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PROGRESS REPORT

SOCKEYE AND PINK SALMON INVESTIGATIONS AT THE SETON CREEK HYDROELECTRIC INSTALLATION

BY

F. J. ANDREW and G. H. GEEN

NEW WESTMINSTER, B. C.
CANADA
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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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ABSTRACT

Investigations conducted in 1956 and 1957 indicated that the potential production of sockeye and pink salmon in the Seton-Anderson watershed has been reduced by the construction of the Seton Creek hydroelectric installation. The upstream migration of adult salmon was not seriously impaired by the 25-foot diversion dam in Seton Creek, provided the radial gate was not used for spilling excess water. Mortality rates of sockeye smolts passing through the turbine, fish-water sluice and siphons were measured and it was estimated that the sockeye populations would be reduced by at least 10 per cent and that portion of the pink salmon population originating above the Seton Dam would be reduced by possibly 13 per cent as a result of mortalities suffered during the seaward migration at the dam and the powerhouse. Adult pink salmon destined for the Seton-Anderson watershed suffered an average delay of one day in the powerhouse tailrace but some individual pink salmon and late-running sockeye salmon were delayed for considerably longer periods. This delay occurred in spite of periodic powerhouse shutdowns and appeared to be related to the level of the Fraser River, the delay being greatest during low water. Some of the pink salmon and particularly Portage Creek sockeye salmon appeared to be seriously affected but further study is required for a more complete evaluation of this problem. Other factors adversely affecting salmon production include a reduction in pink salmon spawning areas and changes in the environmental conditions in Seton Lake.

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INTRODUCTION

The Seton Creek hydroelectric installation built on Seton Creek, a tributary of the Fraser River near Lillooet, British Columbia, was completed in September 1956. As the duties of the International Pacific Salmon Fisheries Commission are to preserve, protect and extend the sockeye salmon (*Oncorhynchus nerka*) and pink salmon (*O. gorbuscha*) of the Fraser River watershed, investigations designed to evaluate the effects of the Seton Creek development on these two species of salmon have been initiated.

The salmon populations of the Fraser watershed suffered a very serious decline as a result of a disastrous slide in 1913 at Hell's Gate in the Fraser Canyon. However, following the construction of fishways at this site in 1945, there has been a marked increase in the size of the spawning populations in all important areas above Hell's Gate.

In the Seton-Anderson watershed, the spawning populations have increased in recent years from relatively few fish to substantial numbers at the present time.

In 1956, there were 9059 early sockeye spawners in Gates Creek, at the upper end of Anderson Lake, increasing from 6883 in the 1952 cycle year. In 1957, 1112 sockeye spawned in Gates Creek compared with 78 in the previous cycle. As a result of a planting of eyed eggs originating from the late Adams River run, 3505 sockeye spawned in Portage Creek, between Anderson and Seton Lakes, in 1954. On the basis of the number of three-year-olds appearing in 1957, a further increase in this population is expected in 1958.

As a result of the Hell's Gate disaster in 1913, no pink salmon were reported in the historical spawning grounds of Portage, Cayoosh and Seton Creeks from 1913 until 1945, when the Hell's Gate fishways went into operation. Early hatchery records indicate that in 1911, the last cycle year preceding the slide at Hell's Gate, 200,000 pinks spawned in the Seton watershed. However, the commercial fishery for this species was not as intense in the early years as it is today and the spawning area may therefore have been overpopulated in the early years. The spawning population calculated at 60,677 fish in 1957 is believed to approximate the size required for maximum utilization of the spawning area available after construction of the Seton and Cayoosh Dams.

Smaller populations of coho and spring salmon, steelhead trout, and resident game fishes are also found in the Seton Creek watershed.

The problems involved in protecting salmon and trout at the Seton Creek hydroelectric installation were first discussed by representatives of the Canadian Department of Fisheries, British Columbia Game Commission, International Pacific Salmon Fisheries Commission and the British Columbia Electric Company at a meeting held on May 15, 1953. Frequent meetings of the technical personnel of the B.C. Electric Company and the fisheries agencies were required in order to design methods of protecting the fisheries resource. It was decided that the minimum requirements for fish protection would be provided when the plant was built and that the need for additional fish-protective facilities would be investigated after the plant was in operation. Accordingly, a fishway was installed to allow salmon and trout to pass upstream over the dam, a coarse screen was provided to prevent adult salmon and trout from being carried down the canal to the powerhouse, and minimum stream flows for fish maintenance were established.

The problems of temperature changes, reduced flow, migration of adult salmon past the powerhouse, disturbance of spawning areas, and smolt mortality were left for study after the plant was in operation. It was also recognized that other problems might develop which would require investigation after completion of the plant.

The studies described in this report were undertaken to determine any adverse effects on the sockeye and pink salmon populations that might have resulted from the completed installation. The numbers of sockeye and pink salmon spawning in the watershed have been enumerated either by tagging or actual count. The survival of pink salmon eggs and alevins under reduced flows in Seton Creek below the dam is currently being studied. The migration of adult sockeye through the fishway was studied in 1956. In 1957, mortalities suffered by sockeye smolts passing through the turbine, siphons, and fish-water sluice were measured and the migration of adult pinks and sockeye past the powerhouse tailrace was studied.

DESCRIPTION OF HYDROELECTRIC INSTALLATION

The hydroelectric installation consists of a concrete diversion dam in Seton Creek 2500 feet below the outlet of Seton Lake and a canal extending 12,500 feet from this dam to a powerhouse on the right bank of the Fraser River 4500 feet below the confluence of Seton Creek with the Fraser River. A low dam on Cayoosh Creek, 6000 feet above its confluence with Seton Creek, and a 1600-foot tunnel from the forebay of this dam to Seton Lake permits diversion of the entire low flow and a portion of the flood flow of Cayoosh Creek to Seton Lake for power generation at the Seton plant. The location of Seton Creek in relation to the lower Fraser River watershed is shown in FIGURE 1, and the layout of the power development is shown in FIGURE 2.

The Seton Dam, shown in FIGURE 3, operates under a maximum head of 25 feet and consists of a radial gate spillway, five siphon spillways, a fish-water sluice, a vertical-slot fishway, and an intake structure to the canal leading to the powerhouse. The radial gate is 40 feet long and 18 feet deep and is designed to pass about 8000 cubic feet per second. Each of the four siphons adjacent to the radial gate is capable of discharging 900 cubic feet per second. At the request of the fisheries agencies, the fifth siphon, with a capacity of 700 cubic feet per second and located adjacent to the fish-water sluice, was designed to start operating at a forebay elevation 3 inches lower than the other four siphons in order to provide a more gradual buildup of discharge below the dam and to provide attracting flows as near as possible to the fishway entrance.

Flow in the natural channel of Seton Creek is maintained by discharges through the fish-water sluice and fishway. A minimum flow of 400 cubic feet per second is provided during the period of adult salmon migration and spawning and 200 cubic feet per second at other times of the year, including the period of egg incubation. The fish-water sluice discharge passes through a 5-foot-square gated opening in the dam, the center of the opening being 14 feet below maximum forebay elevation and 11 feet below minimum forebay elevation. Part of the energy of this high-velocity discharge is dissipated in a chamber immediately downstream from this gate before the water is released below the dam. This energy-dissipating chamber is 45.5 feet long, the width increases from 5 feet at the upstream end to 10 feet at the downstream end, and the maximum water depth varies from 6 feet at the upstream end to 15 feet at the downstream end. All of the water can be released at the downstream end of this chamber through a submerged gated opening or by allowing part of the flow to pass through the gated opening and part over the weir crest at the downstream end of the energy-dissipating chamber.

The fishway consists of a baffled concrete channel 8 feet wide and 350 feet long. The water passes through a vertical slot $16\frac{1}{4}$ inches wide in each of the 32 baffles in this channel. Except at the two 180° turns, the pools formed by the baffles are 8 feet wide by 10 feet long. The water depth is about 5 feet at maximum forebay and minimum tailwater elevations. The discharge ranges from 20 to 45 cubic feet per second, depending on forebay elevation. Longitudinal sections of the radial gate, siphons, and fish-water sluice are shown in FIGURE 4.

The power canal is trapezoidal in cross section, 20 to 36 feet wide across the bottom, 40 to 80 feet across the top, and operates with a water depth of about 15 feet. At the downstream end of this canal, a penstock, 18 feet in diameter and 370 feet long, carries the water to a single 58,500-horsepower vertical-shaft Francis turbine which operates under a head of 131 to 167 feet and discharges a maximum of 4500 cubic feet per second at full load. The minimum clearance between the turbine runner blades is about 6 inches, wheel diameter is 12 feet, and the speed of rotation is 120 revolutions per minute. FIGURE 5 illustrates a longitudinal section of the penstock intake, penstock, turbine and tailrace.

The tailrace channel extends about 250 feet from the powerhouse to the Fraser River. As shown in FIGURE 6, the tailrace channel is almost perpendicular to the Fraser River. The elevation of the tailrace is dependent on the discharge of the Fraser River and varies over a range of 33 feet, from elevation 608 to 641 feet above sea level. When the Fraser River is at its lowest elevation, the tailrace channel is about 20 feet deep.

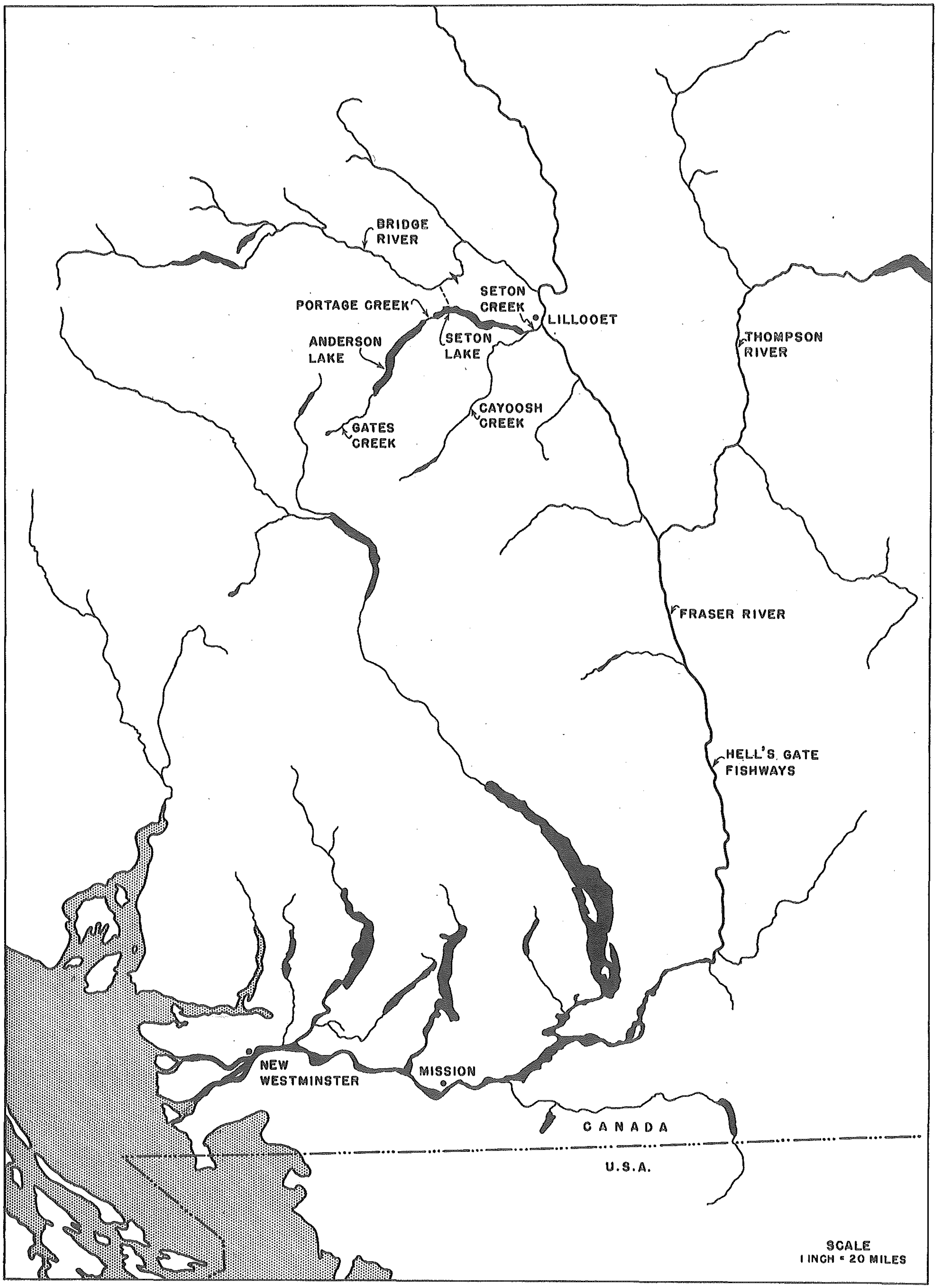


Figure 1. Location of the Seton-Anderson system in relation to the lower Fraser River watershed.

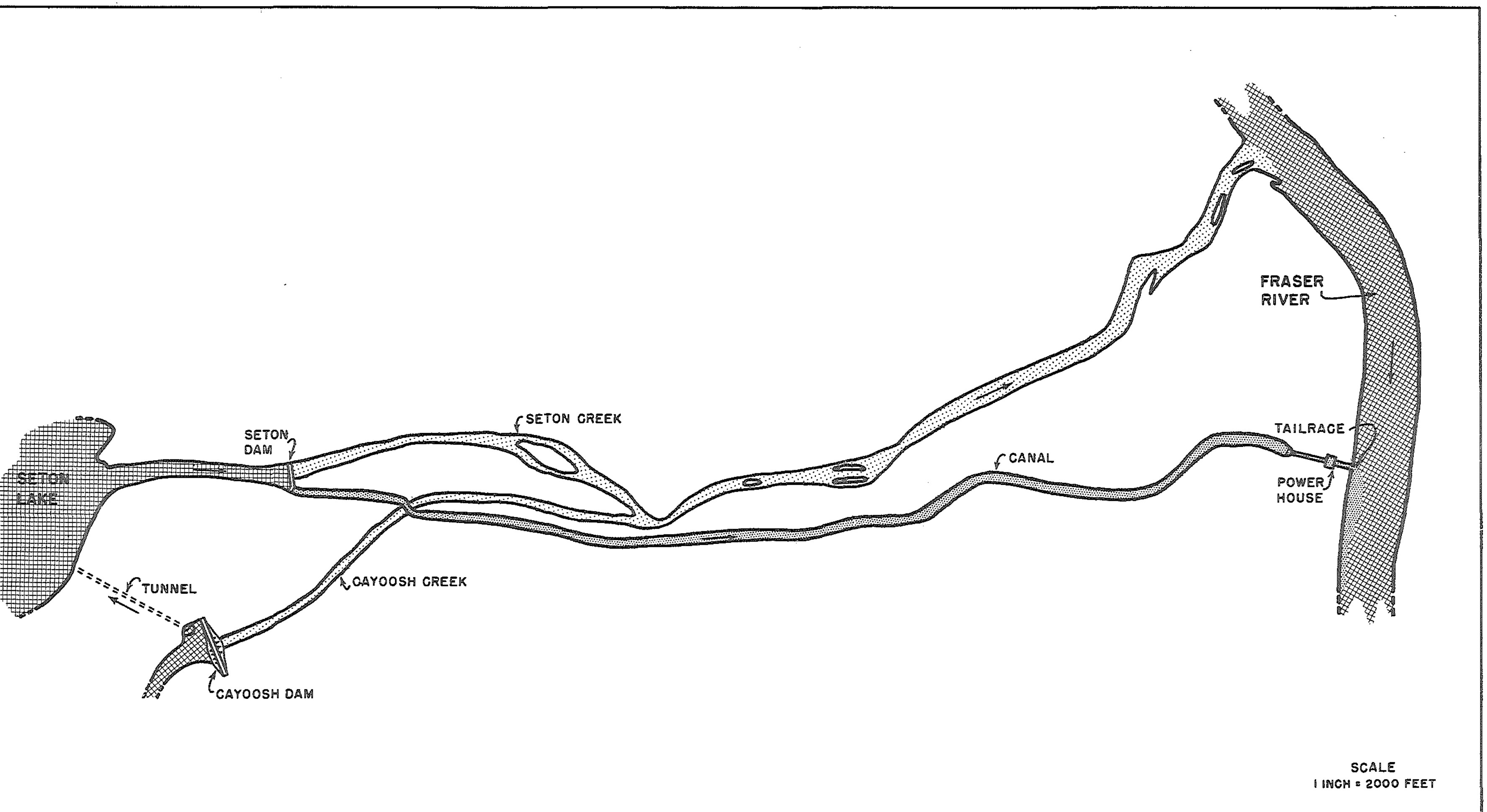
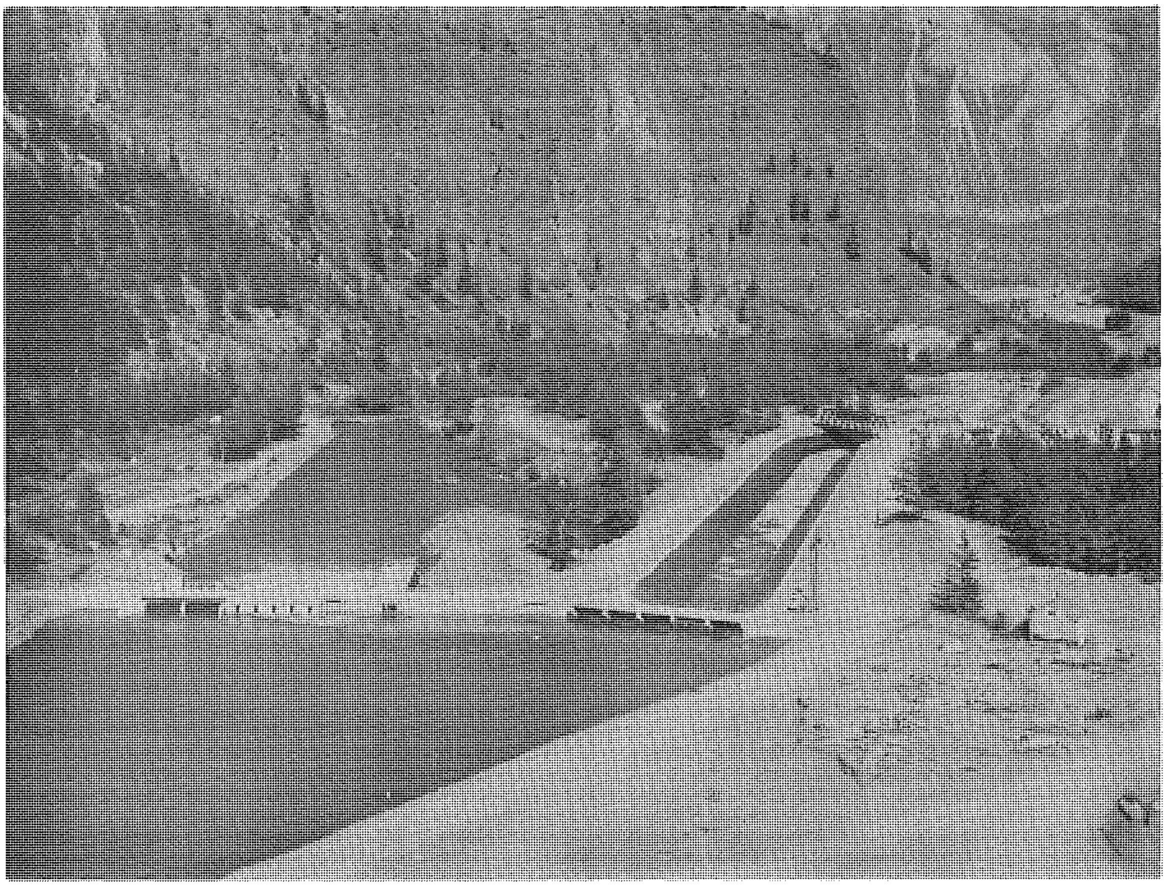


Figure 2. Layout of Seton Creek hydroelectric installation.



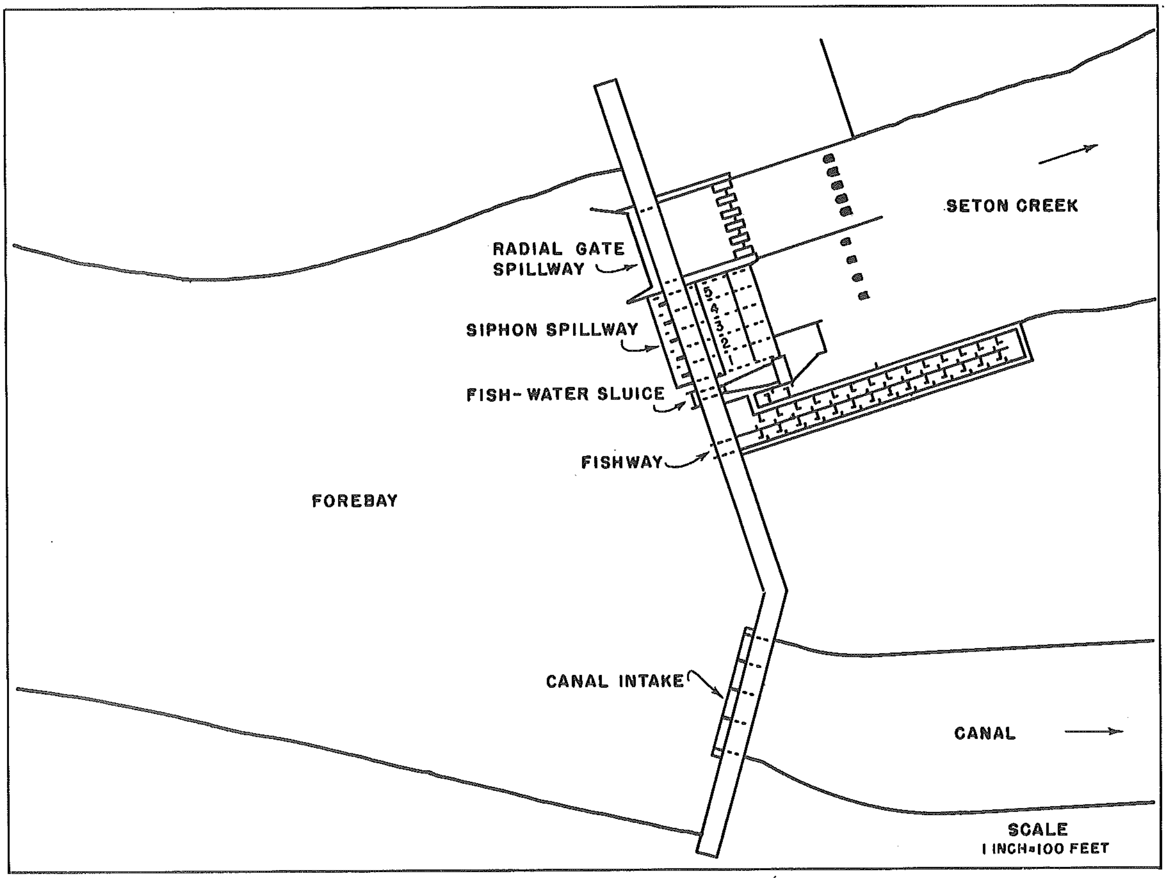


Figure 3. Layout of Seton Dam.

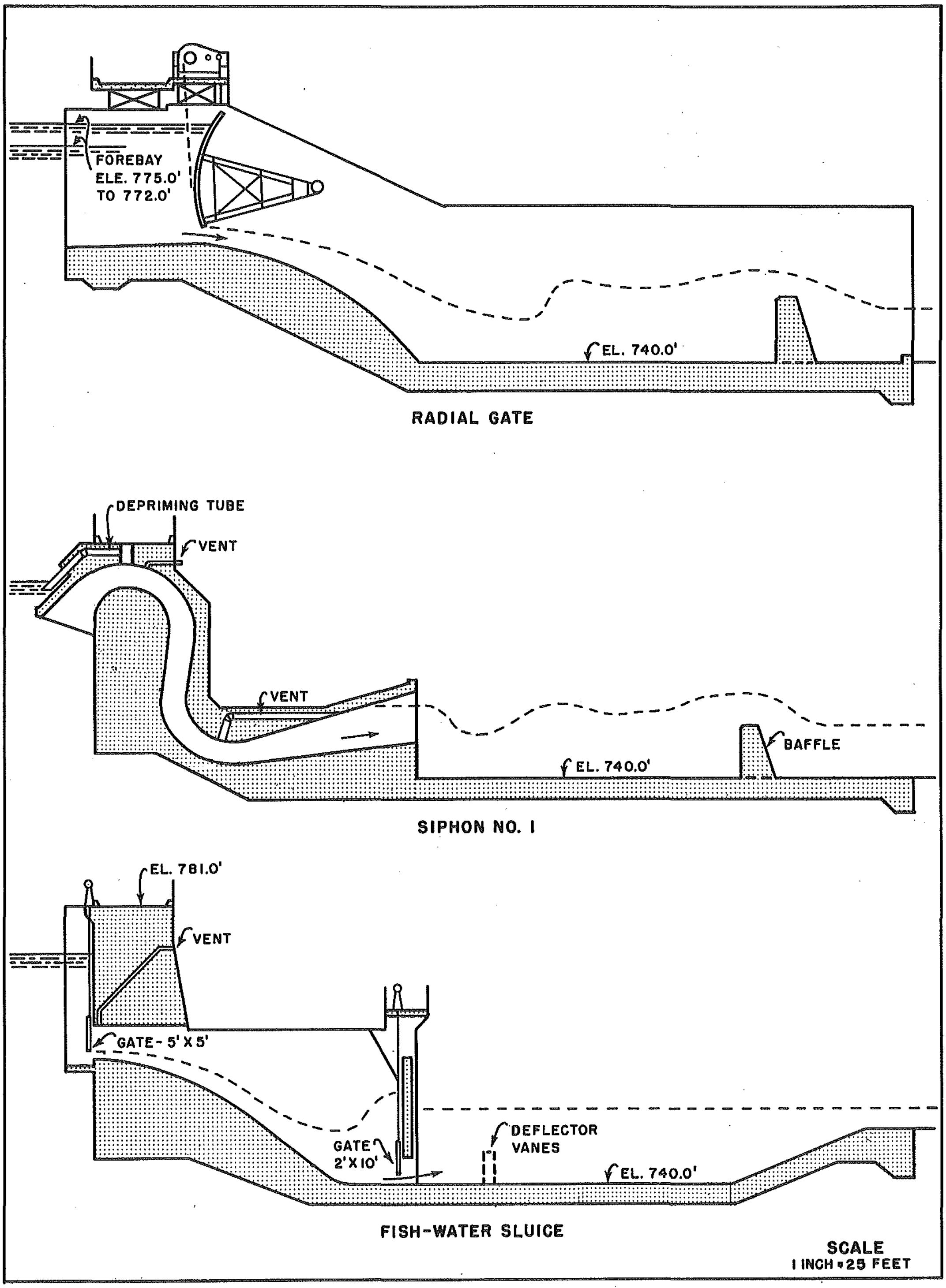


Figure 4. Longitudinal sections through the radial gate, typical siphon, and fish-water sluice.

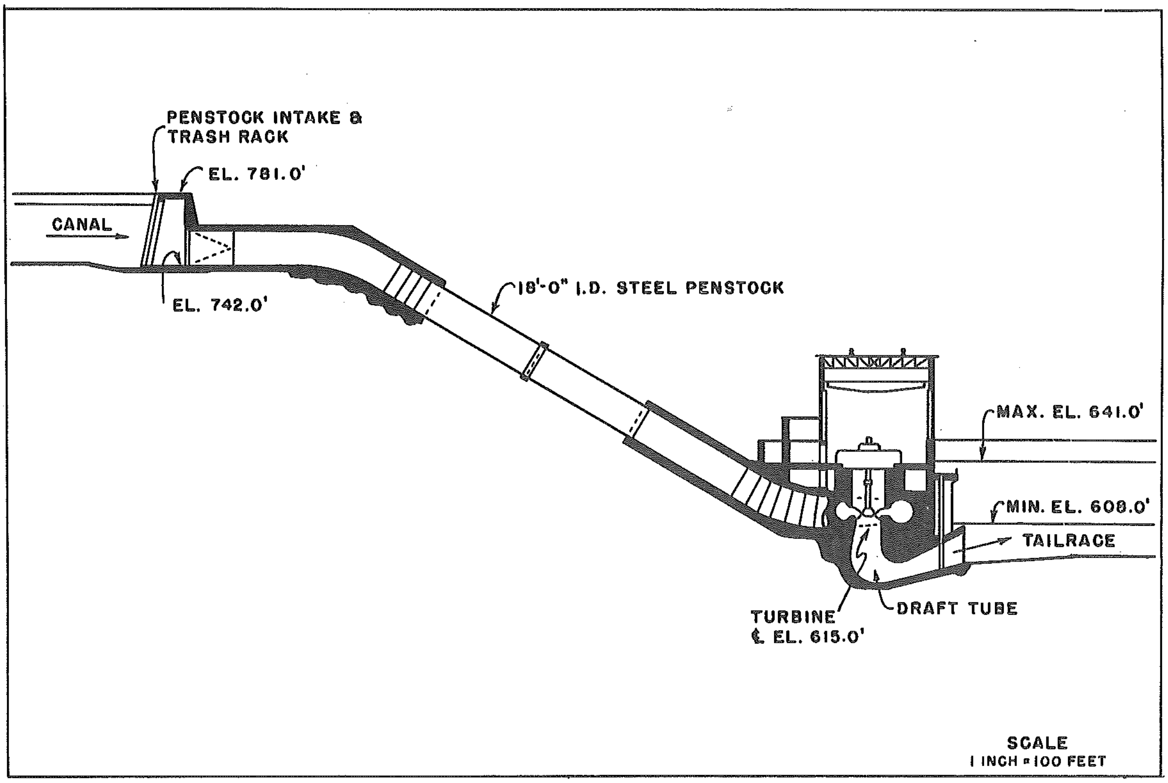


Figure 5. Longitudinal section through the penstock intake, penstock, turbine and tailrace.

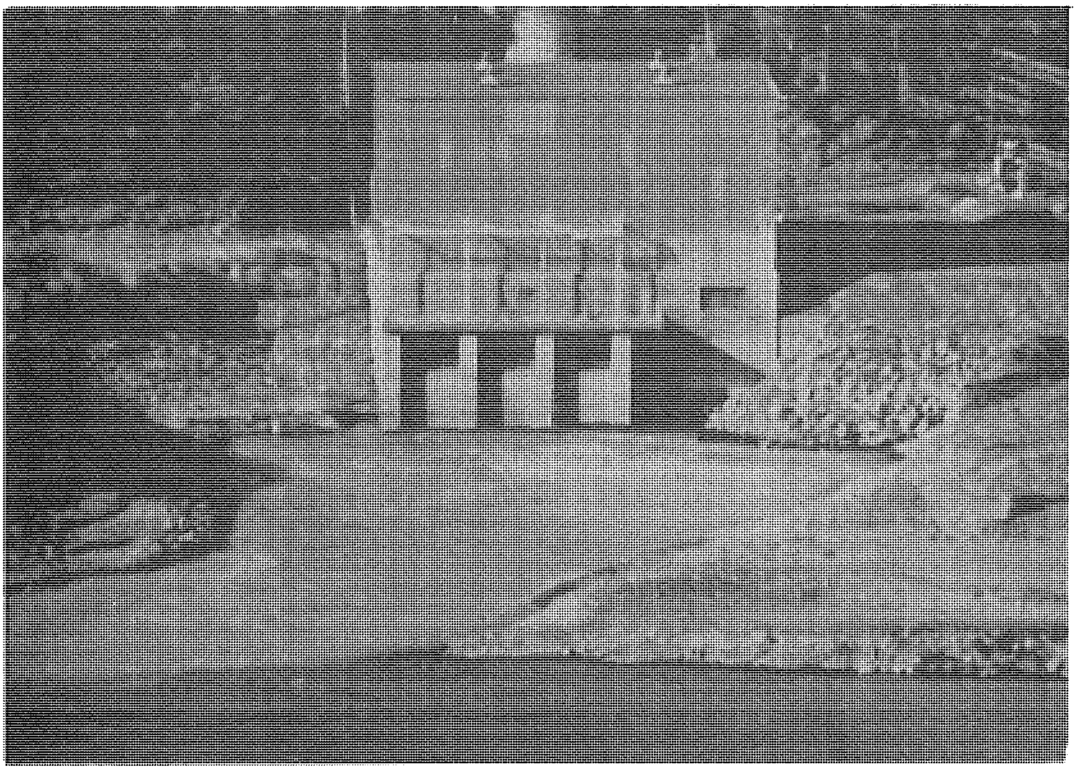


Figure 6. Tailrace of the Seton powerhouse.

PROBLEMS ENCOUNTERED DURING CONSTRUCTION PERIOD

Construction began during the fall of 1953 and was completed in the fall of 1956. During this period there was a great deal of construction activity in Seton Creek at the site of the Seton Dam, in Cayoosh Creek at the site of the canal crossing over the creek, and immediately below the junction of the two creeks, where the stream bed had to be relocated to allow sufficient space for construction of the power canal. The problem of providing maximum possible protection for the fisheries resource during this construction activity was discussed before the work was undertaken. The work was scheduled so that major stream bed excavation would not be undertaken during periods when salmon were migrating through or spawning in the creeks or when eggs or alevins were present in the gravel. Although it was not always possible to avoid interfering with the stream bed during the period of salmon use, excavation of salmon redds and deposition of silt on the spawning grounds was minimized through the co-operative efforts of the Department of Fisheries, the B.C. Electric Company, and the Contractor.

Excavation for Seton Dam was started early in the spring of 1954 but diversion of the creek around the construction area was delayed until the emergence of pink salmon fry was completed. The upstream movement of resident trout past the dam site was blocked from May 22 until July 7, 1955 when the creek was diverted through the partially completed spillway structure. When construction had progressed so that the forebay could be raised to the level of the fishway, the fish again had access to the creek above the dam. During the first few days of operation of this fishway, large numbers of trout, mainly 8 to 10 inches long, were seen passing upstream. The elevation of the fishway floor had been lowered at the upstream end and installation of the three uppermost baffles was delayed in order to permit water to flow through the fishway at the earliest possible time. Visual counts made by the Department of Fisheries showed that 8805 pink salmon passed through the fishway in the fall of 1955 while it was operating with a water depth of 2 to 3 feet and before the three uppermost baffles were installed. The forebay of the dam was raised to operating level and the remaining baffles were installed before the Gates Creek sockeye run arrived in July, 1956.

Construction activity may have had some adverse effect on the passage of adult salmon and on the incubation of eggs and survival of alevins in the gravel near the areas of construction activity but co-operation between the fisheries agencies, the Company and the Contractor minimized any adverse effects on salmon production.

PASSAGE OF ADULT SALMON AT SETON DAM

The upstream passage of Gates Creek sockeye at Seton Dam was studied in July and August of 1956. Since the dam had been completed by this time but the powerhouse was not yet in operation, the total flow of approximately 3000 cubic feet per second was spilled at the dam while these fish were migrating upstream.

Continuous counts of the numbers of fish passing upstream through the fishway revealed the diurnal pattern of migration. In addition, visual observations were made of the speed of migration through the fishway, attraction to the fish passage facilities under different discharge conditions, and behavior of fish in the fishway.

Duration of Run

The main migration of Gates Creek sockeye salmon, as indicated by the Seton Creek fishway counts, extended from July 28 to August 15. Small numbers of fish moved up the ladder before and after the counts were made. The entire population probably passed upstream during the period from July 20 to August 20.

The peak arrival of fish, as shown in FIGURE 7, occurred on August 1. On that day 19 per cent of the total counted population moved through the fishway. Although it was apparent that most of the fish were not seriously delayed at the dam, visual observations indicated that some delay did occur, particularly under certain discharge conditions. Variable numbers of sockeye accumulated below the dam throughout the main migration period. On the basis of previous analyses of the rate of arrival of undelayed runs, it was estimated that the maximum daily escapement should be about 20 per cent of the total migration (Anonymous, 1955). The pattern of upstream migration, depicted in FIGURE 7, is known to result from the weekly restrictions of the commercial fishery at the mouth of the Fraser River (Killick, 1955).

Diurnal Movement into Fishway

The hourly counts revealed a distinct diurnal pattern in the daily migration into the fishway. The average hourly counts for seven days during the peak of the run are presented in FIGURE 8. Counts were generally made from 4:00 a.m. until 12:00 p.m. and it was found that migration practically ceased from 10:30 p.m. until 4:30 a.m.

Two daily periods of pronounced upstream migration were evident. The major period was between the hours of 5:00 and 9:00 a.m. when an average of 34 per cent of the run moved through the fishway. A second peak of migration occurred between 1:00 and 4:00 p.m. when an average of 22 per cent of the migrating fish were counted through the passage facilities. This pattern of migration persisted whenever significant numbers of fish were present.

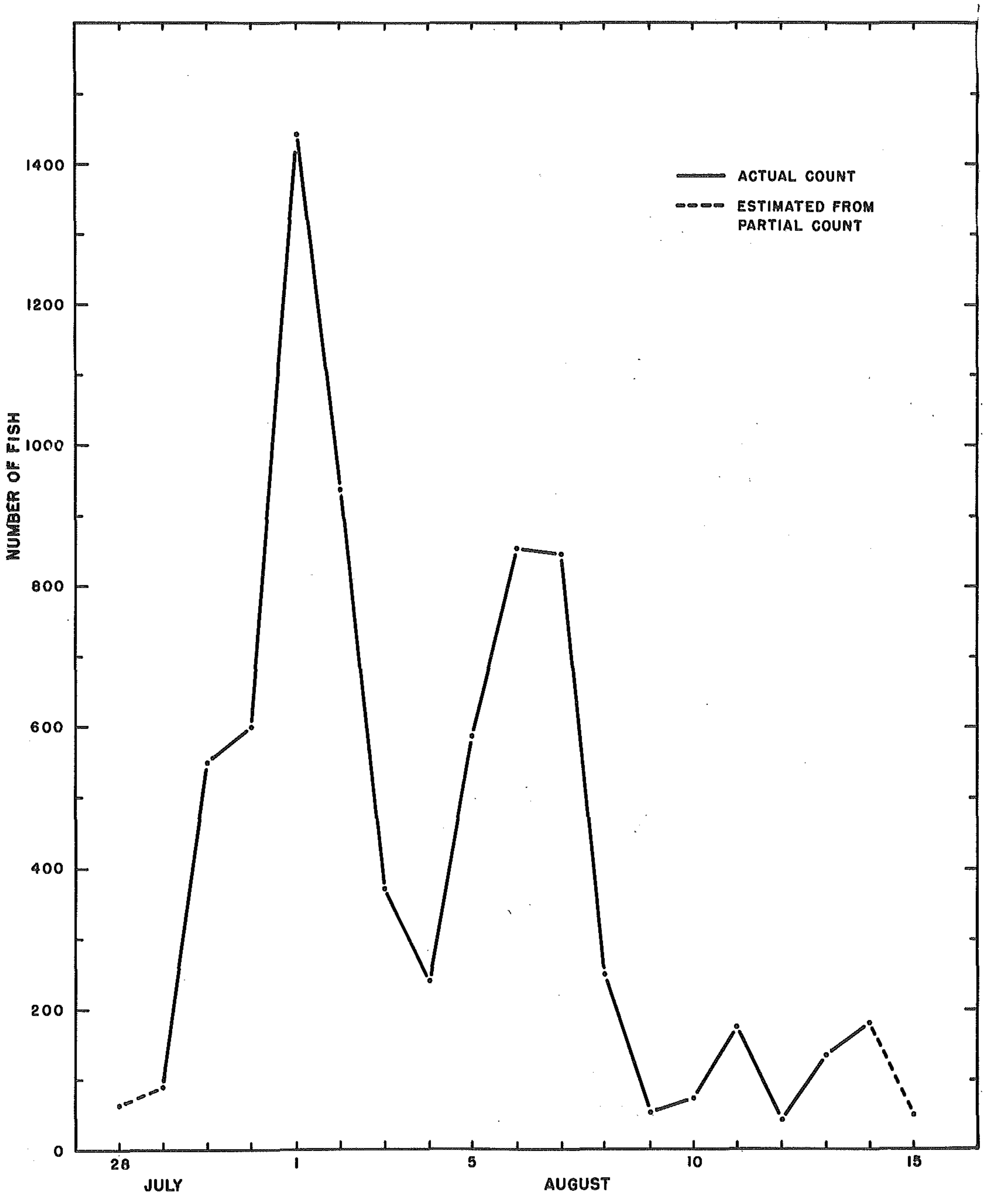


Figure 7. Daily numbers of Gates Creek sockeye migrating through the Seton Creek fishway in 1956.

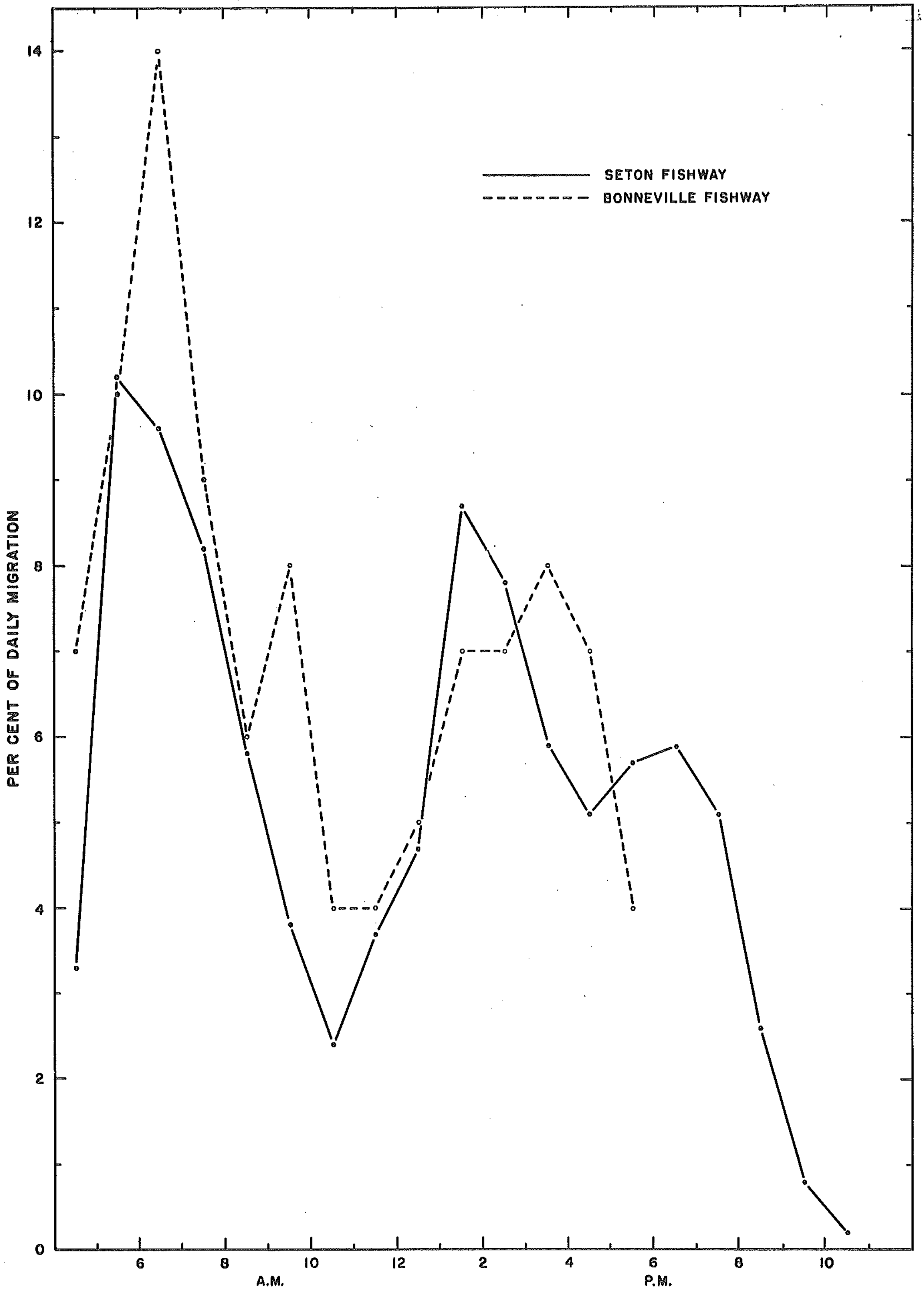


Figure 8. Average hourly percentages of Gates Creek sockeye migrating through the Seton Creek fishway, compared with similar data for a fishway at Bonneville Dam.

These results agree with those obtained at a fishway at Bonneville Dam on the Columbia River. The results are not exactly comparable as the counts at Seton were made over a longer period each day. However, they indicate a similar pattern of diurnal movement at Seton and Bonneville fishways. At Bonneville, 39 per cent of the run moved upstream between 5:00 and 9:00 a.m. and a further 22 per cent moved upstream between 1:00 and 4:00 p.m. (Anonymous, 1955). The results of counts at these two fishways are presented in FIGURE 8 for comparison.

The peak hourly migration of sockeye was 22.5 per cent of a day's total migration and the maximum migration in a 15-minute period was 10.7 per cent of the daily migration.

Attraction of Sockeye Salmon to Fishway

Two methods were used for spilling excess water at the Seton Dam. Infrequently, water was spilled from the radial gate on the left side of the dam. During the main part of the run, water was spilled from at least three of the five siphons located between the radial gate and the fishway entrance.

Visual observations indicated that there was no serious delay as long as the radial gate remained closed. Operation of the siphon adjacent to the fishway seemed to improve attraction of fish to the fishway entrance. There was no evidence of serious adverse effects when all five siphons were in operation. There appeared to be a serious delay, however, when the radial gate was used instead of the siphons for spilling excess water. The fish accumulated in back eddies of this high-velocity discharge and appeared reluctant to move across the low-velocity area below the siphons to the fishway entrance, which was 100 feet away from the area in which fish accumulated below the radial gate. The flow from the radial gate was five to ten times the combined flow from the fishway and fish-water sluice.

Rate of Movement Through Fishway

Conclusions on the speed of migration through the fishway were drawn from observations on individual distinctively marked fish and on groups of fish that had been purposely blocked at the lower end of the fishway and then allowed to proceed upstream. The average time of migration through the fishway was from 20 to 30 minutes. However, one fish ascended the ladder in 11 minutes and some were observed to require at least 45 minutes. Sockeye generally spent time in the low velocities of the exit channel of the fishway after moving up the ladder. These fish were generally inactive and the period of delay extended in many cases from 30 to more than 45 minutes. Sockeye also congregated and remained for some time in the forebay of the dam. Possibly this delay was a rest or recovery period necessitated by fatigue incurred during migration up the fishway.

Discussion

There was no evidence that fish were seriously delayed in their upstream migration at Seton Dam provided the radial gate was not used for spilling excess water. Sockeye appeared to ascend the fishway with little difficulty although there was evidence of possible fatigue. If the delay at the top of the fishway is associated with fatigue, further studies might yield information concerning the ability of salmon to ascend longer fishways of this type. Black (1957) has observed that two-year-old sockeye suffered significant mortalities following severe exercise. He also reported the results of other workers which showed that adult sockeye, held in fresh water for a month, suffered mortalities after severe exertion.

The main peak in the daily migration occurred from 5:00 to 9:00 a.m., during which time an average of 34 per cent of the fish moved upstream. A second daily peak occurred between 1:00 and 4:00 p.m. when an average of 22 per cent of the fish were counted through the passage facilities.

MORTALITIES SUFFERED BY SEAWARD MIGRANTS

Smolt mortality is one of the many problems that result from the construction of hydroelectric installations on salmon migration routes. Investigations have shown that fingerling salmon suffer a high mortality rate in passage over high dams and that the survival rate in the ocean does not increase to compensate for losses occurring during the seaward migration (Hamilton and Andrew, 1954a).

The possibility of a significant smolt mortality rate in the Seton turbine was foreseen when the project was first proposed. To obtain an estimate of the expected mortality, tests were conducted at Ruskin Dam on the Stave River, a tributary of the Fraser River near Mission, B.C. A turbine that had recently been installed at this plant was similar to the one proposed for the Seton plant. These tests indicated that sockeye smolts suffered an average mortality rate of 10.5 per cent (Hamilton and Andrew, 1954b). It was concluded, therefore, that initially no attempt should be made at Seton Creek to screen the turbine intake or otherwise prevent fish from entering the turbine because it was considered that protective devices known at that time might cause a similar mortality. However, it was recognized that known differences between the Ruskin and Seton power projects might result in a significantly different mortality rate at Seton and therefore the loss of downstream migrants at Seton would have to be measured after the plant had started operating.

Mortality tests at the Seton plant were conducted during the period from April 25 to May 25, 1957. Since it was expected that some fish would normally pass downstream through the fish-water sluice and the siphons, test fish were released through these exits as well as through the turbine. An attempt was also made to measure the mortality rates for newly emerged sockeye fry as well as for yearlings, but the fry, which were much smaller, were not retained in the recovery gear and consequently no data on fry mortality were obtained. Both fingerlings and fry were obtained by air transport from Chilko Lake.

Experimental Method

All fish used in the experiment were marked to enable later recognition of experimental and control groups. Since permanent marks were not required, the various groups were identified by clipping a small part of the dorsal or ventral lobe of the caudal fin or the tip of the left or right ventral fin.

The test fish were released into high velocities immediately upstream from the penstock, siphons, or the fish-water sluice. Fish deliberately killed by suffocation were released with the live fish in order to determine the availability of dead fish to the recovery gear. The test fish were transported by tank truck from the holding pens to the point of release and discharged from the tank through a four-inch rubber hose. Separate tests, in which the fish were recaptured immediately after release from the transport tank, showed that this method of release was not injurious to the fish.

The recovery gear consisted of a 10-foot-square fyke net made of nylon bobbinet with 4 1/3 meshes per inch lengthwise and 7 meshes per inch across. The net tapered in 30 feet from the 10-foot-square mouth to a 12-inch-diameter opening, to which a 5-foot tubular canvas live box was attached. Control fish were released near the mouth of this net during each test to measure mortality caused by the net. Fish were removed from the net as soon as possible after each test to avoid the adverse effects of retention in the net. In one test the net mortality rate was found to be one per cent but all of the control fish survived in the other tests.

It was necessary to operate the fyke net in velocities of 4 feet per second or higher to ensure that live fish would not swim out of the net. Work at Baker Dam in the State of Washington showed that sockeye and coho smolts were able to make headway in velocities of 2.28 feet per second but were swept downstream in velocities of 4.2 to 4.5 feet per second (Hamilton and Andrew, 1954a).

In the tailrace, the water was very turbulent and the velocities were much higher than required for preventing escape from the net. At the fishing location immediately below the fish-water sluice, the velocities were even higher than in the tailrace. The velocities at the mouth of the net during the siphon tests were estimated to be 4 or 5 feet per second but the flow was less turbulent than that below the sluice or in the tailrace. It is unlikely that a significant number of fish evaded the net, even at this fishing site.

The average fork length of a sample of 100 yearling migrants used in the tests was 85.8 millimeters or 3.38 inches. The range in length was from 70 to 99 millimeters (2.76 to 3.90 inches).

Analysis of Data

The mortality rate was determined by comparing the relative numbers of live and dead fish recaptured in the fyke net. In its simplest form the formula for determining the mortality was as follows:

$$\text{Mortality rate} = \frac{\text{Number of dead fish recaptured}}{\text{Number of dead + live fish recaptured.}}$$

However, correction factors were applied to allow for the possibility of net mortality and differential catchability of live and dead fish.

From a knowledge of the net mortality rate, which was determined for every test, the actual number of fish that were dead when they entered the net was calculated. The rate of catching dead fish was calculated from the recovery of a known number of dead releases. The rate of catching live fish was determined in terms of the computed number of live fish captured, the known number of live fish released, and the survival rate of test fish.

The formula was derived as follows:

Tr = number of live fish released.

Ta = number of these fish recaptured alive.

Td = number of these fish recaptured dead.

$T'a$ = number of these fish that were alive when they entered the net.

$T'd$ = number of these fish that were dead when they entered the net.

Dr = number of dead fish released.

Dc = number of these fish recaptured.

m = net mortality rate.

p = survival rate of test fish.

Then $T'a = Ta + m\,T'a$

$$= \frac{Ta}{1-m}$$

And $T'd = Td - m\,T'a$

$$= Td - m\,\frac{Ta}{1-m}$$

Rate of catching dead fish $= \frac{Dc}{Dr}$

Rate of catching live fish $= \frac{\frac{Ta}{1-m}}{p\,Tr}$

The number of live fish captured, corrected for net mortality and disproportionate catchability of live and dead fish

$$= \frac{\frac{Dc}{Dr} \qquad \frac{Ta}{1-m}}{\frac{\frac{Ta}{1-m}}{p\,Tr}}$$

$$= \frac{Dc\;p\;Tr}{Dr}$$

The number of dead fish captured, corrected for net mortality

$$= Td - m \frac{Ta}{1-m}$$

Therefore, the mortality rate of test fish = 1 - p

$$= \frac{Td - m \frac{Ta}{1-m}}{\frac{Dc}{Dr} p\ Tr + Td - m \frac{Ta}{1-m}}$$

When several tests were conducted under identical conditions to measure a particular mortality rate, a mean was calculated and the 95 per cent confidence interval for the mean was computed by means of the following formula:

$$u = \bar{x} \pm \frac{St}{\sqrt{n}}$$

Where u = upper and lower 95 per cent confidence levels

$\bar{x}$ = mean mortality rate

n = number of observations

S^2 = variance

t = Student's "t" (5 per cent confidence point for n-1 degrees of freedom).

Computed Mortality Rates

The numbers of fish released and the numbers recaptured are given in TABLE 1. The releases through the turbine consisted of four groups of 1000 live fish and two groups of dead fish, one of 1622 and the other of 663, making a total of 4000 live and 2285 dead. The average recovery rates for the two groups were 8.02 per cent and 4.90 per cent respectively. The live fish were more available because the dead fish tended to sink towards the bottom of the tailrace, which was about 40 feet deep at the time of these tests.

The rate of recapture of both live and dead fish was much higher in the tests of the fish-water sluice. The sluice discharged only 180 cubic feet per second during the tests and it was therefore possible to operate the fyke net in high velocities immediately downstream from this exit. Of the 600 live fish released through the sluice, 50.8 per cent were recaptured and of the 450 dead fish released, 47.8 per cent were recaptured. The net was operated so close to the sluice exit that relatively few dead fish settled out and consequently the rates of recapture of the live and dead groups were nearly equal.

During the tests of the siphon mortalities, the net rested on the stream bottom about 80 feet downstream from the siphon exit. The rate of recapture of dead fish was higher than that for the live fish. Of the 3000 live fish released, 5.90 per cent were recaptured, whereas 13.67 per cent of the 3000 dead fish were recaptured. The rate of recapture of dead fish was high because the net rested on the stream bottom and tended to pick up dead fish being swept along the bottom.

Control fish were released into the mouth of the net to measure any mortality resulting from retention in the net. As shown in TABLE 1, no mortality was suffered by the control fish released into the net below the turbine and siphon but one fish from a group of 100 smolts was killed in the net below the fish-water sluice.

TABLE 1 - Numbers of sockeye smolts released and numbers recaptured in tests of turbine, sluice and siphon at Seton Creek hydroelectric installation.

Date	Place of Release	Number Released		Number Recaptured	
		Alive	Dead	Alive	Dead
Turbine Tests					
May 14	Penstock	1000		67	3
	"	1000		77	2
	"		1622	—	86
	Mouth of Net	100		98	0
May 15	Penstock	1000		80	4
	"	1000		79	9
	"		663	—	26
	Mouth of Net	100		84	0
Sluice Tests					
May 21	Sluice Gate	200		90	8
	" "	200		108	4
	" "	200		83	12
	" "		150	—	69
	" "		150	—	70
	" "		150	—	76
	Mouth of Net	100		98	1
Siphon Tests					
May 23	Siphon Entrance	1000		57	1
	" "	1000		57	2
	" "	1000		58	2
	" "		1000	—	137
	" "		1000	—	145
	" "		1000	—	128
	Mouth of Net	100		88	0

The computed mortality rates, corrected for the one per cent net mortality at the fish-water sluice and the differential availability of live and dead fish, are given in TABLE 2. The average mortality rate of 9.2 per cent for fish passing through the turbine is similar to the 10.5 per cent mortality observed in the tests at Ruskin Dam on the Stave River. The high mortality rate of 7.4 per cent suffered by fish passing through the fish-water sluice might be reduced by operating the sluice in a different manner. This is discussed in the following section. The measured mortality rate of sockeye smolts passing through the siphon was only 1.2 per cent.

TABLE 2 - Rates of mortality of sockeye smolts in passage through turbine, sluice and siphon at Seton Creek hydroelectric installation.

	Mean	Range		Confidence Limits (95%)	
		Upper	Lower	Upper	Lower
	(per cent)	(per cent)	(per cent)	(per cent)	(per cent)
Turbine	9.2	22.9	3.8	14.7	3.6
Sluice	7.4	12.1	2.8	10.2	4.5
Siphon	1.2	1.6	0.7	1.5	0.9

Observed Injuries and Their Possible Causes

Certain generalizations can be made concerning the possible causes of injury among fish that passed through the turbine, fish-water sluice and siphon. Injuries such as scraped or crushed heads, torn opercles, and body scrapes can be attributed directly to abrasion or physical contact with a solid object. Hogan (1941) has shown that fish subjected to a vacuum suffer distended eyes and hemorrhages. Injuries such as ruptured, missing, or distended eyes, and various hemorrhages can be attributed, at least in part, to a sudden release of pressure. Observations have shown that all of these injuries can also be caused by impact, such as in throwing fish against a solid object. Laboratory experiments conducted by the State of Washington Department of Fisheries have shown that juvenile salmon exposed to instantaneous pressure release were not killed when the pressure change was less than 20 pounds per square inch but significant mortalities occurred when the pressure change exceeded this amount (Anonymous, 1957).

Experiments at Baker Dam (Hamilton and Andrew, 1954a) showed that turbulence alone was not a major cause of spillway mortality, although it probably aggravated injuries obtained in passage over the spillway. In this experiment, one group of yearling coho salmon was released at the crest of Baker Dam and another was released into the violently turbulent pool at the base of the dam. Of the fish released into the pool, 5.3 per cent were dead on recovery. Fish released into the pool suffered very few injuries and these injuries were of a relatively minor nature compared with those suffered by fish released at the crest of the dam. These authors concluded: "An injury caused while fish are en route 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."

Many experiments in which fingerlings have been subjected to stress have shown that hemorrhages can be caused by many different factors. Eye and fin hemorrhages, for instance, have been observed among fish subjected to pressure release, turbulence, impact, or certain toxicants. Hemorrhages, therefore, appear to be an indication of severe stress.

The concept of several factors in combination contributing to a mortality appears to be very important. Even if more basic data were available as to the separate effects of pressure change, vacuum, abrasion, impact, turbulence and other factors, it might not be possible to determine the part that each factor plays in contributing to an overall mortality rate. A single stress might have no adverse effect but in combination with one or more other stresses it might be lethal.

All fish captured during the mortality tests were examined for injuries and these injuries were classified as shown in TABLE 3. Fish that suffered obvious physical injury were usually dead on recovery. Injuries were relatively infrequent among live fish and most of these injuries appeared to be relatively minor. There may have been some unmeasured delayed mortality, however.

Pressure change appeared to be one of the important causes of turbine mortality. The turbine was operating at a gross head of 142 feet during these tests. Washington State Department of Fisheries investigations indicated that pressure change of the magnitude occurring through the Seton turbine would cause mortality. However, the adverse effects of pressure change cannot be separated from all abrasion

TABLE 3 - Frequency of injuries among sockeye smolts after passage through turbine, sluice and siphon.

	Turbine		Sluice		Siphon	
	Live	Dead	Live	Dead	Live	Dead**
	(per cent)*		(per cent)*		(per cent)*	
Ruptured or missing eyes	0	55.5	0	12.5	0	40.0
Distended eyes	0	5.6	0.4	12.5	0	20.0
Hemorrhaged eyes	1.3	27.8	3.6	41.7	1.7	40.0
Scraped or crushed head	0	5.6	0.7	29.2	0.6	40.0
Torn opercles	0	16.7	0.4	8.3	1.7	20.0
Torn isthmus	0.3	16.7	0	0	0	0
Hemorrhaged internally	0	5.6	0.7	16.6	0	0
Hemorrhaged fins	0.3	11.1	0.4	0	0	0
Hemorrhaged gills	0	5.6	1.8	4.2	0	0
Abrasions on body	0.3	5.6	1.8	8.3	1.7	0
Number of fish examined	303	18	281	24	172	5**

* The injury frequencies do not total 100 per cent because many fish suffered several injuries.

** This sample of only five fish is too small to be significant.

injuries occurring in the turbine and the draft tube. Both abrasion and pressure change are known to produce ruptured and distended eyes and hemorrhaging. Both probably contributed to the turbine mortality.

Fish passing through the 370-foot penstock were subjected to a pressure change from atmospheric to 62 pounds per square inch above atmospheric in about 25 seconds. The pressure on the downstream side of the runner was 1.5 pounds per square inch above atmospheric. Consequently, fish were subjected to an almost instantaneous pressure release of 60.5 pounds per square inch.

Mechanical injury in the turbine runner might also have contributed to the mortality but since the fish had an average length of only 3.38 inches it is not likely that they suffered serious mechanical injury passing through the 6-inch apertures in the runner. Even at Baker Dam, where the runner apertures were only 2 inches wide, sockeye smolts did not suffer mechanical injuries that could be directly attributed to the turbine runner.

The tests were conducted under conditions which produced the minimum possible turbine mortality rate. There was an early flood on the Fraser River in 1957 and the tailrace was at elevation 631 feet during the mortality tests, which is higher than normal for the main period of smolt migration. The turbine was submerged 16 feet below tailwater. The fish would have been subjected to an even greater pressure change if the tests had been conducted in a normal water year or earlier in the season, when the tailrace would have been at a lower elevation. The early part of the sockeye migration can be expected to reach the Seton powerhouse in March or April when the tailrace will occasionally be 19 or 20 feet lower than it was during the 1957 tests.

In 1945, 1946 and 1948, the tailrace elevation would not have exceeded 612 feet until at least April 20. At this tailwater elevation, with the plant operating at full load, the pressure drop across the turbine runner is from 62 pounds per square inch above atmospheric to 2 pounds per square inch below atmospheric, a total change of 64 pounds per square inch.

Turbulence and eddying on the trailing edges of the runner blades cause localized areas of low pressure, much lower than the average pressure on the downstream side of the turbine, but there is no method of estimating the extent of these local low-pressure areas. Even more hazardous conditions would occur when the plant was operating at part load because the flow through the runner would be less streamlined and turbulence and eddying would therefore be increased.

The high mortality rate of 7.4 per cent suffered by fish passing through the fish-water sluice probably resulted from the combined adverse effects of pressure release, abrasion, and extreme turbulence. The high incidence of distended eyes indicated that these fish suffered from the adverse effects of the minor pressure release of 6 pounds per square inch in passing through the submerged gate at the upstream end of the energy-dissipating chamber. However, it is likely that turbulence and abrasion were major contributing factors. Impact or abrasion on the deflector grill located immediately downstream from the sluice might also have contributed to the mortality.

The high incidence of mechanical and abrasion injuries indicated that the mortalities might have been significantly reduced if the sluice had been operated in a different manner. An alternate gate arrangement, as shown in Figure 4, was provided in the sluice so that the energy-dissipating chamber could be filled and water would spill from the surface over a weir at the downstream end. At the time of the mortality tests, the downstream gate was open about 24 inches. Water depth in the energy-dissipating chamber was only 6 feet and consequently there was no spill over the weir crest. As a result, the turbulence was very intense. If the gate had been partially closed, the depth would have been increased, and the energy dissipation per unit volume reduced. The survival would probably have been increased not only because of the reduction in turbulence and abrasion but also because the fish would probably have been swept over the weir without a long delay in the energy-dissipating chamber.

The mean mortality rate of 1.2 per cent in the tests of the siphon indicated that sockeye smolts suffered very little injury passing through this exit. The highest mortality rate suffered by any of the test groups was only 1.6 per cent. Pressure change was minor, as the pressure at the extreme top of the siphon was less than 2 pounds per square inch below atmospheric pressure. The average velocity, however, was 29 feet per second at the throat of the siphon. Abrasion on the concrete inner surface appeared to be the primary cause of injury.

Discussion

Downstream-migrant sockeye salmon will probably suffer an average mortality of at least 10 per cent as a result of the construction of the Seton Creek hydroelectric installation. The estimated mortality rate of 9.2 per cent suffered by sockeye smolts passing through the turbine applies only for the load and tailwater conditions in effect during the tests. Fish passing through the fishway, siphons or sluice suffer a lower mortality rate but it is not likely that a significant proportion of the downstream migrants will use these exits. The siphons will seldom operate during the period of seaward migration. The combined flow of the fishway and fish-water sluice is only 5 per cent of the turbine flow and will attract only a very small proportion of the seaward migrants. The tailrace elevation during these tests was much higher than the normal expected during the early part of the seaward migration. It is likely that the early migrants, which move downstream in March and April, would pass through the turbine when the tailrace was 10 to 20 feet lower than during these tests. Under these conditions, the mortality rate would be higher than 9.2 per cent as a result of the lower draft tube pressures and the overall increase in pressure change. As previously mentioned, part-load operation of the turbine can also be expected to cause an increased mortality rate.

Although the turbine setting with respect to tailwater elevation is a factor determining the smolt mortality rate, elimination of mortality by increased turbine submergence does not seem likely. Sockeye smolts suffered a significant mortality in these tests even though the turbine was submerged 16 feet below tailwater and the pressure on the downstream side of the runner was greater than atmospheric.

The expected turbine mortality rate of pink salmon fry can only be postulated on the basis of comparable studies conducted elsewhere. It must be emphasized that probably less than 10 per cent of the pink salmon produced in the Seton-Anderson watershed originate upstream from Seton Dam because the Seton Creek spawning area above the dam site has now been seriously affected by increased water depth and reduced velocities. In two experiments conducted by the State of Washington Department of Fisheries, 90-day-old spring salmon fingerlings suffered a higher mortality rate than one-year-old spring salmon in passage through turbines (Pressey, 1958). At Elwha Dam, 90-day-old spring salmon suffered a 3 per cent higher mortality than yearlings in passage through a Francis turbine operating under a head of 100 feet. In another experiment, at Big Cliff Dam, a similar difference in mortality of fingerlings and yearlings was noted in passage through a Kaplan turbine operating under a head of 100 feet. These results suggest a turbine mortality rate of 13 per cent for pink salmon fry at Seton Creek but newly emerged pink salmon fry, which are much smaller and at an earlier stage of development than 90-day-old spring salmon, might suffer an even greater mortality. However, since less than 10 per cent of the pink salmon fry now produced in the Seton-Anderson watershed are expected to pass through the Seton turbine, the loss of production due to turbine mortality appears to be of relatively minor economic importance.

MIGRATION OF ADULT SALMON PAST POWERHOUSE

Adult salmon migrating up the Fraser River destined for Seton, Cayoosh, Portage and Gates Creeks must pass the powerhouse tailrace located approximately 4500 feet downstream from Seton Creek. However, the attraction flow at the powerhouse during the migration period is some 10 times larger than the residual flow of 400 cubic feet per second down Seton Creek. It is important to note that the water in the powerhouse discharge may be chemically and biologically identical to that in Seton Creek as both discharges are drawn directly from the forebay of the dam in Seton Creek. The possibility that adult salmon would delay in the tailrace because of its position and greater attraction flow was recognized in the early negotiations with the British Columbia Electric Company. As a result, it was agreed that the migration of adult salmon past the tailrace would be studied after the plant started operating and, if fish delayed in the tailrace, the effectiveness of plant closures in alleviating this delay would be evaluated.

Investigations of tailrace delay were conducted during the adult pink salmon run in 1957. Some observations were also made during the passage of small runs of sockeye destined for Portage and Gates Creek.

In an attempt to avoid delaying the upstream passage of adult salmon, the Company provided complete plant shutdowns from 4:00 to 7:00 a.m. or longer on Tuesday, Thursday and Sunday of each week during the period of this study. There were numerous other reductions in plant output, resulting from normal plant operation, but not all of these were complete plant shutdowns.

Pink Salmon Spawning Migration

In 1957, the Seton system supported an estimated spawning population of 60,677 pink salmon. Of this number, 58,810 spawned in Seton and Cayoosh Creeks. The remaining 1,867 spawned in Portage Creek at the head of Seton Lake. The population was estimated by tagging some of the live fish and recovering the dead tagged and untagged fish after spawning. Approximately 50 per cent of the tagged fish and 30,626 untagged fish were recovered on the spawning grounds.

Pink salmon were seen in the tailrace of the Seton powerhouse from September 9 to October 30 during the 1957 spawning migration. Greatest numbers were seen from September 23 to October 11. The first fish was seen in Seton Creek on September 10 and spawning started soon after this date. The heaviest spawning occurred from October 1 to 20 and all spawning had been completed by November 10. Most of the Portage Creek population arrived on the spawning grounds during the period from October 1 to 8. The heaviest spawning occurred from October 8 to 10.

Diurnal Migration of Pink Salmon

The relative numbers of pink salmon entering Seton Creek were determined on an hourly basis from September 16 to October 3. Visual counts were made of a proportion of the fish passing under the Seton Creek highway bridge located approximately 2000 feet above the confluence of Seton Creek and the Fraser River. The counts provided only an index of the relative rate of entry as the stream was too wide and too deep to permit counting of all fish. Increasing water turbidity decreased the accuracy of the counts after October 1. Although counts were not made during hours of darkness, data gathered on the Thompson River indicated that the nocturnal migration was much smaller than the daylight migration. TABLE 4 lists, on an hourly basis, the index counts of pink salmon migrating past the Seton Creek bridge. The data presented in FIGURE 9 indicate a daily peak of migration up Seton Creek between 6:00 and 9:00 a.m. on days when the powerhouse was shut down from 4:00 to 7:00 a.m. or longer. On days when the powerhouse was operated continuously, a distinct peak in the daily migration was not evident.

The distinct difference in the daily pattern of migration into Seton Creek, depending on whether or not the plant was operated continuously, is illustrated again in FIGURE 10. The curves shown in this graph were obtained by totalling the index counts of pink salmon entering Seton Creek on 12 days, six days of continuous powerhouse operation and six days when the powerhouse was shut down for at least three hours ending at 7:00 a.m. The percentage of this total number of fish that entered Seton Creek on days of continuous powerhouse operation is shown, by hour, in the lower or dotted line and the percentage of the total that entered on days when the powerhouse was shut down in the morning is shown, by hour, in the upper or solid line. The rate of entry into Seton Creek was markedly increased from 6:00 to 10:00 a.m. on days of powerhouse shutdown; 42 per cent of the fish entered Seton Creek from 6:00 to 10:00 a.m. on days of powerhouse shutdown whereas only 13 per cent entered during this period on days of continuous powerhouse operation.

TABLE 4 - Visual counts of the relative numbers of upstream-migrant pink salmon passing under highway bridge 2000 feet upstream from mouth of Seton Creek.

	a.m.						p.m.				
	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5
Sept.											
16				16	12				16	17	
17		15	10	19	16		12	12	12	9	
18		20	12	9	13		15	8	9	2	
19		15	7	9	8		10	11	9	6	
20		12	9	16	19		5	10	12	14	
21		33	41	45	65		13	10	18	23	
22		58	52					12		15	
23		55	61	57	53		38	32	63	55	
24	191	223	137	64	59		35	33	42	48	
25	51	77	54	41	38		42	40	55	36	
26	258	461	156	53	35		45	53	47	56	
27	53	76	73	58	51		62	70	96	83	
28	93	354	387	413	242		84	71	78	193	
29	144	128	44	57	29	36				37	44
30		76	77	81	72	53		63	54	52	48
Oct.											
1		203	137	71	58	64		47	54	66	51
2		70								85	
3		150								32	

A blank indicates that no count was made during that hour.

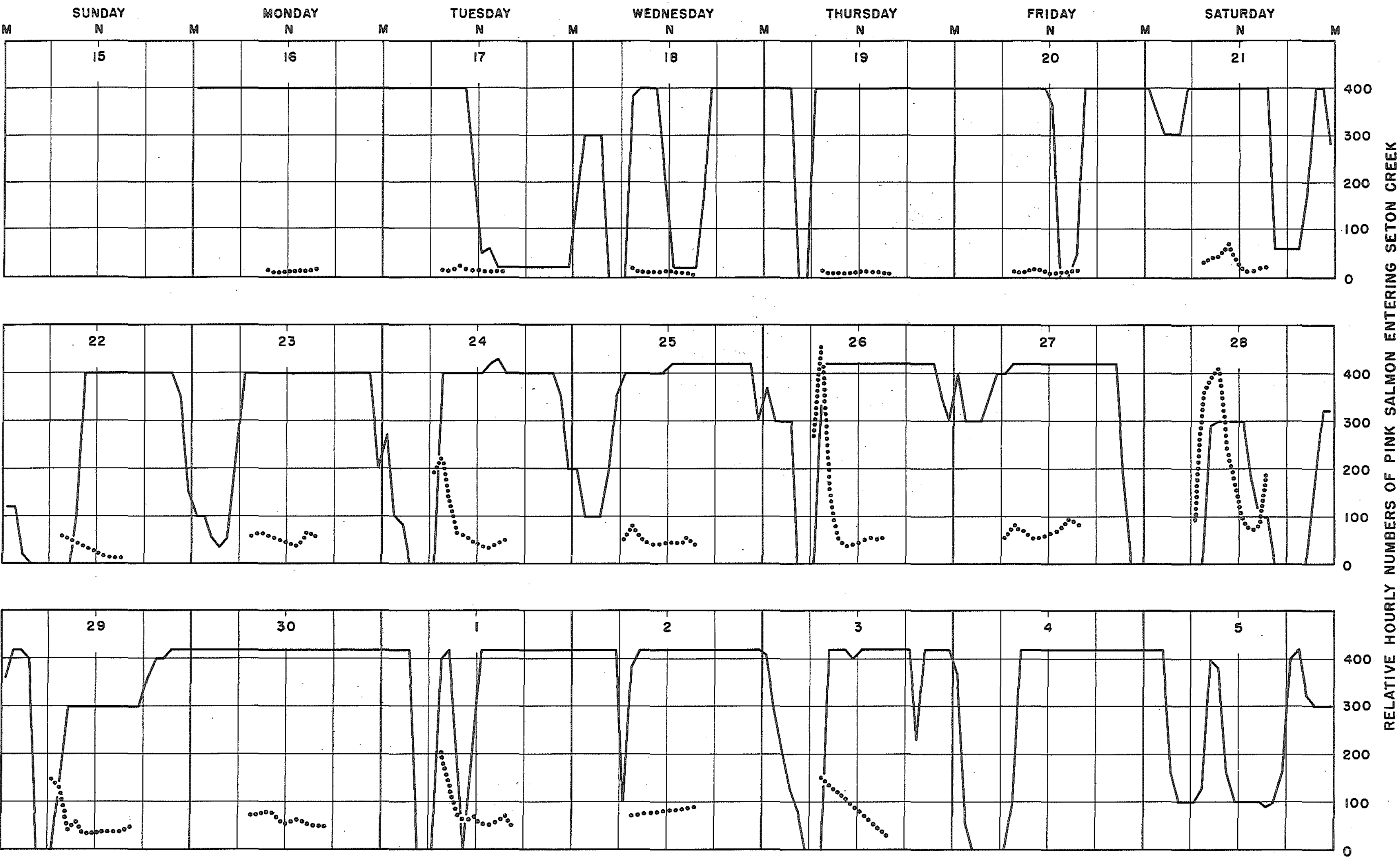


Figure 9. Index numbers of pink salmon entering Seton Creek in relation to operation of the Seton Creek powerhouse from September 16 to October 3, 1957.

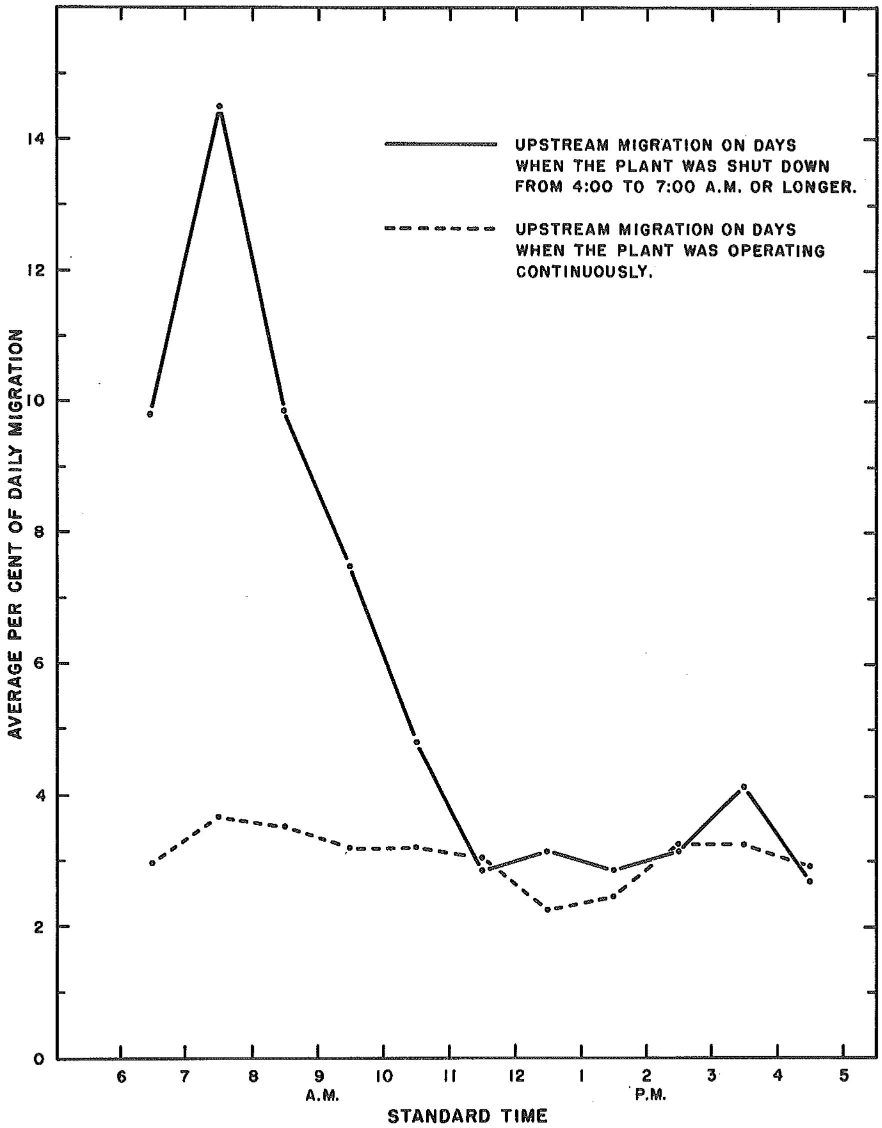


Figure 10. Hourly arrival rate of pink salmon in Seton Creek on days of continuous powerhouse operation and on days when the plant was shut down from 4:00 to 7:00 a.m. or longer.

Complete powerhouse closures between 4:00 and 7:00 a.m. produced a surge of fish past the counting site roughly two hours later. FIGURE 9 shows that operation of the plant at reduced loads did not produce a surge of fish past the counting site. Only complete closures reduced the numbers of pink salmon in the tailrace. While there appeared to be an increase in the numbers of fish moving upstream after a shutdown during the period from September 16 to 21, the numbers were too small to produce a distinct peak in the migration into Seton Creek. On September 22, the accumulation in the tailrace became more evident. A shutdown of seven hours on this day substantially reduced the number of accumulated fish. As the size of the run continued to increase, it became apparent that the numbers of fish migrating up Seton Creek increased after each 4:00 to 7:00 a.m. powerhouse closure. Evidently, continuous powerhouse operation retarded the migration of pink salmon past the tailrace. Periodic closures alleviated this delay but it will be shown that the delay was not completely eliminated by these closures.

The hourly variations in migratory activity of pink salmon were determined by counting the numbers of fish that could be seen entering the tailrace of the Seton powerhouse. Counts were made during the period from 6:00 a.m. to 5:00 p.m. on September 23, 24 and 25. The data suggest that the main migratory activity occurred between 12:00 a.m. and 4:00 p.m.

The average hourly counts were as follows:

a.m.				p.m.		
6-7	7-8	8-9	10-11	12-1	3-4	4-5
56	58	88	80	121	175	88

Index counts of adult pink salmon were also made at the Hell's Gate fishways in 1957. The average hourly counts, as shown below, showed the same general pattern as observed in the Seton Creek tailrace:

a.m.			p.m.		
8-9	9-10	10-11	1-2	2-3	3-4
89	102	100	122	138	165

Since the timing of the daily migration into Seton Creek was distinctly different from the pattern of migratory activity observed among fish entering the Seton Creek tailrace and among undelayed pink salmon at Hell's Gate, it can be concluded that the operation of the Seton powerhouse had a disturbing influence on the normal upstream movement of the Seton Creek pink salmon.

Observations of Fish in Tailrace

Pink salmon could be seen swimming up the right bank of the Fraser River below the Seton Creek powerhouse and it was possible to make some observations of their behavior as they approached and entered the tailrace. Because of the high velocities in the Fraser River at the exit of the tailrace channel, the fish were naturally guided along the bank into the tailrace channel. It is possible that they would have entered this channel even if the tailrace discharge had come from some source other than Seton Creek. On reaching the tailrace, the fish swam up the right bank of the tailrace channel, skirted the high-velocity flow from the draft tube, crossed the face of the powerhouse, and entered a back eddy that extended 100 feet along the left bank of the tailrace. At the lower end of this eddy, the flow changed direction and at this point fish moved away from the bank and swam towards the high velocities from the draft tube. After remaining in this fast, turbulent area for a short time, the majority of the fish reached the area above the draft tube and again entered the eddy on the left bank. This cycle was repeated continuously.

Immediately after the powerhouse was shut down, pink salmon tended to move downstream along the left bank of the tailrace into the Fraser River and then up the right bank of the Fraser towards the natural channel of Seton Creek. For instance, on September 28, the plant was shut down at 4:00 p.m. and at 4:05 p.m. 50 fish per minute were counted moving out of the tailrace and up the Fraser. Fish that had apparently dropped downstream in the Fraser River following the powerhouse shutdown continued to migrate upstream past the tailrace during the period of shutdown but the heavy migration of 50 fish per minute moving out of the tailrace and directly up the Fraser River ended at about 4:10 p.m. when the turbid Fraser River water extended completely across the exit of the tailrace channel. This left a pool of Seton water in the upper half of the tailrace channel. It was estimated that during the main portion of the pink salmon run at least 200 pinks remained in the tailrace during periods of powerhouse closure.

It is conceivable that these fish would have vacated the tailrace channel during the periods of shutdown if the plant cooling water had been shut off. This flow, about 2 cubic feet per second, discharged into the tailrace continuously and caused a substantial amount of turbulence and aeration. The cooling water was shut off for three hours during a 10-hour night closure and no significant reduction in the numbers of fish in the tailrace was noticed but this cannot be considered as an adequate test because it was conducted during darkness and the cooling water discharge was not shut off at the same time as the plant stopped operating.

Fish remained in the tailrace even during hours of darkness whether the plant was operating or not. Shutting off the powerhouse lights over the tailrace channel did not appear to have any effect in reducing the numbers of accumulated fish.

When the plant was started after a complete shutdown, the fish seemed to move out of the tailrace but returned within 30 minutes. Fish were never seen moving upstream out of the tailrace immediately after the plant started.

Accumulation and Delay of Pink Salmon in Tailrace

The total number of pink salmon accumulated in the tailrace at any given time was estimated by visual observations. As previously noted, it was observed that fish usually moved along the left bank of the tailrace in a back eddy then swam out into the turbulent flow from the turbine draft tube and returned to swim in the back eddy again. On several occasions it was possible to identify tagged fish in the tailrace and observe their circuitous movement just described. By counting the number of untagged fish that passed one point of the tailrace during one complete cycle of an identifiable fish, it was possible to estimate the total number of fish in this group.

Using this method of enumeration it was found that the number visible at one time on the surface along the left bank was usually 10 to 20 per cent of the total population along the left bank. In addition, fish were seen along the right bank and along the face of the powerhouse. It was estimated, therefore, that the total population in the tailrace was approximately 10 times the number of fish visible along the left bank at any one time.

The counts of pink salmon in the tailrace are listed in TABLE 5. Counts were usually made at 8:00 a.m. and 5:00 p.m. However, as powerhouse operation was sporadic, morning counts were often made between 7:00 and 10:00 a.m. and afternoon counts between 2:00 and 5:00 p.m. Maximum counts in the tailrace of 450 fish on both September 25 and 27 would suggest that 4500 pinks, about 7.5 per cent of the total Seton Creek population, were accumulated in the tailrace on each of these days.

An indication of the delay in the tailrace was obtained by comparing the timing of peaks of abundance of pink salmon in the tailrace and at the Seton Creek bridge counting site. As shown in FIGURE 11, peaks in the tailrace occurred on September 25 and 27 and at the bridge on September 26 and 28. This indicated an average delay of one day in the tailrace under the operating conditions of three-hour plant closures on Tuesday, Thursday and Sunday of each week.

TABLE 5 - Numbers of pink salmon visible along left bank of Seton Creek tailrace.

Date	Time 7:00-10:00 a.m.	2:00-5:00 p.m.
Sept. 19	0	30
20	70	75
21	90	120
22	80	70
23	110	175
24	125	190
25	250	450
26	140	250
27	350	450
28	100	100
29	200	200
30	250	350
Oct. 1	150	190
2	190	230
3	150	200

This delay was not the result of time required by the fish to migrate between the tailrace and the bridge. FIGURE 9 shows that the peak counts at the bridge occurred about two hours after the powerhouse closures.

An indication of the effectiveness of the plant shutdowns in expediting the migration of pink salmon past the tailrace can be obtained by comparing the index counts of fish entering Seton Creek with the indices of abundance of fish in the tailrace. If plant closures are effective in reducing accumulations of fish in the tailrace, the ratio of the number of fish entering Seton Creek to the number accumulated in the tailrace should be considerably higher

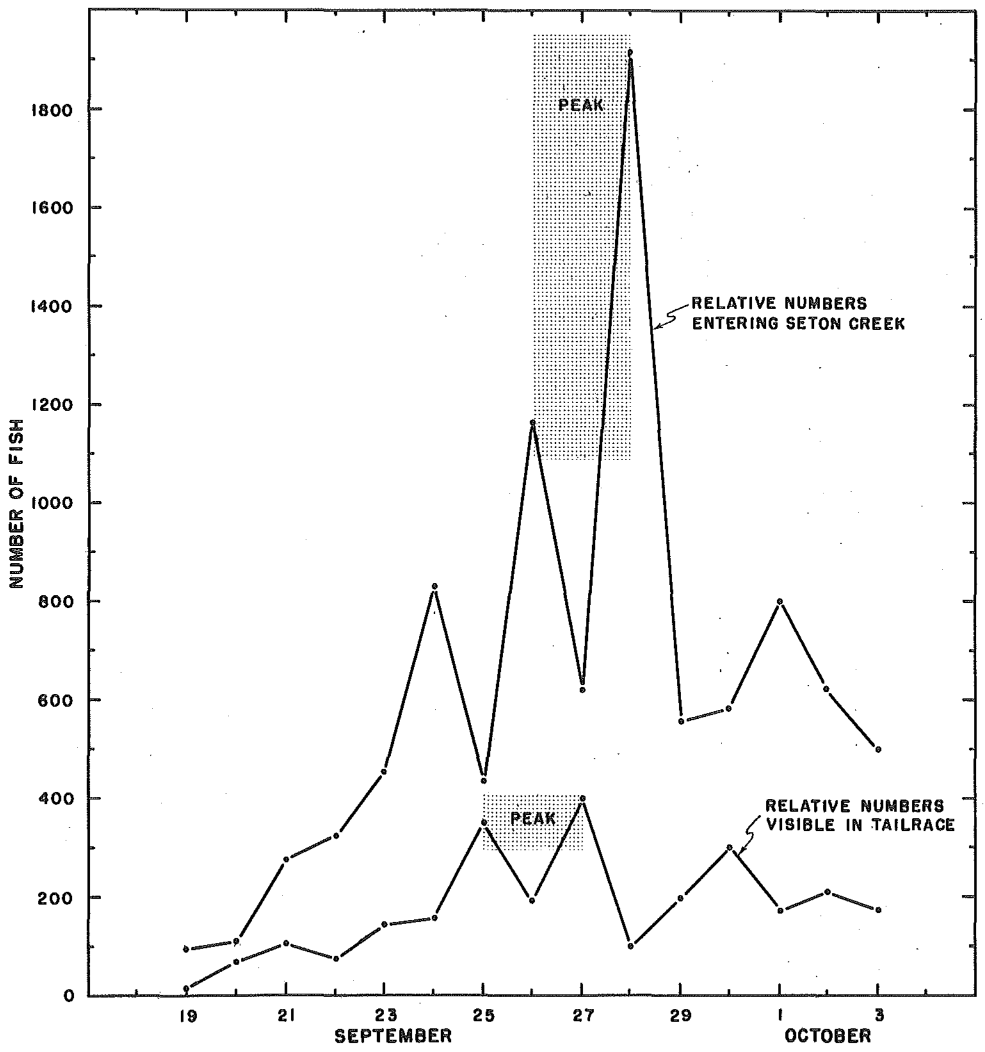


Figure 11. Timing of peak abundance of pink salmon entering Seton Creek in relation to timing of peak abundance in the tailrace.

on days when the powerhouse was shut down in the morning than on days of continuous powerhouse operation. It is apparent, from TABLE 6, that only about half as many fish entered Seton Creek on days of continuous powerhouse operation as on days when the powerhouse was shut down in the morning. An exception occurred on September 29, when relatively few fish were counted into Seton Creek because the prolonged powerhouse closures on September 28 apparently enabled nearly all of the accumulated fish to pass upstream on that day.

The data for the 12-day period shown in FIGURE 10 substantiate the data given in TABLE 6. By totalling the hourly percentages, it is seen that 66 per cent of the fish that entered Seton Creek during this 12-day period did so on days when the powerhouse was shut down for at least three hours ending at 7:00 a.m. and 34 per cent did so on days of continuous powerhouse operation. In other words, the <u>number</u> of fish entering Seton Creek approximately doubled on days of powerhouse closure.

Comparing the ratios shown in TABLE 6, it is seen that the <u>ratio</u> of the number of fish entering Seton Creek divided by the number that accumulated in the tailrace on the previous day also doubled on days of powerhouse closure. A notable exception occurred on September 26. Although the maximum hourly count of fish entering Seton Creek on this day was higher than on any other day (FIGURE 9), the total number entering Seton Creek in relation to the number accumulated in the tailrace was no higher than on days when the powerhouse was operated continuously. The relatively low ratio on this day may have

TABLE 6 - Daily indices of pink salmon entering Seton Creek in relation to the index counts of fish accumulated in the tailrace from 2:00 to 5:00 p.m. on the previous day.

September	Seton Creek Index Count 6:00-11:00 a.m. and 12:00 a.m.-4:00 p.m.	Tailrace Index 2:00-5:00 p.m. Previous Day	Ratio	Powerhouse Operation
24	832	175	4.8	Morning shutdown
25	434	190	2.3	Continuous
26	1164	450	2.6	Morning shutdown
27	622	250	2.5	Continuous
28	1915	450	4.2	Morning shutdown
29	550*	100	5.5	Morning shutdown
30	580*	200	2.9	Continuous

* Calculated from incomplete counts.

been caused by the fact that the duration of powerhouse closure was shorter than the adjacent closures on September 24 and 28. If so, it would appear that the closures should be of longer duration than three hours.

It is apparent that the number of fish entering Seton Creek on days of powerhouse closure was about twice the number that entered on days of continuous powerhouse operation. Of the total number of fish that entered Seton Creek, approximately one-third did so on days of continuous powerhouse operation and two-thirds on days of powerhouse closure. By choosing an arbitrary or theoretical rate of arrival of fish in the tailrace, the rate of arrival in Seton Creek can be calculated if it is assumed that one-third of the fish that accumulate in the tailrace move upstream on days of continuous powerhouse operation and two-thirds on days of powerhouse closure. This calculation is shown in TABLE 7 and a similar calculation, assuming continuous powerhouse operation, with one-third of the tailrace accumulation migrating into Seton Creek each day, is shown in TABLE 8.

Under the conditions assumed in the calculation shown in TABLE 7 (one-third of the tailrace accumulation escaping to Seton Creek on days of continuous powerhouse operation and two-thirds on days of powerhouse closure), there would be a delay of one day in the peak arrival of fish in Seton Creek and a maximum lag of 17.5 per cent in the cumulative per cent of fish entering Seton Creek. However, at the end of the seventeenth day when all of the fish would have reached the tailrace, all but 1.0 per cent would have entered Seton Creek.

Under the conditions assumed in the calculation shown in TABLE 8 (one-third of the tailrace accumulation escaping to Seton Creek each day), the peak arrival of fish in Seton Creek would again have been delayed for one day but the lag in arrival of fish in Seton Creek would have been increased. At the end of the tenth day, 73.0 per cent of the total population would have reached the tailrace but only 48.0 per cent would have entered Seton Creek - a lag of 25.0 per cent. At the end of the seventeenth day, when all of the fish would have reached the tailrace, 5.0 per cent of the total population would still remain in the tailrace.

TABLE 7 - Theoretical rate of arrival of fish in Seton Creek, assuming one-third of the accumulated fish vacate the tailrace on days of continuous powerhouse operation and two-thirds on days of powerhouse closure, with closures occurring on Tuesday, Thursday and Sunday of each week.

Day	Assumed Number Arriving In Tailrace	Number Arriving Plus Residuals	Number Residual In Tailrace At End Of Day	Number Entering Seton Creek	Cumulative Per Cent of Run	
					Entering Tailrace	Entering Seton Creek
1 Sunday	50	50	17	33	0.5	0.3
2 Monday	100	117	78	39	1.5	0.7
3 Tuesday	150	228	76	152	3.0	2.2
4 Wednesday	250	326	217	109	5.5	3.3
5 Thursday	450	667	222	445	10.0	7.8
6 Friday	700	922	615	307	17.0	10.8
7 Saturday	1000	1615	1077	538	27.0	16.2
8 Sunday	1400	2477	826	1651	41.0	32.7
9 Monday	1800	2626	1751	875	59.0	41.5
10 Tuesday	1400	3151	1050	2101	73.0	62.5
11 Wednesday	1000	2050	1367	683	83.0	69.3
12 Thursday	700	2067	689	1378	90.0	83.1
13 Friday	450	1139	759	380	94.5	86.9
14 Saturday	250	1009	673	336	97.0	90.3
15 Sunday	150	823	274	549	98.5	95.8
16 Monday	100	374	249	125	99.5	97.0
17 Tuesday	50	299	100	199	100.0	99.0
18 Wednesday	0	100	67	33		99.3
19 Thursday	0	67	22	45		99.8
20 Friday	0	22	15	7		99.8
21 Saturday	0	15	10	5		99.9
22 Sunday	0	10	3	7		100.0
23 Monday	0	3	2	1		100.0
24 Tuesday	0	2	1	1		100.0
25 Wednesday	0	1	0	1		100.0

TABLE 8 - Theoretical rate of arrival of fish in Seton Creek, assuming one-third of the accumulated fish vacate the tailrace each day, with continuous powerhouse operation.

Day	Assumed Number Arriving In Tailrace	Number Arriving Plus Residuals	Number Residual In Tailrace At End Of Day	Number Entering Seton Creek	Cumulative Per Cent of Run: Entering Tailrace	Cumulative Per Cent of Run: Entering Seton Creek
1	50	50	33	17	0.5	0.2
2	100	133	89	44	1.5	0.6
3	150	239	159	80	3.0	1.4
4	250	409	273	136	5.5	2.8
5	450	723	482	241	10.0	5.2
6	700	1182	788	394	17.0	9.1
7	1000	1788	1192	596	27.0	15.1
8	1400	2592	1728	864	41.0	23.7
9	1800	3528	2352	1176	59.0	35.5
10	1400	3752	2501	1251	73.0	48.0
11	1000	3501	2334	1167	83.0	59.7
12	700	3034	2023	1011	90.0	69.8
13	450	2473	1649	824	94.5	78.0
14	250	1899	1266	633	97.0	84.3
15	150	1416	944	472	98.5	89.1
16	100	1044	696	348	99.5	92.5
17	50	746	497	249	100.0	95.0
18	0	497	331	166		96.7
19	0	331	221	110		97.8
20	0	221	147	74		98.5
21	0	147	98	49		99.0
22	0	98	65	33		99.4
23	0	65	43	22		99.6
24	0	43	29	14		99.7
25	0	29	19	10		99.8
26	0	19	13	6		99.9
27	0	13	9	4		99.9
28	0	9	6	3		99.9
29	0	6	4	2		100.0
30	0	4	3	1		100.0
31	0	3	2	1		100.0
32	0	2	1	1		100.0
33	0	1	0	1		100.0

The calculated daily numbers of fish entering Seton Creek are shown in FIGURE 12, with the theoretical rate of arrival in the tailrace shown for comparison. The theoretical calculations suggest that if one-third of the number of fish accumulated in the tailrace escaped to Seton Creek on days of continuous powerhouse operation and two-thirds on days of powerhouse closure, the overall delay of the whole population would be relatively minor, with the peak of arrival in Seton Creek delayed only one day. With powerhouse closures occurring on Tuesdays, Thursdays and Sundays, the hypothetical 17-day arrival curve would be extended to 25 days and with continuous powerhouse operation it would be extended to 33 days.

It must be emphasized that the problem is not as simple as the theoretical calculations would indicate. There is no assurance that all of the delayed fish reach Seton Creek. Although the average delay appears unimportant, some fish were probably delayed for extended periods and the ability of these fish to reach Seton Creek and to spawn effectively would therefore be seriously affected.

Duration of Tailrace Delay Estimated from Tagging

When it became obvious from visual observations that fish accumulated and delayed in the tailrace, an attempt was made to determine the extent of delay by means of tagging. Fish captured in the tailrace by dip-netting were tagged and then returned to the tailrace.

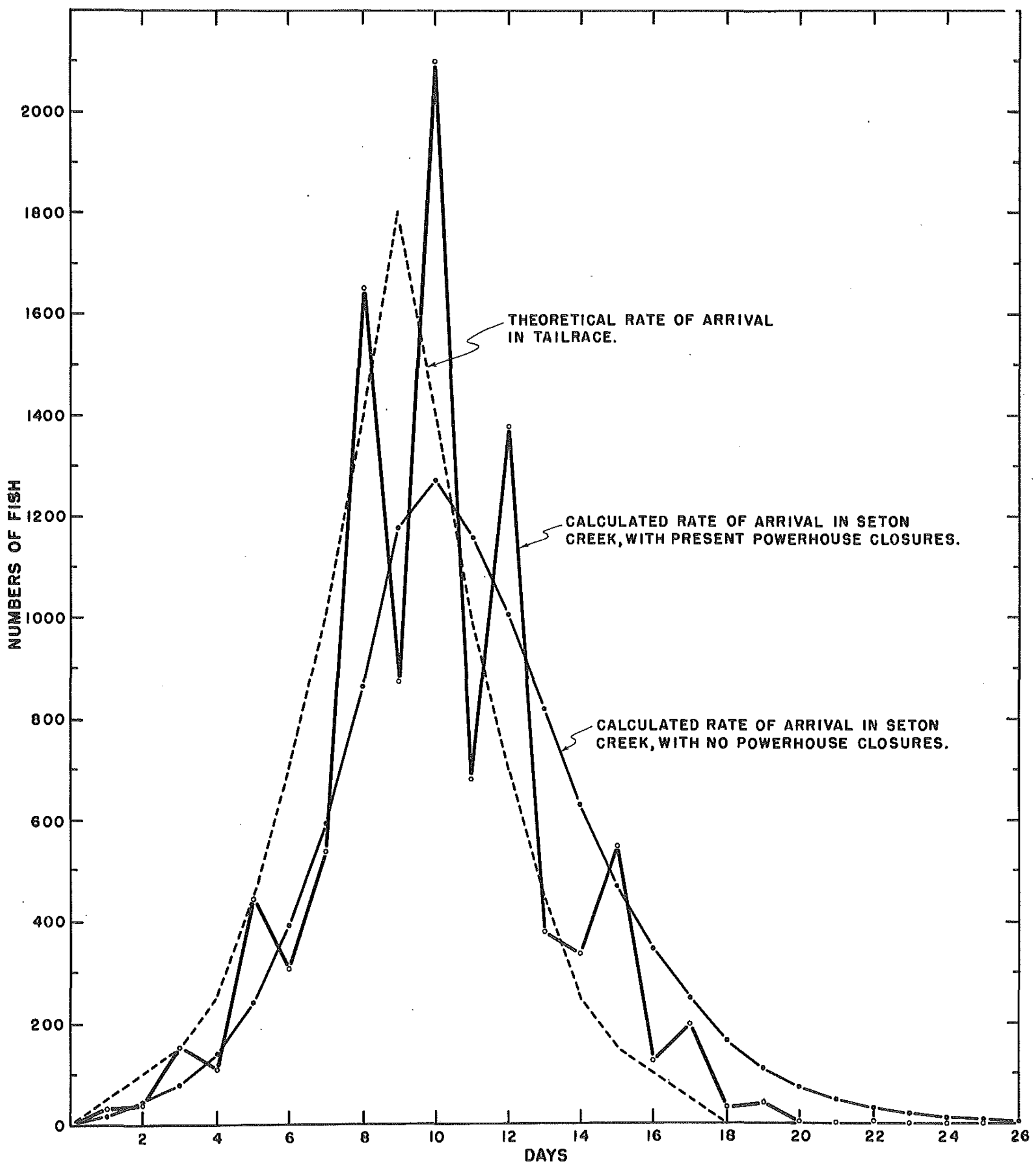


Figure 12. Calculated rates of arrival of fish in Seton Creek, assuming a theoretical rate of arrival in the tailrace, with one-third of the accumulated fish escaping from the tailrace to Seton Creek on days of continuous powerhouse operation and two-thirds on days when the powerhouse is shut down for at least three hours ending at 7:00 a.m. on Tuesdays, Thursdays and Sundays.

On October 5, 26 fish were tagged with separately identifiable colored discs. Extensive observations and dip-netting in the tailrace revealed that at least six fish remained two days after tagging, four for three days, and one for six days.

On October 7, 100 fish were tagged and 16 of these were noted in the tailrace one day after tagging. At least eight were noted two days after tagging and one fish remained until at least October 15, a total of eight days after tagging.

The results of these observations of tailrace delay are given in TABLE 9. Only fish actually recaptured or positively identified in the tailrace were used in the determination of delay. Thus, TABLE 9 shows only the minimum numbers of delayed fish because it was not possible to identify all of the tagged fish in the tailrace on any one day. Most of the tagged fish appeared to vacate the tailrace almost immediately after tagging but it is not known whether they dropped downstream or moved upstream to Seton Creek. Unfortunately, the turbidity of the water in Seton Creek precluded observations of the times of arrival of these fish in Seton Creek.

The results from the first group of tags suggest that some of the fish vacated the tailrace on October 8 but that there was no migration out of the tailrace during the previous two days of continuous powerhouse operation. However, after a two-hour powerhouse shutdown at noon on October 9, there was a definite migration out of the tailrace. The one tagged fish that remained in the tailrace after this powerhouse shutdown did not leave the tailrace during the prolonged closures on October 10.

TABLE 9 - Delay of adult pink salmon at the Seton Creek powerhouse, as determined by recaptures of tagged fish in the tailrace.

Date	Number of Fish Tagged in Tailrace	Powerhouse Closure	Minimum Number of Tagged Fish Identified in Tailrace	
			Group 1	Group 2
Oct. 5	26 (group 1)	None		
6		None	6	
7	100 (group 2)	None	6	
8		2:00-3:00 a.m.	4	16
9		12:00 a.m.-2:00 p.m.	1	8
10		(12:01 a.m.-8:00 a.m.) (12:00 a.m.-2:00 p.m.)	1	2
11		None	1	2
12		11:00-12:00 p.m.		2
13		12:01 a.m.-9:00 a.m.		1
14		None		1
15		12:01 a.m.-8:00 a.m.		1

The results from the second group of tags suggest that there was a substantial migration out of the tailrace during the two-hour powerhouse closure on October 9 and an even greater migration during the prolonged closures on October 10. One-half of the 16 tagged fish that remained in the tailrace on October 8 moved upstream during the two-hour shutdown on October 9 and three-quarters of the eight tagged fish that remained in the tailrace after this shutdown moved upstream during the prolonged shutdowns on October 10.

The observed delay of tagged fish in the tailrace during continuous powerhouse operation and the observed reduction in the numbers of tagged fish in the tailrace following each daytime powerhouse closure substantiate the observations made on untagged fish. However, the results from the tagging experiment indicate that one fish out of 26 remained in the tailrace for six days and one out of 100 remained for eight days. It is known, however, that tagging has an adverse effect on some of the fish. A few fish may be injured or their behavior may be affected so that their migration is abnormally delayed. The prolonged delays of six and eight days observed among tagged fish in the tailrace may therefore not be representative of delays experienced by untagged fish.

Observations of the speed of migration of tagged pink salmon in the Fraser and Thompson Rivers suggest that tagged fish experienced only a minor delay. FIGURE 13, which shows the counts of tagged fish in relation to the corresponding daily counts of untagged fish, indicates that fish tagged in the Fraser River near Mission arrived at the counting station on Seton Creek at the same time as untagged fish. However, an extended delay in the tailrace resulting from prolonged powerhouse operation might have masked any differences in the arrival times of tagged and untagged fish. Data gathered on the Thompson River were therefore examined to check the data obtained at Seton Creek.

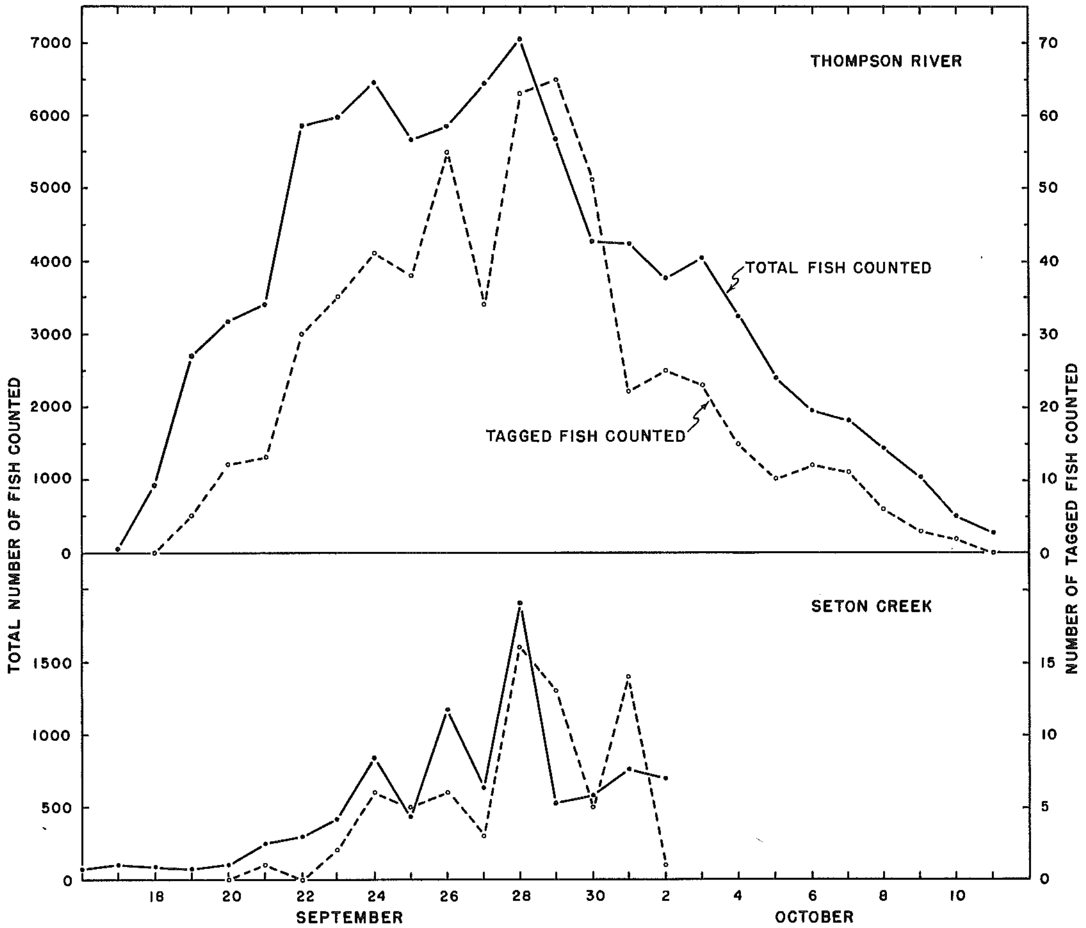


Figure 13. Counts of untagged pink salmon migrating past counting sites in Seton Creek and Thompson River in relation to the arrival times of pinks tagged near Mission.

To compare the speed of migration of tagged and untagged pink salmon, a chi-square "Goodness-of-fit" test was applied to the data obtained at the Thompson River counting station to determine if the arrival curve of tagged fish was significantly different from the arrival curve of untagged fish. A chi-square value of 84.94 for 21 degrees of freedom was determined, indicating a significant difference ($P < 0.01$) between the two arrival curves. This high chi-square value was obtained because the ratio of tagged fish to untagged fish was low at the beginning of the run, very high at the peak of the run, and slightly high during the last half of the run. The very high proportion of tagged fish at the peak of the run was due, at least in part, to an increased tagging efficiency during this period. However, the relatively low numbers of tagged fish at the beginning of the run and the relatively high numbers at the end of the run possibly resulted from a slightly slower rate of migration for the tagged fish. Even if the tagged fish were delayed, however, the data indicate that this delay was of a minor nature. The modes of the two arrival curves were nearly coincident and there was no pronounced "tail" on the latter part of the arrival curve of tagged fish.

Possible Effects on Sockeye Salmon

Productivity of sockeye salmon is known to be adversely affected by delay of adult salmon migrating to the spawning grounds. Thompson (1945) showed, by analysis of results obtained by tagging sockeye at Hell's Gate, that a 12-day delay in migration was sufficient to prevent all Fraser River sockeye from reaching their spawning grounds above Hell's Gate. From a comparison of the escapements of sockeye above Hell's Gate, Royal (1953) concluded that productivity doubled following the construction of the Hell's Gate fishways. Presumably, this substantial increase in the rate of productivity of sockeye spawning in the upper reaches of the Fraser River watershed was due to the elimination of minor delays at Hell's Gate. It would therefore appear essential, for maximum productivity, that adult sockeye destined for spawning grounds in the Seton-Anderson watershed should not be appreciably delayed in the tailrace of the Seton powerhouse.

The sockeye populations spawning in the Seton-Anderson system were small in 1957 and therefore a precise measure of the extent of delay could not be obtained. Casual observations, however, indicated that the Gates Creek run, which migrated past the powerhouse in July and August, was not delayed. During this period, the powerhouse was shut down from 4:00 to 7:00 a.m. or longer on Tuesday, Thursday and Sunday of each week. Delay of the Portage Creek sockeye, which moved upstream at about the same time as the pink salmon in September and October, appeared to be of more extended duration, in spite of the periodic powerhouse closures.

The difference in the extent of delay was evidently related to the level of the Fraser River. Levels were high at the time of the Gates Creek migration and when the powerhouse was not operating Fraser River water replaced Seton Creek water in the tailrace. It appeared that all sockeye moved upstream out of the tailrace under these conditions. However, Fraser River levels were much lower at the time of passage of the Portage Creek sockeye and this run did not readily move out of the tailrace during powerhouse closures. The water in the tailrace was not completely replaced by Fraser River water because a gravel bar extending across the tailrace 150 feet below the powerhouse prevented appreciable flow of Fraser River water into the tailrace during powerhouse closures.

A few Portage Creek sockeye in the tailrace from September 26 to October 31 provided some indication of the possible behavior of this late run. Most of the 1957 Portage Creek sockeye population consisted of three-year-old males ("jacks"). The first Portage Creek sockeye were seen in the tailrace on September 26 and although the first jack sockeye were observed on September 29, none were seen in the fishway at the Seton Dam until October 10. On this day the plant had been shut down for eight hours, a much longer period than usual. The numbers of jack sockeye in the tailrace from October 11 to 20 remained fairly constant. A slight reduction was noted following a 12-hour shutdown on October 13 but a three-hour closure on October 15 did not seem to have any effect in reducing the accumulation of sockeye in the tailrace.

Several sockeye were dip-netted from the tailrace on October 24. All were in poor condition. Their fins were frayed and they resembled spawned-out fish, indicating an extensive delay in the tailrace. Since the peak of sockeye spawning in Portage Creek usually occurs shortly after October 15, it is not likely that sockeye present in the tailrace as late as October 24 would reach Portage Creek and spawn effectively.

These observations suggest that productivity of the Portage Creek sockeye will be adversely affected by tailrace delay. A substantial run of Portage Creek sockeye is expected in 1958 and detailed observations will therefore be required in order to make a more complete assessment of the problem so as to avoid serious damage to the run.

Discussion

Continuous operation of the Seton Creek powerhouse appeared to cause a significant delay in the upstream migration of some of the adult salmon destined for the Seton-Anderson watershed. Observations suggested that periodic powerhouse shutdowns enabled Gates Creek sockeye to move upstream without undue delay. Although the pink salmon suffered an average delay of one day and some were delayed for several days, a significant reduction in spawning efficiency of the fish that reached Seton Creek was not evident. Portage Creek sockeye, on the other hand, appeared to be affected to a much greater extent.

Since the flow from the plant was much greater than that from Seton Creek, fish tended to accumulate in the tailrace. Of the pink salmon that entered Seton Creek only one-third did so when the plant was operated continuously. However, a large surge of fish entered Seton Creek following each complete shutdown of the plant. Although powerhouse closures were effective in reducing the numbers of fish accumulated in the tailrace, some of the pinks and Portage Creek sockeye remained in the tailrace during the shutdown periods. The productivity of these delayed fish may have been seriously affected. It appeared that some of the Portage Creek sockeye were delayed for so long that they would be unable to reach their spawning ground. In spite of the fact that no accumulation of fish was observed in the Fraser River or in tributary streams below the powerhouse, some of the delayed fish may not have moved past the powerhouse.

The extent of delay appeared to be affected by several factors, most important of which was the schedule of powerhouse operation. In addition, the gravel bar across the tailrace channel appeared to be an important factor. When the Fraser River was low this bar prevented complete mixing of Fraser and Seton water in the tailrace during plant closures. Some of the fish remained in the pool of Seton water in the tailrace channel during plant closures, thereby increasing the period of delay. The timing of the plant shutdown periods also appeared to be important. The delay at the powerhouse might have been reduced if the shutdowns had been timed to coincide with peak periods of migratory activity of the species concerned. Instead of the 4:00 to 7:00 a.m. closure, it would appear desirable to shut the powerhouse down from 5:00 to 8:00 a.m. or from 1:00 to 4:00 p.m. during passage of Gates Creek sockeye and from 1:00 to 4:00 p.m. during the pink salmon migration.

These closure times are suggested because the main migratory periods of Gates Creek sockeye occurred from 5:00 to 9:00 a.m. and from 1:00 to 4:00 p.m. and the main migratory period of pink salmon occurred from noon until 4:00 p.m. The fact that relatively few pink salmon entered Seton Creek before 6:00 a.m. even on days such as September 28 (FIGURE 9) when the powerhouse was shut down for 10 hours, suggests that the scheduled closure periods for pink salmon should not start until at least 6:00 a.m. The observed variations in migratory activity suggest that afternoon closures would be considerably more effective than morning closures. The hourly variations in migration of Portage Creek sockeye have not been defined.

The problem of ensuring adequate passage for upstream-migrant salmon will be more serious after the present expansion of the Bridge River hydroelectric installation is completed. In a few years, there will be enough flow available in the Seton system to permit almost continuous operation of the Seton plant during the period of adult salmon migration. Powerhouse shutdowns will therefore be less frequent. In 1957, the accumulations of salmon in the tailrace were materially reduced by daylight closures of the plant, which were required for conserving water in Seton Lake.

Evidence of the adverse effect of powerhouse operation on the upstream migration of adult salmon indicates that further study of this problem is required. A more complete investigation of the migration of Portage Creek sockeye than was possible in this preliminary study seems essential.

OTHER FACTORS AFFECTING PRODUCTIVITY

Several other factors resulting from hydroelectric construction may have contributed to an overall reduction in the capacity of the Seton watershed for producing salmon. The adverse effects of smolt mortality, loss of spawning ground, and obstructing or delaying adult salmon en route to their spawning grounds are fairly obvious but the effects of changes in temperature, turbidity and flow are difficult to assess at the present time.

One obvious adverse effect on productivity is the loss of about 1.5 miles of spawning ground in Cayoosh Creek above the Seton-Cayoosh junction. The Cayoosh Dam diverts all but the flood flow of Cayoosh Creek to Seton Lake. The stream bed below the dam is therefore dry, except for a small seepage flow, for lengthy periods each year. Furthermore, spilling of occasional flood flow over this dam during the pink salmon run will result in fish entering the area below the dam and spawning in areas that will be dry when spilling stops. Since the diversion flow is greatly reduced by debris accumulating on the trash rack of the diversion tunnel, it will be necessary to keep this trash rack as clean as possible during pink salmon spawning runs to minimize the frequency and duration of such spills. At the beginning of the 1957 pink salmon run there was a small spill over the Cayoosh Dam but the trash rack on the diversion tunnel was cleaned and the spilling stopped before the fish started spawning in this flood flow.

From 1945 to 1951, when only small numbers of pink salmon spawned in the Seton watershed, Cayoosh Creek was seldom used as a spawning area. It was therefore considered unnecessary in 1953, when fish facilities were being designed for the Seton hydroelectric project, to require a minimum flow for spawning in Cayoosh Creek or a fishway over the Cayoosh Dam. With the increase in spawning populations in later years, however, a significant number of pinks have spawned in this creek. In 1957, about 1500 fish spawned in the seepage flow in the lower 3500 feet of Cayoosh Creek.

Another adverse effect of the Seton development is the loss of an excellent spawning area between the dam site in Seton Creek and the outlet of Seton Lake. This area previously extended 3500 feet below the lake but construction of the dam practically eliminated 2500 feet of this spawning area, leaving an area only 1000 feet long immediately below Seton Dam for efficient spawning. The natural channel from the lake to the dam was excavated to provide a more formalized channel about 150 feet wide and 15 feet deep. Water velocities in this channel are negligible when the plant is not operating and although a few pinks spawned in this area in 1957, particularly along the margins and in the shallow areas near the outlet of Seton Lake, the survival of their eggs may have been very low as a result of the reduced flow of oxygen-carrying water through the gravel during the plant shutdown periods. To illustrate the former importance of the 3500-foot section of spawning area immediately downstream from Seton Lake, it should be noted that in

1957 approximately 30 per cent of the total population of spawning pink salmon in Seton Creek utilized the remaining 1000 feet of this section of the spawning area. The density of spawners was much higher in this 1000 feet of spawning area than in any other area of Seton Creek.

In 1957, several thousand pink salmon migrated through the fishway at the Seton Dam, either because they were seeking their native spawning area above the dam or because they were seeking spawning areas that were less competitive than the heavily populated area immediately below the dam. Upon reaching the deep channel above the dam, many of these fish attempted to return downstream past the dam. Frequently, as many as 100 fish were seen swimming at one time near the water surface immediately upstream from the coarse screen at the canal intake, which had been installed for the specific purpose of preventing adult salmon and trout from being swept into the canal and destroyed in passage through the turbine. Because these fish were unable to pass through the coarse screen, they were forced to pass through the fishway or the turbulent, energy-dissipating chamber of the fish-water sluice in order to return to the spawning area below the dam.

Production of salmon in the Seton-Anderson watershed may also have been affected by the Bridge River hydroelectric development. Since 1934, cold, turbid water has been diverted from Bridge River to a powerhouse near the upstream end of Seton Lake. From 1934 to 1948, the diversion of Bridge River water to Seton Lake was approximately 30 cubic feet per second but with completion of a new hydroelectric installation in 1948, the flow was increased until by 1954 an average of about 2000 cubic feet per second was diverted. The individual turbines at the Bridge River power plant, using about 500 cubic feet per second each, were placed in operation on the following dates:

Number 1. October, 1948
2. May, 1949
3. December, 1949
4. July, 1954.

Four additional units are scheduled for installation in the next year or two. After completion of this additional generating capacity, the average diversion flow will be at least 3000 cubic feet per second, with a maximum flow of about 4500 cubic feet per second.

This large discharge of glacial water into the Seton system has already produced two distinct changes in Seton Lake. The lake has become turbid and cold. In August 1943, a Secchi disk was visible to a depth of 37 feet in Seton Lake whereas Secchi disk readings of only 2 feet are obtained at the present time. Temperatures taken in Seton Creek from July 27 to August 15, 1941 can be compared with temperatures taken at the same location and at the same times in 1956 to illustrate the marked reduction that has occurred in the temperature of Seton Lake. The average 8:00 a.m. water temperature in Seton Creek during this period was 69.3°F in 1941 and 59.0°F in 1956. This decline of 10.3°F, which cannot be attributed to meteorological conditions, illustrates the severe change that has occurred in Seton Lake as a result of the Bridge River diversion. However, it cannot be considered that the same magnitude of change would occur during the critical periods of migration, spawning, and egg incubation. The differences in temperature in Seton Creek resulting from the inflow of Bridge River water into Seton Lake must be determined throughout the year before the effects of any temperature change on the pink salmon spawning in Seton Creek can be determined.

Studies are underway at the present time to investigate the effect of observed changes in temperature, turbidity, and plankton production on the survival and growth rate of sockeye fingerlings in Seton Lake. The changes in physical and chemical properties of the water in Seton Lake appear to be due primarily to the large diversion flow of glacial water from Bridge River, although the diversion of cold water from Cayoosh Creek to Seton Lake may also have had some effect. What effect these changes will have on the production of sockeye fingerlings in Seton Lake remains for further investigation but preliminary data suggest that plankton production in Seton Lake is very low at the present time and the growth rate of sockeye appears to have been reduced. Data collected at Cultus Lake (Foerster, 1954) show that sockeye smolts that are small at migration time have a much lower rate of survival than larger smolts during seaward migration and ocean residence. A significant reduction in food supply in Seton Lake can therefore be expected to reduce sockeye production.

Another factor that reduces salmon production in the Seton-Anderson watershed at the present time is the mortality of seaward-migrant salmon in the powerhouse cooling-water system. A flow of approximately 2 cubic feet per second is drawn from the penstock and passed through fine screens in the powerhouse. Several thousand sockeye yearlings and pink fry were killed on these screens during the seaward migration in the spring of 1958.

The possibility that the previously mentioned controlled flows of 400 cubic feet per second during adult migration and spawning periods and 200 cubic feet per second during the egg incubation period might provide more stable conditions for spawning and egg incubation than would normally occur under natural conditions is under study at the present time. Preliminary results suggest that the possible benefits from flow stabilization are minor in relation to the various adverse effects of the Bridge River and Seton Creek hydroelectric developments. Also, sporadic spill discharges down Seton Creek will have a serious adverse effect on the efficiency of spawning and on the survival of deposited eggs.

SUMMARY AND CONCLUSIONS

Activity during the construction of the Seton Creek hydroelectric development did not materially affect salmon production. Construction was scheduled to minimize interference with upstream migration of adult salmon, spawning in Seton and Cayoosh Creeks, and incubation of eggs in the gravel near the construction areas.

Investigations conducted in 1956, before the powerhouse started operating, indicated that the upstream migration of sockeye was not greatly impaired by the 25-foot dam in Seton Creek. Sockeye were attracted to the fishway entrance with little delay provided water was not spilled from the radial gate, which produced a strong attracting flow along the opposite bank of the creek.

The vertical-slot fishway provides adequate passage for sockeye salmon. Gates Creek sockeye required an average of 20 to 30 minutes to move through the fishway. Approximately 19 per cent of the Gates Creek sockeye population passed through the fishway on the peak day. Migration of these sockeye through the fishway occurred mainly from 4:30 a.m. to 10:30 p.m. and there were two peak periods of daily migratory activity. An average of 34 per cent of the daily migration moved through the fishway between 5:00 and 9:00 a.m. and 22 per cent moved upstream between 1:00 and 4:00 p.m. The peak hourly migration through the fishway was 22 per cent of the total migration for that day and the maximum migration in a 15-minute period was 11 per cent of the daily total.

A significant loss of yearling sockeye salmon occurred as a result of mortalities suffered in passage at the Seton Dam and at the powerhouse. The computed mortality rates were 9.2 per cent in the turbine, 7.4 per cent in the fish-water sluice, and 1.2 per cent in the siphons. The seaward-migrant sockeye populations will probably be decreased by at least 10 per cent since nearly all of the fish will pass downstream through the turbine and the conditions for passage through this exit at low tailwater and at part load would probably be more hazardous than those tested. Mortalities in the fish-water sluice could probably be reduced by discharging as much of the flow as possible over the weir crest at the downstream end of the energy-dissipating chamber.

The expected turbine mortality rate of pink salmon fry can only be estimated using results of experiments conducted elsewhere. On this basis, the fry would be expected to suffer a mortality rate of 13 per cent. However, it appears that less than 10 per cent of the pink salmon fry produced in the Seton-Anderson watershed originate in areas upstream from the Seton Dam.

A delay of upstream-migrant adult salmon was observed in the powerhouse tailrace even though the plant was shut down from 4:00 to 7:00 a.m. or longer on Tuesday, Thursday and Sunday of each week. On the average, pink salmon were delayed in the tailrace for only one day but some were delayed for much longer periods. The extent of delay of pink salmon was affected by powerhouse operation. The number of pink salmon entering Seton Creek was relatively low when the plant was operated continuously but following each plant shutdown a surge of fish up Seton Creek was evident. Partial plant shutdowns were not effective in reducing the accumulation of adult salmon in the tailrace. A significant number of pink salmon remained in the tailrace channel even during complete plant shutdowns but most of the fish appeared to vacate the tailrace and move upstream to Seton Creek when the plant stopped operating.

The delay of adult sockeye salmon in the tailrace appeared to be related to the level of the Fraser River. At high levels, which occurred during passage of the Gates Creek sockeye, the Seton Creek water in the tailrace was replaced by Fraser River water when the powerhouse was not operating. During passage of Portage Creek sockeye, the Fraser River was at a much lower level and mixing of tailrace and Fraser River water during plant closures was prevented by a gravel bar extending across the tailrace. Fish tended to remain in the tailrace during the latter condition.

The problem of delay of upstream migrants, particularly of sockeye, in the powerhouse tailrace requires further study.

The loss of part of the pink salmon spawning area in Seton and Cayoosh Creeks has reduced the salmon-producing potential of the Seton Creek watershed. Any sporadic spills over the Seton Dam might have a further adverse effect on spawning and egg incubation in the remaining spawning areas below the dam. Current investigations suggest that the potential of Seton Lake for rearing sockeye salmon has been reduced as a result of the diversion of Bridge River water to Seton Lake.

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