INTERNATIONAL PACIFIC SALMON
FISHERIES COMMISSION

PROGRESS REPORT

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LIMNOLOGICAL CHANGES IN SETON LAKE RESULTING FROM HYDROELECTRIC DIVERSIONS

By
G. H. GEEN and F. J. ANDREW

NEW WESTMINSTER, B.C.
CANADA
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the Fraser River System

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ABSTRACT

Limnological changes occurring in Seton Lake and Seton Creek as a result of hydroelectric diversions from Bridge River and Cayoosh Creek into Seton Lake were investigated to provide information that would be of value in assessing effects of other proposed diversions in the Fraser River system. The changes included reduced temperatures and dissolved mineral content and increased turbidity and flushing rate. Plankton production appeared to be greatly reduced, primarily because of a pronounced increase in turbidity.

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INTRODUCTION

Several proposals have been made in recent years to develop hydroelectric power in the Fraser River system by diverting water from one drainage area to another. The possibility of generating power by diverting water from Taseko Lake to Chilko Lake and from there to tidewater has been studied for several years. In another power development scheme, water would be diverted from the Columbia River into Shuswap Lake. In both of these cases, large discharges of turbid water would be introduced into valuable sockeye rearing lakes. Being responsible for the conservation of sockeye and pink salmon in the Fraser River system, the International Pacific Salmon Fisheries Commission has been concerned that these power development schemes would alter the natural environment to such an extent that salmon production would be adversely affected.

To provide information that would be of value in assessing possible effects of hydroelectric diversions, a limnological investigation was made of Seton and Anderson Lakes, near Lillooet, B.C. The object of this study was to determine the physical, chemical and biological effects of the diversion of water from Bridge River and Cayoosh Creek to Seton Lake. Some data obtained prior to the construction of these hydroelectric diversions permitted direct comparison of pre- and post-diversion conditions in Seton Lake. Since pre-diversion data were limited, the present limnological characteristics of Anderson Lake, lying immediately upstream from Seton Lake, were determined to provide an indication of conditions existing in Seton Lake prior to the introduction of diverted water. The two lakes have similar morphometric, climatic and edaphic characteristics. Changes in flushing rate, turbidity, plankton abundance, temperature, and dissolved nutrients are discussed in this report in relation to their possible effects on sockeye production in Seton Lake and pink salmon production in Seton Creek.

DESCRIPTION OF THE STUDY AREA

The Seton-Anderson system discharges into the Fraser River approximately 200 miles from the estuary. In its natural state, this system received nearly all of its inflow from Gates Creek at the head of Anderson Lake. As shown in FIGURE 1, the outflow from Anderson Lake enters Seton Lake by way of Portage Creek, which is approximately 1.7 miles long. Prior to the construction of hydroelectric facilities in this system, all of the outflow from Seton Lake passed through Seton Creek to enter the Fraser River. In six years of recorded discharge, from October 1914 to September 1918 and from October 1924 to August 1926, the average annual outflow was about 660 c.f.s. (Dept. Northern Affairs and National Resources).

Since 1934, water has been diverted to Seton Lake from Bridge River, lying a few miles to the north at an elevation 1200 ft. above Seton Lake. Until 1948, a small flow of approximately 30 c.f.s. was diverted to a powerhouse near the upper end of Seton Lake for the generation of power for local use. Expansion of the development was undertaken between 1948

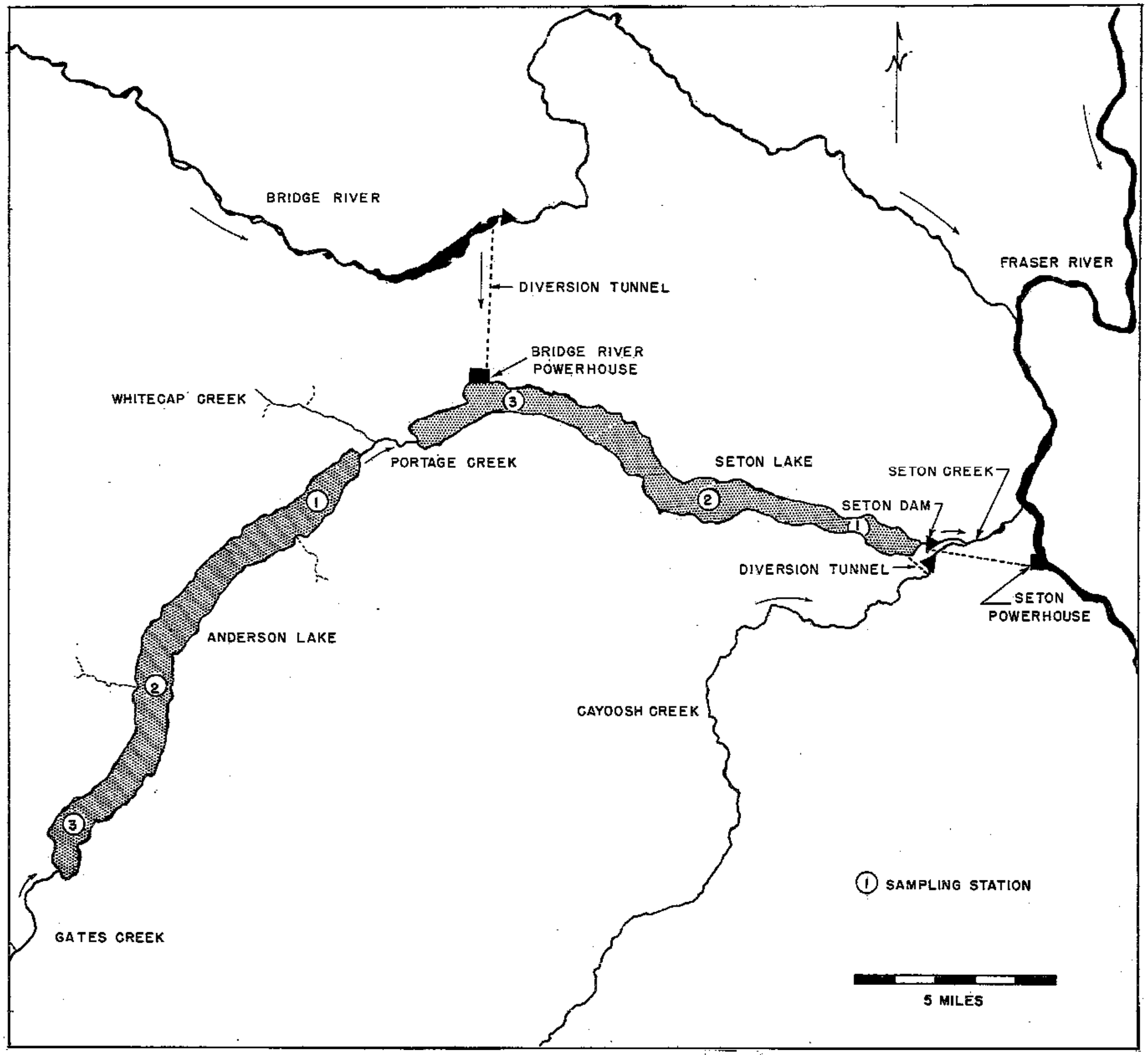

FIGURE 1. The Seton-Anderson system.

and 1954 when four turbines, each discharging 500 c.f.s., were installed and put into operation. Construction of a second powerhouse with four additional turbines was completed in 1960, resulting in an average diversion discharge of over 3000 c.f.s.

The increased discharge into Seton Lake has been utilized by the construction of a low-head dam on Seton Creek near the lake outlet that diverts most of the water to a canal leading to a powerhouse on the Fraser River. This latter development, completed in 1956, receives additional water from a diversion of Cayoosh Creek into the lower end of Seton Lake.

Seton and Anderson Lakes lie in the same long, narrow valley and, as shown in TABLE 1, have similar physical characteristics. Both lakes are 13.5 miles long and have a maximum width of slightly more than one mile. They would be considered oligotrophic, according to the

TABLE 1 - Morphometric features of Seton and Anderson Lakes.

	Anderson Lake	Seton Lake
Area	7000 acres	6000 acres
Volume	3,000,000 acre ft.	1,700,000 acre ft.
Mean Depth	460 ft.	280 ft.
Maximum Depth	705 ft.	494 ft.
Elevation	846 ft.	777 ft.
Length of Shoreline	28.3 miles	30.3 miles
Shore Development*	2.41	2.84

*Ratio of length of shoreline to length of the circumference of a circle of area equal to that of the lake.

classification presented by Welch (1952). The lakes are also subject to the same climatic conditions. Chapman (1952) categorized the Seton-Anderson area as humid continental with cool dry summers. The geological nature of the watershed is such that a relatively low level of dissolved minerals would be expected in both lakes. According to Gunning (1943), both lakes lie in an area of volcanic and sedimentary rock of Carboniferous to Jurassic origin.

Four species of Pacific salmon are found in the Seton-Anderson system. Two races of sockeye salmon (*Oncorhynchus nerka*) are reared in the area. One race spawns in Gates Creek and the other in Portage Creek. Pink salmon (*O. gorbuscha*) spawn in Seton, Cayoosh and Portage Creeks. Coho (*O. kisutch*) and chinook salmon (*O. tshawytscha*) also spawn in Gates, Portage and Seton Creeks. Kokanee and other resident fish are also found in the two lakes, including rainbow trout (*Salmo gairdnerii*) and dolly varden (*Salvelinus malma*). The present dominant-year salmon populations consist of a maximum of 9000 sockeye spawners in Gates Creek and 4800 in Portage Creek, 58,000 pink salmon in Seton Creek, about 800 in Cayoosh Creek, and 1900 in Portage Creek, and probably less than 500 each of coho and chinook salmon distributed throughout the three main streams of the system.

HISTORY OF SOCKEYE RUNS

Early records indicate that large numbers of sockeye formerly spawned in the Seton and Anderson system. A large hatchery constructed on Seton Creek in 1903, capable of incubating 40,000,000 eggs, appears to have been a major factor in the early decline of the Seton-Anderson sockeye populations. The runs were further depleted in 1913 and for several years following, by obstructions in the Fraser Canyon that prevented most of the upriver runs of Fraser River sockeye from reaching their spawning streams.

The hatchery was located just above the confluence of Seton and Cayoosh Creeks. Weirs constructed across Seton Creek at the outlet of Seton Lake and in Portage Creek near its entrance into Seton Lake retained the adults in holding pools, thus preventing them from spawning in their native areas. The Gates Creek sockeye run, arriving in Seton Creek during the summer months, was severely affected by the hatchery operations because the adults were held in the very warm water of Seton and Portage Creeks for long periods -- about a month or more. The hatchery superintendent's reports indicated that the resulting losses of adults and eggs were very heavy. He stated that the water temperature at the hatchery weir in Seton Creek, above the Seton-Cayoosh junction, sometimes reached as high as 71° during this retention period. The late run was also seriously affected by prolonged retention in Seton Creek. In an inter-office report dated September 24, 1912, the hatchery superintendent stated that 6000 sockeye were being held in Seton Creek for egg taking and that the mortality was about 800 fish per day.

The size of the original populations of salmon in the Seton-Anderson system can be estimated from the Annual Reports of the Commissioner of Fisheries for British Columbia and the records of the early years of operation of the Seton hatchery. The Gates Creek population consistently appeared in Seton Creek from about July 20 to the end of August. This race was very abundant in the cycle years 1901 and 1905. The dominant-year run was followed by a run of about one tenth its size, after which followed two annual runs of very small size. This consistent variation in the size of each annual run within each quadrennial cycle was characteristic of all upriver sockeye populations in the Fraser basin prior to the Hell's Gate block in 1913.

The native population of Portage Creek sockeye entered Seton Creek at the same time as large numbers of sockeye that were destined for other spawning areas in the upper reaches of the Fraser River watershed. These stray fish entered Seton Creek after their migration had been naturally blocked by low water conditions at Bridge River Rapids, located on the Fraser River about five miles above Seton Creek. The number of blocked sockeye entering Seton Creek in 1909 was estimated to have been about a million fish (Babcock, 1910). These blocked sockeye are no longer found in Seton Creek because fishways constructed at Bridge River Rapids in 1946 permit the fish to migrate to their native spawning grounds. Because of this mixing of blocked fish with Portage Creek fish, there is no way of estimating the original size of the Portage Creek population except on the basis of available spawning area, which appears to be about one quarter of that in Gates Creek.

From a thorough examination of historical data, Royal (1953) estimated the pre-1913 Seton-Anderson sockeye spawning populations as follows:

Cycle Year	Gates Creek	Portage Creek
1901	150,000	40,000
1902	15,000	4,000
1903	2,000	500
1904	1,000	300

The historical records furnish convincing evidence that both Seton and Anderson Lakes formerly produced very large numbers of sockeye smolts that migrated seaward in April, May and June. Local residents can still recall the large migrations of juvenile and adult salmon and the weirs that Indians used for catching sockeye smolts at the outlets of Seton and Anderson Lakes.

Babcock (1904), in describing these weirs, stated: "On the 2nd of May last (1903), at the head of Portage Creek, the outlet of Anderson Lake, I found a brush and rock dam which prevented the passage of the young salmon from that lake, which was constructed and used by the Indians for the purpose of enabling them to take these immature fish for food. It was an ingenious and most destructive contrivance, built in the form of a great funnel. Its wings were made of logs, green boughs, willow brush and rock. At its lower end there was a basket-trap into which the fish were swept by the swift waters, and from which they were removed by the Indians. While the water passed more or less freely through the wings of the dam, the brush prevented the fish from doing so. Many fish, either in seeking to pass through the brush, or being drawn into it by the current, became enmeshed and were killed. The Indians make no attempt to remove the fish thus entrapped, as they secure all they can use from the basket-trap at the lower end. After photographing it, this brush dam was wholly removed by my assistants, many thousands of dead young salmon being found in the brush wings. Evidently few or none of the young salmon which attempted to pass through it did so alive. At every Indian house on Portage Creek were found young salmon taken from this trap. The Indians eat these yearlings in a fresh state, and smoke and dry many more. A similar but smaller trap was found at the lower end of Portage Creek, which was maintained by some of the Indians who live at that end of the creek, but no fish were found in it, and we were told by the Indians that they had caught none for over a week, because none could pass the dam above. They complained of the fact that the dam above them had been placed entirely across the creek, and indignantly protested against our destroying their traps, claiming that they had always been permitted to catch these young fish for food."

In the 1901 report of the Commissioner of Fisheries for British Columbia it is stated that the young salmon started migrating from Seton Lake on the first rising water in the spring and continued to migrate until July, suggesting that the number of spawners two years earlier had been quite large. In 1903, it is stated that the migration of yearlings from Seton Lake began with the spring flood early in April and continued to the end of May, the migration being heaviest the first two weeks of May. A few migrants were seen in June. A very large migration from Anderson Lake was also seen during the spring months of this year.

Hatchery operations were terminated in Seton Creek in 1915 because the runs, especially the Gates Creek population, had been almost destroyed. In 1914, less than 100 Gates Creek adults returned and all of these were artificially spawned, yielding less than 200,000 eggs for the hatchery. In 1915, the runs were so poor that no eggs were obtained from the Seton-Anderson system.

Rehabilitation of Seton-Anderson sockeye populations has progressed very slowly in relation to the rapid increases shown by other upriver sockeye populations following construction of the Hell's Gate fishways. The dominant-year population of 6883 sockeye that spawned in Gates Creek in 1952 increased to 9012 in 1956 but decreased again to 5449 in 1960. The dominant-year population in Portage Creek increased slightly, from 3495 in 1954 to 4791 in 1958.

METHODS

This study was largely based on measurements of physical conditions and plankton abundance in Seton and Anderson Lakes. Measurements were made at three sampling stations on each lake (FIGURE 1) from April 1958 to May 1961.

Adult crustacean zooplankters were sampled at each station to index the relative abundance of sockeye food organisms in the two lakes. The procedure and techniques of plankton sampling followed in this study were similar to those described by Ward (1957), who discussed the utility and limitations of the methods and concluded that they were adequate for deriving an index of plankton abundance. Using a No. 10 Wisconsin-type net, six vertical hauls were made at each station from a depth of 100 ft. to the surface. The vertical distribution of plankton was measured on several occasions by means of six vertical hauls within each 20-ft. depth interval in the top 100 ft. On one occasion, stage hauls were made in 50-ft. intervals to a depth of 200 ft.

A particular effort was made to sample consistently in both lakes and during all sampling periods. Sampling was conducted by the same person throughout the study and was carried out during daylight hours only. The plankton net was washed, rinsed, and dried after each day's sampling and was replaced after six months' use. The same procedures were used consistently for washing plankton off the net after each haul, and for determining the volume of each sample. Plankton was carefully washed off the net into 1-oz. vials and taken to the laboratory. Each sample was washed for one minute to remove phytoplankton and small zooplankters and then centrifuged for 20 minutes, after which time the volume was read off a calibrated centrifuge tube.

In conjunction with the plankton sampling, physical data were collected at each station. Turbidity was measured with a white Secchi disk 20 cm. in diameter. Water samples were regularly taken at the lake surface. The specific conductivity of these water samples was measured by means of an Industrial Instruments Type RC conductivity bridge. These values permitted estimation of the relative total dissolved solid content (T.D.S.) of the two lakes by using the T.D.S.-conductivity relationship described by Northcote and Larkin

(1956). Temperatures at each sampling station were recorded to a depth of at least 100 ft. with a bathythermograph. Temperatures of important streams and diversion flows were measured regularly and water samples taken for determining the T.D.S. levels. In addition, continuous temperature records of Seton and Portage Creeks were obtained as follows: Seton Creek - from October 1957 to May 1960, Portage Creek - from April 1958 to May 1960, and Cayoosh Creek - from December 1958 to May 1960.

EFFECTS OF DIVERSION ON PHYSICAL AND CHEMICAL FACTORS

Mixing of Diverted Water in Seton Lake

Knowledge of the distribution of the diverted water in Seton Lake is important in assessing its effects on physical, chemical and biological conditions in the lake. A gross measure of the distribution of the diverted water was obtained by visual observations and by measurements of turbidity and subsurface temperatures.

A variable pattern of mixing of Bridge River and Seton Lake water was observed in the immediate area of the powerhouse near the upper end of Seton Lake. Bridge River water, initially directed downlake from the powerhouse at high velocities, appeared to deflect across the lake after flowing along the north shore for about 1000 ft. The pattern of this flow could be observed when the foreign water was much more turbid than the surface of the lake. On several occasions an area of turbid water was observed, extending in a wide arc from the powerhouse, down the north shore, across the lake and up the south shore, leaving an area of less turbid water in midlake directly opposite the powerhouse.

Series of temperature and turbidity measurements showed that the area of mixing sometimes extended at least 8000 ft. downlake from the powerhouse. The "area of mixing" was considered to be that area in which the surface turbidity and the subsurface temperature pattern differed significantly from turbidities and temperatures in downstream areas of the lake. The extent of this area of mixing appeared to be dependent on the temperature of the incoming water in relation to thermal stratification of the lake. For instance, on June 12, 1958, the temperature of the incoming water was 49°F and undisturbed temperatures in other areas of the lake were 65°F at the surface and 49°F at a depth of 60 ft. Nine bathythermograph measurements made to a depth of 160 ft. in the immediate vicinity of the powerhouse suggested that the area of mixing extended about 2500 ft. downlake from the powerhouse. However, on August 14, 1948, the temperature of Bridge River water was 59°F and the lake was 70°F at the surface and 59°F at a depth of 30 ft. Thirteen bathythermograph measurements suggested that the area of mixing extended about 8500 ft. downlake. It appeared that, in reaching its own density level in the lake, Bridge River water became thoroughly mixed with the surface layers and that this mixing extended across the whole lake. The size of the mixing area was relatively small in relation to the area of Seton Lake, however.

In addition to this mixing of Bridge River and Seton Lake water in the immediate vicinity of the powerhouse, a further extensive mixing occurred during the spring and fall when the lake became isothermal. The winds that prevail in the Seton-Anderson area would probably cause extensive mixing of water from all levels in the lake in the spring and fall of each year. It was concluded, therefore, that water from the Bridge River diversion would affect all areas of Seton Lake rather than only a local area near the powerhouse. Data presented in later parts of this report show the general uniformity of conditions throughout Seton Lake.

The Cayoosh Creek diversion, on the other hand, caused only local changes in the immediate vicinity of the outlet of Seton Lake. Water from the Cayoosh Creek diversion was not observed to enter more than 1000 ft. into the lake before curving abruptly towards the outlet, which lies approximately 1000 ft. north of the point of entry of the Cayoosh Creek diversion. On several occasions, a continuous band of turbid Cayoosh Creek water was seen extending in a wide arc towards Seton Creek. This turbid water could be seen as a continuous band in the lake and at the upper end of Seton Creek. It was concluded that although the Cayoosh Creek diversion flow would directly affect the temperature of Seton Creek, it would have a negligible effect on the temperature and productivity of Seton Lake.

Water Temperatures in Relation to Meteorological Conditions

Available temperature data were analyzed to determine the extent of temperature changes resulting from the diversion of foreign flow into Seton Lake. In these analyses it was necessary to consider climatic conditions because any differences in water temperature before and after the diversion might be attributable to natural variation in climatic conditions rather than to the effects of the foreign flow.

Analysis of average water temperatures at the outlets of the large lakes in the Fraser River system demonstrated that annual variations in meteorological conditions can be used to provide a general indication of annual water temperature variations. Water temperatures in Stellako River, at the outlet of Francois Lake, were correlated with meteorological data obtained at Prince George, about 90 miles to the east; and water temperatures in Adams River, at the outlet of Adams Lake, were correlated with meteorological data obtained at Salmon Arm, about 20 miles to the southeast. General similarity of the climate at each meteorological station to that at the particular river with which it was compared has been indicated by Chapman (1952) and by the British Columbia Atlas of Resources (1956). Meteorological data were taken from published and unpublished records of the Department of Transport. The period of the year considered in this comparison has been restricted to the seven-month period from April to October, inclusive.

Average Stellako River temperatures showed a statistically significant relationship with the duration of sunshine and the average air temperature at Prince George for the 11 years of record, 1950 to 1960 inclusive (FIGURE 2). The correlation coefficients were 0.928 ($p < 0.01$) for duration of sunshine vs. water temperature and 0.806 ($p < 0.01$) for air temperature vs. water temperature. The relationships between Adams River temperatures and meteorological conditions at Salmon Arm for the 11-year period from 1950 to 1960 inclusive were not as precise, presumably because of the increased cloud cover at Adams Lake. The relationship between Adams River

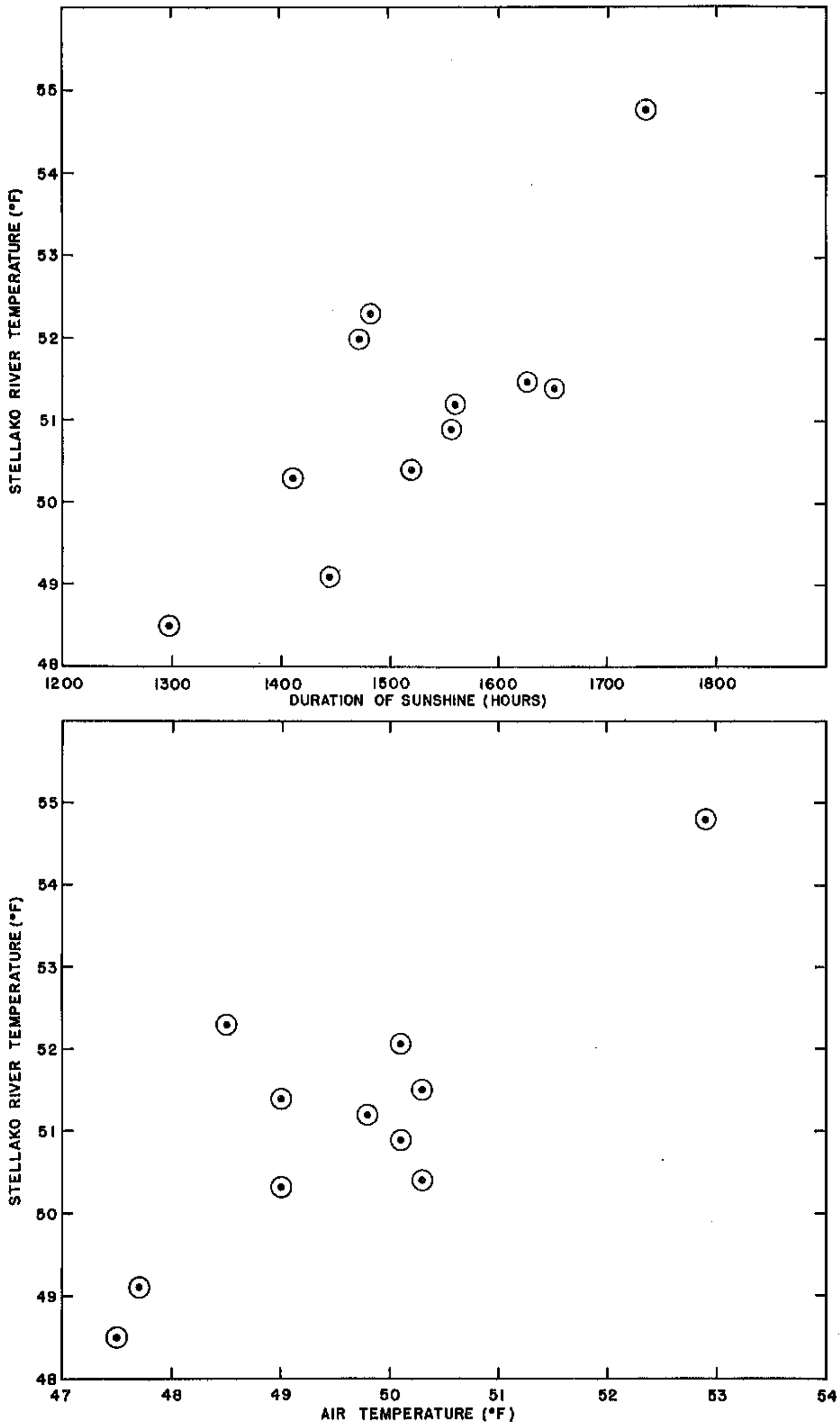

FIGURE 2. Mean temperature of Stellako River from April to October inclusive in relation to the duration of sunshine and mean air temperature at Prince George during the same period, for the years 1950 to 1960 inclusive.

temperatures and Salmon Arm air temperatures was statistically significant ($r = 0.675$, $p < 0.05$) but the relationship between Adams River temperature and the duration of sunshine at Salmon Arm was not significant. The data suggest, however, that average water temperatures in the April through October period are generally related to the duration of sunshine and the average air temperatures.

Average air temperatures or the total duration of sunshine at Lillooet in the April through October period would therefore be expected to give a general indication of annual variations in water temperature in Seton Lake and Seton Creek. Since the hours of sunshine were not recorded at the Lillooet meteorological station, it was necessary to use data obtained at Kamloops as a basis for comparison of pre- and post-diversion water temperatures. Although it lies about 100 miles to the east, Kamloops is in the same climatic zone as Lillooet. Comparison of Lillooet air temperature data with corresponding data from Kamloops for the years 1935 to 1944 inclusive demonstrated that meteorological conditions at Kamloops and Lillooet are very similar (FIGURE 3). The correlation was highly significant ($r = 0.889$, $p < 0.01$). It was concluded, therefore, that air temperatures and duration of sunshine at Kamloops would provide a general indication of climatic variations affecting the temperature of Seton Lake and Seton Creek in the pre- and post-diversion periods.

Comparison of Pre- and Post-diversion Seton Lake Temperatures

Limited data on subsurface temperatures of Seton Lake in 1943 were available for comparison with bathythermograph measurements made in 1958 and 1959. These temperatures have been considered in relation

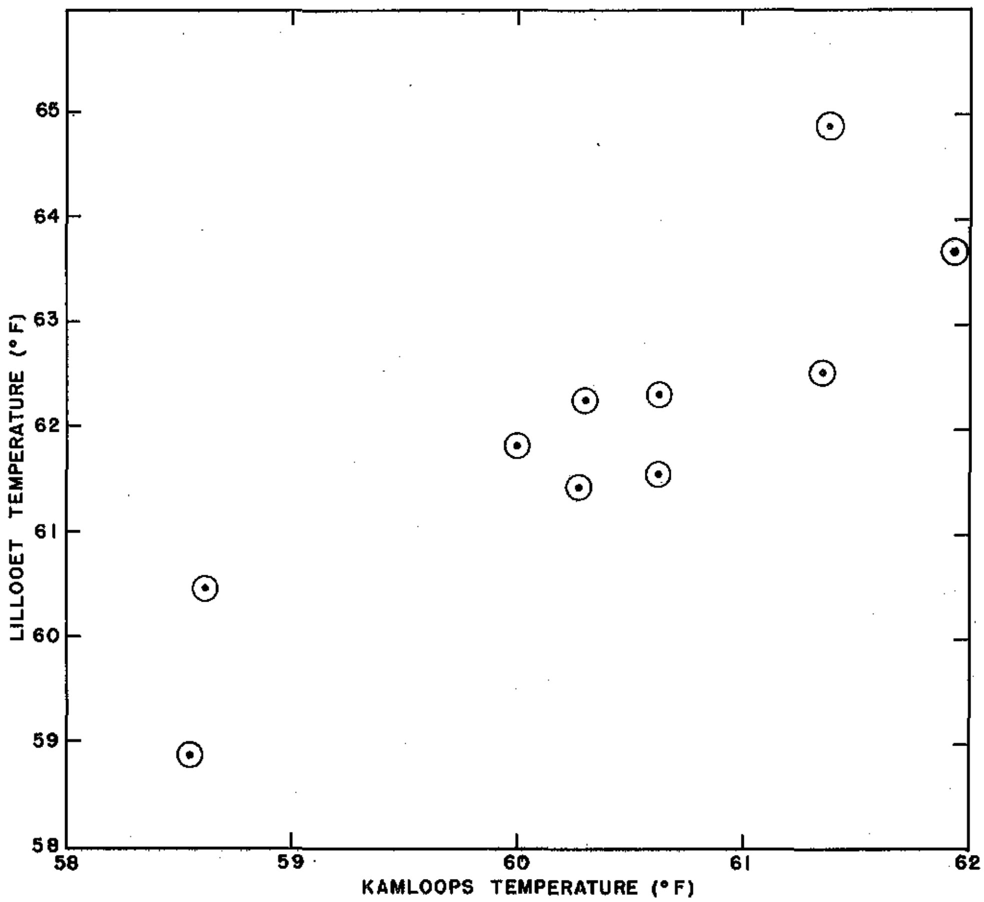

FIGURE 3. Average April to October air temperatures at Lillooet and Kamloops for the years 1935 to 1944 inclusive.

to the total amount of sunshine and the air temperatures at Kamloops in these years (TABLE 2). Meteorological conditions were similar in 1943 and 1959 but the summer of 1958 was much warmer than the other two years. Under natural conditions it would therefore be expected that lake temperatures in 1943 and 1959 would be quite similar and the 1958 temperatures considerably higher. However, water temperatures measured in 1958 were not higher than those of 1943. In 1959, when meteorological conditions were similar to 1943, Seton Lake temperatures appear to be lower than in the pre-diversion year. A cooling effect due to the diversion of cold water from Bridge River to Seton Lake is therefore suggested.

TABLE 2 - Average water temperatures at Station 1 in Seton Lake in 1943, 1958 and 1959 in relation to meteorological conditions.

DEPTH	PRE-DIVERSION	POST-DIVERSION	
	1943	1958	1959
0 - 50 ft.	Aug. 7 - 64.3° Aug. 9 - 64.0° Aug.21 - 64.8° Oct. 7 - 60.0°	July 8 - 59.2° Aug.14 - 63.9° Sept.22 - 58.2° Nov. 5 - 48.5°	July 28 - 57.7° Sept. 4 - 56.1° Oct. 29 - 50.1°
0 - 100 ft.	Aug. 7 - 56.0° Aug. 9 - 55.2° Aug.21 - 56.6° Oct. 7 - 55.4°	July 8 - 53.2° Aug.14 - 55.7° Sept.22 - 53.0° Nov. 5 - 48.1°	July 28 - 52.8° Sept. 4 - 55.6° Oct. 29 - 49.4°
Mean Air Temperature	58.7°	62.1°	57.8°
Duration of Sunshine (Hours)	1496	1809	1555

Comparison of Pre- and Post-diversion Seton Creek Temperatures

All available temperature records from Seton Creek were examined so that changes occurring since the diversion of large discharges of foreign water into Seton Lake could be determined. The earliest available temperature records were obtained in 1915 at the salmon hatchery on Seton Creek. Daily temperatures were taken by Commission observers at a weir near the upper end of the creek in 1940, 1941 and 1942. More recently, temperatures have been measured during studies associated with the hydroelectric development of the system.

The Seton Creek temperature information is presented graphically in FIGURE 4. Pre-diversion temperatures were considered as those from 1915, 1940, 1941 and 1942. Although a small flow of about 30 c.f.s. was diverted from Bridge River to Seton Lake during the period 1934 to 1948, it was assumed that the temperature change caused by this small discharge was not significant. Differences in the time of day that the temperatures were recorded are of some importance in the comparison. Data from 1915, 1949, 1957, 1958 and 1959 permitted calculation of daily mean water temperatures. However, temperatures measured in 1940, 1941 and 1942 were recorded at 8:00 a.m. only and are therefore somewhat lower than the daily mean temperatures. Thus the mean monthly temperatures for these years, as well as the mean for the pre-diversion period, should be slightly higher than shown in FIGURE 4.

The pronounced differences between pre- and post-diversion temperatures of Seton Lake are even more significant when considered in terms of meteorological conditions. As shown in TABLE 3, it is

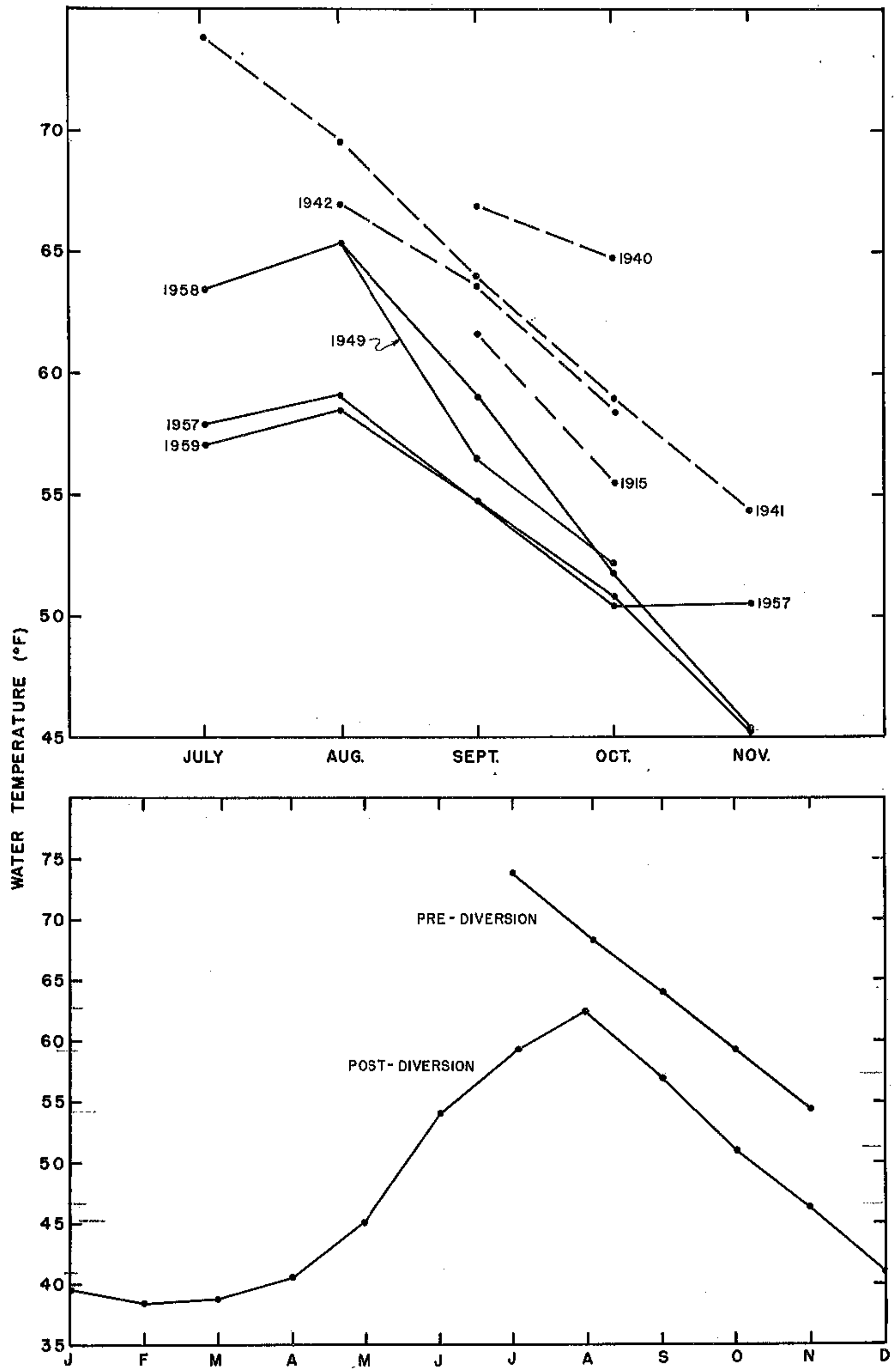

FIGURE 4. Seton Creek water temperatures from pre-diversion and post-diversion periods. Monthly mean temperatures for individual years in upper graph and means of monthly temperatures prior to and following diversion in lower graph.

TABLE 3 - Pre- and post-diversion temperatures of Seton Creek in relation to the duration of sunshine and the mean air temperatures at Kamloops.

	Creek Temp. (°F.)			Mean Air Temp. (°F.)	Total Hours of Sunshine
	Aug.	Sept.	Oct.	Apr.-Oct. Incl.	Apr.-Oct. Incl.
Pre-diversion years					
1915	--	61.6	55.5	60.7	1563
1940	--	66.8	64.7	61.4	1518
1941	69.5	64.0	58.8	60.6	1205
1942	66.9	63.6	58.3	60.3	1449
Post-diversion years					
1949	65.3	56.5	52.0	59.7	1553
1957	--	--	50.3	58.5	1547
1958	65.3	59.1	51.7	62.1	1809
1959	58.6	54.7	50.7	57.8	1555

very unlikely that the pronounced temperature changes could have been caused by natural variations in climatic conditions. The unusually high air temperature and number of hours of sunshine recorded in the April to October period in 1958 would be expected, under undisturbed lake conditions, to be associated with unusually high water temperatures. However, the temperatures of Seton Creek were well below those of any pre-diversion year.

In considering the post-diversion temperature data from Seton Creek, the effect of the Cayoosh Creek diversion, which was completed in 1956, must be taken into account. As previously discussed, the Cayoosh flow enters Seton Lake and flows towards Seton Creek. This flow probably has only a small local effect on the lake but directly affects the temperature of Seton Creek. Available summer temperature data from Cayoosh Creek indicate that it is 6 to 8°F colder than Seton Creek. Calculations shown later indicate that during summer months a reduction in Seton Creek temperature of about 1°F occurs as a result of the Cayoosh Creek diversion. It is evident that even after correction for the effects of the Cayoosh Creek diversion flow in the years 1957, 1958 and 1959, the temperature of Seton Creek has been markedly reduced.

Comparison of Post-diversion Temperatures Within the Seton-Anderson System

Temperatures were taken with a bathythermograph to depths of at least 100 and usually 150 ft. concurrent with the plankton sampling. Mean water temperatures, at each sampling station, from the surface to 100 ft. are presented in TABLE 4. Calculation of the mean temperature of the upper 100 ft. minimizes the effects of diurnal variations and permits comparison of temperatures in the productive zone. It is evident that Anderson Lake was warmer than Seton Lake in the period under consideration.

As would be expected from the observed temperature differences between Seton and Anderson Lakes, Seton Creek was considerably colder than Portage Creek (TABLE 5).

The effect of the Bridge River diversion in reducing the average temperatures of Seton Lake and Seton Creek is even more evident when it is considered that under natural conditions the outlet stream of the lower lake in a chain is generally warmer than the outlet streams of upstream lakes. Unpublished data collected by the Commission from the Stuart Lake and Fraser Lake systems can be used to illustrate the

TABLE 4 - Mean temperatures of the upper 100 ft. of Seton and Anderson Lakes, April 1958 to May 1961.

		ANDERSON LAKE			
		Station			Mean
		1	2	3	
1958	May 4	45.5°	42.7°	42.2°	43.5°
	May 15	47.4°	45.5°	45.0°	46.0°
	June 11	51.6°	50.6°	47.7°	50.0°
	July 9	53.1°	53.5°	54.3°	53.6°
	Aug. 18	59.6°	57.9°	58.0°	58.5°
	Sept.30	54.5°	55.9°	56.3°	55.6°
	Nov. 4	51.8°	52.0°	50.7°	51.5°
	Dec. 4	44.0°	44.0°	44.0°	44.0°
1959	Mar. 5	39.0°	38.5°	38.5°	38.7°
	Apr. 7	40.0°	40.0°	40.0°	40.0°
	June 13	48.3°	45.9°	44.2°	46.1°
	July 29	52.8°	52.4°	52.0°	52.4°
	Oct. 28	52.7°	51.6°	51.6°	52.0°
1960	May 3	40.0°	43.0°	40.6°	41.2°
1961	May 4	41.4°	43.3°	42.6°	42.4°
Mean		48.1°	47.8°	47.2°	47.7°
		SETON LAKE			
1958	Apr. 28	42.5°	41.8°	41.4°	41.9°
	May 15	44.2°	45.0°	45.3°	44.8°
	June 12	51.2°	49.3°	50.9°	50.5°
	July 8	53.2°	51.8°	52.3°	52.4°
	Aug. 14	56.7°	55.6°	56.1°	56.1°
	Sept.22	53.0°	53.6°	52.7°	53.1°
	Nov. 5	48.1°	47.9°	46.8°	47.6°
	Dec. 9	40.6°	41.0°	41.0°	40.9°
1959	Mar. 6	36.5°	36.5°	36.5°	36.5°
	Apr. 6	38.0°	38.0°	38.0°	38.0°
	June 12	46.5°	44.7°	43.3°	44.8°
	July 28	52.7°	54.0°	51.7°	52.6°
	Oct. 29	49.4°	49.2°	49.4°	49.3°
1960	May 5	43.8°	39.5°	40.7°	41.3°
1961	May 3	42.5°	41.2°	42.0°	41.9°
Mean		46.6°	45.9°	45.9°	46.1°

TABLE 5 - Monthly mean temperatures of Seton and Portage Creeks, April 1958 to May 1960.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1958						
Seton	--	--	--	42.7	50.1	57.6	63.4	65.3	59.1	51.7	45.2	40.3
Portage	--	--	--	43.8	52.9	60.2	67.5	69.4	62.1	54.5	47.4	40.7
						1959						
Seton	38.6	37.5	37.4	39.3	43.0	50.4	57.1	58.6	54.7	50.7	44.3	41.4
Portage	39.9	38.8	39.4	42.2	45.9	54.7	--	61.8	56.9	51.7	44.5	40.8
						1960						
Seton	39.3	38.0	38.1	39.7[1]	44.7[2]	--	--	--	--	--	--	--
Portage	38.4	38.3	39.1	41.8	47.2	--	--	--	--	--	--	--

[1]Based on Apr. 1-24 records.

[2]Based on May 1-21 records.

trend of temperatures occurring in a chain of lakes. The Stuart system comprises Takla Lake at the upper end of the chain, Trembleur Lake centrally, and Stuart Lake at the lower end. These lakes are drained by Middle, Tachie and Stuart Rivers respectively. The data presented in TABLE 6 show the consistent increase in mean temperature in lower lakes of the chain. A similar trend towards increased temperatures is evident from data obtained in the Francois-Fraser Lake system. Francois Lake, lying immediately above Fraser Lake, is several degrees colder in the summer and fall months than Fraser Lake.

Comparison of temperature differences in the Takla-Trembleur-Stuart and Francois-Fraser chains may not be entirely valid because of morphometric differences between the lakes in each chain. However, data from other lake systems in British Columbia also indicate that lower lakes of a chain tend to be warmer than the upper lakes. Data

TABLE 6 - Mean temperatures of the upper 100 ft. in Takla, Trembleur and Stuart Lakes. Temperatures are averages of three stations in each lake except for Trembleur Lake in 1958, where temperatures were measured at only two stations.

	Takla Lake	Trembleur Lake	Stuart Lake
July, 1956	50.3	51.6	55.7
September, 1956	51.0	53.8	57.1
July, 1958	48.7	49.9	53.3
September, 1958	48.2	51.0	54.1

from a series of lakes in Tweedsmuir Park were collected prior to the flooding associated with the Alcan hydroelectric development. Unpublished data from Commission files and further information reported by Lyons and Larkin (1952) show that temperatures in the lower lakes of the system were somewhat higher than in the upper lakes. Northcote and Larkin (1956) also presented data from British Columbia lake surveys. Their data for several chains of smaller lakes showed thermal trends similar to those noted for large lakes. The Paul-Pinantan-Hyas chain, the Bridge-Sheridan system, and other chains of lakes in the interior of British Columbia showed similar patterns. McMynn and Larkin (1953) presented temperature records from Buttle and Upper Campbell Lakes that were consistent with the trend of increased temperatures in downstream lakes. While the pattern may be modified by morphometric and climatic differences as well as by inflow from sources other than upstream lakes, all available data suggest that a temperature increase from the upper to lower lake of a chain can be expected.

An increase in outlet stream temperatures in a chain of lakes can also be expected. Temperatures measured in Tachie and Middle Rivers of the Stuart system and Stellako and Nautley Rivers of the Fraser system show that during July and August the lower streams in both systems are considerably warmer than the upper streams. The relationship is apparently more variable in the fall months when the lakes begin to cool and the fall overturns occur.

Under natural conditions, Seton Lake and Seton Creek were undoubtedly warmer than Anderson Lake and Portage Creek respectively, at least during the summer months. It has been shown, however, that during the period of this study Seton Lake and Seton Creek were colder than Anderson Lake and Portage Creek. It may be concluded, on the basis of this significant departure from the thermal characteristics of undisturbed series of lakes, that the diversion of water from Bridge River to Seton Lake resulted in substantial cooling of both Seton Lake and Seton Creek.

Theoretical Comparison of Pre- and Post-diversion Lake Temperatures

Theoretical calculations have been made in an attempt to demonstrate the extent of thermal changes that have occurred in Seton Lake as a result of the Bridge River diversion. By determining the approximate amount of heat energy that Seton Lake gained and lost through inflowing and outflowing streams in pre- and post-diversion years, the magnitude of the thermal changes in the lake can be estimated. The following approximations have been made for the purpose of these calculations:

1. Based on spot temperatures taken in August 1958 and 1959, the temperature of the Bridge River diversion flow was 8 to 10°F lower than

the temperature of Seton Creek. Cayoosh Creek temperatures were approximately 8°F lower than Seton Creek temperatures. The following calculations are based on August 1959 conditions when the mean Seton Creek temperature was about 59°F. The Bridge River diversion flow had a temperature of about 50°F and the Cayoosh diversion flow was about 51°F.

2. On the basis of observations of the temperature characteristics of outlet streams in a series of lakes, it was assumed that prior to diversion Seton Creek temperatures in August were on the average 2°F higher than those of Portage Creek. Since the mean August 1959 temperature of Portage Creek was 62°F, a Seton Creek temperature of 64°F was used in pre-diversion calculations.

3. Portage Creek had a mean discharge of 900 c.f.s. in August, based on six years of discharge data. However, the gauging station was located above the confluence of Portage Creek and Whitecap Creek, a small tributary. A limited number of observations indicated a discharge of approximately 100 c.f.s. in Whitecap Creek in August. This, added to the Portage discharge, produced a mean flow of approximately 1000 c.f.s. into Seton Lake from the only tributary of any practical significance. The mean August flow down Seton Creek prior to any diversion was approximately 1000 c.f.s., based on information from 1913 to 1926 (Dept. of Northern Affairs and National Resources).

4. The discharge of the Bridge River diversion was estimated to average 2000 c.f.s. during August 1959. Additional flow was diverted to a new powerhouse in 1959 and 1960.

5. The discharge from Cayoosh Creek to Seton Lake was not accurately determined but was estimated at 500 c.f.s. in August. The flow through this diversion tunnel was highly variable, depending not only on the stream discharge but also the amount of gravel deposited behind the diversion dam, whether or not the trash racks were installed at the tunnel intake and, if they were, the amount of debris accumulated on them.

6. It was assumed that the Cayoosh Creek diversion flow does not affect the temperature of Seton Lake as a whole but contributes to a reduction in Seton Creek temperatures in proportion to its flow and temperature.

7. Insolation, back radiation, convection and evaporation have been assumed to have the same total effect on the heat budget of the lake in pre- and post-diversion years. As discussed later, this assumption introduces some error in the calculations.

Prior to the construction of the Bridge River and Cayoosh diversions, the heat balance of the inflowing and outflowing streams may be expressed as follows:

Portage Creek Inflowing Heat
(c.f.s.)($^{\circ}$F)(Sec./day)(lbs./cu.ft.)
1000 (62) (86,400) (62.4)

equals

Seton Creek Outflowing Heat
(c.f.s.)($^{\circ}$F)(Sec./day)(lbs./cu.ft.)
1000 (64) (86,400) (62.4)

plus

Stored Heat
R

$$R = -1.08 \times 10^{10} \text{ B.T.U./day.}$$

In other words, 1.08×10^{10} B.T.U.'s more heat energy was drawn from the heat stored in Seton Lake in one day than was brought into the lake by Portage Creek. Inclusion of the effect of solar radiation could make the residual heat a positive value.

A correction was applied to the Seton Creek temperature in post-diversion years to eliminate the influence of Cayoosh Creek. In this way an estimate of the temperature of water leaving Seton Lake affected only by the Bridge River diversion flow was obtained. The calculation was made as follows:

Total Outflow	=	Seton Creek	+	Cayoosh Creek Diversion
(c.f.s.)(^{o}F)		(c.f.s.)(^{o}F)		(c.f.s.)(^{o}F)
3500 (59)		3000 (x)		500 (51)

$$x = 60.3^{o}$$

A temperature of 60.3^{o} was used in these calculations as representing Seton Creek temperatures unaffected by Cayoosh Creek diversion flow.

With the inclusion of the Bridge River diversion flow, the heat balance of inflowing and outflowing streams in Seton Lake may be expressed as follows:

Portage Creek Inflowing Heat
1000(62)(86,400)(62.4)

plus

Bridge River Inflowing Heat
2000(50)(86,400)(62.4)

equals

Seton Creek Outflowing Heat
3000(60.3)(86,400)(62.4)

plus

Stored Heat
R

$$R = -10.19 \times 10^{10} \text{ B.T.U./day.}$$

The amount of heat drawn from that stored in the lake has therefore increased from 1.08×10^{10} B.T.U./day in the pre-diversion period to 10.19×10^{10} B.T.U./day in the post-diversion period, a difference of 9.11×10^{10} B.T.U./day.

The significance of this increased heat drawoff is possibly more apparent when converted to a figure indicating the change per unit area of lake surface. Since Seton Lake has an area of 6000 acres (2.61×10^{8} sq. ft.) and the increase in heat drawn off was 9.11×10^{10} B.T.U./day, there would be about 350 B.T.U./sq. ft./day less heat stored in the lake. This amount of heat energy per square foot would theoretically be capable of raising the temperature of a 100-ft. column of water 0.056°F/day or about 1.7°F/month.

The amount of heat energy lost each day as a result of the Bridge River diversion is relatively high in terms of the total uptake from solar radiation in a mid-summer day. Calculated monthly averages of sun and sky radiation reaching the earth's surface at Vancouver, B.C., assuming perfect conditions, amount to 2910 B.T.U./sq. ft./day (Anon., 1952). A variable proportion, frequently as much as one half of the total solar radiation, is lost to the atmosphere by back radiation, convection and evaporation. While adequate data are not available for calculation of these factors at Seton Lake, an estimate of loss of one half of the total solar radiation is not unreasonable. If the net amount of solar energy actually being received by the lake is assumed to be 1500 B.T.U./sq.ft./day, about 20 per cent more solar radiation would now be required to maintain summer temperatures at the pre-diversion level.

It is significant that following diversion the increase in outlet temperature relative to the temperature of inflowing water appears to be greater than in the pre-diversion period. This apparent change may have resulted from the different thermal characteristics of clear and turbid water. For a given amount of solar radiation, turbid waters tend to be warmer than clear waters (Welch, 1952). Apparently, particles in the water absorb heat slightly faster than does the water itself; these particles then radiate their heat to the surrounding water. Sverdrup et al. (1942) presented data indicating that the temperature increase of ocean water is affected by turbidity of the water. It appears, therefore, that the turbid surface layers of Seton Lake may gain more heat from solar radiation than if the diverted water had been relatively clear. Changes in thermal structure that facilitate mixing within the lake may also contribute to greater heating. It is apparent, however, that the increase in heat gained from solar radiation did not compensate for the increased loss of heat in the outflowing discharge.

Turbidity

Secchi disc measurements of turbidity were taken during the regular sampling program on Seton and Anderson Lakes. TABLE 7 summarizes the Secchi disc measurements made in the period April 1958 to May 1961. Distinct differences in the transparency of the two lakes are evident. While the use of the Secchi disc as a measure of transparency has been criticized on the basis of the subjective element involved in its use, this limitation is of little practical significance in comparisons of two bodies of water such as Seton and Anderson Lakes that are so markedly different.

TABLE 7 - Secchi disc measurements, in feet, in Seton and Anderson Lakes, April 1958 to May 1961.

		ANDERSON LAKE			
		Station			Mean
		1	2	3	
	May	45.5	53.1	51.1	49.9
	June	19.1	17.3	15.7	17.4
	July	28.0	36.5	26.5	30.3
1958	Aug.	33.2	28.2	23.6	28.3
	Sept.	33.3	31.1	28.0	30.8
	Nov.	30.0	27.0	25.0	27.3
	Dec.	30.0	31.0	34.5	31.8
	Mar.	33.5	29.0	27.5	30.0
	Apr.	45.0	39.0	43.0	42.3
1959	June	26.3	27.8	19.6	24.6
	July	34.5	31.3	39.0	34.9
	Oct.	38.0	31.0	26.0	31.7
1960	May	38.0	36.0	33.0	35.7
1961	May	39.9	38.6	35.6	38.0
Mean		33.9	32.3	30.6	32.4

SETON LAKE

	May	2.0	2.0	2.0	2.0
	June	2.5	3.0	3.0	2.8
	July	7.0	4.5	3.5	5.0
1958	Aug.	2.6	1.9	1.3	1.9
	Sept.	1.9	1.7	1.3	1.6
	Nov.	1.7	1.5	1.2	1.5
	Dec.	1.4	1.3	1.1	1.3
	Mar.	1.4	1.1	1.0	1.2
	Apr.	1.9	1.6	1.8	1.8
1959	June	1.8	1.7	1.5	1.7
	July	3.1	2.9	2.7	2.9
	Oct.	4.6	4.1	3.8	4.2
1960	May	2.3	2.3	1.9	2.2
1961	May	9.6	7.7	6.1	7.8
Mean		3.2	2.7	2.3	2.7

Comparisons of pre- and post-diversion Secchi disc measurements in the system are presented in TABLE 8. Whereas Anderson Lake remained non-turbid, Seton Lake obviously became much more turbid in the post-diversion period. The relatively low Secchi disc reading in Seton Lake on September 13, 1943 resulted from a local increase in turbidity caused by a large discharge of turbid water from Whitecap Creek and possibly also from the small flow of turbid Bridge River water diverted into Seton Lake near the point where this measurement was taken.

TABLE 8 - Secchi disc measurements in Seton and Anderson Lakes, 1943, 1958 and 1959.

	ANDERSON LAKE	SETON LAKE	
	Station 1	Station 1	Station 3
1943	Sept.13 - 49.2 ft.	Aug. 7 - 36.5 ft. Aug. 9 - 37.0 ft.	Sept.13 - 13.1 ft.
1958	Aug. 17 - 33.2 ft. Sept.30 - 33.3 ft.	Aug.14 - 2.6 ft. Sept.22 - 1.9 ft.	Aug. 14 - 1.3 ft. Sept.22 - 1.3 ft.
1959	July 29 - 34.5 ft. Oct. 28 - 38.0 ft.	July 28 - 3.1 ft. Oct. 29 - 4.6 ft.	July 28 - 2.7 ft. Sept. 4 - 2.6 ft. Oct. 29 - 3.8 ft.

The observations made in May 1961 give good indication that in future years Seton Lake will be less turbid than it was during the main period of this study. The lake was more turbid in 1958 and 1959 than in previous years. Considerable clarification was noted during August, 1960. A marked change in the characteristics of the diverted water may have occurred during the summer of 1960, when the storage and diversion dams on Bridge River were increased in height and additional water was diverted to Seton Lake. The average Secchi disc reading of 7.8 ft. in May 1961 was about four times higher than in the spring months of the previous three years. There seems little doubt that the enlarged storage facilities on Bridge River have reduced the turbidity of Seton Lake from the extreme condition observed in 1958 and 1959 but the lake is still much more turbid than it was in its natural state. It is likely that the future turbidity of the lake will depend to a large extent on the method of operation of the enlarged diversion facilities on Bridge River but annual climatic conditions will also have an important effect because they control the amount of glacial melt as well as the thermal stratification in the lake.

Total Dissolved Solids

Dissolved mineral levels in the Seton-Anderson system, as measured by the previously described conductivity-T.D.S. relationship, are shown in TABLES 9 and 10. No T.D.S. measurements were made prior to the diversion of Bridge River water into Seton Lake. It appears that the T.D.S. was higher in Anderson than in Seton Lake. The T.D.S. increased from Gates Creek to Portage Creek but decreased from Portage Creek to Seton Creek. Water entering Seton Lake from the Bridge River diversion had a consistently lower dissolved mineral content than water entering from Portage Creek. There was much variation in the mineral content of Cayoosh Creek but its average T.D.S. was only slightly lower than that of Portage Creek.

TABLE 9 - Total dissolved solids content (p.p.m.) of surface water samples from Seton and Anderson Lakes, April 1958 to May 1961.

		ANDERSON LAKE				SETON LAKE			
		Station				Station			
		1	2	3	Mean	1	2	3	Mean
1958	May	81	81	83	82	70	74	74	73
	June	73	77	79	76	81	80	79	80
	July	81	81	71	78	71	71	67	70
	Aug.	84	-	85	85	87	76	73	79
	Sept.	83	82	82	82	68	71	66	68
	Dec.	61	52	87	67	83	81	78	81
1959	Mar.	90	91	91	91	79	78	77	78
	Apr.	90	93	90	91	80	80	76	79
	June	97	94	94	95	85	87	90	87
	July	102	104	99	102	96	96	96	96
	Oct.	78	78	78	78	71	70	71	71
1960	May	100	104	104	103	88	80	88	85
1961	May	106	106	106	106	91	91	90	91
Mean		87	87	88	87	81	80	79	80

TABLE 10 - Total dissolved solids content (p.p.m.) of inflowing and outflowing water in the Seton-Anderson system, May 1958 to May 1961.

		Gates Creek	Portage Creek	Bridge River	Cayoosh Creek	Seton Creek
1958	May 19-20	47	66	62	-	66
	June 11-12	47	75	62	-	77
	July 9-10	59	78	57	59	67
	Aug. 16-18	77	84	59	90	86
	Dec. 4-9	57	94	67	99	82
1959	Mar. 5-7	-	90	59	106	76
	Apr. 6-7	133	89	69	-	76
	June 12-13	71	97	93	76	83
	July 28-29	88	103	82	79	94
	Oct. 28-29	74	78	71	67	71
1960	May 3-5	115	-	117	87	87
1961	May 3-4	130	114	88	99	91
Mean		82	88	74	85	80

Data from other series of lakes were examined in an attempt to determine the trend in dissolved mineral content in lake chains. In the Takla-Trembleur-Stuart chain, the T.D.S. increased from the upper to lower lake. Data presented by Lyons and Larkin (1952) for the Tweedsmuir Park lakes suggest a pattern of increasing T.D.S. in the lower lakes of the system. Northcote and Larkin (1956) have also presented data that suggest this general pattern. Lower Arrow Lake had a higher dissolved mineral content than Upper Arrow Lake. The One-Mile Chain and the Osprey-Link series in the Princeton area, while not in complete agreement, seemed to follow the same pattern. The T.D.S. of Buttle Lake was lower than Upper Campbell Lake some distance downstream. Rawson (1951) demonstrated a similar pattern for the Great Lakes. Inconsistencies in this general pattern have been observed in some series of lakes but these may be due to the nature of inflow from sources other than the upper lakes in the chain.

The general trend towards higher T.D.S. levels in the lower lakes in a chain appears to be fairly well established. "Mineralization", described by Kleerekoper (1953) as the enrichment of lakes as a result of the decay of planktonic organisms, may be an important factor. Evaporation would also contribute towards increasing T.D.S. levels.

It is evident that the T.D.S. levels in Seton and Anderson Lakes do not conform to the trend observed in other lake chains. In view of this information and the fact that the T.D.S. of Portage Creek was higher than that of Gates Creek whereas the T.D.S. of Seton Creek tended to be lower than that of Portage

Creek, it may be concluded that the large discharge of Bridge River water of relatively low T.D.S. has reduced the dissolved mineral content of Seton Lake.

Flushing Rate

An increase in the replacement rate of water in Seton Lake has occurred as a result of the increased discharge into the lake. Calculations based on the average inflow and total lake volume showed that the total volume of water in Seton Lake would theoretically have been replaced in about 1300 days prior to the diversion, 320 days following diversion of the initial 2000 c.f.s. to Seton Lake and 230 days following the increase of the diversion flow to an average of 3000 c.f.s. Since the incoming water dilutes and flushes the surface layers to a greater extent than the subsurface layers, the actual flushing rate in the productive zone is much higher than the theoretical rate calculated on the basis of total lake volume. However, as discussed later, it is unlikely that the increase in discharge has increased the flushing rate to a level that would have an important effect on plankton production.

EFFECTS OF DIVERSION ON PLANKTON AND FISH PRODUCTION

Extensive physical and chemical changes have occurred in Seton Lake and Seton Creek following the diversion of Bridge River and Cayoosh Creek water to Seton Lake. Temperatures in both the lake and the outlet stream have been reduced and the turbidity has been markedly increased. The dissolved mineral content of the lake has been reduced and the flushing rate increased.

Analysis of the effects of these changes on the productivity of sockeye in Seton Lake has been approached in two ways. Plankton production in Seton Lake has been compared with that in Anderson Lake, and the growth rates of sockeye, from the fry to the smolt stage, have been examined. Possible effects of the diversion flow on production of pink salmon in Seton Creek have also been examined.

Plankton Production

Data obtained in the regular plankton sampling program on Seton and Anderson Lakes are given in TABLE 11. These data refer only to the vertical hauls from a depth of 100 ft. to the surface, the volume recorded for each sampling station being the average obtained in six consecutive hauls. It is readily apparent that the standing crop of zooplankters was consistently much higher in Anderson than in Seton Lake. Over the period of the study, the volume of plankton obtained in the samples was about five times greater in Anderson than in Seton Lake.

Series of 20-ft. stage hauls were made in both lakes in May and August 1958, March and June 1959, and May 1960 and 1961. It was often impossible to measure accurately the small volumes of plankton obtained in these short hauls. Since the centrifuge tubes were not calibrated below 0.10 c.c., smaller volumes could only be approximated. When only a few plankters were taken in the sample, a volume of 0.01 c.c. was arbitrarily recorded. The total volume of plankton obtained in each series of stage hauls was usually

TABLE 11 - Mean centrifuged volumes (c.c.) of plankton from Seton and Anderson Lakes, April 1958 to May 1961.

		ANDERSON LAKE				SETON LAKE			
		Station				Station			
		1	2	3	Mean	1	2	3	Mean
1958	April	0.81	0.63	1.03	0.82	0.07	0.06	0.04	0.06
	May	0.65	0.97	1.43	1.02	0.10	0.12	0.10	0.11
	June	1.21	0.98	0.81	1.00	0.38	0.39	0.36	0.38
	July	1.46	1.50	1.71	1.56	0.96	0.50	0.27	0.58
	Aug.	1.06	1.30	1.15	1.17	0.73	0.55	0.61	0.63
	Sept.	0.82	0.82	0.92	0.85	0.13	0.19	0.24	0.19
	Nov.	0.97	0.88	1.16	1.00	0.07	0.13	0.19	0.13
	Dec.	0.98	0.82	0.91	0.90	0.04	0.05	0.05	0.05
1959	Mar.	0.19	0.44	0.26	0.30	0.04	0.04	0.04	0.04
	Apr.	0.77	0.54	0.20	0.50	0.04	0.05	0.03	0.04
	June	1.51	2.67	1.43	1.87	0.26	0.17	0.08	0.17
	July	1.57	2.38	2.18	2.04	0.54	0.38	0.34	0.42
	Oct.	1.27	0.63	0.95	0.95	0.31	0.23	0.31	0.28
1960	May	0.52	0.57	0.43	0.51	0.05	0.03	0.08	0.05
1961	May	1.07	1.32	0.87	1.09	0.48	0.14	0.06	0.23
Mean		0.99	1.10	1.03	1.04	0.28	0.20	0.19	0.22

slightly greater than the volume obtained in a single vertical haul over the same distance. Despite these causes of variability, the results shown in TABLE 12 provide a sufficiently reliable indication of the vertical distribution of planktonic forms to be useful in demonstrating major differences in their depth distribution in the two lakes.

The results of the 1958 vertical-distribution sampling are shown in FIGURE 5. The volumes shown are the averages of 18 hauls -- six hauls through each 20-ft. stratum at each of the three stations. In general, the plankton tended to be more uniformly distributed in the upper 100 ft. of Anderson Lake than in Seton Lake. Greatest

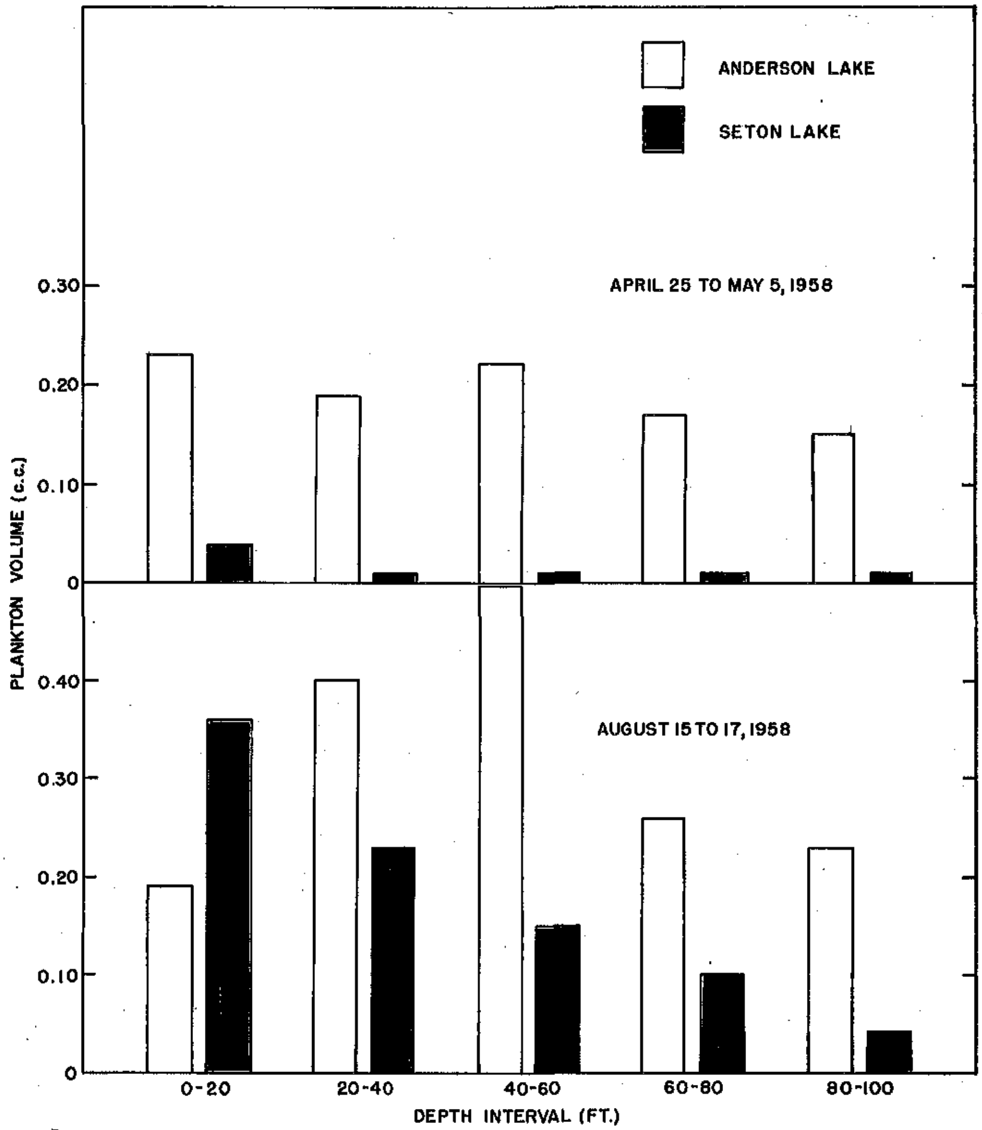

FIGURE 5. Vertical distribution of zooplankters in Seton and Anderson Lakes as indicated by stage hauls at 20-ft. depth intervals.

TABLE 12 - Vertical distribution of zooplankton in Seton and Anderson Lakes as measured by stage hauls at 20-ft. intervals to a depth of 100 ft.

	STATION NO.	ANDERSON LAKE				
		0-20	20-40	40-60	60-80	80-100
1958						
May 5	1	0.16	0.17	0.22	0.12	0.21
4	2	0.14	0.13	0.18	0.25	0.13
4	3	0.40	0.26	0.25	0.15	0.12
Aug. 17	1	0.12	0.14	0.45	0.24	0.20
17	2	0.09	0.33	0.42	0.23	0.29
17	3	0.35	0.74	0.62	0.30	0.21
1959						
Mar. 5	2	0.07	0.07	0.09	0.15	0.07
June 13	2	0.05	0.26	0.65	0.45	0.56
1960						
May 3	2	0.08	0.06	0.16	0.21	0.19
1961						
May 3	2	0.11	0.34	0.35	0.33	0.24
		SETON LAKE				
1958						
Apr. 28	1	0.04	0.01	0.01	0.01	0.01
26	2	0.06	0.01	0.01	0.01	0.01
25	3	0.03	0.02	0.01	0.01	0.01
Aug. 16	1	0.22	0.33	0.05	0.03	0.06
15	2	0.31	0.19	0.36	0.28	0.03
15	3	0.56	0.16	0.04	0.03	0.04
1959						
Mar. 7	2	0.01	0.01	0.01	0.01	0.01
June 12	2	0.07	0.02	0.01	0.01	0.02
1960						
May 6	2	0.01	0.01	0	0	0
1961						
May 3	2	0.02	0.01	0.03	0.02	0.04

concentrations were often found well below the surface in Anderson Lake while the highest concentrations in Seton Lake generally occurred near the surface. Often, virtually no plankton was obtained below 20 ft. in Seton Lake. The volume obtained from any 20-ft. layer was usually greater in Anderson Lake but in August, 1958, a greater volume of plankton was obtained in the upper 20 ft. of Seton Lake than in Anderson Lake.

Stage hauls were also made at Station 2 in Seton and Anderson Lakes in September 1958 to determine the depth to which appreciable quantities of plankters were found in the two lakes (TABLE 13). Hauls were made at 50-ft. intervals to a depth of 200 ft. Not only was the total volume of plankton much greater in Anderson Lake, but considerable numbers of plankters were obtained from a much greater depth.

TABLE 13 - Vertical distribution of zooplankton in Seton and Anderson Lakes as measured by stage hauls at 50-ft. intervals to a depth of 200 ft., September 1958.

Depth Interval (ft.)	Anderson Lake Plankton Volumes (c.c.)	Seton Lake Plankton Volumes (c.c.)
0 - 50	0.56	0.19
50 - 100	0.28	0.04
100 - 150	0.10	0.02
150 - 200	0.08	0.02

Although a precise quantitative evaluation was not made of the species composition of zooplankton populations in the two lakes, relative numbers of the main genera were estimated. Two main groups, the Copepoda and Cladocera, were represented in the samples.

Occasionally a few rotifers were noted. Cladoceran genera occurring in the samples included Daphnia and Bosmina, while Cyclops, Diaptomus and occasional Epischura were the main Copepod representatives. Cyclops and Daphnia were the most abundant forms in both lakes. Copepods appeared to be most abundant during the spring and fall months, while cladocerans were most numerous in the mid-summer months. This seasonal trend is in general agreement with unpublished data from Shuswap Lake and that described by Ricker (1938) from Cultus Lake. It was concluded that there were no gross differences in the species composition of the plankton populations in Seton and Anderson Lakes.

Since the peaks of plankton abundance in the two lakes do not necessarily coincide, some error may have been introduced in comparisons of plankton production in Seton and Anderson Lakes. The differences in plankton abundance were so great, however, that a significant error would be unlikely. Further, plankton abundance during the winter months was consistently much lower in Seton Lake than in Anderson Lake. Ward (1957) showed that crustacean zooplankton populations generally remain at a stable, low level during this period. It is concluded, therefore, that the plankton sampling program demonstrated that total zooplankton production was much lower and the vertical distribution more restricted in Seton than in Anderson Lake.

Available evidence indicates that greater plankton abundance can generally be expected in the lower lake of a chain than in upstream lakes. It has previously been noted that higher temperatures and higher levels of dissolved minerals would be expected in the lower lake of a chain. Such higher levels would be expected to result in greater plankton production. Northcote and Larkin (1956) showed that, in general, both T.D.S. and mean mid-summer epilimnial temperatures were directly related to plankton abundance in British Columbia lakes. Examination of data collected by the Commission in the Takla-Trembleur-Stuart and Francois-Fraser systems indicated that plankton production increased from the upper to lower lake of the chain. Data obtained in a survey of lakes in Tweedsmuir Park also showed increased plankton production in lower lakes of the system (Lyons and Larkin, 1952).

Measurements of plankton abundance in Seton and Anderson Lakes indicate a marked departure from the observed trend in other lake systems. In spite of the apparent similarity of the two lakes with respect to morphometric, climatic and edaphic features, Seton Lake was much less productive than Anderson Lake during the period of this survey. All available evidence suggests that in pre-diversion years Seton Lake was more productive than Anderson Lake.

Lacustrine Growth of Sockeye Salmon

Since data were not available with which to determine growth rates of sockeye fingerlings in Seton Lake in pre-diversion years, it was necessary to examine present growth rates in Seton and Anderson Lakes in relation to the observed limnological differences. An evaluation of growth rate data requires an understanding of the distribution of the two races of juvenile sockeye during their residence in the Seton-Anderson system. Fyke netting demonstrated that fry emerging from Portage Creek moved downstream into Seton Lake, as would be expected. The behavior of Gates Creek fry was found to be more complex. Examination of the scales of adult Gates Creek sockeye revealed two markedly different freshwater growth rates. The bimodal pattern of the ring counts indicated that the fish were being reared in two different areas. Since neither of the two lakes is of a multi-basin nature, it appeared that Gates Creek sockeye were reared in both Seton and Anderson Lakes.

To further investigate the possibility that Gates Creek sockeye rear in both lakes, and to obtain samples of smolts for growth studies, a weir was placed in Portage Creek in 1958 and 1959 and scoop nets were operated in this stream in 1959 and 1960. Similar nets were operated in Seton Creek in 1958, 1959 and 1960. Since 9012 sockeye had spawned in Gates Creek and few, if any, in Portage Creek in the brood year, it was expected that a large proportion of the smolts migrating in the spring of 1958 would have been reared in Anderson Lake. It was intended that these smolts would be enumerated at the weir in Portage Creek and that they would again be sampled by means of the scoop net in Seton Creek. In spite of the fact that the Portage Creek weir was operated continuously and maintained in fish-tight condition from March 30 to May 5, only 587 sockeye smolts were taken. The scoop net operated in Seton Creek at the same time, from April 8 to May 15, captured 8745 smolts, virtually all of which originated from Gates Creek spawners. Based on the proportion of the total discharge strained by this net and the area of the net in relation to the total stream cross section, it was estimated that the total smolt population migrating out of Seton Lake was 300,000 to 500,000.

Since local residents had reported a migration of small fish down Portage Creek in January 1958, the 1959 observations in Portage Creek were made much earlier than in the previous year. Observations were made from January to the end of June. The weir was installed on January 24 and operated continuously until April 29, when it was replaced with a scoop net. This net was removed on May 16. In spite of the fact that 1112 sockeye spawned in Gates Creek in the brood year, only 100 smolts were captured in Portage Creek in this four-month period. These were captured from March 20 to April 21, which is only slightly earlier than the usual time of sockeye smolt migrations in other lake systems.

Since these observations provided further evidence that Gates Creek fry utilize Seton Lake as a rearing area, studies were conducted in the spring of 1960 to determine the behavior and distribution of these fry during the spring months in Anderson Lake. Although no numerical estimates were obtained, a rapid dispersion of fry from the upper to the lower end of Anderson Lake was apparent. In previous years, fry had been taken at the weir and in scoop nets in Portage Creek but these fish could have emerged from Portage Creek. Additional observations in 1960 at the extreme upper end of Portage Creek, beyond the upper limit of spawning of Portage Creek sockeye, demonstrated that fry were migrating out of Anderson Lake, down Portage Creek, and into Seton Lake. As in 1958 and 1959, the 1960 migration of fry from Anderson Lake occurred during the latter part of April and the first half of May.

On the basis of the field data obtained in 1958, 1959 and 1960 and the previously mentioned bimodal distribution of scale ring counts, it was concluded that all of the Portage Creek sockeye and a portion of the Gates Creek sockeye were reared in Seton Lake.

The measure of lacustrine growth of young sockeye commonly used by the Commission is the number of rings or circuli laid down on the scale during freshwater residence. Clutter and Whitesel (1956) described this method in detail and showed that enumeration of circuli is an accurate measure of lacustrine growth. Thus, low ring counts would suggest that either environmental conditions were unfavorable or that population pressure or competition between sockeye and other species was adversely affecting growth.

The data shown in TABLE 14 demonstrate the distinct difference between growth rates in Seton and Anderson Lakes. Growth of Portage Creek fish in Seton Lake was consistently high. Gates Creek sockeye reared in Seton Lake showed better growth than fish of the same race and brood in Anderson Lake. In spite of the apparent reduction in plankton abundance in Seton Lake, growth rates in this lake were much higher than in Anderson Lake. The observed differences in growth rates in the two lakes seem inconsistent in view of the observed differences in limnological conditions. There seems little doubt that the growth rate of sockeye in Seton Lake is higher than in Anderson Lake but possible reasons for this inconsistency have not been determined.

TABLE 14 - Freshwater scale ring counts of Seton-Anderson sockeye, with spring growth rings excluded from the total ring count.

Brood Year	Number of Scales in Sample	Mean Ring Count of Whole Sample	Mean Count of Spring Growth Rings	Mean Ring Count of First Mode	Per Cent of Sample	Mean Ring Count of Second Mode	Per Cent of Sample
Scales Obtained from Jacks and Adults in Gates Creek							
1948	151	19.95	0.12	12.00 A	2.65	20.17 S	97.35
1952	202	21.54	0	13.00 A	0.50	21.59 S	99.50
1953	29	23.07	0.41	14.00 A	10.34	24.12 S	89.66
1953	5[1]	22.80	0	-	-	22.80 S	100.00
1954	5	19.30	0	12.00 A	20.00	21.12 S	80.00
1955	35	19.03	0	11.33 A	8.57	19.75 S	91.43
1956	7[1]	12.86	5.57	12.86 A	100.00	-	-
1956	377	14.31	3.49	12.49 A	66.31	17.94 S	33.69
Scales Obtained from Jacks and Adults in Portage Creek							
1950	185	19.84	0.43	-	-	19.84 S	100.00
1954	14[1]	19.50	0.64	-	-	19.50 S	100.00
1954	192	22.04	0	-	-	22.04 S	100.00
1955	76	18.97	0.35	-	-	18.97 S	100.00
Scales Obtained from Smolts Captured at Outlet of Anderson Lake							
1956	113[2]	13.11	0.37	13.11 A	100.00	-	-
1957	7	14.57	0	14.57 A	100.00	-	-
Scales Obtained from Smolts Captured at Outlet of Seton Lake							
1956	109[2]	12.89	3.92	12.14 A	83.49	16.67 S	16.51
1956	32[3]	14.78	2.35	11.67 A	53.13	17.53 S	46.87
1956	7[4]	11.71	3.86	11.71 A	100.00	-	-
1957	71	21.55	0	-	-	21.55 S	100.00
1958	100	20.59	0	13.50 A	2.00	20.73 S	98.00

S Ring counts of fish considered to have reared in Seton Lake.
A Ring counts of fish considered to have reared in Anderson Lake.

[1] Sample of jacks only. All other spawning ground samples contain adults (4_2's) only.

[2] Sample of smolts taken on April 15.

[3] Sample of smolts taken May 5-12.

[4] Sample of two-year-old smolts. Ring count shown is for first year in the lake.

The variable proportion of Gates Creek sockeye reared in Anderson Lake is of some interest. Analysis of the scales of returning adults showed that the proportion reared in Anderson Lake varied from 0.5 to 66.3 per cent in the six years of record. In spite of the fact that the largest proportion reared in Anderson Lake was from the 1956 brood, the largest run in recent years, very few smolts were captured in Portage Creek in the spring of 1958. The large catches in Seton Creek in 1958 suggest that the fingerlings migrated from Anderson Lake during the late fall or winter months. Migration from Seton Lake, however, occurred at the usual time.

Analysis of the scale ring counts of smolts captured at the lake outlets in 1958 suggested that the fingerlings that migrated from Anderson Lake before the normal migration time were smaller than those that did not migrate until April 15. Smolts captured at the outlet of Anderson Lake on April 15, 1958 had a ring count of 13.11 whereas those sampled on the same day at the outlet of Seton Lake had a ring count of 12.14. Since these ring counts did not include growth beyond the first annulus, the data suggest that the smolts that remained in Anderson Lake until the normal migration time were slightly larger than those that migrated out of the lake some time after the first summer's growth but before the usual migration time. It is also seen that of the smolts migrating from Seton Lake on April 15, 83 per cent had reared in Anderson Lake during the 1957 growing season whereas only 53 per cent of the sample collected during the May 5 to 12 period had reared in Anderson Lake. The sample taken on April 15 was from the early part of the migration whereas the

May 5 to 12 sample was from the latest migrants.

The difference in the amount of spring growth in the two lakes is also of some interest. Any scale rings that are laid down after the formation of the winter check, or annulus, but before the typical sea-type growth rings, are considered to be "spring growth rings". Although sockeye reared in Seton Lake do not show extensive spring growth, their growth prior to the winter check is much greater than for fish reared in Anderson Lake. There is also very little spring growth among sockeye that remain in Anderson Lake until the normal migration time. However, sockeye reared in Anderson Lake in the summer of 1957 apparently migrated out of this lake during the winter months and remained in Seton Lake until the normal time of seaward migration. They put on enough spring growth in Seton Lake that their total ring count at the time of seaward migration was almost equal to the ring count of smolts that had reared in Seton Lake. About 66 per cent of the adults returning to Gates Creek in 1960 had reared in Anderson Lake until migrating to Seton Lake during the winter months and all of these had put on spring growth in Seton Lake. About 67 per cent of the Gates Creek adults spawning in 1960 showed extensive spring growth. The smolt samples show that this spring growth was put on in Seton Lake. Whereas only 12 per cent of the smolts migrating from Anderson Lake in the spring of 1958 showed spring growth, 84 per cent of those migrating at the same time from Seton Lake did so.

Only one earlier record of ring counts of Seton-Anderson sockeye was found. Gilbert (1915) reported that 219 sockeye smolts captured in Seton Creek in the spring of 1914 had ring counts ranging from 8 to 19, with an average of 14.5. Up to five rings of spring growth were noted, the average ring count being 16.0 when spring growth was included. These scales were obtained by taking a scrape sample from the side of the fish. Clutter and Whitesel (1956) showed that this method tended to give lower ring counts than the single-scale method currently used by the Salmon Commission. In a sample of Gates Creek sockeye, the mean ring count by the scrape-sample method was 1.1 rings lower than by the single-scale method. A difference of 2.7 rings was obtained in a similar comparison, using another race of sockeye. It is likely that the fish sampled by Gilbert would have shown an average ring count of about 15.5 if the single-scale method had been used. The low ring count and the fact that the frequency distribution was not bimodal would suggest that these fish had reared in Anderson Lake. Babcock (1913) estimated that 2000 Gates Creek adults were allowed to pass the Seton Creek hatchery weirs in 1912. It seems most likely, therefore, that the smolts sampled by Gilbert were the progeny of these natural spawners and that they had reared in Anderson Lake, at least during the summer of 1913.

The observed limnological changes in Seton Lake should logically have reduced the growth of sockeye fingerlings in recent years. The fact that the growth rate has not declined is probably a result of the very low density of fingerlings in the lake. As shown in TABLE 15, only five times in recent years have more than 100 sockeye spawned in either Gates or Portage Creeks. The maximum spawning occurred in 1956 and there is an indication of a reduced growth

TABLE 15 - Number of adult sockeye spawning in Gates and Portage Creeks and the scale ring counts of their progeny, without spring growth, using mean ring counts from samples of smolts and adults.

Year of Spawning	Gates Creek	Portage Creek	Total	Mean Ring Count of Fish Apparently Reared in Anderson Lake	Mean Ring Count of Fish Apparently Reared in Seton Lake
1948	-	-	-	12.00	20.17
1950	-	-	-	-	19.84
1952	6883	-	6883	13.00	21.59
1953	78	50	128	14.00	23.30
1954	47	3495	3542	12.00	21.85
1955	86	43	129	11.33	19.20
1956	9012	-	9012	12.53	17.76
1957	1112	38	1150	14.57	21.55
1958	61	4791	4852	13.50	20.73
			Mean	12.87	20.66

rate among the progeny of these 9000 spawners. Only 34 per cent of the adults returning in 1960 had ring counts characteristic of rearing in Seton Lake, however. Whereas the mean ring count for sockeye reared in Seton Lake was 20.66 for the nine years of record, the 1956 brood year had a mean ring count of 17.76. Although this was lower than for any of the other years, it was only 1.4 rings lower than for the 1955 brood year, when little more than 100 sockeye spawned in the system. The lack of a consistent relationship between ring count and numbers of spawners is probably due to the fact that the growth rate of sockeye fingerlings varies inversely with population density only after a certain density level has been reached. Good growth of small numbers of fingerlings may therefore be expected in Seton Lake, even with the reduced abundance of plankton. The previously mentioned concentration of plankton near the surface of Seton Lake may be an important factor contributing to the relatively good growth rates of small numbers of fingerlings. It seems likely that the reduced plankton abundance has significantly lowered the productive capacity of the lake but this would only affect much larger fingerling populations than those reared in the lake during the period of this study.

Limited data concerning kokanee populations in Seton and Anderson Lakes were also examined. Very large populations of kokanee have existed in the Seton-Anderson system for many years. Babcock (1903) reported: "The Evermann, or permanently small form of the sockeye salmon, is found in Seton Lake in October, and in Anderson Lake in November. Their presence there at other times has not been recorded. These small fish annually appear in great numbers in Seton Lake, about the middle of October, at that time rising to the surface of the water with the abdomen so distended with gas that they are held there, where they struggle for a few days and die. Their fins are frayed and covered with fungus, the tail in many specimens being entirely gone. They are of a dark, muddy colour, and show dark spots on the back, and never show any of the brilliant red colour which so distinguishes the larger variety. They average about 8 inches in length and weigh only a few ounces. At times the surface of the lake is practically covered with their remains. The Indians term them "oneesh" and gather them in great quantities by means of scoop nets when they first come to the surface. Nothing regarding their spawning habits is known. They never enter the creeks, so far as reported. I saw none save in the lake proper. These fish are common to both Seton and Anderson Lakes, but come to the surface of the latter some three or four weeks later than the former."

Many of these "floaters" or "bloaters", as they are now called by the local residents, are seen in Anderson Lake but few have been seen in Seton Lake in recent years. A resident near the lower end of Anderson Lake regularly collects these dead and dying fish for garden fertilizer. In the winter of 1958-1959 he collected nearly a ton of them. Contrary to the early report of Babcock, he states that they come to the surface in January and sometimes in February in Anderson Lake. Only rarely are kokanee seen spawning in the tributary streams in the Seton-Anderson system.

Thirty kokanee (10 males and 20 females) were collected from Anderson Lake in January 1959 for laboratory examination. These fish were found at the surface close to the lake outlet. With the exception of one ripe female, these fish had recently completed spawning. Secondary sexual characteristics were well developed, the males having humped backs, hooked snouts and very deep bodies. Tails of the females were well worn. Standard lengths of these fish ranged from 230 to 264 mm., the males averaging 252 mm. and the females 245 mm. Only 16 kokanee "floaters" have been collected from Seton Lake for laboratory examination; 12 were collected on an unspecified date in 1938, and four on October 17, 1940. Lengths of these fish averaged 174 mm. for the males and 167 mm. for the females.

Although growth rates of kokanee in the two lakes could not be compared on the basis of scale ring counts, the size of the spawned-out adults strongly suggested that growth was much better in Anderson Lake. Because of false checks on the scales, it was not possible to determine with any degree of certainty the total number of circuli in the first year's growth. At maturity, however, the length of both the males and females was almost 50 per cent greater in Anderson Lake. It appears, therefore, that kokanee are not only more numerous in Anderson Lake but also show much better growth in this lake. Sockeye smolts, on the other hand, show better growth in Seton Lake.

Interacting factors controlling the growth and migratory behavior of young sockeye are so poorly understood that it is impossible at the present time to explain the anomalies observed in the Seton-Anderson system. In spite of the fact that very large numbers of sockeye formerly utilized the Seton-Anderson system, rehabilitation of these populations has been slow in relation to the rapid growth of other upriver races of sockeye. The unusual and variable behavior of Gates Creek fry in migrating through Anderson Lake and the large annual variation in the proportion of these fish that rear in Seton Lake cannot be explained at the present time. Neither is there an explanation as to why a large portion of the sockeye fingerlings sometimes migrate from Anderson Lake to Seton Lake during the winter months. Whereas the smolts migrate from Seton Lake during the usual spring period, as in other lake rearing areas of the Fraser system, very few have migrated from Anderson Lake in the spring months during the three years of this study in spite of the fact that early records clearly show a substantial spring migration. The greater growth of sockeye fingerlings in Seton Lake is even more difficult to understand in view of the fact that kokanee appear to be more abundant and show more growth in Anderson Lake. It is apparent that much more research is required before adequate conclusions can be drawn concerning factors controlling lacustrine growth of sockeye.

The fact that very large numbers of sockeye were formerly reared in Seton and Anderson Lakes indicates that in earlier years conditions in these lakes were favorable for sockeye rearing. However, large numbers of sockeye smolts cannot be produced without an adequate food supply. Since the introduction of cold, turbid water into Seton Lake has reduced the abundance of zooplankton, the food of young sockeye during their lacustrine existence, it can be assumed that the rearing capacity of the lake has been proportionately reduced.

Environmental Changes in Seton Creek

It has previously been demonstrated that the Bridge River and Cayoosh Creek diversions have caused two major changes in Seton Creek -- increased turbidity and decreased temperatures. The increase in turbidity has probably been of no significance as far as sockeye and pink salmon are concerned. Other salmonids that rear or are resident in Seton Creek may be affected, however, through reduction of their food supply or changes in predator populations. Although it might be expected that fine material would settle out of the turbid water and adversely affect percolation of flow through the spawning gravel in Seton Creek, examination of gravel samples from the stream bed has indicated that this has not occurred. The coarse gravel and high stream velocities tend to prevent deposition of sediment.

The reduced creek temperatures brought about by diversion of Bridge River and Cayoosh Creek water to Seton Lake are of more significance. There is some evidence that stream temperatures in pre-diversion years were very high during the period of pink salmon spawning, from about September 20 to October 20. In 1940, 1941 and 1942, temperatures of Seton Creek were measured daily at 8:00 a.m. and these may be compared with temperatures measured at the same time of day in 1957, 1958 and 1959. The 8:00 a.m. temperatures during the September 20 to October 20 period ranged from 57 to 69°F in the three pre-diversion years and from 49 to 59°F in the three post-diversion years. The average 8:00 a.m. temperatures were about 62 and 53°F respectively. Based on knowledge of other salmon species, it would be expected that temperatures in the pre-diversion years would have a serious adverse effect on spawning and egg survival. It is known that high temperatures cause salmon to die without spawning and, further, eggs deposited in high water temperatures generally have a low survival rate (Andrew and Geen, 1960). Vernon (1958) noted that temperatures in the Fraser River in 1941 averaged 61.2°F during the pink salmon spawning period and that this was 5.3° higher than a 12-year mean. He suggested that these high temperatures may have contributed to the very low survival of this brood year.

Temperature changes during the winter months may also have had a beneficial effect on pink salmon production. Although no winter temperatures are available from the pre-diversion period, it is likely that fall and winter temperatures of Seton Creek have been somewhat reduced. The discharge into Seton Lake from Bridge River and Cayoosh Creek is 5 to 6°F colder than inflowing Portage Creek water. Both flows, being colder than Portage Creek, would probably tend to reduce Seton Creek temperatures. Vernon (1958) demonstrated an inverse relationship between winter incubation temperatures and the numbers of adult pink salmon returning two years later. This apparent relationship suggests that the indicated temperature reduction in Seton Creek may have had a beneficial effect on pink salmon production.

Although not directly related to the subject of this report, other changes occurring in Seton Creek should be briefly mentioned. One of the most important changes, of course, is that most of the sockeye smolts migrating to the ocean are diverted out of Seton Creek and into the canal leading to the powerhouse, where they suffer a mortality of about 10 per cent (Andrew and Geen, 1958). The spawning area of pink salmon has been affected by the construction of Seton Dam and consequent flooding of the upper 3500 ft. of the creek. The adverse effects of this dam were compensated for by the provision of a minimum flow of 400 c.f.s. during the spawning period and 200 c.f.s. at other times of the year but severe flooding can occur when the single turbine in the Seton plant has to be removed from service. Since there is very little storage capacity on Seton Lake, and since no spillway was provided at the Seton powerhouse, an unscheduled plant shutdown often necessitates spilling of surplus water down Seton Creek. The discharge may increase from the guaranteed minimum of 200 c.f.s. to more than 4000 c.f.s., possibly with serious adverse effects on fish and incubating eggs and alevins in the creek.

DISCUSSION

The pronounced physical and chemical changes in Seton Lake and the reduction in zooplankton abundance suggest that during the period of this investigation the rearing capacity of the lake was much lower than under natural conditions. This reduction in rearing capacity was a direct result of the diversion of cold, turbid water from Bridge River to Seton Lake. The observed changes in Seton Lake are indicative of the dangers involved in diverting foreign water to major sockeye rearing areas such as Chilko or Shuswap Lakes.

Several studies have suggested that plankton abundance is a limiting factor in sockeye production. It is well documented that crustacean zooplankters form the bulk of the diet of young sockeye in the lake environment. Ricker (1937) found an inverse correlation between the size of the population of downstream migrants at Cultus Lake and the abundance of Entomostraca. Plankton abundance was expressed as a percentage of the mean abundance of Entomostraca in August compared with that in June. Increased competition for the planktonic food supply was indicated in years of large sockeye populations. Further indication of competition was the fact that much more rapid decreases in the standing plankton crop occurred in years when large sockeye populations were in the lake. Foerster (1944) suggested that plankton abundance was an important factor limiting the production of sockeye salmon in Cultus Lake.

More recently, studies have been conducted on Babine Lake in the Skeena River system. From these studies, Johnson (1956) suggested that intensive foraging resulted in a lowered zooplankton abundance. More recent studies, as yet unpublished, have implied a direct relationship between growth rate and zooplankton abundance. Increased intraspecific competition appeared to depress growth of sockeye fingerlings after densities exceeded 4000 fish per acre in late August. Although the relationship was not as simple as might appear, the dependence of sockeye growth on plankton abundance was evident.

Various Russian workers have examined the relation of plankton abundance to growth. Krogius and Krohkin (1956) studied the production of sockeye in Lake Dalnee in relation to specific food conditions in the lake. They maintained that in spite of relatively high plankton abundance, strained inter- and intraspecific relationships can exist. Extensive competition unfavorably affected growth of the young and caused them to be detained in the lake.

The Commission has collected data on sockeye growth and plankton abundance in several lakes of the Fraser River system. Although there is considerable annual variation in freshwater growth, particularly in Shuswap Lake, it is only in those years when populations are large that there is any suggestion of sockeye reducing zooplankton abundance. Ward (1957) suggested that the large sockeye population in Shuswap Lake in 1955 might have caused the lowered plankton abundance of that year. Plankton production was reduced again in 1959 when a very large smolt population was being reared in the lake. Little Shuswap Lake, immediately downstream from Shuswap Lake, had a particularly low level of plankton in both 1955 and 1959, suggesting that the substantial numbers of fish in this lake grazed the plankters to a low level. Ring counts of sockeye reared in the Shuswap system are lower for dominant-year Adams River populations than for off-year populations.

At low population densities, food abundance appears to have little bearing on the growth of young salmon. However, at high densities, growth can be reduced by limited plankton abundance. Where spawning areas are adequate to produce large numbers of fry, a reduction in plankton abundance could critically reduce the rearing capacity of a lake.

Some information is available to suggest possible mechanisms by which the physical and chemical changes occurring in Seton Lake have reduced the rearing capacity of the lake. Prowse (1955) has cautioned against over-simplification of the food-chain relationships, suggesting that they are more complex than is generally appreciated. Ultimately, however, the phytoplankton populations, the primary producers of the aquatic environment, provide the food for the zooplankters which in turn are utilized by plankton feeding organisms including young sockeye salmon. Slobodkin (1954) has demonstrated experimentally a direct linear relationship between the population size of *Daphnia obtusa* and its algal food supply. In general, zooplankton abundance is directly related to phytoplankton abundance in the natural environment. Changes that reduce phytoplankton abundance in a lake can therefore be expected to reduce zooplankton production and reduce the growth and survival of sockeye salmon during their lacustrine existence. If the numbers of sockeye are very small in relation to the available food supply, this generalization will, of course, not apply.

All available information suggests that the reduced zooplankton production in Seton Lake is associated with the effects of the environmental changes on phytoplankton populations. McCombie (1953) maintained that "the growth of phytoplankton is influenced by factors of supply (limiting factors) and factors of control. Among the limiting factors are the intensity of light and duration of illumination, which govern the supply of energy for photosynthesis, and the concentration of nutrient elements, which constitute the structural units of carbohydrates. Temperature, ionic balance, concentration of catalysts and probably pH may be the controlling factors which determine the rate at which phytoplankton can exploit the limiting factors." This would suggest that the greatly increased turbidity of the water in Seton Lake is a primary factor limiting the production of plankters and that the reduced temperatures and T.D.S. may be contributing factors.

Suspended material in water restricts light penetration, and therefore limits primary aquatic production. The significance of light intensity to the rate of photosynthesis was investigated by Ryther (1956) for several species of marine plankton. His work showed a linear increase in photosynthesis with increasing light intensity to a point of light saturation, after which a decrease in photosynthesis occurred. The light intensity in most lakes, except in the extreme surface layers, is such that a decrease in water transparency would reduce photosynthesis and therefore limit primary production. It appears that the rapid absorption of light in turbid lakes restricts photosynthesis to a thin surface stratum.

The limiting effect of turbidity on phytoplankton production has been indicated by several authors. Chandler (1940) discussed the relation of plankton production and turbidity in the western basin of Lake Erie. He suggested that turbidity, by reducing the intensity of illumination and the depth to which photosynthesis can occur, could limit the production of phytoplankton and therefore reduce zooplankton production. Verduin (1954) noted an increase in phytoplankton production associated with turbid waters but this was attributed to an increase in phosphorus at the time of spring runoff, which was also the main source of the turbid water. Chandler (1942) reported a concentration of zooplankters near the surface during periods of high turbidity and suggested that these organisms probably changed their vertical position as the vertical position of their food organisms changed. Meyer and Heritage (1941) showed that the rate of photosynthesis of *Ceratophyllum demersum*, a rooted aquatic, was markedly reduced when water in Lake Erie attained its maximum turbidity. Roy (1955) showed an inverse relationship between plankton production and water turbidity in a river in Bengal.

Penetration of the various spectral components of light is influenced by turbidity of the water. McCombie (1953) pointed out that plants carry on photosynthesis only in a certain spectral range, greatest efficiency occurring in orange-red light. Clarke (1938) outlined the variations in spectral absorption that can occur and showed that the utilization of light is low even under most favorable conditions. Where turbidity is extreme for extended periods, such as in Seton Lake, there can be little doubt that phytoplankton production will be adversely affected.

General support for the suggestion that the diversion of turbid water to Seton Lake has reduced phytoplankton production was obtained from the sampling work on Seton and Anderson Lakes. Although sampling procedures were not designed to measure phytoplankton abundance quantitatively, substantial numbers of these forms (primarily filamentous green algae) were frequently retained by the No. 10 Wisconsin nets. The color of the unwashed samples provided a good indication of the amount of phytoplankton. Gross estimates of relative abundance were obtained when the samples were washed. The samples from Anderson Lake consistently showed far greater amounts of phytoplankton than the Seton Lake samples.

The reduction in Seton Lake temperature may also have contributed to reduced productivity. McCombie (1953), describing the effects of temperature on phytoplankton, maintained that "Water temperature may be a controlling factor or a lethal factor for phytoplankton, depending on the temperature level in the environment. As a controlling factor, the water temperature controls the rates of metabolism and growth of phytoplankton, but unlike a limiting factor it does not act through restriction of the supply of energy or materials. Rather, water temperature sets the tempo at which the phytoplankton can exploit the limiting factors (e.g. light and nutrient conditions)". Northcote and Larkin (1956) surveyed several

British Columbia lakes and showed that plankton abundance was directly correlated with T.D.S. and mean mid-summer epilimnial temperatures. A reduction in temperature, such as has been noted in Seton Lake, would be expected to reduce phytoplankton and zooplankton populations. Temperature level and rate of increase often appear to be associated with the development of population maxima. A decrease in temperature might therefore be expected to limit population growth. Substantial changes in temperature may also alter the species composition. Although the average temperature in the top 100 ft. of Seton Lake was about 2°F less than in Anderson Lake during the spring and fall months, it seems unlikely that this relatively small temperature difference was primarily responsible for the reduced plankton abundance.

Alterations in the dissolved nutrient content of a lake could also influence phytoplankton populations. Although no pre-diversion data on T.D.S. were available from the Seton-Anderson system, a reduction in the dissolved solids content of Seton Lake would be expected on the basis of the T.D.S. of the diverted water from Bridge River. Whereas the T.D.S. of the lower lake in a chain is usually higher than that of upstream lakes, the T.D.S. of Seton Lake was slightly lower than that of Anderson Lake, suggesting that the Bridge River diversion had reduced the dissolved mineral content of the lake. This diversion into Seton Lake of water having a low dissolved mineral content may be partially responsible for the reduction in plankton abundance, through dilution of one or more elements to limiting levels. It seems unlikely that dissolved substances that inhibit plankton production would be introduced into Seton Lake from the Bridge River diversion. Although the level of available nutrients has in all probability been reduced in Seton Lake, thus possibly reducing the ultimate size that phytoplankton populations can attain, the fact that the T.D.S. levels in Seton and Anderson Lakes were not greatly different suggests that other factors were more important in limiting plankton production during the period of this investigation.

Although it is known that high flushing rates adversely affect the productivity of lakes, it is unlikely that the increase in flushing rate of Seton Lake has had an important effect on plankton production. The diversion of 3000 c.f.s. from Bridge River to Seton Lake reduced the replacement time from about 1300 days to 230 days. Brook and Woodward (1956) maintained that the rate of flow through a lake may be of overriding importance in determining productivity but these authors dealt only with relatively high flushing rates. They compared a lake having a replacement time of 91 days with a lake and two reservoirs having replacement times of five days or less. Plankton production was low in the bodies of water having short replacement times. Evidence was presented to suggest that plankters were being washed downstream following heavy rains. Mottley (1936) suggested that the high flushing rate of Jones Lake was detrimental to lake productivity. This lake had a volume replacement time of about two months on the average but only three weeks in the spring. McMynn and Larkin (1953) suggested that the volume replacement time of less than 30 days on both Upper and Lower Campbell Lakes seriously impaired production of plankton and bottom fauna. Larkin and Northcote (1958) felt that rate of flushing of coastal lake basins may be an important factor in limiting standing crops of organisms not only because organisms are carried out of the lakes but also because of the low nutrient level of the inflowing water.

Whereas small lakes are adversely affected by high flushing rates, studies made by the Salmon Commission have suggested that variations in the low flushing rates of the large sockeye rearing lakes of the Fraser River system do not have a significant effect on plankton production. A direct relationship between T.D.S. and plankton production has been indicated in these lakes. Kamloops Lake has an average replacement time of about 70 days, the lowest of the major sockeye-producing lakes of the watershed. If flushing rates were a controlling factor, then production of plankton in Kamloops Lake would be particularly low. However, based on information concerning plankton production and T.D.S. in the sockeye-rearing lakes of the system, there was no indication of a significant departure of plankton production in Kamloops Lake from that expected on the basis of its T.D.S. It is very unlikely, therefore, that the replacement time of about 230 days for Seton Lake in its new condition could have a significant effect on plankton production.

It is apparent that an important series of environmental changes have occurred following the diversion of foreign water to Seton Lake. The rearing capacity of the lake appears to have been lowered because of a reduced abundance of zooplankton. The reduction in zooplankton abundance in Seton Lake, probably from a level at least equal to that in Anderson Lake, appears to have been the direct effect of a decrease in the suitability of the lake for the development of phytoplankton. Available information suggests that the reduced temperature and dissolved mineral content and the increased flushing rate contributed to a minor extent in reducing zooplankton production. Increased turbidity appears to be the main factor responsible for the decrease in primary production, the direct cause being reduced photosynthesis associated with the reduced light penetration.

Available data are not adequate to permit prediction of the effects of the Bridge River diversion on the productivity of Seton Lake in future years. A pronounced reduction in turbidity was noted in the summer of 1960, following completion of enlarged storage facilities on Bridge River. La Joie Dam, the upstream storage dam, was increased in height, as was the diversion dam on Bridge River. Much of the glacial material apparently settled in these reservoirs, resulting in a less turbid flow into Seton Lake. In the spring of 1961, the turbidity was greatly reduced from the extreme conditions observed in the previous three years. Nevertheless, the lake was considerably more turbid than it was in its natural state. It seems likely, therefore, that plankton production will continue to be lower than in pre-diversion years.

SUMMARY AND CONCLUSIONS

To provide information that would be of value in assessing possible effects of proposed hydroelectric diversions of foreign water into valuable sockeye rearing lakes in the Fraser River system, limnological changes resulting from the diversion of water into Seton Lake were examined.

In its natural state, Seton Lake received nearly all of its inflow from Portage Creek, which drains Anderson Lake. The average annual outflow of Seton Lake was about 660 c.f.s. Discharge from the Bridge River diversion was about 2000 c.f.s. in 1954 and this was increased to about 3000 c.f.s. in 1960. A diversion from Cayoosh Creek to the lower end of Seton Lake was completed in 1956, the discharge being highly variable but possibly averaging about 500 c.f.s.

Evaluation of the effects of these diversions on salmon productivity was approached as follows:

1. Temperatures and turbidities measured in pre-diversion years were compared with measurements made in post-diversion years.

2. Since Anderson Lake was not affected by hydroelectric development, and since it is similar to Seton Lake in morphometric, edaphic and climatic characteristics, a comparison was made of temperatures, turbidities, dissolved mineral levels, and plankton abundance measured at three sampling stations on each lake.

3. Temperatures of the outflowing and inflowing streams of Seton and Anderson Lakes were compared.

4. Growth rates of sockeye reared in Seton and Anderson Lakes were examined.

Pronounced limnological changes in Seton Lake were evident. The turbidity was greatly increased and the average temperature and dissolved mineral levels were reduced. It appeared that plankton production was greatly reduced. The high level of turbidity apparently limited photosynthesis and therefore reduced the production of phytoplankters, which provide the basis of the aquatic food chain. The reduction in phytoplankton abundance reduced the production of zooplankton, the food supply of fingerling sockeye in the lake.

The growth of young sockeye in Seton and Anderson Lakes was examined on the basis of the number of circuli on the scales of smolts captured at the lake outlets and adults on the spawning grounds. Studies indicated that most of the sockeye in the system were reared in Seton Lake. Their growth rate was generally high in spite of the low plankton abundance but it appeared that the populations of fingerling sockeye in the lake were so small that plankton abundance was not a limiting factor. While it seems evident that the rearing capacity of the lake has been greatly reduced, conclusive data concerning the total effects of the environmental changes in Seton Lake can only be obtained by further study involving larger populations than those now utilizing the system.

Environmental changes resulting from diversion of water to sockeye rearing lakes may affect the production of sockeye in many ways that have not yet been investigated. Anomalies observed in the behavior and growth of young sockeye in the Seton-Anderson system indicate that there may be many factors controlling lacustrine production of sockeye that could be affected by environmental changes. In several respects, the observations of growth and behavior of young sockeye in Seton and Anderson Lakes were found to be at variance with observations in other sockeye rearing lakes. The unusual and variable behavior of Gates Creek fry in migrating through

Anderson Lake to rear in Seton Lake and the migration of fingerlings from Anderson Lake during the winter months cannot be explained at the present time. In spite of the fact that zooplankton was far more abundant in Anderson Lake, sockeye showed better growth in Seton Lake. These and other peculiarities in behavior and growth of young sockeye show that current knowledge of factors affecting lacustrine production of young sockeye is far from complete. Although the need for much more research is apparent, it was reasoned that the sockeye rearing capacity of Seton Lake had been reduced because the introduction of cold, turbid water had reduced the abundance of zooplankton, the food supply of young sockeye.

Temperature changes in Seton Creek have probably had a beneficial effect on pink salmon production. Temperatures in Seton Creek in pre-diversion years appear to have been at critically high levels, at least during the early part of the pink salmon spawning period. The lower temperatures occurring in recent years may improve spawning efficiency and subsequent egg and fry survival.

The completion of enlarged storage facilities on Bridge River and power generation facilities on Seton Lake in 1960 may result in further limnological changes. Important variations in temperature and turbidity may occur in Seton Lake, depending on climatic conditions and the method of operation of the hydroelectric developments. Uniformly stable conditions may not be attained and the effect on salmon production may therefore be variable from year to year. Because of the possibility of large annual variations in limnological conditions and because of the lack of an adequate understanding of factors controlling lacustrine production of sockeye salmon, further study will be required before final conclusions can be drawn as to the future effects of the diversion of foreign flow to Seton Lake.

LITERATURE CITED

Andrew, F.J. and G.H. Geen. 1958. Sockeye and pink salmon investigations at the Seton Creek hydroelectric installation. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 4, 74 pp.

1960. Sockeye and pink salmon production in relation to proposed dams in the Fraser River system. Internat. Pacific Salmon Fish. Comm., Bull. 11, 259 pp.

Anonymous. 1952. Report on the fisheries problems created by the development of power in the Nechako-Kemano-Nanika River systems. Supp. No. 1. Temperature changes in the Nechako River and their effects on the salmon populations. Can. Dept. of Fish. and Internat. Pacific Salmon Fish. Comm., 42 pp.

Babcock, J.P. 1903. Report of the Fisheries Commissioner for British Columbia for the year 1902. pp. 3-34.

1904. Report of the Fisheries Commissioner for British Columbia for the year 1903. pp. 1-10.

1910. Report of the Fisheries Commissioner for British Columbia for the year 1909. pp. 5-21.

1913. The spawning beds of the Fraser. Rept. B.C. Comm. Fish., 1912, pp. 25-30.

British Columbia Atlas of Resources. 1956. B.C. Nat. Resources Conf., 92 pp.

Brook, A.J. and W.B. Woodward. 1956. Some observations on the effects of water inflow and outflow on the plankton of small lakes. J. Animal Ecol., 25: 22-35.

Chandler, D.C. 1940. Limnological studies of Western Lake Erie. 1. Plankton and certain physical-chemical data of the Bass Islands Region, from September, 1938 to November, 1939. Ohio J. Sci., 40(6): 291-336.

1942. Limnological studies of Western Lake Erie. 2. Light penetration and its relation to turbidity. Ecol., 23(1): 41-52.

Chapman, J.D. 1952. The climate of British Columbia. Trans. 5th B.C. Nat. Res. Conf., pp. 8-54.

Clarke, G.L. 1938. Seasonal changes in the intensity of submarine illumination off Woods Hole. Ecol., 19(1): 89-106.

Clutter, R.I. and L.E. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Internat. Pacific Salmon Fish. Comm., Bull. 9, 159 pp.

Department of Northern Affairs and National Resources. Surface water supply of Canada, Pacific drainage. (Annual).

Department of Transport. Meteorological observations in Canada. (Monthly).

Foerster, R.E. 1944. The relation of lake population density to size of young sockeye salmon (Oncorhynchus nerka). J. Fish. Res. Bd. Can., 6(3): 267-280.

Gilbert, C.H. 1915. Contributions to the life-history of the sockeye salmon, No. 2. Rept. B.C. Comm. Fish., 1914, pp. 45-75.

Gunning, H.C. 1943. Geology and mineral resources of British Columbia. The Miner, 16(6): 35-39.

Johnson, W.E. 1956. On the distribution of young sockeye salmon (Oncorhynchus nerka) in Babine and Nilkitkwa Lakes, B.C. J. Fish. Res. Bd. Can., 13(5): 695-708.

Kleerekoper, H. 1953. The mineralization of plankton. J. Fish. Res. Bd. Can., 10(5): 283-291.

Krogius, F.V. and E.M. Krohkin. 1956. Results of a study of the biology of sockeye salmon, the conditions of the stocks, and the fluctuations in numbers in Kamchatka waters. Fish. Res. Bd. Can., Translation Series, No. 176, 19 pp.

Larkin, P.A. and T.G. Northcote. 1958. Factors in lake typology in British Columbia, Canada. Verh. int. Ver. Limnol., 13: 252-263.

Lyons, J.C. and P.A. Larkin. 1952. The effect on sport fisheries of the Aluminum Company of Canada Ltd. development in the Nechako drainage. B.C. Game Commission, Unpubl.

McCombie, A.M. 1953. Factors influencing the growth of phytoplankton. J. Fish. Res. Bd. Can., 10(5): 253-282.

McMynn, R.G. and P.A. Larkin. 1953. The effects on fisheries of present and future water utilization in the Campbell River drainage area. B.C. Game Comm., Manag. Publ. 2, 61 pp.

Meyer, B.C. and A.C. Heritage. 1941. Effect of turbidity and depth immersion on apparent photosynthesis in Ceratophyllum demersum. Ecol., 22(1): 17-22.

Mottley, C. McC. 1936. A biological survey of Jones Lake. Rept. B.C. Prov. Game Comm. for 1935, pp. 27-30.

Northcote, T.G. and P.A. Larkin. 1956. Indices of productivity in British Columbia lakes. J. Fish. Res. Bd. Can., 13(4): 515-540.

Prowse, G.A. 1955. The role of phytoplankton in studies on productivity. Verh. int. Ver. Limnol., 12: 159-163.

Rawson, D.S. 1951. The total mineral content of lake waters. Ecol., 32(4): 669-672.

Ricker, W.E. 1937. The food and food supply of sockeye salmon (Oncorhynchus nerka Walbaum) in Cultus Lake, British Columbia. J. Biol. Bd. Can., 3(5): 450-468.

1938. Seasonal and annual variations in the quantity of pelagic net plankton, Cultus Lake, British Columbia. J. Fish. Res. Bd. Can., 4(1): 33-47.

Roy, H.K. 1955. Plankton ecology of the River Hooghly at Palta, West Bengal. Ecol., 36(2): 169-175.

Royal, L.A. 1953. The salmon fisheries of Seton Creek watershed. Internat. Pacific Salmon Fish. Comm., Unpubl., 8 pp.

Ryther, J.H. 1956. Photosynthesis in the ocean as a function of light intensity. Limnol. and Oceanog., 1(1): 61-70.

Slobodkin, L.B. 1954. Population dynamics in Daphnia obtusa Kurz. Ecol. Monog., 24: 69-88.

Sverdrup, H.U., M.W. Johnson and R.H. Fleming. 1942. The Oceans: Their physics, chemistry and general biology. Prentice-Hall, New York, 1087 pp.

Verduin, J. 1954. Phytoplankton and turbidity in Western Lake Erie. Ecol., 35(4): 550-561.

Vernon, E.H. 1958. An examination of factors affecting the abundance of pink salmon in the Fraser River. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 5, 49 pp.

Ward, F.J. 1957. Seasonal and annual changes in availability of the adult crustacean plankters of Shuswap Lake. Internat. Pacific Salmon Fish. Comm., Prog. Rept. 3, 56 pp.

Welch, P.S. 1952. Limnology. McGraw-Hill Book Co., New York, 538 pp.