

In considering the rates of return of marked sockeye it is quite evident that the spillway fish suffered a higher mortality than the tunnel fish and that both suffered a higher mortality than the river releases. It is highly unlikely that this difference in return can be attributed to marking mortality. The fish released over

TABLE XXVI

Number of Marked Sockeye and Coho Available from Releases Over the Spillway, into the Tunnel and into the River in 1951, and the Number of Returning Adults Recovered

	Spillway	*Tunnel*	*River (control)*
		Sockeye	
Number Released	4,398	2,546	926
Number Recovered	46	45	26
Percentage Recovered	1.05	1.77	2.81
		Coho	
Number Released	8,105	5,557	3,618
Number Recovered	144	135	68
Percentage Recovered	1.78	2.43	1.88

the spillway were marked by the excision of the dorsal fin and left ventral fin. The tunnel fish had the dorsal fin and right ventral removed while the river or control fish were marked by the excision of the dorsal fin and both ventral fins. It is therefore assumed that if there was any adverse effect due to the removal of fins it would occur to the greatest extent in the control group. Therefore the differences between the returns of the test groups and control group are not attributed to variation in marking mortality.

The differences in the rates of return of marked adults from the three groups of releases were examined for significance by the method of Chi-square. A Chi-square value of 18.23 with a corresponding P value of less than one per cent for 2 degrees of freedom was obtained. This shows that the differences in the numbers of fish returning were significant.

A comparison of the rates of return of spillway and river releases revealed that the rate of survival of spillway releases was 37.3 per cent of the rate of survival of the control. By making a similar comparison between the rates of recoveries of river releases and tunnel releases it is shown that the rate of survival of tunnel fish was 63.0 per cent of the rate of survival of the control group. That is, the spillway mortality rate was *62.7 per cent* and the turbine mortality rate was *37.0 per cent.*

Ninety-five per cent confidence limits were calculated for each mortality estimate. The method used was identical to that employed by Holmes (unpublished manuscript) for calculating confidence limits for the losses incurred by chinook salmon passing over Bonneville Dam. As outlined by Holmes the method consists of calculating confidence limits for the term $\frac{1}{1+p}$ which is equivalent to $\frac{x}{x+y}$ where p is the rate of survival of test fish, x the rate of return of river releases and y the rate of return of test releases. Knowing the value of $\frac{1}{1+p}$ and the number of test fish and control fish which return reference can then be made to Figure 4 of Clopper and Pearson (1934) which provides a means for obtaining confidence limits for the terms of a binomial. The probable spillway and turbine mortality rates and the 95 per cent confidence limits are presented in Table XXVII.

TABLE XXVII

Probable Mortality Rates for Yearling Sockeye Passing Over the Spillway and Through the Turbines Based on Returns of Marked Adults

	Recoveries		*Estimated Mortality in*	*Confidence Limits* *	
	Number	*Per Cent*	*Per Cent*	*Upper*	*Lower*
River	26	2.81			
Spillway	46	1.05	62.7	1.27	.57
Tunnel	45	1.77	37.0	1.67	0

* Confidence limits expressed as a factor of mortality estimate.

Although the confidence limits indicate that a considerable range in mortality estimates could be expected under similar conditions of experimentation the calculated mortality estimates from adult sockeye returns do not differ significantly from the results already obtained from the fyke net studies in 1951 and 1952. In the case of the spillway mortalities the figure provided by the adult returns is a measure of the losses incurred principally during one-gate spill. It will be recalled from the fyke net experiments that the mortality to native unmarked sockeye for this spill condition was *64.9 per cent* in 1951 and *62.1 per cent* in 1952. These results are in close agreement with the mortality rate of *62.7 per cent* based on the return of marked adult sockeye. The return of marked adults from releases into the tunnel in 1951 indicates a mortality of *37.0 per cent.* A mortality of *33.6 per cent* was calculated for tunnel migrants using the fyke net catches.

The data pertaining to the coho, given in Table XXVI cannot be used in the same manner as the sockeye to estimate spillway and turbine mortality rates. Only 1.88 per cent of the control fish were recovered whereas 2.43 per cent of the tunnel releases were recovered. The relatively low rate of return of marked control fish in 1952 may be explained, in part at least, by the composition of the release groups. The releases of marked coho fingerlings in 1951 consisted of hatchery fish as well as native fish. The hatchery fish were given the same permanent mark as the native fish and were distinguished for the fyke net studies in 1951 by a temporary mark which was not recognizable when the fish reached maturity. The spillway release consisted of 30 per cent hatchery fish, the tunnel release of 20 per cent hatchery fish but the release into the river consisted of 54 per cent hatchery fish. The investigations conducted at Minter Creek in the State of Washington have shown that the returns from releases of hatchery coho are considerably lower than the returns of naturally spawned native fish (Annual Report, State of Washington Department of Fisheries, 1953). Therefore, it is possible that the low return of control fish can be directly attributed to the high proportion of hatchery individuals in the river release.

The results in Table XXVI clearly show that a greater mortality occurred in the spillway releases than in the tunnel releases. The rate of return for marked coho released over the spillway was 1.78 per cent and the rate of return for marked coho passing through the turbines was 2.43 per cent. When analysed statistically by the method of Chi-square the difference in the rates of return of tunnel and spillway releases was found to be significant. A Chi-square value of 7.00 was obtained which for 1 degree of freedom corresponded to a P value of less than 1 per cent.

It is possible with the aid of one of the mortality estimates derived from the fyke net studies to convert the rates of return of adults to comparative mortality rates incurred at the dam. If either the spillway or turbine mortality rate is known the other can be calculated from comparison of the rates of return of marked adults as follows:

$$\frac{1 - \text{spillway mortality rate}}{1 - \text{turbine mortality rate}} = \frac{\text{rate of return of spillway fish}}{\text{rate of return of turbine fish}}$$

The turbine mortality rate of 28.3 per cent (Table XXV) as determined from the fyke net studies in 1951 and 1952 has been selected as a basis for determining the spillway mortality rate from adult returns. In terms of survival rate the turbine mortality rate of 28.3 per cent becomes 71.7 per cent and is equated to the rate of return of tunnel releases of 2.43 per cent. Knowing the rate of return of adults from the spillway releases (1.78 per cent) the survival rate of spillway fish is calculated to be 52.5 per cent and the mortality 47.5 per cent, based upon adult returns.

However, an error may be introduced as a result of the different proportions of hatchery fish in the two groups. The above calculations have been made on the assumption that the hatchery fish survive and return at the same rate as the native fish. But it is possible that this is not true. Consequently the calculated spillway mortality of 47.5 per cent may be too high because there was a greater proportion of hatchery fish in the spillway release than in the tunnel release. If on the other hand it is assumed that no hatchery fish returned and the marked adults recovered consisted of native fish only the estimate of mortality becomes 40.1 per cent. But if the calculation is made on this assumption the spillway mortality will be too low for in all probability some hatchery fish would return. It is evident, therefore, that the spillway mortality rate calculated in this manner must lie between 40.1 per cent and 47.5 per cent. In 1951 the spillway mortality as computed from the fyke net studies was 49.9 per cent. The returns of marked coho adults indicate a spillway mortality a little lower than this figure but in general the estimates from the two methods are in fairly close agreement.

OBSERVED INJURIES OF SPILLWAY AND TUNNEL MIGRANTS AND THEIR POSSIBLE CAUSES

An indication of the causes of mortality to migrant fish at the dam can be obtained by an examination of the injuries sustained and the physical characteristics of the spillway and the turbines and their associated structures.

There are a number of physical conditions which are possible sources of mortality in the spillway. The gates at the crest of the dam are normally operated fully open, discharging under a head of 0 to 13 feet. In this case there is some turbulence and pressure change at the square upstream corners of the gate piers. Near the crest of the dam the water from the fully opened gates jumps free of the spillway face but is nevertheless maintained in a fairly solid stream. Probably most of the injuries sustained by fish passing over the spillway are caused below the point where this freely falling stream impinges on the spillway face about 100 feet below the crest. At this point the stream spreads out to a thin sheet of extremely turbulent and fast-flowing water (Figure 17). The concrete face of the spillway is very rough, as shown by Figure 18, and this roughness in combination with the extreme turbulence and the high velocity could cause a great deal of injury through abrasion. Also, the high velocity flow of water over the rough spillway undoubtedly causes severe cavitation which could cause mortality. Perhaps the spreading of the flow in the bucket or curving section at the base of the spillway results in injuries from abrasion, turbulence and cavitation. Another possible source of injury is in the spillway pool where the energy of the spillway discharge is dissipated. This violently turbulent volume of water could conceivably injure the fish or aggravate existing injuries by tearing tissues or by scraping the fish on rough rocks.

FIGURE 17. Flow over the spillway at Baker Dam with one gate fully open and adjacent gates cracked one foot.

Cavitation, probably one of the most important possible causes of injury to downstream migrant salmon in spillways and turbines, occurs when bubbles of water vapor, formed in an area of low pressure, subsequently collapse with great explosive force when they are carried to an area of slightly higher pressure. The phenomenon of cavitation is sometimes referred to as a local vacuum because the pressure in flowing water is locally reduced when the water is forced to suddenly change direction or to flow over or around a roughness or solid object projecting into the stream. The pressure is reduced immediately downstream from the point of direction change and if the velocity is sufficiently high, bubbles of water vapor may form in the area of low pressure. This vapor can form only when the pressure is reduced below the vapor pressure of water. Cavitation can therefore be prevented by maintaining a sufficiently high pressure at the points of direction change so that even though the pressure is reduced, it cannot be reduced to below the vapor pressure. Undoubtedly fish encountering an area of very low pressure after being accustomed to high pressures will suffer some ill effects but considerably more injury, if not death, would ensue if this area of low pressure is followed immediately by violent cavitation explosions.

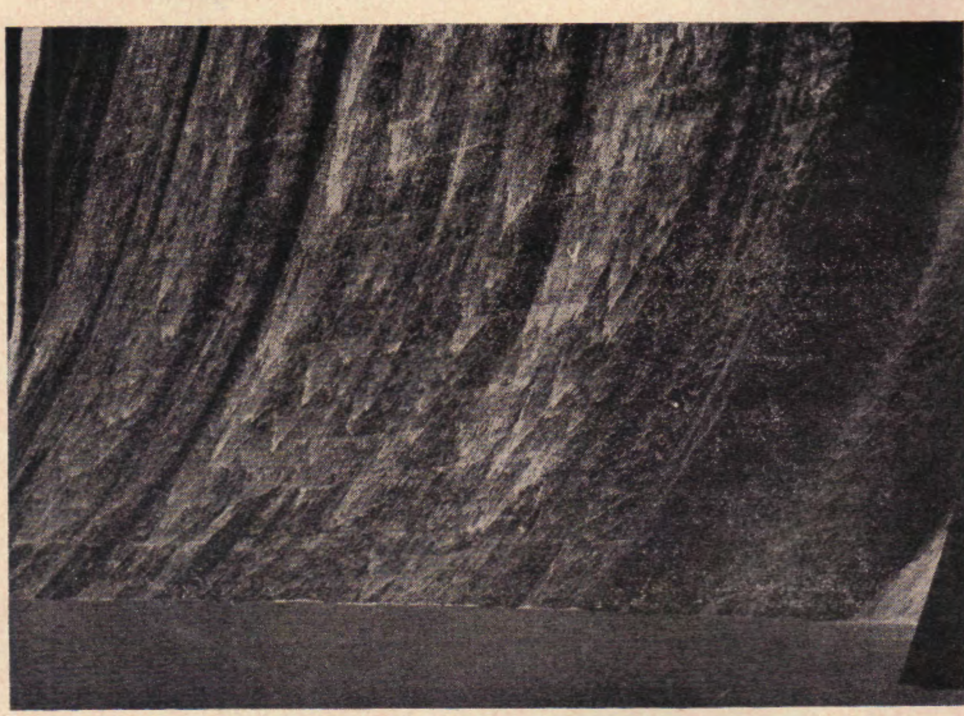


FIGURE 18. Rough concrete on the face of the spillway bucket at Baker Dam. The flow shown results from slight leakage at the spillway gates.

A sample of the fyke net catches was obtained each day and the fish were carefully examined for injuries and activity. The injuries suffered by native sockeye and coho migrants are shown in Tables XXVIII and XXIX. The frequency of injury has been expressed in percentage. Since a fish may sustain more than one type of injury a summation of the percentage values in any single column will not necessarily add up to 100 per cent. Some of the types of injuries referred to in the tables are illustrated in Figure 19.

The results for native spillway migrants of both species show that injuries directly attributable to abrasion (head scraped or crushed, opercles torn, body scraped or torn, scaling, split fins, and ruptured eyes) are the most frequent. Most

Table XXVIII

Frequency of Injuries to Unmarked Native Sockeye
After Passage Over the Spillway and Through the Turbines.
Frequency Expressed as a Percentage.

	Spillway			*Turbine*		
Condition on Recovery	*Dead*	*Live*	*Total*	*Dead*	*Live*	*Total*
No visible injury	3.1	31.3	21.4	13.1	41.8	36.1
Scales missing	55.7	36.4	43.2	68.4	47.7	41.4
Fins split or frayed	37.9	21.3	27.2	18.4	3.9	6.8
Eye Injuries—						
Ruptured or missing	44.9	5.0	19.0	0	.6	0.5
Distended	3.1	1.6	2.2	13.1	.6	3.1
Head Injuries—						
Scraped or crushed	27.1	5.4	13.0	7.8	0	1.6
Opercles torn	37.2	6.6	17.4	7.8	3.2	4.2
Isthmus torn	5.4	.4	2.2	2.6	0	0.5
Hemorrhages—						
Eyes	14.7	8.3	10.6	2.6	3.2	3.1
Jaws	2.3	.4	1.1	5.2	0	1.0
Base of fin or fins	8.5	10.4	9.8	15.7	.6	3.7
Internal	17.0	0	6.0	10.5	.6	2.6
Body scraped or torn	31.7	5.0	14.4	7.8	1.9	3.1
Total Number of Fish Examined	129	239	368	38	153	191

Table XXIX

Frequency of Injuries to Unmarked Native Coho
After Passage Over the Spillway and Through the Turbines.
Frequency Expressed as a Percentage.

	Spillway			*Turbine*		
Condition on Recovery	*Dead*	*Live*	*Total*	*Dead*	*Live*	*Total*
No visible injury	1.7	36.2	29.1	24.5	66.0	61.0
Scales missing	64.9	38.9	44.2	54.7	35.2	37.7
Fins split or frayed	22.5	10.5	13.0	20.6	4.3	6.3
Eye Injuries—						
Ruptured or missing	35.9	4.8	11.3	15.0	0	1.8
Distended	6.4	1.8	2.8	7.5	2.2	2.9
Head Injuries—						
Scraped or crushed	31.1	6.7	11.8	9.4	.5	1.8
Opercles torn	27.7	9.2	13.0	5.6	1.0	1.6
Isthmus torn	4.3	0	0.9	1.8	0	0.2
Hemorrhages						
Eyes	25.5	14.5	16.8	15.0	2.2	3.8
Jaws	3.8	.6	1.3	3.7	0	0.4
Base of fin or fins	6.4	4.1	4.6	7.5	1.0	1.8
Internal	8.2	.3	2.0	5.6	.2	0.9
Body scraped or torn	22.5	9.0	11.8	18.8	1.2	3.4
Total Number of Fish Examined	231	888	1,119	53	394	447

of these injuries would probably ultimately result in death although the seriousness of some did not immediately appear. Injuries directly attributable to cavitation or pressure change (distended eyes and hemorrhages) were not as common as those assigned to abrasion.

FIGURE 19. Some injuries sustained by sockeye and coho during passage over the spillway at Baker Dam. Fish at top is uninjured.

In an attempt to locate the possible causes of spillway mortality, one group of marked hatchery coho was released over the crest of the dam and another group was released into the pool at the toe of the dam. Releasing over the spillway was accomplished in the usual manner. Fish were released into the pool from a bucket on a high-line. The bucket was lowered to within 10 or 15 feet of the water surface and was then tipped, thus releasing the fish into the most turbulent part of the pool immediately downstream from the crest of the hydraulic jump at the foot of the spillway. Shown in Table XXX are the uncorrected numbers of live and dead fish recovered in Nets S_1 and S_{2a} from the two groups. Of the fish released into the pool 5.3 per cent were dead on recovery whereas 13.3 per cent of the spillway releases were dead.

TABLE XXX

Mortality of Marked Hatchery Coho Released Over the Spillway and Into the Pool at the Foot of the Dam

Location of Release	*Number Released*	*Number Recovered*		*Per Cent Dead*
		Live	*Dead*	
Pool	1,284	143	8	5.3
Crest of Spillway	2,824	280	43	13.3

The frequency of injury to the two groups (Table XXXI) clearly shows that the group released into the pool suffered very few injuries and that these injuries were not serious compared with those suffered by the group released at the crest of the dam. Of the fish released into the pool, and recovered alive, 84.9 per cent were uninjured whereas only 40.5 per cent of the fish released into the spillway and recovered alive were uninjured. In addition, the high incidence of fish from the spillway release with missing scales and frayed fins indicates that these injuries, which may or may not be of importance, are caused in large part by the spillway. An injury caused while fish are enroute down the spillway may not in itself be lethal but the conditions in the pool may be such that the injury may be sufficiently aggravated to cause death. It may be concluded that the turbulence in the spillway pool was a minor cause of the total spillway mortality, although it may have aggravated existing injuries.

TABLE XXXI

Frequency of Injuries to Hatchery Coho Released Over the Spillway and into the Spillway Pool. Frequency Expressed as a Percentage.

Condition on Recovery	*Spillway Release*			*Pool Release*		
	Dead	*Live*	*Total*	*Dead*	*Live*	*Total*
No visible injury	21.4	40.5	38.3	25.0	84.9	83.4
Scales missing	50.0	40.5	41.6	50.0	10.8	12.5
Fins split or frayed	14.2	13.2	13.3	0	2.1	2.1
Eye Injuries—						
Ruptured or missing	14.2	3.7	5.0	25.0	0	1.0
Distended	0	3.7	3.3	0	1.0	1.0
Head Injuries—						
Scraped or crushed	14.2	.9	2.5	0	0	0
Opercles torn	21.4	7.5	9.2	0	0	0
Isthmus torn	7.1	0	0.8	0	0	0
Hemorrhages—						
Eyes	14.2	5.6	6.7	0	0	0
Jaws	0	0	0	0	0	0
Base of fin or fins	0	2.8	2.5	0	0	0
Internal	0	0	0	0	0	0
Body scraped or torn	0	4.7	4.1	0	0	0
Total Number of Fish Examined	14	106	120	4	92	96

The probable causes of mortality in Francis turbines are: pressure change or cavitation near the trailing edges of the wicket gates and the runner blades; impact or abrasion at the blades and in the draft tube; and turbulence in the runner, draft tube and tailrace. The runner of each turbine at Baker Dam as shown in Figure 20, consists of a wheel 5 feet in diameter with 19 curved blades. On the upstream or pressure side of the runner the spaces between the blades are approximately 10 inches by 14 inches and the blades at the periphery of the wheel travel at a linear velocity of about 80 feet per second. The minimum clearance between the blades in the runner is two inches. When the turbine is operating at full load the water flowing through the wicket gates and through the runner follows a streamlined path and for this condition there should be a minimum of injury from cavitation and turbulence. However, at reduced loads the flow is less streamlined and turbulence and cavitation are consequently increased. The possibility that fish would suffer abrasion in passing through the draft tube cannot be ignored because of the high velocities and the possibility that the surface may be rough, particularly at the points where the flow changes direction. Pressure change and cavitation would appear to be the most important possible causes of injury and mortality to fish passing through the turbines.

During the period of experimentation the tailrace water surface was only 5 feet below the center of the turbine runner. This abnormal condition resulted

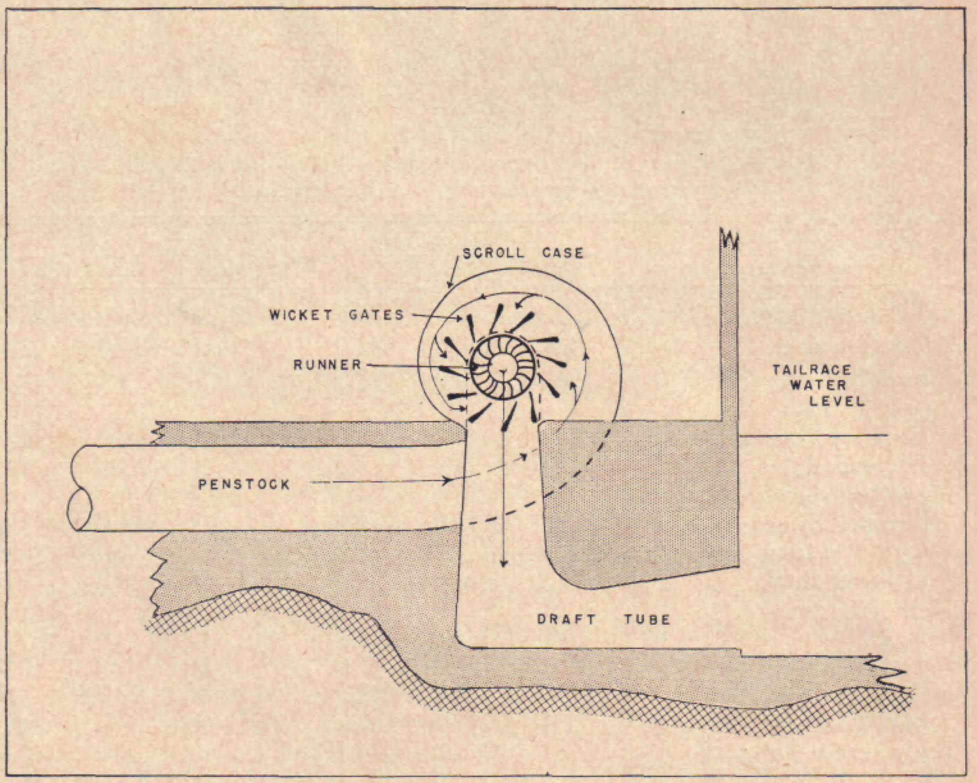


FIGURE 20. Diagrammatic sketch of one of the Francis-type turbines at Baker Dam.

in a slight positive pressure, usually from 0 to 2 pounds per square inch above atmospheric, in the draft tubes 2 feet below the center of the runners. Under these conditions cavitation would be less severe than it would under more typical conditions where the tailrace elevation is maintained at a lower level with respect to the center of the turbine runners. Following the investigation in 1952 the river bed downstream from the plant was excavated and the tailrace surface dropped almost 3 feet. This reduced tailrace level resulted in draft tube pressures which varied from 0.5 pounds per square inch above atmospheric to 2 pounds below atmospheric pressure. Under this new condition there were audible cavitation explosions in the draft tube whereas with the higher tailrace level, cavitation explosions were seldom heard.

Examination of the native tunnel migrants showed that the sockeye suffered more injuries than the coho and that the frequency of injury was lower in general to the tunnel migrants than to the spillway fish (Tables XXVIII and XXIX). One noticeable feature about the data in these tables is the higher incidence of dead tunnel fish that had no apparent external injuries. It would appear that these mortalities had resulted from some unobserved internal injury caused by the sudden reduction in pressure from 108 pounds per square inch on the pressure side of the runners to about 15 pounds per square inch on the downstream side. The frequency of injuries attributable, at least in part, to pressure change were about the same for both the spillway and tunnel migrants. The infrequent occurrence of such external injuries to tunnel fish suggests that the turbine mortalities were lower than would be expected because cavitation was partially eliminated as a result of the abnormally high tailrace. Also, injuries to fish migrating through the tunnel were minimized because the turbines were operated only at full load.

ENVIRONMENTAL CONDITIONS IN THE RESERVOIR WITH RELATION TO MIGRATION

As previously stated, at least 95 per cent of the migrants leaving the reservoir used the spillway exit. Although the tunnel was available as an exit during all or nearly all of every day it was rarely used as a means of access to the river. Certain physical conditions in the forebay were measured in an attempt to determine causes of this migration pattern. Water temperature records were obtained in the reservoir and tailrace. Fluctuations in water surface elevation of the reservoir were studied in relation to use of the tunnel exit by migrating fish. The flow pattern of the forebay was studied by means of extensive velocity measurements and construction of a dynamic model.

The daily mean temperatures of the reservoir measured at a point three feet below the surface and 50 feet upstream from the dam are shown in Figure 21. Also shown are the water temperatures of the turbine discharge at the tailrace. The mean daily temperature of the surface layers of the reservoir seldom exceeded 55°F. The tailrace was always several degrees colder.

The water temperatures of the reservoir at various depths 1650 feet upstream from the dam are shown in Figures 22 and 23. In 1951 a thermocline had started to form by June 1. In 1952 the thermocline was forming on May 15 and appeared to be well established between the 20- and 35-foot depths by June 9.

Depth-temperature records obtained 31 feet in front of the tunnel intake are shown in comparison with similar records obtained 1650 feet upstream from the dam in Figures 24 and 25. These revealed that the temperature pattern in the immediate forebay tended to remain the same as that 1650 feet from the dam. The thermocline 31 feet in front of the tunnel intake tended to remain intact despite the constant withdrawal of water into the tunnel. When depth-temperature records were taken during periods of spilling (May 22 and June 9, 1952) there was no appreciable change in the temperature pattern in the tunnel intake area (Figure 25).

As far as can be determined, both the sockeye and coho occupied principally the surface layers of the reservoir. The presence of a zone of sharp temperature change may have confined the fish to the upper warmer layers. As the thermocline tended to become deeper the fish may have followed it downward. But since it at no time reached the level of the tunnel the fish would have had to pass through the zone of sharp temperature change in order to use the tunnel exit from the reservoir.

From April 12 until about April 30 in 1952 the hourly rate of migration of coho through the tunnel exceeded that at any time to follow. The combination of an ill-defined thermocline and the low reservoir elevation, which prevailed during this period (Figure 10), probably contributed to the larger migration.

It was observed during the migration periods in 1951 and 1952 that the water discharging from the tailrace was much more turbid than that in the surface layers of the reservoir. For instance on May 23 in 1952 a Secchi disk measurement in the forebay was 99 inches while in the tailrace it was 53 inches. The increased

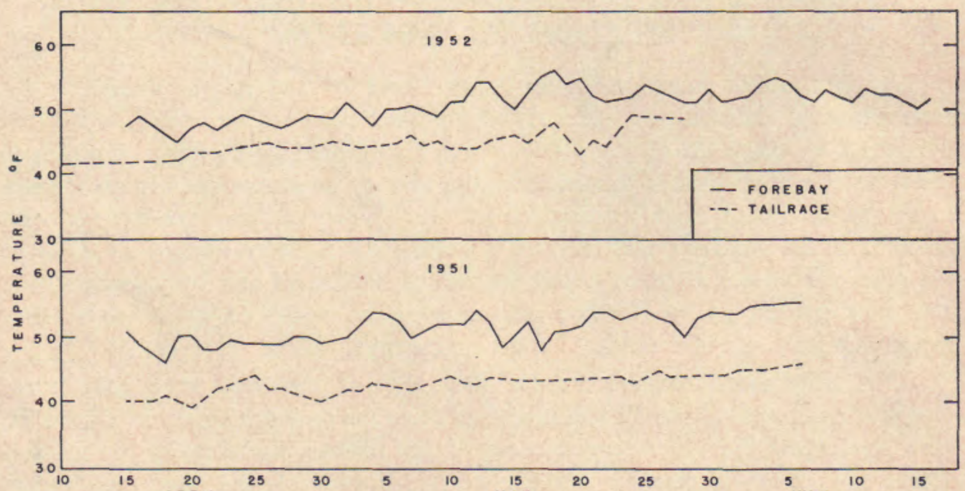


FIGURE 21. Mean daily temperature of reservoir and tailrace. Reservoir temperature taken three feet below the water surface and 50 feet upstream from the dam.

turbidity at the level of the tunnel intake may have had some bearing on distribution of the fish in the reservoir and may have influenced the relative numbers of fish using the tunnel and spillway in their migration.

One of the most important factors apparently influencing the choice of exit from the reservoir was the approach velocity at the two exits when both exits

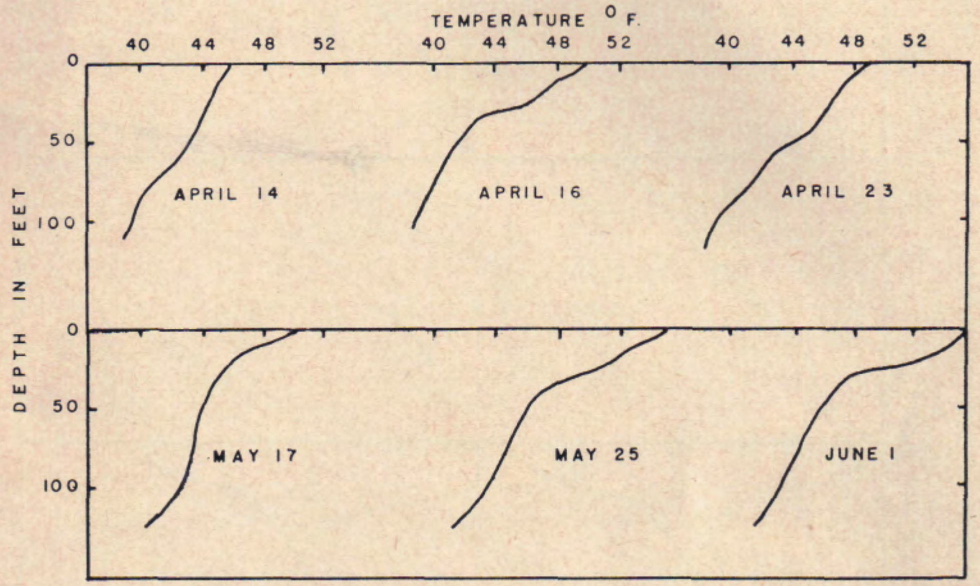


FIGURE 22. Reservoir water temperatures taken 1650 feet upstream from Baker Dam in 1951.

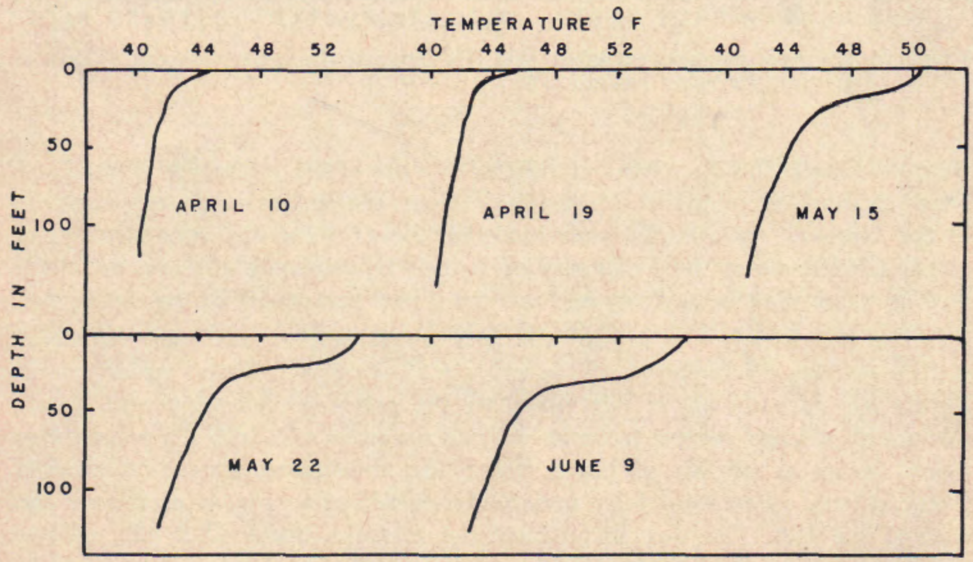


FIGURE 23. Reservoir water temperatures taken 1650 feet upstream from Baker Dam in 1952.

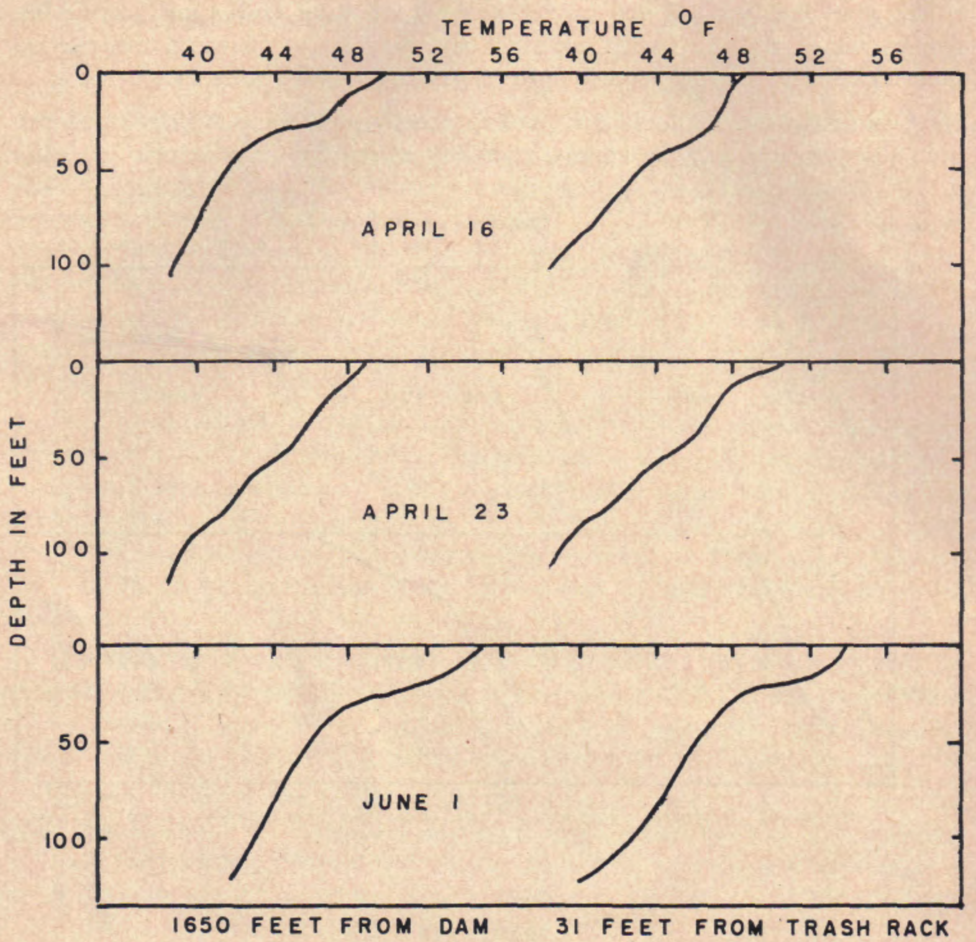


FIGURE 24. Reservoir temperatures taken 1650 feet upstream from the dam and 31 feet in front of the tunnel intake in 1951.

were available. The direction and velocity of flow in the forebay at Baker Dam were obtained from model studies and from current velocity measurements in the forebay. An accurate scale model of Baker Dam was constructed in a glass-walled flume at the University of British Columbia. The direction of the flow of water over the spillway and into the tunnel was traced by the use of dye.

The pattern of flow toward the spillway as determined from the model studies without consideration of thermal stratification is indicated by arrows in Figure 26. Also shown on this figure are the prototype velocity measurements taken with a Price current meter at varying distances and depths along an axis perpendicular to the face of Baker Dam. The measurements were made when three spillway gates were fully open and one adjacent gate on each side was cracked one foot. The flow pattern and the velocities measured 2 feet, 14 feet and 31 feet in front of the trash rack are given in Figure 27.

Two almost distinct flow patterns are set up in the forebay when the reservoir

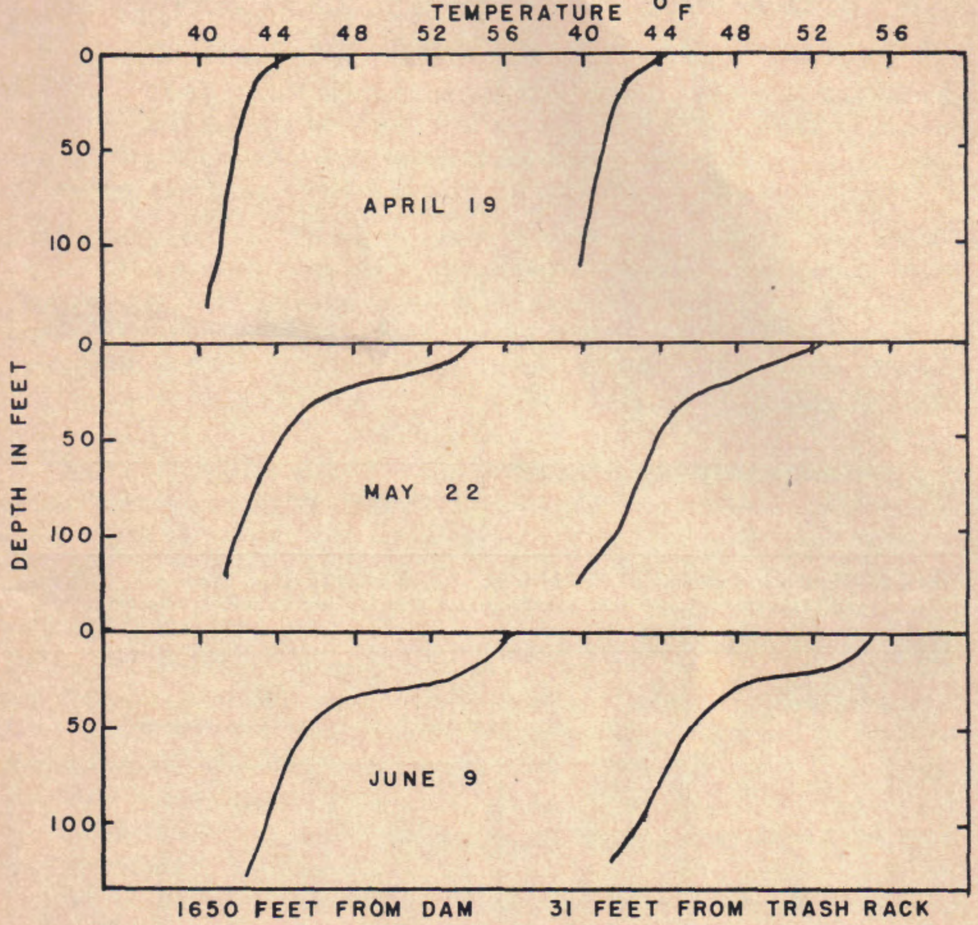


FIGURE 25. Reservoir temperatures taken 1650 feet upstream from the dam and 31 feet in front of the tunnel intake in 1952.

is full and spilling is in progress. The water discharged over the spillway is drawn largely from the surface layers. The tunnel intake, located between the 85- and 107-foot levels, draws little or no water from the upper 20 feet at full reservoir. Surface migrating coho and sockeye, therefore, on approaching the dam when the reservoir is full and spilling is in progress encounter, at best, a very weak attractive velocity in the direction of the tunnel. They are drawn to the spillway exit because the prevailing flow is in that direction. When there is no spilling the only remaining attraction is in the direction of the tunnel. But apparently it is not sufficient to induce any significant numbers of fish to take this route.

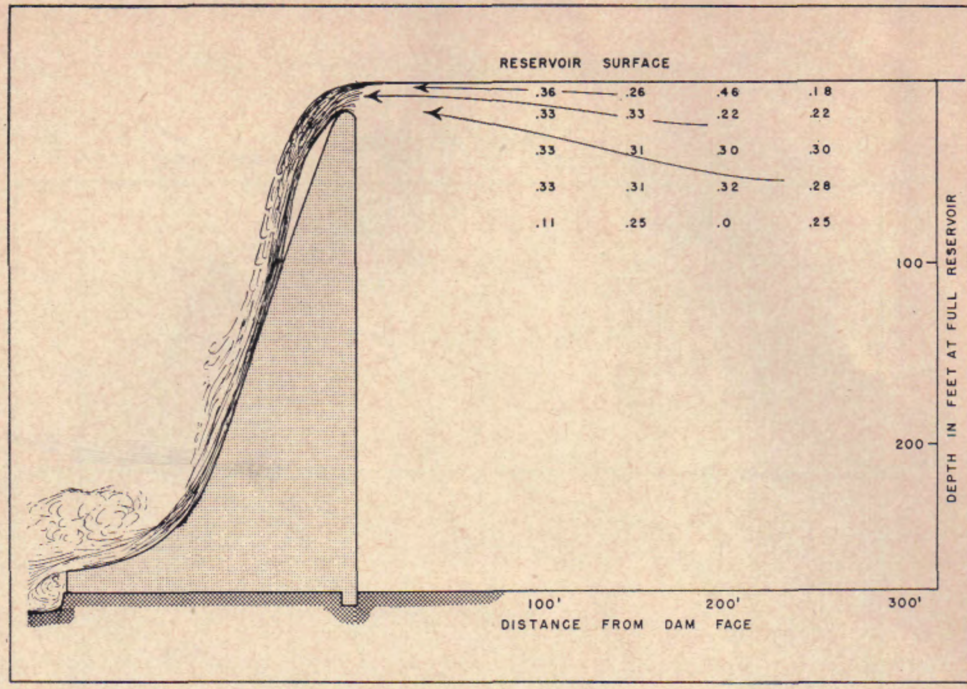


FIGURE 26. Pattern and velocity of flow in front of open spillway gates. Three gates full open and two cracked one foot. Velocities shown in feet per second. Discharge 4650 cfs.

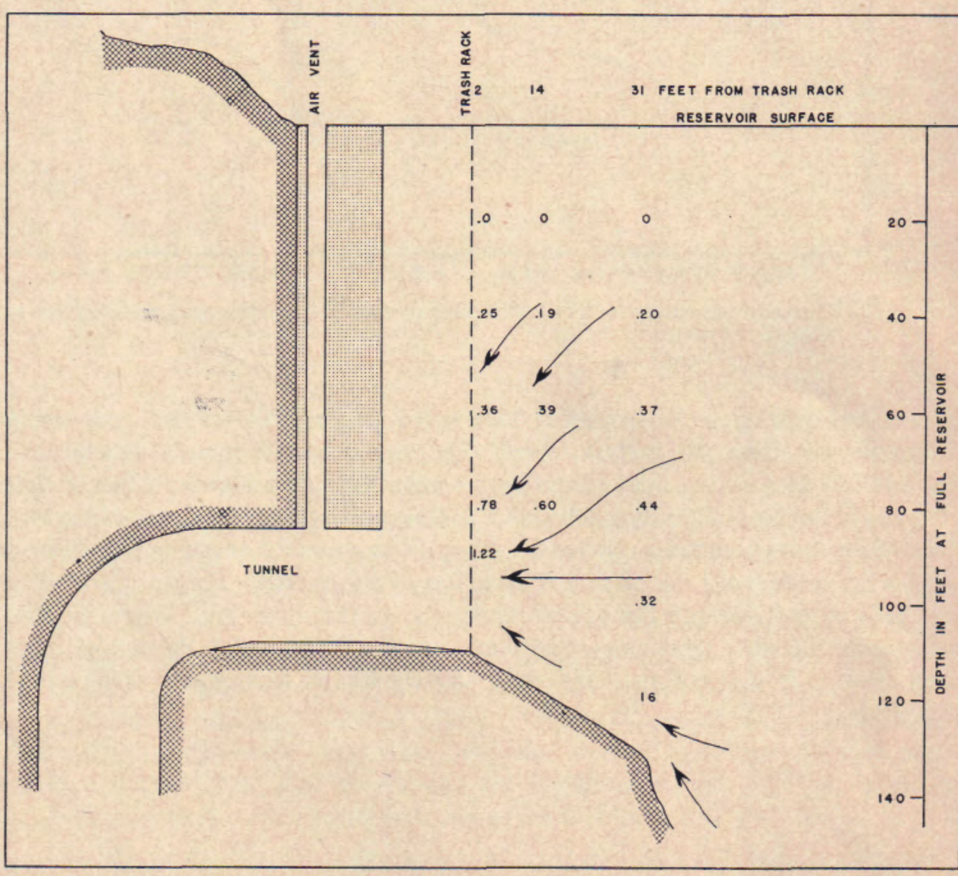


FIGURE 27. Pattern and velocity of flow at tunnel intake. Velocities shown in feet per second. Discharge 2240 cfs.

PRODUCTION OF SOCKEYE SALMON BEFORE AND AFTER CONSTRUCTION OF DAM

An indication of the effect of Baker Dam on the survival of downstream migrant salmon can also be obtained by a comparison of the annual production of adults before and after construction of the dam. This comparison can be made for sockeye only, since complete records are not available for coho.

The magnitude of the annual return of adult sockeye salmon from a given number of spawners is controlled by mortalities which occur throughout the entire life span. These mortalities occur during incubation, fry migration, lake residence, seaward migration and sea residence and are followed by mortalities imposed by the commercial fishery. The mortalities during the period of freshwater residence are considered to be the most important in limiting the production of adults (Foerster, 1936).

As already discussed in the introduction, mortalities incurred at certain stages of the life history are compensated for by increased survival at later stages. But the evidence already cited indicates that compensation is not effective in the sea. That is, there is no increased survival of sea residents with a reduction of survival in fresh water. Mortalities to young seaward migrating salmon incurred at Baker Dam should therefore be reflected directly in the abundance of adult salmon produced. If the mortality estimates determined from the fyke net studies and from the return of marked adults are valid it seems only reasonable that there must be a proportionate decline in the production of adult sockeye since the construction of the dam.

As previously discussed, the annual production of Baker River sockeye has been obtained from records of the annual catches and escapement. The catch was determined from statistics furnished by the State of Washington Department of Fisheries. Prior to construction of the dam the escapement records were obtained from the files of the Baker Lake Hatchery, built in 1896. Records for consecutive years date back to 1916. Except for the years 1905, 1908 and 1911 all previous records were destroyed by fire. Beginning in 1925 escapement records were kept by the operators of the fish hauling device at the dam. Prior to 1934 the sockeye were trapped at the entrance to Baker Lake. The fish were artificially spawned and the eggs incubated in the hatchery. After 1933 with the closure of the hatchery the fish reproduced naturally.

The dam, started in the summer of 1924, was not completed until 1925. The reservoir commenced filling in October of that year but not until the spring of 1926 was any water released over the crest of the dam. It was in 1926 that the young fish were first subjected to a fully developed power project. These fish produced the adult run of 1928.

The annual commercial catch and escapement of Baker River sockeye for the years 1905, 1908, 1911 and from 1916 to 1953 are presented in Figure 28. The escapement (8000 fish) shown in the graph for 1925 is only an estimate of the number of fish that reached the dam. It is thought that only a very small portion of this run ascended to the spawning areas above the dam. From 1905 to 1927, inclusive, the commercial fishery captured 39.7 per cent of the fish migrating to the spawning grounds. For the short period from 1928 to 1934 the fishery caught an even greater proportion, 67.6 per cent. In 1935 the fishery was eliminated but was resumed again in 1936 at a much lower intensity. From 1936 until 1953 only 23.3 per cent of the returning adults were taken by the commercial fishery.

The average annual production of adults from 1905 to 1927 was 10,416 sockeye, whereas from 1928 to 1953 the average annual production was only 4631 fish. The runs in general maintained themselves at a much higher level of abundance prior to 1927 than for the period 1928 to 1953. The increase in the escapement following the reduction in the fishery in 1935 resulted in a noticeable increase in the size of the runs from 1939 to 1942 but this higher level of abundance was not maintained. Following 1942 the run again decreased in size and since that date has continued at the 1928 to 1934 level. Despite the reduction in the fishery the runs were still unable to reach the level of abundance established in the period prior to 1927.

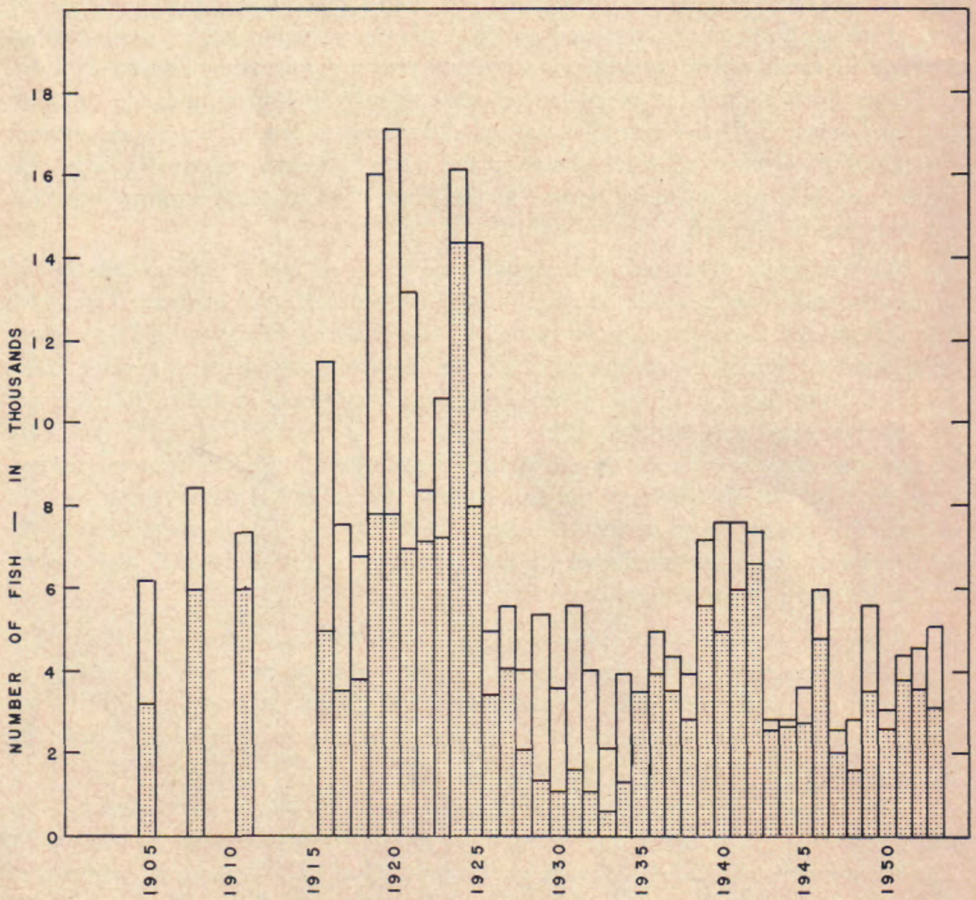


FIGURE 28. Annual escapement and commercial catch of Baker River sockeye for the years 1905, 1908, 1911 and 1916 to 1953. Escapement shown as lower bar and catch as upper bar.

The sharp and sustained decrease in the annual production from 1928 to 1953 must be attributed to either the ill effects of Baker Dam or to normal fluctuations in productivity. If the decline is to be explained on the basis of normal fluctuations the cause or causes must lie in the spawning and rearing areas located above the dam. However, there is no evidence of changes in the original sockeye spawning and rearing areas. Evidence is presented in Figure 12 which indicates that Baker River sockeye compensate for reduced numbers of spawners by increased survival at later stages. This observation is in agreement with the findings of Withler (1953). Therefore it seems apparent that the race could compensate for losses caused by natural variations in the incubation and rearing areas above the dam. Consequently the sustained decline in the run cannot be explained on the basis of normal fluctuations in productivity but must be assigned to the dam itself.

The decline in the size of the runs from 1928 to 1953 cannot be attributed entirely to mortalities caused during the downstream migration. It has been noted in an earlier section that lack of spill during the time of upstream migration caused the adult fish to be delayed below the weir and in most instances this delay resulted in a noticeable decrease in the rate of return four years hence. A decline in the size of the runs would also become evident if the catching devices below the dam failed to capture any significant proportion of the escapement. Failure to capture the adult salmon during the early development of these devices may explain in part why the runs in 1926 and 1927 showed such a sharp decline over the preceding years. Subsequent improvements in this equipment have undoubtedly aided in reducing this loss in later years.

Comparison of the average annual production of Baker River sockeye before and after construction of the dam clearly indicates the serious effect of the dam on the production of sockeye salmon. The average annual production from 1928 to 1953 in comparison with the average annual production for the period 1905 to 1927 declined 55.5 per cent. Omitting those runs (1944-1946 and 1948 and 1949) whose parents were delayed in their migration to the spawning grounds, the average number of salmon produced from 1928 to 1953 becomes 4,743 fish which in comparison to the average size of the runs from 1905 to 1927 shows a decline of 54.5 per cent. The fyke net catches showed that practically all of the downstream-migrant sockeye used the spillway exit where they suffered a mortality of 63.5 per cent for one gate of spill and an estimated 82.2 per cent for two-gate spill. The adult returns from marked sockeye releases showed a spillway mortality of 62.7 per cent for one-gate spill. If the decline in the adult run is a reliable approximation of the adverse effect of the dam on seaward migrant sockeye it would appear that the mortalities established both from the fyke net experiments and the adult returns of marked fish may be too high or that there has been a certain amount of variability in mortality from year to year, the decline in the run of 54.5 per cent being the average loss over the years. Whatever may be the explanation for the difference, it is apparent from these three independent sources that the mortality to sockeye passing over the spillway is high and that this mortality has resulted in a very significant reduction in the number of adult salmon produced.

SUMMARY AND CONCLUSIONS

A research program was undertaken at Baker Dam in Western Washington to determine the effect of a high dam on downstream-migrant salmon. The experiments, conducted from 1950 to 1952, utilized native runs of sockeye and coho salmon augmented by hatchery fish. The research was aided by the State of Washington Department of Fisheries and the Department of Fisheries of Canada. The specific objectives of the investigation were: first, to determine the character of the downstream migration from the reservoir; second, to evaluate the effect of the turbines and spillway on survival of the seaward migrants; third, to isolate the cause or causes of any existing mortality.

The work conducted in 1950 was largely of an exploratory nature to determine what method or methods might best be employed to accomplish the above objectives. The principal method adopted in 1951 and 1952 consisted of sampling the native sockeye and coho seaward-migrant population with fyke nets located in the tailrace below the power house and in the river below the spillway pool. Two additional methods were employed for measuring the mortalities incurred by downstream-migrant sockeye passing over the spillway and through the tunnel. In the first of these, marked downstream-migrant sockeye were released over the spillway and into the tunnel and the rates of return of these fish as adults were compared with the rate of return of marked control fish that had been released as seaward migrants into the river. A comparison between the average annual production of sockeye salmon before and after construction of the dam served as the second of these two supplementary methods for measuring the mortality incurred by yearling migrant sockeye salmon.

The data indicated that the migration of sockeye from the reservoir occurred from April 25 to June 18 whereas the coho migration began before April 11 and had not ended by June 18. The peak of migration of both coho and sockeye occurred about May 15 but the sporadic spilling made it difficult to define the date exactly.

Although no measure of the vertical distribution of the coho or sockeye in the forebay was attempted it seemed that a significantly large portion of the migrating fish were present in the surface layers of the reservoir. These fish were observed to move in the shadows around the margin of the reservoir during bright days, but during periods of overcast or during twilight the fish could be seen dispersed throughout the whole area of the forebay.

The fyke net catches in the tailrace and in the river below the spillway revealed that the migration was principally over the spillway. The tunnel with its entrance 85 feet below the surface at full reservoir was used by less than 5 per cent of the migrating stock. Even during periods when the spillway gates remained closed there was no increase, or at best, an insignificant increase in the number of fish using the tunnel. It was found, however, that when the reservoir was low and the tunnel was only 44 feet below the surface a significantly greater number of coho passed through the tunnel and as the reservoir filled there was a gradual and pronounced decline in the number of fish using the tunnel. Other environmental variables such as turbidity and temperature gradients, and approach velocities may also have influenced use of the tunnel as an exit but their effects could not be separately assessed.

A review of the annual return of Baker River adult sockeye to the commercial fishery and to the dam provided evidence that delayed spillway opening at the time of seaward migration had little or no effect on the number of yearling migrants eventually leaving the reservoir nor on the ultimate production of adults.

The effect of the spillway and turbines on the migrating sockeye and coho was assessed from the relative numbers of active, weak and dead fish present in the fyke net catches. These catches, however, were not representative of the stocks of fish that were emerging from the spillway pool and from the draft tubes. It was found from the recoveries of marked dead releases and marked live releases that the dead fish were less available than the live fish. Consequently a correction for the lower availability of dead fish was applied. It was shown by auxiliary experiments that the survival gears used in the mortality studies captured and retained the active swimming fish and that they had no noticeable injurious effect on the captives providing the fish were not retained for too long a period. The delayed effect of injuries was examined by holding live fish for several days. It was concluded from these special studies that about 18 per cent of the active spillway fish, 8 per cent of the active tunnel fish and 54 per cent of all weak fish would ultimately die as a result of their injuries. They were therefore considered as potential mortalities.

Taking into consideration the disproportionate availability of live and dead fish to the nets and the delayed effect of injuries, the mortalities to sockeye and coho migrants passing over the spillway during one gate of spill were estimated to be 63.5 per cent and 54.0 per cent respectively. The turbines killed 33.6 per cent of the sockeye and 28.3 per cent of the coho.

The return of marked adult sockeye to Baker Dam in 1953 from the spillway, tunnel, and river releases of 1951 provided another measure of spillway and tunnel mortality. Comparison of the rates of adult returns indicated that the sockeye passing over the spillway suffered a mortality of 62.7 per cent whereas 37.0 per cent of the tunnel releases were killed. The returns of marked adult coho, while not directly providing a measure of spillway and tunnel mortality, did serve to confirm the relationship between the tunnel and spillway mortalities obtained from the fyke net studies.

All captured fish were examined for injuries and a study was made to determine the possible causes of these injuries. Many fish that had passed over the spillway had superficial injuries such as damaged operculi, ruptured and crushed eyes, scraped and crushed heads, and scraped and torn body walls, which were directly attributable to the rough and irregular nature of the spillway face. Internal hemorrhaging and distended eyes were also evident, indicating that the fish also suffered from the effects of pressure change and cavitation. To determine the effect of the extremely turbulent spillway pool, a number of hatchery coho were released from a high-line bucket at the most turbulent point of the upstream end of the pool. In these special tests fish passing over the spillway had a mortality rate 2.5 times greater than fish released directly into the pool. Injuries to fish released over the spillway exceeded those sustained by fish released into the pool in number and severity. It was concluded that mortalities and injury to fish using the spillway exit were incurred primarily during the fall from crest to pool and were caused principally by abrasion and pressure change. The fish passing through the tunnel suffered comparatively few injuries. The injuries that were evident were mainly distended eyes, hemorrhages and body scrapes. It is possible that reduced cavitation resulting from an abnormally high tailrace level may have been responsible for a lower mortality and injury rate than might otherwise occur to fish passing through Francis turbines under 250 feet of head. All experiments were conducted when the turbines were operating at full load, and it is thought that this also tended to minimize the injuries.

The records of production of Baker River sockeye before and after the construction of the dam were examined to determine whether or not the estimated mortalities to the downstream migrants caused a proportionate reduction in the total numbers of adult sockeye returning to the commercial fishery and to the spawning grounds. The data showed that the production of adult sockeye has declined 54.5 per cent since the construction of the dam. This information agrees quite closely with the results previously obtained which established that at least 95 per cent of the sockeye used the spillway in gaining access to the river and that these migrants suffer a mortality for one gate of spill of 63.5 per cent as determined by fyke net studies or 62.7 per cent based on adult returns of marked releases of sockeye.

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