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by

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ABSTRACT

Inexpensive equipment for sampling intragravel water for dissolved oxygen is described. Water samples were withdrawn from plastic standpipes driven into the streambed. Dissolved oxygen values representative of points sampled were obtained from 30-ml. samples of water taken about 24 hours after standpipes were placed.

Fourfold seasonal and yearly changes in dissolved oxygen levels were observed. Spatial differences in dissolved oxygen levels were greatest when discharge was low and temperature was high.

For routine measurement of dissolved oxygen level random sampling was tried and found to be satisfactory.

INTRODUCTION

Pink salmon *(Oncorhynchus gorbuscha)* and chum salmon *(O. keta)* spend only brief periods in fresh water as fry and spawning adults, but their eggs and larvae commonly remain in the streambed 6 to 8 months. During this period mortality is influenced largely by physical conditions, and a decline in quality of the streambed environment may cause considerable mortality.

Mortality of pink and chum salmon is high in fresh water. Neave and Foerster (1955) summarized data obtained over several years on mortality observed in five British Columbia and Southeastern Alaska streams. The stream experiencing the highest mortality had a geometric mean yearly mortality of 99.7 percent, while the stream experiencing the lowest mortality had a geometric mean yearly mortality of 86.8 percent. Because mortality estimates were based on counts of adult females migrating into the streams and of their progeny migrating out of the streams, it was not possible to differentiate among prespawning, egg, larval, and postemergent losses. There is evidence, however, that a considerable portion of fresh-water mortality of pink and chum salmon occurs during embryonic development.

Estimated mortality of chum salmon eggs and larvae ranged from 75 to 95 percent over a 4-year period in a controlled stream (Wickett, 1952). In another experiment (Neave and Wickett, 1955), eyed pink salmon eggs were planted in an artificial spawning channel. Approximately 19 percent were estimated to have died prior to hatching. Mortality up to time of migration was estimated to be 58 percent.

Hunter (1948) excavated natural redds in British Columbia streams during January and found that 86 percent of the chum salmon embryos and 97 percent of the pink salmon embryos were dead. Natural mortality of embryo pink and chum salmon has been observed in three streams in the Hollis area of Southeastern Alaska by the Fisheries Research Institute. Mortality prior to hatching has been observed to exceed 95 percent in certain important spawning areas. A high mortality during early stages of development was observed to occur in 1957 in association with low levels of dissolved oxygen.

Embryonic mortality has been attributed to a number of causes. Wickett (1958) proposed that the most important causes of mortality among eggs and larvae were closely associated with extreme low and high stream discharge. Further, the rate of oxygen supply to eggs was thought to be an important factor limiting survival during certain periods of low stream discharge.

The rate of oxygen supply to embryos has recently received attention by a number of investigators. Wickett (1954) pointed out that the rate of supply is a function of the flow velocity past the embryo, as well as the dissolved oxygen content of the intragravel water. He devised techniques and portable equipment for measuring seepage rate along with dissolved oxygen content. Other workers (Pollard, 1955; Terhune, 1958) have recently refined Wickett's method of measuring seepage rate. Gangmark and Bakkala (1959) also have

Note.--The author is presently with the Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska.

described a method for measuring seepage rate with equipment designed for permanent installation in the streambed.

Equipment required for measuring seepage rate is expensive. Furthermore, it is possible that the sampling effort required for statistical precision in measuring seepage rate in a natural stream will limit the application of this equipment.

Compared with measuring seepage rate, measuring dissolved oxygen content of intragravel water is a simple task requiring inexpensive equipment. It is also possible that oxygen content alone will provide a suitable index of quality of intragravel water in terms of survival of salmon embryos.

In view of these considerations, it is surprising that more attention has not been given to the observation of dissolved oxygen content of intragravel water and to the manner in which oxygen levels change with time and differ between sites. Based on samples obtained from nine points, Wickett (1954) made comparisons of oxygen levels among areas having normal gravel, consolidated gravel, and heavy silt deposits. Chambers, Allen, and Pressey (1955) sampled dissolved oxygen content of water seeping through salmon redds by withdrawing 250-ml. water samples from standpipes driven into the streambed. They found much spatial variation. Data on oxygen levels presented by Gangmark and Bakkala (1959) showed temporal changes in dissolved oxygen content of intragravel water to be of considerable magnitude, but their data were not intended to define precise relationships between time and oxygen level.

Observation of the dissolved oxygen content of intragravel water was undertaken by the Fisheries Research Institute in 1956 as a part of a study to evaluate the effects of logging on productivity of pink and chum salmon spawning streams in the Hollis area of Southeastern Alaska. The study was financed by the Bureau of Commercial Fisheries, with Saltonstall-Kennedy Act funds. Figure 1 shows the location of streams where the reported observations were made.

The study of dissolved oxygen content of intragravel water had two broad objectives: (1) to establish whether or not oxygen supply was an important factor associated with mortality in spawning beds and (2) to develop sampling techniques whereby dissolved oxygen level could be measured routinely as an index of environmental quality as it pertains to mortality of salmon embryos. It is the purpose of this paper to describe the methods adopted to obtain samples of intragravel water for the analysis of their dissolved oxygen content and to report observed spatial differences and temporal changes in dissolved oxygen levels.

The author wishes to acknowledge the many helpful suggestions given by William L. Sheridan, who was project leader during the period this study was conducted.

SAMPLING INTRAGRAVEL WATER FOR DISSOLVED OXYGEN CONTENT

It will be shown that dissolved oxygen levels of intragravel water vary greatly in space and with time. The nature of these variations requires that large numbers of oxygen readings be obtained simultaneously if precise estimates of dissolved oxygen levels are desired. It is also essential that water samples be as small as possible to avoid "contamination" of the sample with water from other strata. The sampling requirements therefore dictate to a great extent the design of equipment and the methods employed.

Obtaining Water Samples from Standpipes

Water samples were obtained from standpipes which were open cylinders having 20 holes, three-sixteenths of an inch in diameter, spaced in the lower 3 inches of pipe. A small hand drill was used to make the 3/16-inch holes. Standpipes were constructed of rigid plastic pipe sold under the trade name "Carlon." The inside diameter of the pipe was three-quarters of an inch.

Standpipes were driven into the streambed with a driving rod as illustrated in figure 2. The removable driving rod eliminated the need of having a solid head on each standpipe.

For routine sampling, the pipes were driven to a depth of 10 inches beneath the streambed surface. At this depth intragravel water could enter a standpipe only from 7 to 10 inches beneath the surface of the gravel. It was observed that pink salmon commonly buried their eggs at this depth in Hollis area streams.

After a standpipe was driven into the streambed, turbid water was removed by pumping. Terhune (1958) described a vacuum pump that was efficient for removal of turbidity. Standpipes were left overnight before dissolved oxygen determinations were made, since driving a pipe and clearing it of turbidity disturbed the streambed and may have temporarily facilitated the infiltration of above-gravel water.

A plastic standpipe could be driven into the streambed three to eight times, depending on gravel size and compaction, before damage to its lower edge made it unserviceable. Damaged standpipes were made serviceable

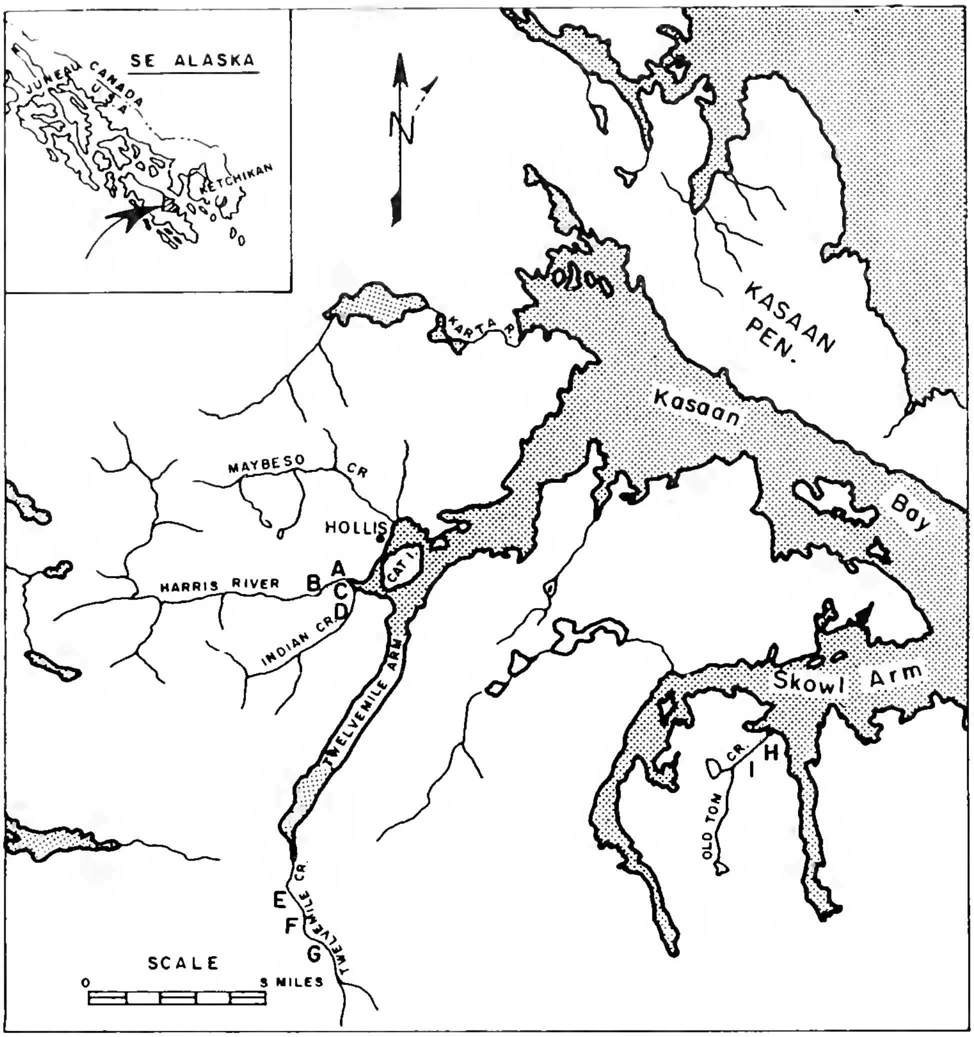

Figure 1.--Location of study streams, Hollis area, where dissolved oxygen levels reported in this paper were observed. Location of study areas is shown by capital letters.

again by removing the lower 3 inches and drilling new holes. Driving rods manufactured from high-quality steel withstood at least 1,000 drives.

Driving rods 36, 33, and 30 inches long were used. Standpipes were initially cut to fit the longest driving rod, and they were subsequently shortened to 33 and 30 inches, respectively, as their lower edges became damaged.

Water samples were sucked from standpipes with an apparatus constructed of tubing and a two-holed, No. 4 rubber stopper, and collected in 8-dram shell vials. Stoppers for the vials were one-holed, No. 3 rubber stoppers with a short piece of 6-mm. glass tubing inserted. Each component of the water sampling apparatus is illustrated in figure 3. Harper (1953) describes similar equipment.

To obtain a sample, the suction apparatus is connected to a vial. The glass tubing through which water enters the vial must extend nearly to the bottom. The suction line is inserted into a standpipe, and water is sucked from near the bottom of the well. About 10 cc. of water is discarded before the sample is collected. The suction line is pinched off before discarding the first 10 cc. of water, preventing the suction line from becoming drained and reducing contact of the water surface with the atmosphere. As the stopper is placed after collecting a sample, a column of water is allowed to rise about halfway up the glass tube in the stopper. Chemicals used to fix the water sample are introduced

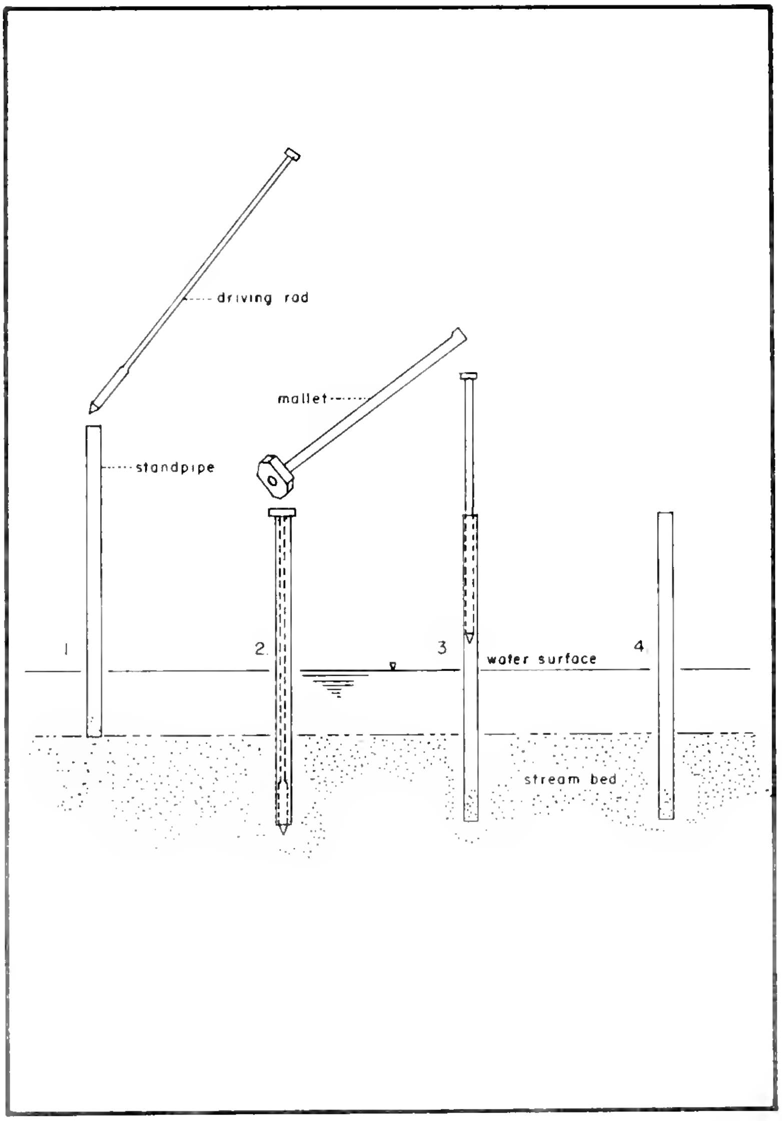

Figure 2.--Method of placing standpipe in streambed for collection of water samples for determination of dissolved oxygen content.

from dropper bottles through this tube. Before the sample is agitated, the column of liquid is forced to the top of the tube by applying pressure to the stopper and is sealed from the atmosphere by closing the opening of the tube with the forefinger.

Analyzing Water Samples

The unmodified Winkler Method was used to analyze water samples for their dissolved oxygen content. The volume of water used for an oxygen determination was only 30 ml., and it was necessary to employ semi-micromethods of analysis to obtain precise readings. A 25-ml. aliquant was titrated against 0.0125 N sodium thiosulfate solution delivered from a microburette having 0.02-ml. subdivisions. The 0.0125 N sodium thiosulfate solution was prepared from a stock solution which was periodically standardized against 0.025 N potassium dichromate.

Dissolved oxygen analyses were made in the field near sampling areas. There was very little delay from the time samples were collected to the time they were titrated; thus the possible influence of interfering substances was minimized.

The collection and analysis of water samples from 200 standpipes required about 1 day

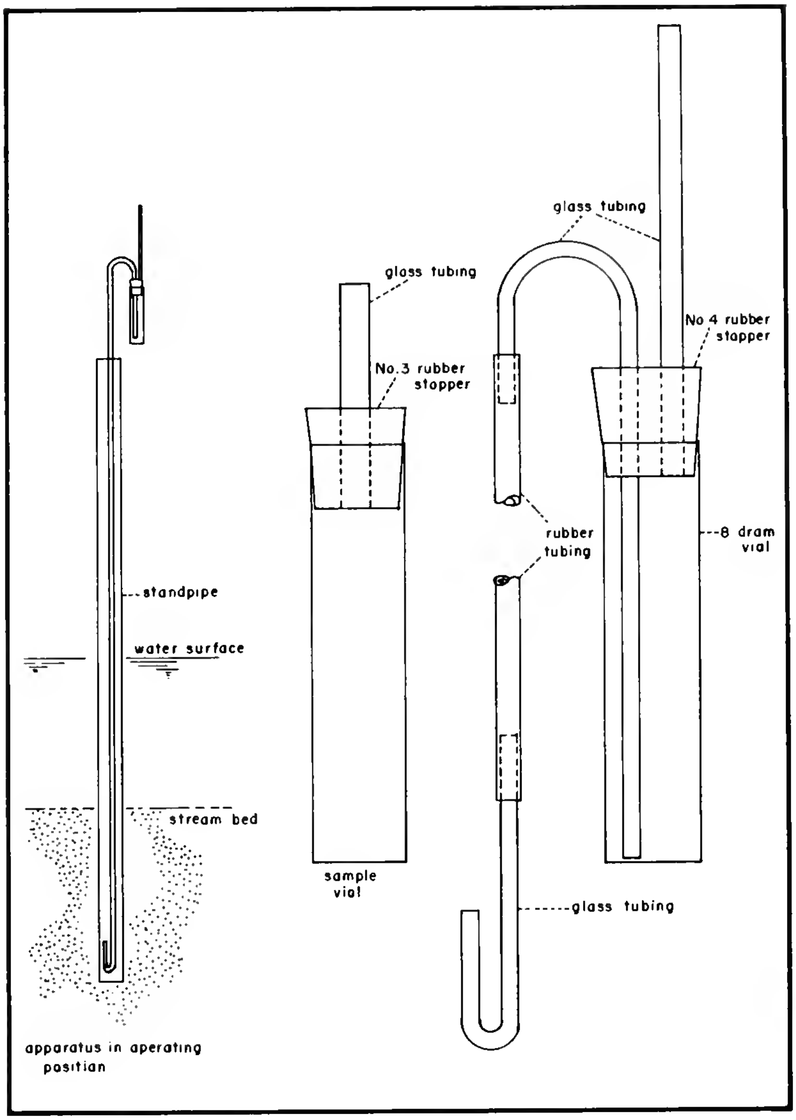

Figure 3.--Apparatus for collecting water samples from standpipes.

for three men. An automatic burette with a three-way stopcock was used for making titrations.

Reliability of Samples

Two precautions are necessary to insure collection of water samples that are representative of points sampled. First, it is essential to leave standpipes in the streambed about 24 hours before sampling to allow conditions within the gravel to stabilize. Second, the withdrawal of large water samples should be avoided to prevent water originating at other levels from entering a standpipe.

With regard to the first precaution, Wickett (1954) reported that points normally having very low dissolved oxygen values required several days after driving a standpipe for their dissolved oxygen levels to return to their normal levels. In the present study, consecutive readings were made at six points over a period of 95 hours after placement of standpipes. At points where oxygen level was relatively low at time of the first determination, oxygen levels declined for at least 24 hours. At points having relatively high oxygen values at time of the first determination, consecutive readings did not show any trend in their variation. Data on oxygen levels are given in table 1. Temperature of intragravel water was not uniform at all points sampled. Temperature increased about 4° F. at each point during the 95-hour sampling period.

TABLE 1.--Temporal changes in dissolved oxygen levels[1] after placing standpipes

Time elapsed after placing standpipes (hour)	Mg./l. of dissolved oxygen in standpipes					
	I	II	III	IV	V	VI
0.3	3.9	4.5	4.1	8.2	9.6	10.0
2.5	3.2	3.4	3.9	8.6	10.7	8.9
24	2.6	2.9	2.7	8.8	8.9	9.3
28	2.4	2.6	2.6	8.5	9.4	8.0
30	2.4	2.8	2.8	8.4	8.8	-
52	2.2	2.4	2.8	8.9	9.4	9.5
73	2.2	2.1	3.0	8.6	8.7	9.4
95	2.0	1.7	2.5	9.6	9.5	9.4

[1] Temperature at each point increased about 4° F. during the period of sampling.

With regard to the second precaution, a test was run to find the effect of removing relatively large volumes of water from standpipes. Two 125-ml. water samples were obtained in rapid sequence from each of 41 points. The average absolute difference between the sequential samples was 0.5 mg./l. (range 0.0 mg./l. to 3.2 mg./l.). Figure 4 shows the relationship between first and second readings. Those points having no change in dissolved oxygen content fell on the line y = x. At points where the oxygen values were high, the second sample generally gave higher readings than the first, and most of these points were above the line y = x. Lower readings were generally obtained for second samples at points having low oxygen values, with most readings falling below y = x. Results of this nature might be expected if intragravel water originated from highly oxygenated stream water at points high in dissolved oxygen content and from poorly oxygenated ground water at points low in dissolved oxygen content.

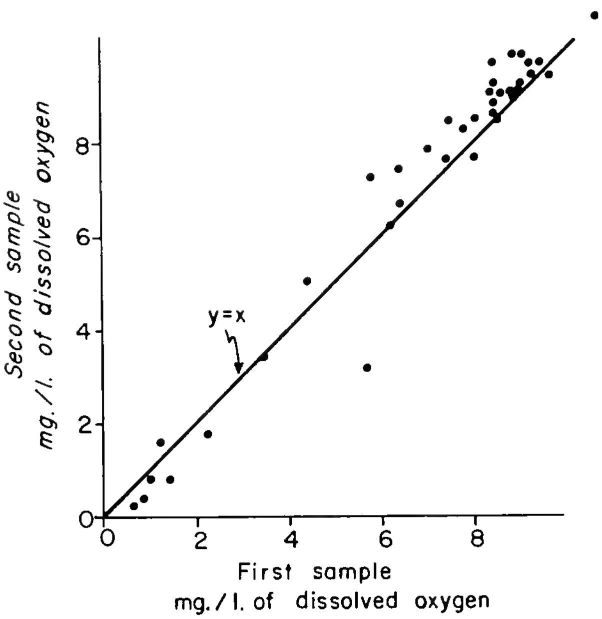

Figure 4.--Relationship between dissolved oxygen content of two 125-ml. water samples withdrawn less than 1 minute apart.

<u>Obtaining Data on Spatial Differences and Temporal Changes</u>

Two sampling procedures were used to obtain data on spatial differences and temporal changes in dissolved oxygen level of intragravel water. The first procedure involved systematic sampling of relatively small spawning areas, referred to as study areas. Study areas were located in Harris River and Twelvemile, Indian, and Old Tom Creeks (fig. 1). The second procedure involved random sampling within extensive spawning areas which were called sampling areas. The sampling areas described in this report were located in Twelvemile Creek.

Systematic Sampling

One purpose of systematic sampling was to obtain detailed information on spatial distribution of intragravel dissolved oxygen levels within a spawning bed. To accomplish this, standpipes were distributed uniformly at 5- to 10-foot intervals over each study area. No attempt was made to stratify pipes with respect to surface water depth or velocity. In several study areas, standpipes were driven into bars that received seepage water from the stream. Efforts were made to confine sampling to periods of low to moderately low stream discharge. During each sampling period an oxygen reading was obtained from every point sampled on two or more consecutive days. The purpose of sequential sampling was to obtain a mean dissolved oxygen value for each point. Mean values are more representative of dissolved oxygen level at the points sampled than single readings, and they are used to describe the dissolved oxygen content of the intragravel water at each point.

Nine study areas were sampled in 1957 and 1958. A brief description of each study area and a summary of the sampling effort in summer 1957 and 1958 are given in table 2. Figure 1 shows the locations of the study areas sampled.

Temporal changes in dissolved oxygen content.--The dissolved oxygen content of intragravel water changes continually at every point with time. Daily changes, seasonal changes, and yearly changes are discussed separately.

Daily.--Day-to-day changes at a point were often appreciable and occurred in a random fashion. Table 3 shows daily oxygen levels

TABLE 2.--Area and location of study areas with respect to tide level, sampling effort, and sampling dates

Study spawning area	Location in stream	Area sq. ft.	Number of points sampled 1957 and 1958	Dates of sampling	
				1957	1958
A	11-foot tide level	3,240	72	8/10-8/14	8/11-8/13
B	Above influence of tide	7,000	29	8/21-8/23	8/12-8/14
C	13-foot tide level	4,150	88	8/14-8/18	8/16-8/19
D	17-foot tide level	2,800	76	8/16-8/22	8/16-8/19
E	11-foot tide level	6,980	90	8/24-8/30	8/22-8/24
F	14-foot tide level	4,000	96	8/27-9/4	8/24-8/30
G	17-foot tide level	5,220	35	9/2 -9/4	8/26-8/30
H	14-foot tide level	3,500	22	9/12-9/13	9/5 -9/7
I	Above influence of tide	2,700	18	9/12-9/13	9/5 -9/7

TABLE 3.--Daily change in the dissolved oxygen content of intragravel water[1] at 8 points sampled concurrently

[In milligrams per liter]

Time after placing standpipe (days)	Mean daily discharge of Indian Creek[2] (c.f.s.)	Standpipe numbers							
		I	II	III	IV	V	VI	VII	VIII
1	7	1.8	1.0	5.4	7.6	9.4	0.6	8.1	9.3
2	6	1.1	0.8	6.8	7.5	9.8	0.9	8.7	10.2
3	6	2.9	0.8	6.5	6.1	10.4	0.8	9.6	10.2
4	6	3.5	1.9	8.6	7.2	10.3	1.6	8.7	9.4
5	85	3.2	0.9	9.5	7.8	9.3	2.2	9.9	9.8
6	60	5.4	1.2	8.2	8.8	11.4	1.0	6.6	10.1
7	51	--	--	--	--	--	--	--	--
8	100	4.3	2.5	8.6	7.0	10.3	0.6	7.9	10.2
9	67	3.9	1.5	9.0	5.2	11.0	1.4	8.3	10.5
Difference between maximum and minimum dissolved oxygen readings		4.3 mg./l.	1.7 mg./l.	4.1 mg./l.	3.6 mg./l.	2.1 mg./l.	1.6 mg./l.	3.3 mg./l.	1.2 mg./l.

[1] Stream temperatures remained near 52° F. when these observations were made.
[2] Data provided by Northern Experiment Station, U.S. Forest Service, Juneau, Alaska.

observed over a 9-day period at eight points sampled concurrently in study area D. The least difference between minimum and maximum readings was 1.2 mg./l. while the greatest difference was 4.3 mg./l. Oxygen levels increased slightly with discharge at points low in dissolved oxygen. Points high in dissolved oxygen showed little change with increased discharge. Temperature remained near 52° F. during the period of sampling.

Seasonal.--Seasonal changes in dissolved oxygen content of intragravel water were of large magnitude. Samples were obtained from 31 points in study area C during August and November 1957 and during March and August 1958 (table 4). Dissolved oxygen levels were at a very low level during August 1957. They had increased significantly, however, by November 1957, and a second significant increase had occurred by March 1958.

There was only a slight decline in oxygen level during August 1958, which was in sharp contrast to the previous year. Furthermore, the mean dissolved oxygen level of points sampled was significantly higher during August 1958 than during November 1957, despite the fact that water temperatures were approximately 10° F. cooler in November than in August.

Yearly.--Examination of dissolved oxygen levels observed in nine study areas during late August and early September of 1957 and 1958 revealed that a pronounced difference existed between these years (see appendix). Very low dissolved oxygen levels prevailed

TABLE 4.--Seasonal change in dissolved oxygen content of intragravel water (study area C)

Point number	Dissolved oxygen content (mg./l.)			
	Aug. 1957	Nov. 1957	Mar. 1958	Aug. 1958
	Water temp. 60° F.	Water temp. 45° F.	Water temp. 38° F.	Water temp. 55° F.
1	6.0	6.8	10.6	8.6
5	5.3	8.0	10.6	8.1
11	6.7	8.2	12.7	8.7
12	6.6	7.5	11.5	8.6
15	5.7	5.7	11.7	8.1
16	7.4	8.6	12.4	9.6
17	5.2	8.6	12.3	8.8
19	7.6	8.6	10.8	9.0
21	7.4	8.5	11.4	9.3
22	6.3	8.0	10.0	9.6
24	0.0	7.6	8.9	5.7
25	1.8	8.4	11.5	8.1
26	6.0	8.9	12.7	9.4
27	6.1	7.9	11.3	9.1
28	0.0	6.9	9.1	7.6
29	0.6	8.1	12.0	8.9
30	7.0	7.9	12.6	9.3
31	0.0	8.3	10.6	5.9
32	0.4	7.8	11.1	7.0
33	0.2	6.8	11.7	9.0
35	0.0	7.9	7.9	5.1
36	0.0	7.3	10.1	9.4
37	0.0	8.0	11.6	9.1
39	6.1	6.8	8.5	4.8
41	0.2	6.8	11.3	8.5
43	0.0	7.7	9.8	9.5
48	0.0	7.3	10.1	8.3
52	0.0	6.0	6.5	7.2
63	0.9	6.7	4.5	8.0
65	5.7	7.5	9.4	8.0
70	3.4	4.9	9.0	7.9
Mean	3.3	7.6	10.5	8.2

over a considerable portion of each study area during 1957, whereas in 1958 oxygen levels were high by comparison. Figure 5 presents a comparison of mean dissolved oxygen values obtained for each study area in 1957 and in 1958. The mean values shown were obtained from points that were sampled both years (see appendix).

In 1957 sampling was carried out during a period of warm weather, light precipitation, and cloudless days. In 1958 weather conditions were quite different; freshets occurred periodically and most days were overcast. Mean daily discharge of Indian Creek was 20 c.f.s. in August 1957 and 60 c.f.s. in August 1958.

Wickett (1958) has proposed that certain periods of low stream discharge were associated with low oxygen levels of the intragravel water. The data obtained in 1957 supported this contention. The relatively high dissolved oxygen levels observed in 1958 were probably the result of more favorable hydrological conditions.

Spatial differences in dissolved oxygen levels.--Spatial differences in dissolved oxygen content of intragravel water were generally more extreme in 1957 than in 1958. Many points were deficient in dissolved oxygen during the 1957 sampling period, and it was possible to define extensive areas of low (less than 2.5 mg./l.)[1] oxygen levels. These are shown in figures 6 through 11 for study areas A, B, C, D, F, and G. Points sampled both years are indicated in these figures by dots.

In 1958 dissolved oxygen levels exceeded 5.0 mg./l. at most of the points sampled.

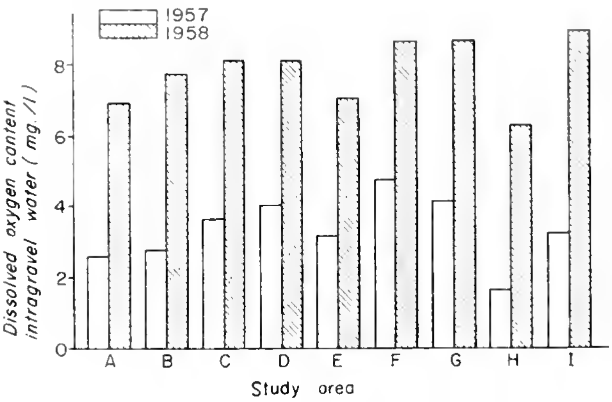

Figure 5.--Mean dissolved oxygen values obtained at study areas in late August and early September of 1957 and 1958.

[1] No physiological significance is attached to a dissolved oxygen content of 2.5 mg./l. This value was selected purely for purposes of illustration.

Relatively few points exhibited low levels of dissolved oxygen. The areas of relatively low and high oxygen values occurring in 1958 are also shown in figures 6 through 11.

A table of dissolved oxygen values observed within each study area appears in the appendix.

Random Sampling

By sampling randomly it was possible to obtain estimates of mean dissolved oxygen level of intragravel water within large spawning areas (sampling areas). Spatial differences in dissolved oxygen levels were detected by sampling two or more areas simultaneously. Temporal changes in dissolved oxygen levels were detected by sampling each sampling area two or more times. Standard statistical techniques were employed to test for significant differences between estimated mean dissolved oxygen values.

Two sampling areas on Twelvemile Creek were sampled concurrently in a random manner during early September and late November, 1958. The lower sampling area, extending from the 12- to 16-foot tide level, incorporated 60,000 square feet of streambed and included most of the intertidal spawning area. The upper sampling area extended upstream from the intertidal zone and incorporated 68,000 square feet of streambed. The heaviest observed spawning intensity above the intertidal zone occurred in this area.

The general sampling procedure employed was to place standpipes at randomly selected points 1 day prior to sampling. One dissolved oxygen reading was obtained from each point, and an attempt was made to obtain all readings for both sampling areas on the same day.

In September 1958, dissolved oxygen readings were obtained from approximately 100 points within each sampling area. In November 1958, it was possible to reduce the sampling effort to 50 points per area, since the variability among readings was considerably less in autumn than in late summer.

Ninety-five percent confidence interval estimates of mean dissolved oxygen content of intragravel water within the two Twelvemile Creek sampling areas are given in table 5. These estimates indicated that:

1. Oxygen levels were significantly higher within both sampling areas during midautumn than during late summer, i.e., there was a change in oxygen levels with time.

2. Dissolved oxygen levels were significantly lower in the upstream sampling area than in the intertidal sampling area

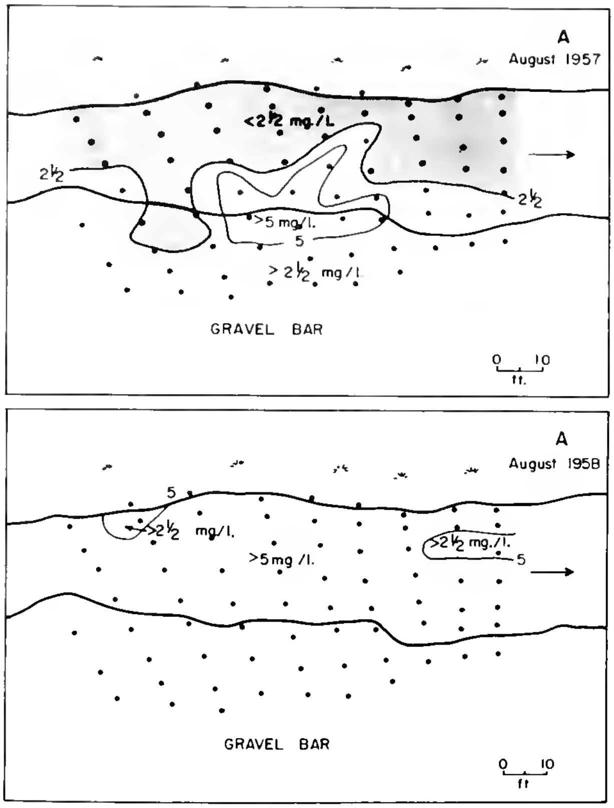

Figure 6.--Dissolved oxygen levels at study area A (11-foot tide level of Harris River). Samples were obtained 7 to 10 inches beneath gravel surface at points shown.

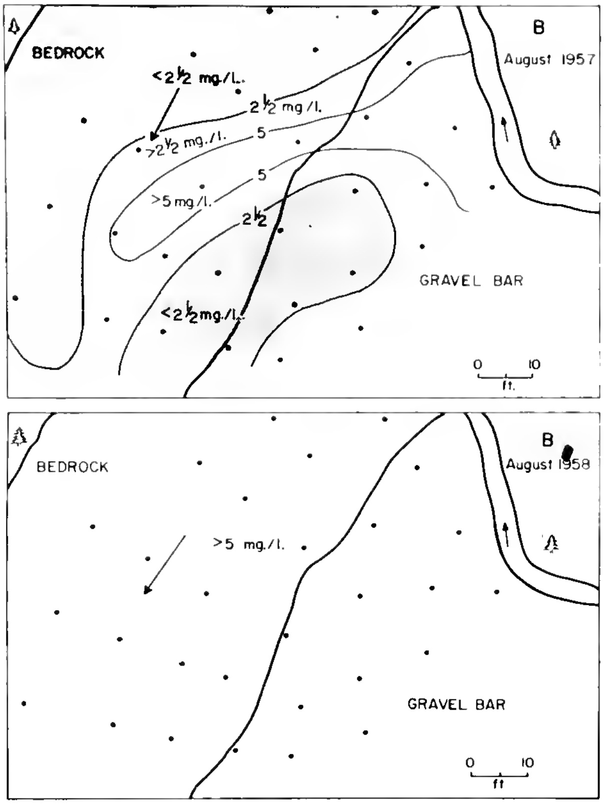

Figure 7.--Dissolved oxygen levels at study area B (upstream Harris River). Samples were obtained 7 to 10 inches beneath gravel surface at points shown.

during the early September spawning period, i.e., average oxygen levels differed spatially between two large spawning areas in late summer.

3. There was no significant difference in oxygen levels between the two sampling areas in midautumn.

ROUTINE EVALUATION OF OXYGEN LEVELS

An important objective of the study of dissolved oxygen content of intragravel water is to determine the importance of oxygen level as a factor associated with natural mortality of salmon embryos. Field observations of dissolved oxygen levels and mortality are not intended to define oxygen levels lethal to embryos. Instead, they are designed to establish general relationships between oxygen level and mortality in natural environments. Determination of rates of oxygen supply necessary to sustain embryos is primarily a laboratory problem, and some progress has been reported on the study of the oxygen requirements of embryos (Alderdice, Wickett, and Brett, 1958; Doudoroff, 1957; Silver, 1960; Shumway, 1960).

There was evidence that the low dissolved oxygen levels observed in late summer 1957 were associated with high mortality; whereas, the high dissolved oxygen levels observed in late summer 1958 were associated with low mortality. The ratio of dead to total pink salmon eggs collected from 18 random points in Indian and Twelvemile Creeks in November 1957 was 68.6 percent. In November 1958, the ratio of dead to total pink salmon eggs collected from 20 random points in Indian and Twelvemile Creeks was only 11.4 percent. This evidence suggested that low oxygen levels observed in 1957 were indicative of environmental conditions detrimental to the survival of salmon embryos.

It has been shown that spatial and temporal variations in oxygen levels may be of great magnitude. These variations are apparently influenced by complex environmental factors that are not well understood.

Sampling methods described in this report when used with statistically designed sampling

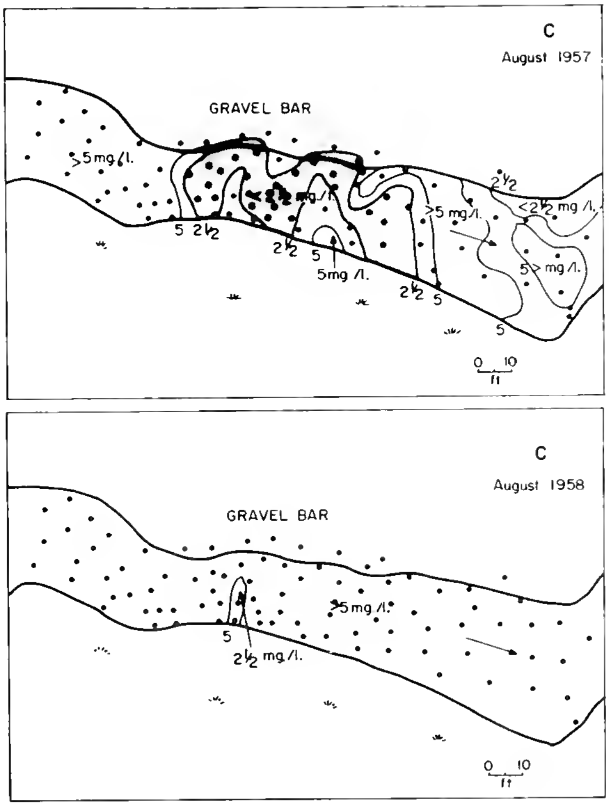

Figure 8.--Dissolved oxygen levels at study area C (13-foot tide level of Indian Creek). Samples were obtained 7 to 10 inches beneath gravel surface at points shown.

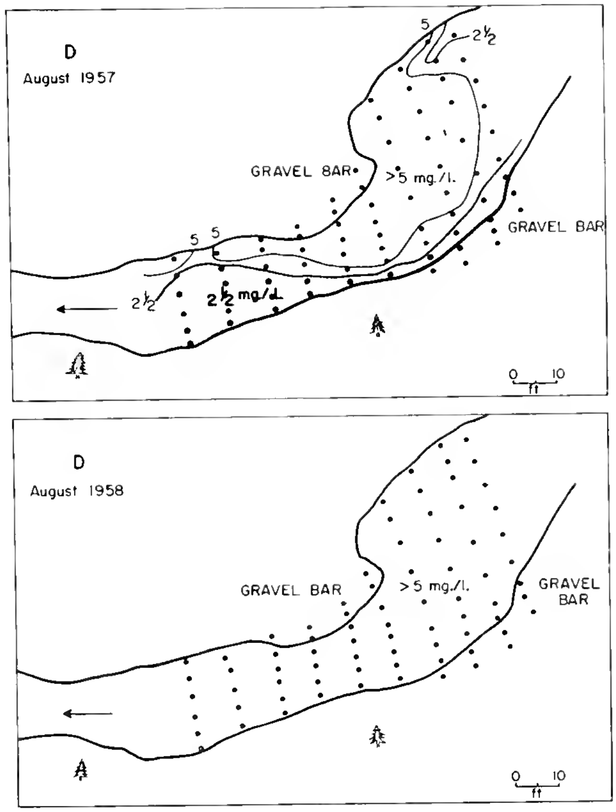

Figure 9.--Dissolved oxygen levels at study area D (17-foot tide level of Indian Creek). Samples were obtained 7 to 10 inches beneath gravel surface at points shown.

schemes are sufficiently precise to detect significant differences in oxygen levels in spawning gravels. For routine evaluation of oxygen levels, there are certain advantages to sampling randomly. They are:

1. Sampling areas may be of any size.

2. To obtain uniformly precise estimates of mean dissolved oxygen levels at any time, sampling effort may be equally allocated among areas, regardless of their size.

3. The sampling effort required to obtain a fairly precise estimate of mean dissolved oxygen level of intragravel water is not excessive.

4. Changes in dissolved oxygen levels with time may be determined by sampling individual areas on two or more occasions.

5. Spatial differences in dissolved oxygen levels may be determined by sampling two or more areas simultaneously.

With regard to points 1 and 2 above, examination of data given in the appendix indicates that temporal and spatial variations are of a similar magnitude in most spawning riffles. It is therefore possible by sampling equal numbers of random points to estimate the mean dissolved oxygen content for a stream or a single riffle with almost equal precision.

With regard to point 3, it has been observed that the greatest variations in dissolved oxygen levels occur in late summer during and after spawning. By sampling 100 random points at this time, the expected 95-percent confidence limits of the mean dissolved oxygen content of intragravel water is approximately ± 0.5 mg./l. of the sample mean. At other times, the mean dissolved oxygen level can be estimated with almost equal precision by sampling 50 points.

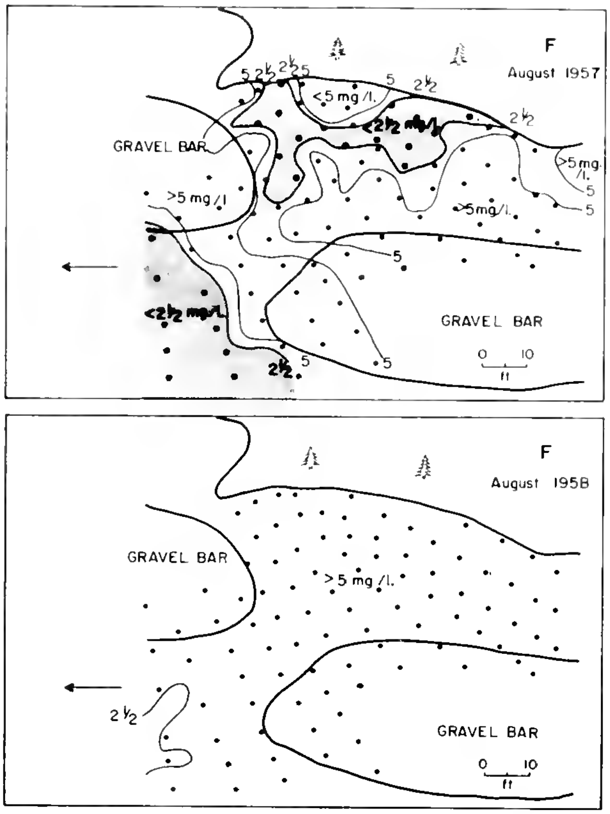

Figure 10.--Dissolved oxygen levels at study area F (14-foot tide level of Twelvemile Creek). Samples were obtained 7 to 10 inches beneath gravel surface at points shown.

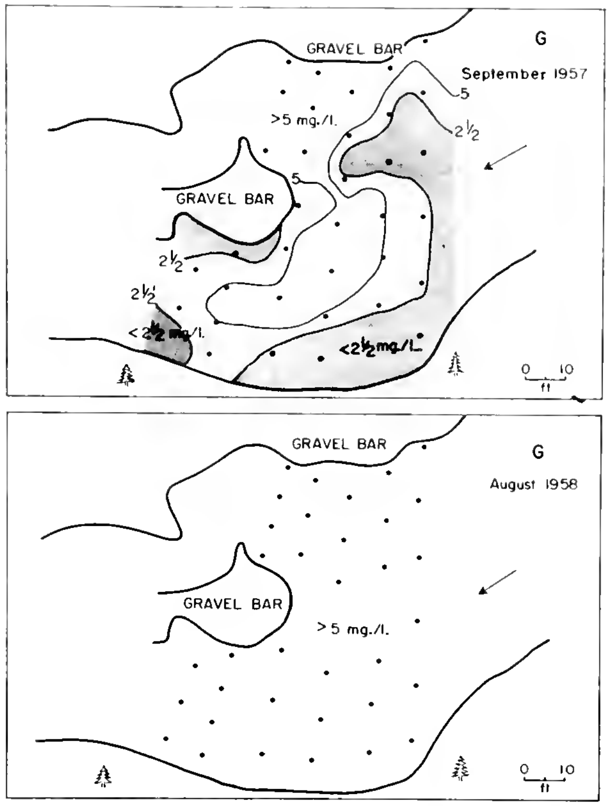

Figure 11.--Dissolved oxygen levels at study area G (17-foot tide level of Twelvemile Creek). Samples were obtained 7 to 10 inches beneath gravel surface at points shown.

TABLE 5.--Estimates of the mean dissolved oxygen levels of intragravel water in Twelvemile Creek

Sampling area	September 1958		November 1958	
	Sample size	95-percent confidence interval estimates of mean	Sample size	95-percent confidence interval estimates of mean
Intertidal	93	6.3 mg./l. $< \mu <$ 7.4 mg./l.	50	8.3 mg./l. $< \mu <$ 9.5 mg./l.
Upstream	100	4.8 mg./l. $< \mu <$ 6.1 mg./l.	50	8.0 mg./l. $< \mu <$ 9.6 mg./l.

SUMMARY

1. Evidence is presented that mortality of pink and chum salmon embryos is high. One factor thought to contribute to high mortality is low streamflow which may be accompanied by a ·eduction of dissolved oxygen content of intragravel water.

2. Equipment and techniques employed to sample dissolved oxygen content of intragravel water are described. An important component of this equipment is a lightweight, inexpensive plastic standpipe.

3. Two precautions necessary to insure the procurement of reliable water samples are discussed. They are (1) standpipes which should be left in the streambed for 24 hours or longer before sampling and (2) only small water samples (about 30 ml.) which should be removed.

4. Temporal changes in dissolved oxygen content of intragravel water are reported. Observed temporal changes are discussed under three categories--daily, seasonal, and yearly. It was found that dissolved oxygen content of intragravel water fluctuated daily

at most points. Seasonal and yearly changes were of much greater magnitude, however, and they affected extensive spawning areas.

5. Spatial differences in dissolved oxygen levels of intragravel water are described. It was found that spatial differences were greatest during periods of low discharge and warm weather.

6. A random sampling procedure to evaluate mean dissolved oxygen levels within major spawning areas is described. Random sampling was found to provide a low-cost and precise estimate of mean oxygen level within spawning gravels.

LITERATURE CITED

ALDERDICE, D. F., W. P. WICKETT, and J. R. BRETT.
1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. Journal of the Fisheries Research Board of Canada, vol. 15, no. 2, p. 229-250.

CHAMBERS, J. S., G. H. ALLEN, and R. T. PRESSEY.
1955. Research relating to a study of spawning grounds in natural areas. Annual Report of Washington Department of Fisheries to U.S. Army Corps of Engineers under contract no. DA. 35-026-Eng-20572, 175 p.

DOUDOROFF, PETER.
1957. Water quality requirements of fishes and the effects of toxic substances. In Brown, Margaret Elizabeth, editor, Physiology of Fishes. Academic Press, New York, vol. 2, chap. 9, p. 403-430.

GANGMARK, HAROLD A., and RICHARD G. BAKKALA.
1959. Plastic standpipe for sampling streambed environment of salmon spawn. U.S. Fish and Wildlife Service, Special Scientific Report--Fisheries No. 261, 20 p.

HARPER, E. L.
1953. Semimicrodetermination of dissolved oxygen. Analytical Chemistry, vol. 25, p. 187-188.

HUNTER, J. G.
1948. Natural propagation of salmon in the central coastal area of British Columbia. Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Stations, no. 77, p. 105-106.

NEAVE, FERRIS, and R. E. FOERSTER.
1955. Problems of Pacific salmon management. Transactions of the Twentieth North American Wildlife Conference, p. 426-439.

NEAVE, F., and W. P. WICKETT.
1955. Transplantation of pink salmon into the Fraser Valley in a barren year. Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Stations, no. 103, p. 14-15.

POLLARD, R. A.
1955. Measuring seepage through salmon spawning gravel. Journal of the Fisheries Research Board of Canada, vol. 12, no. 5, p. 706-741.

SHUMWAY, DEAN LEE.
1960. The influence of water velocity on the development of salmonid embryos at low oxygen levels. M.S. thesis, Oregon State College, Corvallis, Oregon, 49 p.

SILVER, STUART JAYSON.
1960. The influence of water velocity and dissolved oxygen on the development of salmonid embryos. M.S. thesis, Oregon State College, Corvallis, Oregon, 50 p.

TERHUNE, L. D. B.
1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. Journal of the Fisheries Research Board of Canada, vol. 15, no. 5, p. 1027-1063.

WICKETT, W. P[ERCY].
1952. Production of chum and pink salmon in a controlled stream. Fisheries Research Board of Canada, Progress Reports of the Pacific Coast Stations, no. 93, p. 7-9.

1954. The oxygen supply to salmon eggs in spawning beds. Journal of the Fisheries Research Board of Canada, vol. 11, no. 6, p. 933-953.

1958. Review of certain environmental factors affecting the production of pink and chum salmon. Journal of the Fisheries Research Board of Canada, vol. 15, no. 5, p. 1103-1126.

APPENDIX

Dissolved oxygen values* obtained for all study areas in late summer of 1957 and of 1958
(Dissolved oxygen content in mg./l.)

Study area																	
A		B		C		D		E		F		G		H		I	
1957	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*
3.9	6.3	3.6	8.7	6.0	8.6	0.8	6.2	5.6	4.5	7.1	9.6	5.3	8.8	1.4	9.7	5.6	9.5
5.3	9.9	2.2	8.3	5.5	9.0	3.7	9.7	2.4	5.2	8.8	9.3	6.0	9.0	5.3	2.1	5.9	9.0
2.7	9.6	1.6	7.1	5.3	8.1	6.9	9.4	1.3	8.5	0.5	7.1	2.4	8.4	0.0	3.2	7.2	10.3
0.6	7.1	1.8	8.0	5.9	9.1	5.0	9.7	1.5	6.1	1.8	3.1	1.8	9.5	0.0	5.6	0.7	8.6
0.9	4.9	4.0	9.6	7.3	8.2	3.3	9.8	3.2	9.4	5.7	5.2	1.3	7.3	0.0	7.0	4.5	8.4
0.0	7.2	2.3	9.1	7.3	7.6	2.2	8.4	4.0	1.9	1.8	2.2	2.3	9.4	2.4	3.7	5.2	10.0
0.0	1.7	0.7	7.2	6.7	8.7	1.3	4.7	1.8	1.3	1.4	8.9	6.1	10.5	0.0	0.6	3.6	8.6
4.0	6.5	5.4	7.1	6.6	8.6	0.8	3.3	1.2	5.6	8.5	10.3	0.6	9.9	0.5	9.4	1.8	9.0
3.5	5.2	1.2	9.3	3.5	9.4	0.4	4.0	4.6	4.4	8.0	9.4	1.8	8.7	5.0	9.1	0.2	10.1
3.3	8.3	1.2	4.6	6.3	9.4	5.4	7.7	1.1	8.8	0.8	7.3	5.3	10.0	1.6	2.3	2.5	10.3
0.8	9.1	1.3	7.0	5.7	8.1	6.2	9.0	2.0	8.9	2.0	7.6	6.8	10.6	0.2	8.4	1.0	9.7
1.8	4.0	6.3	8.4	7.4	9.6	6.8	9.3	7.4	8.9	2.6	7.0	4.7	5.8	0.0	9.4	1.8	9.2
0.0	5.9	4.0	8.8	5.2	8.8	6.6	10.0	6.8	8.8	0.0	5.1	0.2	0.7	2.6	9.3	4.8	10.5
0.6	3.5	0.4	9.5	5.4	9.1	0.7	9.4	2.1	1.0	7.9	9.2	8.2	10.8	0.0	4.2	4.0	8.7
2.1	6.8	3.2	5.2	7.6	9.0	8.2	10.4	1.5	0.9	7.8	8.8	5.4	10.7	1.2	9.2	2.1	9.5
3.0	6.3	2.3	5.5	6.0	9.2	1.6	4.8	0.4	0.8	6.1	8.6	0.0	8.2	4.2	6.7	3.0	9.4
1.9	10.0	5.8	2.7	7.4	9.3	1.2	3.8	0.4	3.1	6.5	5.0	4.9	10.3	3.8	6.8	5.3	10.3
1.2	5.5	2.1	7.4	6.3	9.6	1.1	5.9	0.5	3.4	8.0	7.0	8.2	9.9	2.9	1.6	0.1	0.7
0.0	9.1	0.8	9.1	6.6	9.5	6.0	8.0	1.8	3.3	8.2	7.3	8.0	10.2	0.8	5.9		
0.1	8.0	3.5	9.4	0.0	5.7	7.9	8.8	8.4	5.4	2.3	5.0	1.1	3.3	0.3	6.9		
3.7	6.9	5.2	9.2	1.8	8.1	5.7	9.4	5.8	9.0	8.6	10.0	7.0	10.8	1.5	9.5		
3.1	6.1	1.2	4.9	6.0	9.4	8.2	10.0	6.1	8.2	0.2	10.2	7.4	10.5	4.0	7.9		
6.0	7.5	1.6	9.0	6.1	9.1	8.2	9.9	6.4	9.3	0.3	8.1	7.4	10.5				
5.2	6.8	7.0	7.7	0.0	7.6	7.3	10.3	3.3	9.3	7.2	7.8	3.4	10.2				
0.9	8.0	7.0	9.3	0.6	8.9	0.3	2.5	7.2	3.5	8.4	9.3	1.5	7.5				
4.7	6.4	4.8	7.5	7.0	9.3	0.3	9.7	4.5	3.9	8.2	6.3	8.2	9.0				
1.2	6.5	0.2	8.3	0.0	5.9	2.3	9.7	6.6	1.9	7.6	6.7	4.4	10.1				
1.4	5.6	0.2	9.1	0.4	7.0	3.4	9.0	1.8	2.1	9.2	10.5	4.8	10.0				
2.2	5.4	0.0	8.6	0.2	9.0	6.7	5.1	0.6	1.2	0.8	10.0	6.9	10.0				
1.8	4.9			5.8	9.7	7.3	9.4	0.4	2.3	4.8	9.8	4.7	10.2				
7.8	6.7			0.0	5.1	6.3	9.8	1.0	8.2	8.9	10.5	6.3	10.0				
4.5	6.8			0.0	9.4	7.1	10.0	7.4	7.3	2.2	9.0	2.2	7.5				
7.5	9.3			0.0	9.1	7.8	10.1	7.0	8.4	9.0	9.0	3.6	2.4				
0.0	9.6			7.1	9.6	1.6	1.6	8.1	7.3	6.5	7.8	3.7	8.1				
0.0	6.1			6.1	4.8	2.2	7.2	7.8	7.1	8.0	8.0	1.2	5.8				
2.8	7.4			4.7	4.1	6.6	9.5	6.3	9.3	6.2	5.0						
2.8	5.6			0.2	8.5	5.9	7.7	5.2	7.9	5.2	10.7						
3.4	4.7			2.2	9.2	7.1	7.0	7.3	6.6	0.2	7.7						
7.1	8.3			0.0	9.5	7.7	9.6	7.3	6.5	5.1	10.3						
6.3	9.6			0.0	8.2	7.9	9.6	7.8	3.9	0.6	9.4						
1.7	10.8			0.0	7.5	7.6	9.5	4.3	7.3	6.9	9.6						
2.6	9.1			2.7	9.2	0.6	2.4	4.5	6.5	7.0	9.4						
2.1	4.9			3.9	9.6	1.4	8.6	5.5	7.5	6.2	9.9						
0.4	5.4			0.0	8.5	4.8	9.6	5.7	6.5	6.1	8.7						
3.4	6.0			3.4	9.6	5.3	9.5	5.3	8.0	0.4	8.2						
3.2	5.5			6.1	8.7	6.0	8.4	2.5	7.9	0.2	9.3						
2.3	5.2			0.0	7.2	5.7	9.2	7.2	8.6	6.4	9.4						
9.7	6.5			0.0	7.7	6.5	9.3	7.1	7.2	6.1	9.8						
8.0	8.9			0.0	7.3	2.5	8.8	8.1	7.4	5.2	9.8						
6.1	8.3			0.7	7.7	1.0	9.8	5.9	4.9	6.9	10.1						
0.0	5.9			0.0	7.4	0.3	9.6	2.2	7.5	8.0	9.9						
2.0	8.9			0.6	6.9	3.8	9.8	0.0	5.1	6.3	7.2						
0.0	5.3			4.0	6.5	5.1	9.9	0.0	4.9	0.6	5.2						
3.0	6.4			0.2	7.8	5.5	9.0	0.2	8.5	2.9	8.2						
2.2	6.4			0.7	8.0	7.1	8.9	0.0	8.7	1.6	9.2						
2.8	5.4			0.9	8.0	6.9	9.4	0.1	9.4	0.2	9.6						

See footnote at end of table

Study area																	
A		B		C		D		E		F		G		H		I	
1957	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*	*1957*	*1958*
1.4	7.7			2.9	4.4	0.0	5.1	7.1	9.9	4.2	10.1						
1.0	9.4			5.7	8.0	2.2	9.4	0.2	9.1	6.1	10.4						
0.3	9.6			6.2	9.4	0.0	9.0	6.9	9.3	6.5	10.0						
0.1	8.5			5.6	9.4	2.7	9.2	6.2	8.9	5.1	9.9						
2.3	3.5			3.8	7.0	5.4	9.6	8.0	9.1	7.3	10.4						
3.4	5.7			3.4	7.9	5.0	9.7	0.0	7.1	5.1	10.5						
2.3	5.7			0.1	6.2	6.8	9.6	1.0	9.6	0.0	3.4						
2.8	6.7			5.5	9.5	0.4	3.4	0.0	8.9	6.9	8.0						
1.7	9.0			4.5	7.2	0.1	4.6	0.0	9.6	6.6	9.6						
3.1	8.1			0.0	6.6	5.8	9.4	0.0	8.4	0.6	8.8						
4.0	8.0			0.0	7.3	0.2	5.6	5.9	9.9	2.9	10.2						
0.0	8.3			5.1	8.5	2.6	8.3	4.1	9.5	0.6	9.8						
0.0	9.0			5.0	9.9	1.4	7.9	8.0	9.1	3.2	9.8						
2.9	8.0			0.5	9.4	4.4	6.9	9.2	9.6	6.6	9.8						
4.0	8.2			5.8	9.7	0.0	8.8	3.4	10.0	0.2	10.6						
2.2	8.0			4.8	8.6	0.3	9.8	2.5	9.0	7.6	9.7						
				1.3	6.4	0.6	9.4	0.0	9.0	6.6	10.0						
				1.4	6.9	5.7	9.4	3.4	8.6	7.5	9.2						
				5.1	6.9	2.2	9.7	0.0	9.0	0.7	9.0						
				6.6	7.3	6.2	9.0	2.7	8.4	5.5	10.6						
				5.2	9.8			3.9	8.4	0.9	8.8						
				0.9	9.7			0.0	8.9	7.1	10.6						
				0.8	8.0			2.4	6.6	4.9	9.9						
				5.4	5.6			0.0	9.4	7.5	10.0						
				5.6	8.3			0.0	8.6	8.2	10.1						
				2.2	9.2			7.5	9.6	7.5	9.6						
				6.7	9.4			5.8	8.3	4.6	7.9						
				7.4	9.5			3.9	7.7	6.6	8.9						
				6.7	8.1			0.0	7.4	1.8	10.0						
				6.6	7.8			0.0	5.4	2.3	7.8						
				4.1	8.9			1.2	7.1	4.5	9.8						
				7.7	8.0			0.1	8.9	8.2	9.6						
								9.1	8.4	6.6	9.4						
								0.0	8.8	3.7	9.9						
										4.6	10.2						
										0.0	2.5						
										0.3	6.8						
										4.4	6.8						
										2.6	7.6						
										6.2	6.2						

*These are mean values of two or more sequential samples taken at each point.

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