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WATERFLOW THROUGH A SALMON SPAWNING RIFFLE IN SOUTHEASTERN ALASKA

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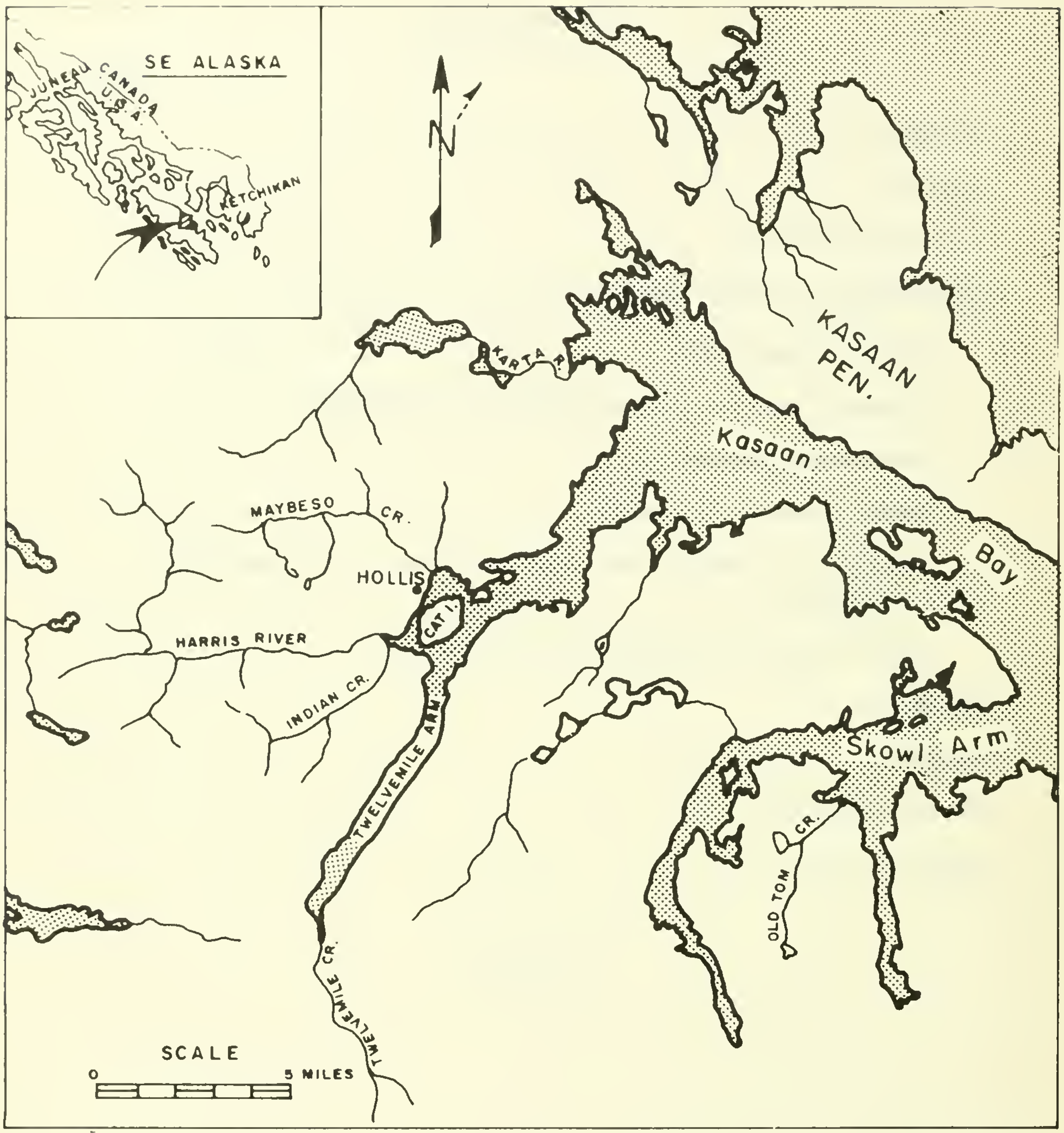

Figure 1.--Location of study streams, Hollis area.

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ABSTRACT

The following characteristics were studied in a small salmon stream in Southeastern Alaska from 1956 through 1959: (1) dissolved oxygen content of ground water, (2) variation of dissolved oxygen with depth in streambed, (3) temperature of ground water, (4) extent of ground-water seepage, (5) interchange of flowing stream water and water of streambed gravels, and (6) flow of water in the gravel of streambank and gravel bar.

Ground water was generally low in dissolved oxygen content, and dissolved oxygen levels decreased with depth in streambed. Because of these and other points discussed in this paper, I conclude that the main source of intragravel water of high oxygen content is the flowing stream.

INTRODUCTION

In 1956 the Fisheries Research Institute started a study of the effects of logging on the productivity of pink salmon *(Oncorhynchus gorbuscha)* streams in Alaska, and work has been conducted on four streams in the Hollis area of Kasaan Bay in Southeastern Alaska (fig. 1). The general plan of research was to define normal conditions in the stream before logging, to measure any changes that might accompany logging operations, and to define limits within which environmental changes could occur and yet permit survival of salmon eggs and larvae. The Fisheries Research Institute, in cooperation with the U.S. Forest Service, performed the work under a contract awarded by the Bureau of Commercial Fisheries utilizing Saltonstall-Kennedy funds.

Part of this research involves the mechanics of waterflow within the gravel of a spawning riffle in Indian Creek, one of the study streams. Knowledge of the nature of waterflow through spawning gravels is basic to our study of effects of logging because survival of salmon eggs and larvae depends to a large extent upon water quality (Royce, 1959).

The investigation included: (1) determining dissolved oxygen content of ground water, (2) measuring variation of dissolved oxygen with depth in streambed, (3) measuring ground-water temperatures, (4) determining extent of ground-water seepage, (5) demonstrating the existence of interchange of flowing stream water and water of the streambed gravel, and (6) studying flow characteristics of water in the gravel of streambanks and gravel bars.

The object of this paper is to present and discuss parts of the Indian Creek study.

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STUDY AREA

Indian Creek is a small stream with a watershed area of 8.6 square miles. It is confluent at the 12-foot tide level with the larger Harris River, which flows into Twelvemile Arm. Pink salmon spawn only in the lower portion of Indian Creek. Median flood flow of this stream has been recorded as 456 c.f.s. and median flow as 3 c.f.s. (James, 1956). Visual estimates of peak abundance of pink salmon ranged from 100 to 16,000 during the years 1950 through 1958 (peak abundance is that time when the most fish are in the stream).

The valley floor through which Indian Creek flows ascends sharply as it leaves the stream mouth. The sides of the valley are steep in places and heavily wooded, chiefly with Sitka spruce and western hemlock. Although I made no detailed examination of the nature of the valley or of the valley floor, they are probably similar to those of other streams in the area. Zach (1950) reported that many of these watersheds are composed primarily of thin soils over bedrock on steep slopes and waterlogged peat in the muskegs.

There are two major sources of water to Indian Creek--surface runoff during rains and ground-water seepage during periods of drought. Rain-water is charged with dissolved oxygen. On its way to the stream, however, as ground water it is subject to a biochemical oxygen demand imposed by the type of aquifer through which it passes. The entire watershed does not contribute a large amount of ground water as the base flow decreases from approximately 5 c.f.s. 10 days after cessation of rain to 3 c.f.s. 30 days after (James, 1956).

Although most work was done at the 16- to 19-foot tide level, one experiment was done at the 11- to 13-foot tide level.

EQUIPMENT AND METHODS

Dissolved oxygen determinations were made on 25-milliliter portions of water that were withdrawn from plastic standpipes driven to specified depths in banks and streambed. Water samples were fixed and analyzed at once by the Winkler method (for a description of standpipes, method of driving, etc., see McNeil, 1962).

Vertical and horizontal variation of dissolved oxygen content of water within the gravel was determined from Latin square and randomized block designs in standpipe placement.

Water temperatures were measured with a Moeller hand thermometer, a Moeller dial thermometer, and a TRI-R thermistor thermometer. Dial and thermistor thermometers were fitted with 6-foot cables so that the sensitive portions of the bulbs could be inserted into standpipes.

Ground water was detected and traced by means of its difference from stream water in dissolved oxygen content and temperature.

Fluorescein dye was used to chart flow directions of water within the gravel of the streambanks, gravel bars, and streambed and to demonstrate interchange of flowing stream water and water within the gravel. Points of origin and emergence of dye-marked water were located with an engineer's transit.

CHARACTERISTICS OF INDIAN CREEK GROUND WATER

Ground water extends from the water table down to the first impervious stratum. The migratory behavior of ground water in this surface zone is controlled by local topography and gravity flow characteristics; hence, the general trend of flow under the influence of gravity is into lakes and streams. The rate and direction of flow conform primarily to slopes of the land surface and to the form of the first impervious layer below the water table. (A detailed discussion of ground water is given by Todd (1959) and others.)

Dissolved Oxygen Content

The sources of ground water are mainly rain and snow. When rain-water falls upon the ground it is saturated with oxygen at the prevailing temperature, but is subject to a biochemical oxygen demand as it percolates through the ground and after it reaches the water table. The extent of this biochemical oxygen demand depends on temperature and on the quality and quantity of organic matter through which the water must pass.

Despite depletion of its oxygen by organic matter, ground water in certain places contains a relatively large amount of dissolved oxygen, even as it enters a stream or lake beach. Benson (1953) wrote that attempts to locate ground water in Pigeon River, Mich., by chemical methods were futile. This implies that ground water that entered spawning areas of Pigeon River was neither higher nor lower in dissolved oxygen content than any other water he sampled in the stream. Upwelling ground water in lake beaches in Alaska and the Kamchatka Peninsula must contain sufficient dissolved oxygen to support the races of sockeye salmon *(Oncorhynchus nerka)* that successfully spawn on these beaches year after year. Krogius and Krokhin (1948) reported that dissolved oxygen in ground water in sockeye salmon spawning grounds in Lake Dalnee ranged from 1.5 to 13.5 mg./l. but more often from 5 to 6 mg./l. Kurenkov (1957) said that oxygen saturation of spring water in Kamchatka was as high as 90 to 95 percent.

Sampling of Indian Creek ground water was confined to point locations in 1958. In 1959 the same points plus two 4 by 4 Latin squares were used. (Figure 2 shows locations of the installations.)

Sampling points were distributed in the banks and over the gravel bar. Depths of standpipes in relation to a datum plane and each other are shown in figure 3. Water-table heights were determined by measuring distance from top of pipe to surface of water within the pipe.

The two 4 by 4 Latin squares were installed so that the shallowest four standpipes would usually reach the top of the water table (missing data in tables 2 and 8 resulted when standpipes did not reach the water table). Each of the three remaining sets of four pipes was placed 7 inches deeper. Distance from the shallowest four pipes to the deepest four pipes was then 21 inches.

Data from point locations in 1958 and 1959 (table 1) indicate that, in general, ground water that contributed to the Indian Creek riffle was characterized by low dissolved oxygen levels, except in late winter and early spring. At this time of year, when ground-water temperatures are lowest, increase in dissolved oxygen is attributed to decreased biochemical oxygen demand of organic materials in the ground-water aquifer.

Data from the Latin squares (table 2) indicate that during the sampling period dissolved oxygen in ground water was generally low. Oxygen levels in Latin square 1 were

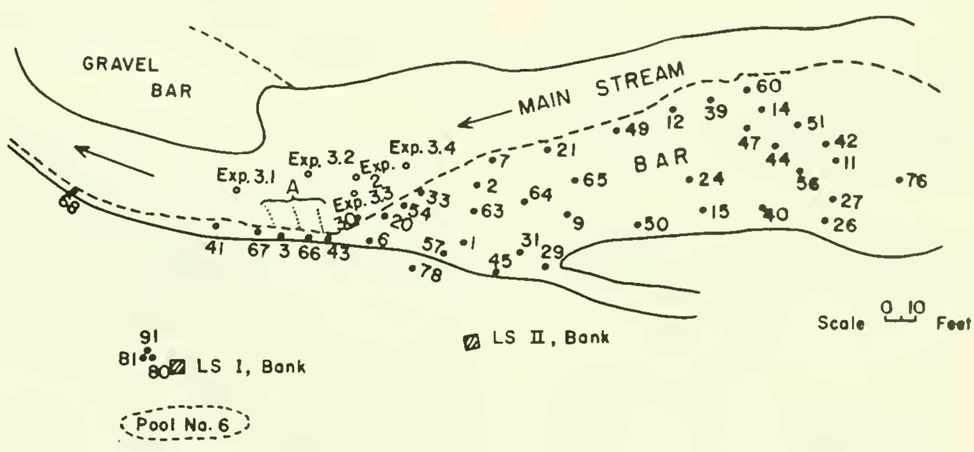

Figure 2.--Indian Creek study area 1 showing location of standpipes, Latin squares, and ground-water extension from bank to stream experiment (A).

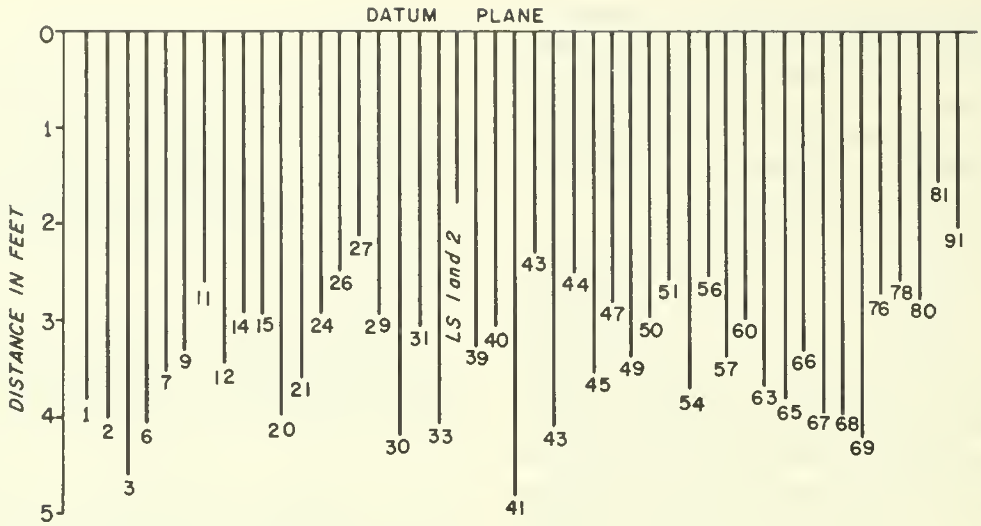

Figure 3.--Distance of bottom of standpipes in gravel bar and bank from established datum plane, Indian Creek, 1958-59.

slightly higher, and more gradation with depth is apparent than in Latin square 2.

Variation of Dissolved Oxygen with Depth in the Streambed

To substantiate results of measurements of dissolved oxygen content of ground water, the variation of dissolved oxygen with depth in the streambed was measured. If the dissolved oxygen content increased with depth or remained the same at different depths, then upwelling ground water could be credited as a source of the water of high oxygen content. If, on the other hand, dissolved oxygen content decreased with depth, a shallower source would be indicated.

Chambers, Allen, and Pressey (1955) have previously reported that the results of tests on streams in Washington State showed that dissolved oxygen of intragravel water decreased with depth regardless of whether or not salmon had used the gravel for spawning.

Variation of dissolved oxygen content with depth in streambed gravel was examined in Indian Creek spawning riffles by means of designed experiments. I first used a randomized block placement of standpipes, but shifted to 4 by 4 and 3 by 3 Latin squares, because Latin square arrangements could be installed in less time. To define spatial variation several installations were made in different places in the riffle (fig. 2).

In experiment 1 (fig. 4), 20 standpipes were used, 5 each of which were randomly placed in study area 3 in a 10- by 10-foot square at depths of 5, 10, 15, and 20 inches in the gravel. In 1958 these pipes were sampled on June 3, 5, 7, and 9, and September 13.

In experiment 2, standpipes were placed in a 4 by 4 Latin square design in study area 1 at depths of 5, 10, 15, and 20 inches in the gravel. These pipes were sampled in 1958 on June 4, 5, 7, and 9.

Experiment 3 was made up of four 3 by 3 Latin squares in the same general area as experiment 2. Within each square there were three pipes at 5 inches, three at 10 inches, and three at 20 inches in the gravel. In 1959 these pipes were sampled on September 4, 10, and 13.

Analysis of the random block experiment (experiment 1) shows significant differences in time and with depth (table 3). The 4 by 4 Latin square (experiment 2) revealed a significant difference with depth but no significant difference because of location of pipes (table 4). Analysis of the four 3 by 3 Latin squares (experiment 3) indicates significant differences between depths for squares 3.1, 3.3, and 3.4, but no significant difference with depth in square 3.2 (table 5). Also indicated is a significant difference because of placement of pipes in square 3.3.

Table 1.--Dissolved oxygen concentration in ground-water standpipes - mg./l. Indian Creek study area 1, 1958-59

Date		Stream	Standpipe numbers												
			3	6	41	43	45	57	66	67	68	78	80	81	91
1958	6/8	>9.0	0.6	2.2	2.3	1.9	2.9	2.7							
	6/10	"	0.6	2.8	3.2	2.2	3.3	2.8							
	8/20	"	1.1	6.4		3.8		3.9	6.3	8.8	8.6				
	8/22	"	0.4	1.9	4.0	3.7	1.7		3.8	6.0	5.1	0.3	2.2	5.1	
	8/26	"							2.2	3.4	3.1		1.6		
	9/29	"	0.6	1.0	3.4	2.7									
	9/3	"	2.0	1.9	6.8	2.0	2.7	3.7	4.9	3.0	3.7		1.4		
	9/7	"								5.6		5.0	2.2	9.2	
	9/10	"											3.0	6.0	
	9/16	"										2.1	3.6	10.0	
	9/18	"								5.8		0.4	4.3	9.6	
	9/19	"								7.5		1.6	3.3	7.1	3.6
	9/25	"	6.6	7.3			5.7	4.9	8.4	10.1	8.3	1.6		7.0	1.8
	9/26	"					2.9	5.0							
	10/16	"	0.8	3.6		2.6	4.4	4.6	4.9	4.0	4.0		2.7	4.1	2.2
	12/23	"				7.5	12.2		4.4				10.1	11.0	8.2
	12/29	"	11.8			8.0	8.6		2.7				6.9	8.6	6.2
1959	3/17	"				7.8							9.8	10.6	
	3/24	"				7.4				8.0		3.9	9.0	9.0	7.4
	4/9	"				10.1						3.0	9.2	9.7	8.8
	4/28	"				4.4						2.9	4.5		4.3
	6/15	"				3.2						3.2	3.4		3.3
	9/1	"											1.8	4.8	4.2
	9/2	"											3.0	3.8	3.4
	9/14	"											3.0	3.6	3.1
	9/15	"											2.6	3.5	2.7
	9/21	"											1.2	1.3	1.3

Table 2.--Dissolved oxygen values (mg./l.) for Latin square ground-water standpipes, Indian Creek, 1959

Sampling dates							By depth (shallowest to deepest)		
Pipe number		9/1	9/2	9/15	9/21	Mean	Pipe number	Mean of 4 dates	Mean of depth
LS1	1	-	4.0	2.2	0.8	2.3	4	2.7	
	2	2.2	2.8	2.8	0.8	2.2	7	5.3	4.1
	3	4.3	4.2	2.3	-	3.6	10	3.3	
	4	-	-	2.5	2.8	2.7	13	4.9	
	5	3.9	3.7	2.3	4.8	3.7	3	3.6	
	6	1.9	3.2	1.8	0.8	1.9	12	3.7	3.6
	7	7.0	6.8	2.2	-	5.3	5	3.3	
	8	3.6	4.5	2.8	1.0	3.0	14	3.6	
	9	2.8	3.8	2.4	0.9	2.5	2	2.2	
	10	3.8	3.9	2.2	-	3.3	8	3.0	2.5
	11	2.4	2.2	1.7	0.7	1.8	9	2.5	
	12	3.4	3.8	2.6	3.2	3.3	15	2.4	
	13	7.0	5.8	2.0	-	4.9	1	2.3	
	14	4.2	4.2	2.3	-	3.6	6	1.9	2.0
	15	2.6	3.2	2.5	1.4	2.4	11	1.8	
	16	-	5.0	2.2	1.8	3.0	16	1.8	
LS2	1	0.8	1.1	0.6	-	0.8	3	2.0	
	2	0.9	1.0	1.3	1.0	1.1	8	2.2	2.1
	3	-	2.2	1.8	-	2.0	10	1.5	
	4	-	2.1	4.3	1.2	2.5	13	2.7	
	5	-	1.8	0.9	1.1	1.3	1	0.8	
	6	-	1.6	1.0	-	1.3	6	1.3	2.0
	7	-	1.3	3.9	1.4	2.2	12	1.0	
	8	-	2.0	2.3	-	2.2	15	0.9	
	9	3.1	2.0	3.6	1.6	2.6	2	1.1	
	10	1.4	1.3	1.9	-	1.5	5	1.3	2.0
	11	-	0.7	0.4	1.6	0.9	11	0.9	
	12	1.3	0.8	1.0	-	1.0	16	0.7	
	13	3.1	2.6	2.3	-	2.7	4	2.5	
	14	1.3	1.1	2.6	0.8	1.5	7	2.2	2.2
	15	0.7	1.1	1.0	-	0.9	9	2.6	
	16	0.6	0.8	1.0	0.5	0.7	14	1.5	

Figure 4.--Randomly placed standpipes at depths of 5, 10, 15, and 20 inches, experiment 1, Indian Creek, 1958.

When the four squares are considered in a factorial analysis (table 6), there are significant differences between depths, between squares, and in interaction. The variance ratio (F) is higher, however, for depths than for the other sources of variation. Statistically significant interactions are due to normal differences found between one point in a streambed and another.

Decrease in dissolved oxygen levels with depth in the streambed is shown in figure 5, where experiments 1, 2, and 3 are combined. Because of this decrease, no deeper source is indicated as contributing to high dissolved oxygen content of intragravel water. This further confirms that the primary source of dissolved oxygen is the stream.

Ground-Water Temperatures

Ground-water temperatures were sampled at the same points and usually at the same time as dissolved oxygen (discussed on page 2). Although not measured consecutively throughout the year, ground-water temperatures at various depths below the water table appeared to be lower than stream temperatures in the summer and higher in the winter (table 7). This agrees with Benson's (1953) findings for the Pigeon River, Mich., and with the ground-water temperature regimen of Cabin Creek in Southeastern Alaska, which was investigated by Institute personnel from 1949 to 1952.

Table 3.--Experiment 1. Dissolved oxygen measurements (in mg./l.) from 20 standpipes placed at random in a 10- by 10-foot square in Indian Creek study area 3, 1958

Pipe number	Depth in inches	Sampling dates					Means
		6/3	6/5	6/7	6/9	9/13	
1	5	8.6	10.0	9.2	9.5	9.6	9.4
2	"	8.4	9.0	8.8	9.7	9.4	9.1
3	"	9.0	8.2	7.9	8.5	9.9	8.7
4	"	8.8	9.3	8.2	9.3	8.9	8.9
5	"	5.6	8.6	7.8	8.8	8.1	7.8
Mean		8.1	9.0	8.4	9.2	9.2	
6	10	7.2	8.6	7.8	9.0	8.3	8.2
7	"	7.8	8.8	8.0	9.0	9.1	8.5
8	"	8.4	8.9	8.7	9.5	10.1	9.1
9	"	8.6	9.4	8.4	9.5	9.1	9.0
10	"	7.1	7.6	6.7	7.7	7.4	7.3
Mean		7.8	8.7	7.9	8.9	8.8	
11	15	7.0	7.9	7.8	8.5	8.6	8.0
12	"	5.9	6.6	5.7	6.6	6.8	6.3
13	"	6.6	6.8	5.9	7.1	6.5	6.6
14	"	5.8	7.9	6.4	7.5	7.7	7.1
15	"	8.3	9.2	8.2	8.9	9.4	8.8
Mean		6.7	7.7	6.8	7.7	7.8	
16	20	6.8	8.1	6.6	7.8	7.6	7.4
17	"	5.4	4.4	4.3	4.8	8.0	5.4
18	"	5.4	6.8	6.5	7.0	6.1	6.4
19	"	7.2	8.0	7.6	8.4	8.8	8.0
20	"	6.1	7.8	6.6	7.4	7.2	7.0
Mean		6.2	7.0	6.3	7.1	7.5	
Grand Mean		7.2	8.1	7.4	8.2	8.3	

Analysis of variance of above data

Source	Sum of squares	Degree of freedom	Mean square	Variance ratio
Time	21.96	4	5.49	5.53*
Depth	61.74	3	20.58	20.75*
Time x depth (Interaction)	0.67	12	0.054	nonsignificant
Error	79.37	80	0.992	

*Significant at 1-percent level.

Table 4.--Experiment 2. Dissolved oxygen measurements (in mg./l.) from 16 standpipes placed in a 4 by 4 Latin square in Indian Creek study area 1, 1958

Pipe number	Depth in inches	Sampling dates 6/4	6/5	6/7	6/9	Means
1	5	7.3	7.8	7.4	7.1	7.4
2	5	8.6	8.8	8.7	9.0	8.8
3	5	9.0	9.0	8.8	8.9	8.9
4	5	6.8	6.6	6.4	6.4	6.6
5	10	8.8	9.1	8.6	9.0	8.9
6	10	6.6	6.5	6.1	6.2	6.4
7	10	5.0	7.0	6.2	6.2	6.1
8	10	6.2	5.4	5.1	5.1	5.5
9	15	5.9	5.4	5.2	4.8	5.3
10	15	6.2	6.4	6.0	5.9	6.1
11	15	6.2	5.8	5.1	5.4	5.6
12	15	6.6	6.0	6.0	5.8	6.1
13	20	5.1	5.4	5.3	5.0	5.2
14	20	5.1	4.4	4.6	4.1	4.6
15	20	5.7	5.6	5.0	4.6	5.2
16	20	6.7	6.7	6.5	6.4	6.1

Analysis of variance of average of four dates above

Source	Sum of squares	Degree of freedom	Mean square	Variance ratio
Columns	8.73	3	2.91	4.69 nonsignificant
Rows	0.45	3	0.15	0.24 nonsignificant
Depths	15.34	3	5.11	8.24*
Error	3.74	6	0.62	

*Significant at the 1-percent level.

Table 5.--Experiment 3. Dissolved oxygen measurements (mg./l.) from four 3 by 3 Latin squares, Indian Creek study area 1, 1958

Latin square	Pipe number	Depth in inches	Sampling dates			Analysis of variance				
			9/4	9/10	9/13	Source	Sum of squares	Degree of freedom	Mean square	Variance ratio
3.1	1	5	10.5	10.4	10.3	Rows	0.81	2	0.405	1.976nonsignificant
	2	5	10.6	10.0	10.4	Col.	1.08	2	0.540	2.634nonsignificant
	3	5	11.3	10.1	9.8	Depths	83.96	2	41.98	204.78 *
	4	10	9.8	10.5	10.4	Error	0.41	2	0.205	
	5	10	10.0	10.0	9.6					
	6	10	10.1	9.9	8.8					
	7	20	3.8	4.0	2.3					
	8	20	8.4	3.6	2.5					
	9	20	1.8	4.6	2.0					
3.2	10	5	10.2	10.8	10.1	Rows	1.18	2	0.590	0.887nonsignificant
	11	5	10.6	11.0	10.3	Col.	4.06	2	2.030	3.053nonsignificant
	12	5	9.4	10.4	10.2	Depths	2.99	2	1.495	2.248nonsignificant
	13	10	10.0	10.5	10.1	Error	1.33	2	0.665	
	14	10	9.6	10.2	9.6					
	15	10	10.2	10.2	4.9					
	16	20	9.3	9.8	9.8					
	17	20	9.9	2.0	9.6					
	18	20	9.7	10.2	10.2					
3.3	19	5	10.4	10.6	10.3	Rows	0.37	2	0.185	18.50nonsignificant
	20	5	-	10.6	10.4	Col.	0.57	2	0.285	28.50 **
	21	5	10.6	10.5	9.4	Depths	21.17	2	10.585	105.85 **
	22	10	10.5	10.5	10.1	Error	0.02	2	0.01	
	23	10	10.4	10.2	7.7					
	24	10	10.1	11.3	7.5					
	25	20	10.3	3.4	7.2					
	26	20	7.4	6.0	7.1					
	27	20	6.6	-	7.8					
3.4	28	5	11.0	-	10.2	Rows	0.04	2	0.020	1.00nonsignificant
	29	5	10.9	-	10.2	Col.	0.00	2	0.000	0.00nonsignificant
	30	5	11.0	10.5	10.2	Depths	1.94	2	0.970	48.50 *
	31	10	10.3	10.4	9.8	Error	0.04	2	0.020	
	32	10	10.6	-	9.8					
	33	10	10.7	10.3	9.1					
	34	20	7.7	10.6	10.6					
	35	20	9.2	9.6	9.7					
	36	20	10.6	8.4	8.9					

*Significant at the 1-percent level.

Table 6.--Analysis of variance of four 3 by 3 Latin squares in Indian Creek study area 1.

Source	Sum of squares	Degree of freedom	Mean square	Variance ratio
Depths	68.75	2	34.37	83.22 *
Squares	21.68	3	7.23	17.51 *
Interaction	40.82	6	6.803	16.47 *
Error	9.91	24	0.413	

*Significant at the 1-percent level.

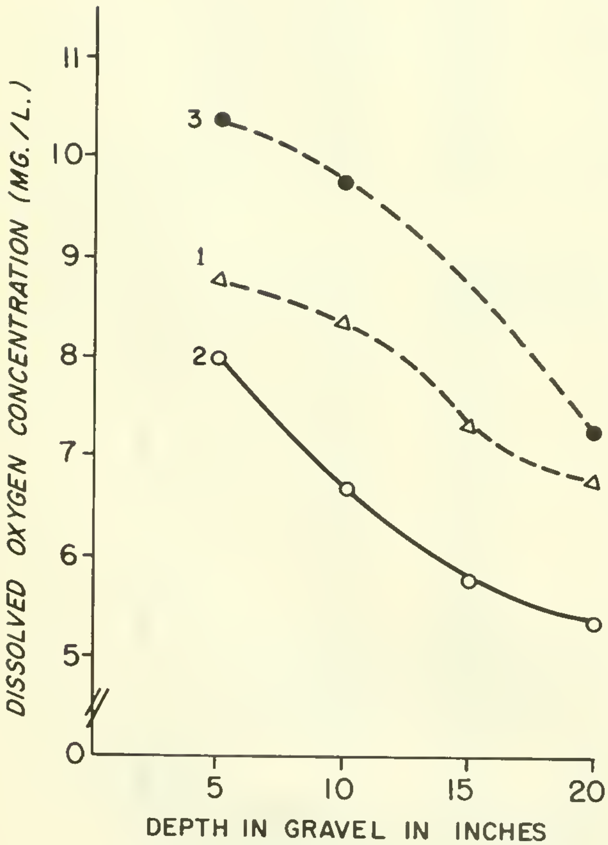

Figure 5.--Decrease in dissolved oxygen with depth in streambed gravel, experiments 1, 2, and 3, Indian Creek, 1958.

Temperature data from the two 4 by 4 Latin squares (table 8) show little variation in ground-water temperatures with time or depth in water table at the time of sampling.

Tracing Ground-Water Seepage

In Indian Creek, riffle ground water flows from the bank into the streambed because of a pressure gradient formed by the slope of the water table (fig. 6). Ground water was traced from the streambank into the streambed by means of dye and through dissolved oxygen and temperature differences. These differences were first determined in 1956 through routine sampling of points throughout the riffle. Figure 7 shows gradual increase in dissolved oxygen content of water 10 inches under the gravel with distance away from the bank.

In 1959 three sampling stations were installed (location shown as A in figure 2) to obtain specific data on oxygen and temperature differences. At the three stations, water within the gravel was sampled at points 1 foot apart extending from the bank 8 feet into the stream. Measurements showed that at the time of sampling (September) both temperature and dissolved oxygen increased (fig. 8) with distance away from the ground-water source until influence of ground-water seepage was no

Table 7.--Ground-water temperatures in degrees Fahrenheit at various depths below the water table, Indian Creek study area 1, 1958-59

Date	Stream	Pipe numbers												
		3	6	41	43	45	57	66	67	68	78	80	81	91
1958														
8/13	57.0	47.0	51.0	53.0	50.0		51.0							
8/17	55.0	47.0	50.0	51.0	50.0	51.0	51.0	50.0	51.0	51.0				
8/20	56.0	50.0	52.0	55.0	52.0	51.0	51.0	53.0	54.0					
8/22	56.0	50.0	48.5		50.5	51.5	53.0	50.5	54.5	52.0	49.0	49.0	50.5	
8/29	57.0	48.0	51.5	49.5	49.0			49.0	50.5	50.5				
9/21									48.0			49.0	49.0	49.0
10/3	42.0		44.5		44.0	44.5	44.5	44.0	44.0	44.0		45.0		46.0
12/23	36.5				39.0	37.5		39.0				36.5		36.0
12/29	35.5				36.5	35.5		37.0				37.0		37.0
1959														
3/17	35.0				36.0							36.0		34.0
3/24	34.0				37.0							33.5		33.5
4/9	35.0				37.0							36.5		37.0
4/28	37.0				40.0							38.5		38.5
6/15	52.0				46.0							48.0		45.0
9/1	57.5											48.2	48.5	48.5
9/2	57.7											48.2	48.0	48.3
9/9	49.0											47.5	48.0	47.5
9/14	53.0											50.0	50.5	50.0
9/15	54.0											49.5	50.0	49.5
9/21	49.5											48.5	49.0	48.0

See figure 3 for depths of these standpipes.

Table 8.--Temperatures in degrees Fahrenheit for Latin square ground-water standpipes, Indian Creek, 1959

Pipe No.		Sampling dates					
		9/1	9/2	9/14	9/15	9/21	Mean
LS1	1	49.0	49.0	49.0	49.0	48.0	48.8
	2	49.0	48.6	49.5	49.0	48.0	48.8
	3	48.5	48.6	49.5	49.0	-	48.9
	4	48.5	-	50.0	49.5	48.0	49.0
	5	49.0	49.2	49.0	49.0	48.5	48.9
	6	48.5	48.4	49.0	49.0	48.0	48.6
	7	49.0	49.2	49.0	49.0	-	49.1
	8	48.3	48.1	49.5	49.0	48.0	48.6
	9	48.9	48.8	49.0	49.0	48.0	48.7
	10	48.5	48.7	49.0	49.0	-	48.8
	11	48.5	48.4	49.0	49.0	48.0	48.6
	12	48.5	48.8	49.0	49.0	48.0	48.7
	13	49.2	49.2	49.0	49.0	-	49.1
	14	48.6	48.9	49.0	49.0	-	48.9
	15	48.5	48.7	49.0	49.0	48.0	48.6
	16	48.2	48.1	49.0	49.0	47.5	48.4
Stream		-	57.7	53.0	54.0	49.5	53.6
LS2	1	48.0	49.0	-	48.0	-	48.3
	2	47.5	48.0	-	47.5	47.0	47.5
	3	49.0	49.5	-	49.0	-	49.2
	4	47.0	46.5	-	50.0*	46.0	47.4
	5	48.2	48.5	-	48.0	47.0	47.9
	6	49.0	49.6	-	48.5	-	49.0
	7	47.0	47.0	-	50.5*	45.5	47.5
	8	49.5	49.5	-	49.5	-	49.5
	9	48.0	48.5	-	48.0*	46.5	47.8
	10	49.5	49.5	-	49.5	-	49.5
	11	48.5	48.0	-	47.5	47.0	47.8
	12	48.5	48.5	-	48.0	-	48.3
	13	50.2	50.0	-	49.5	-	49.9
	14	48.5	48.5	-	50.5*	47.0	48.6
	15	49.0	49.0	-	48.5	-	48.8
	16	48.0	48.0	-	48.0	46.5	47.6
Stream		-	57.7	53.0	54.0	49.5	53.6

* Surface water entered standpipes.

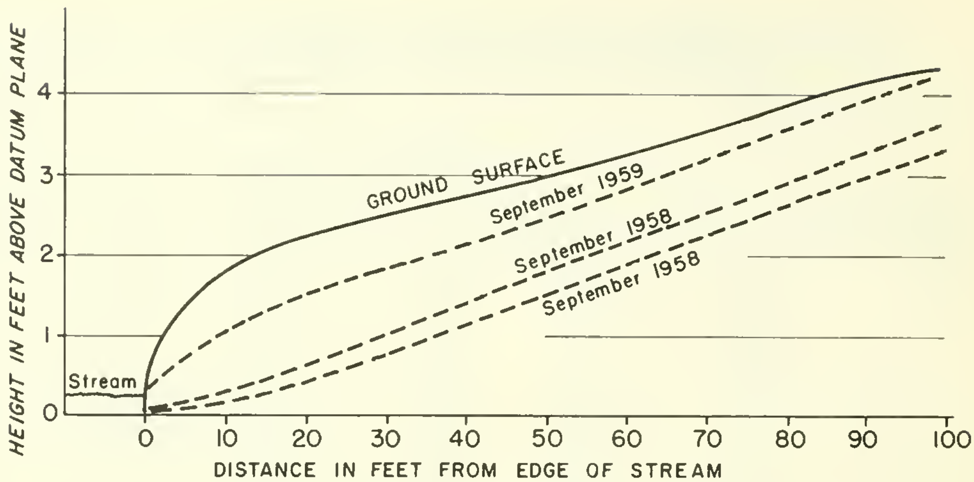

Figure 6.--Water-table gradient for three water-table levels, Indian Creek, study area 1.

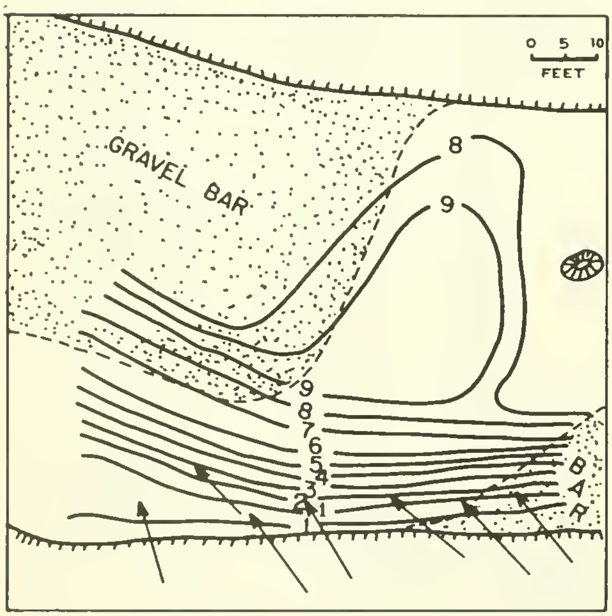

Figure 7.--Indian Creek study area 1 showing mean dissolved oxygen levels at 10 inches in the gravel in contour intervals of 1 mg./1., August 1956. (Arrows indicate direction of ground-water flow.)

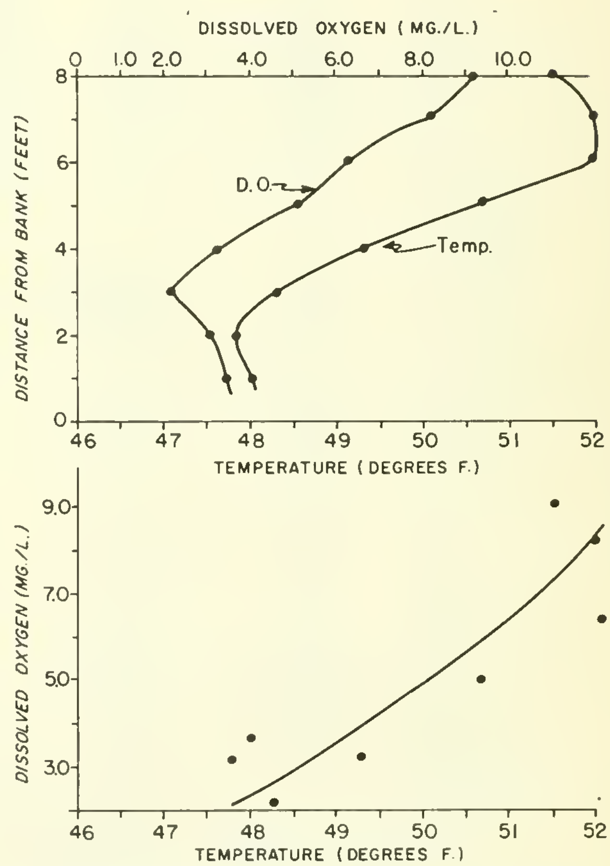

Figure 8.-- Indian Creek study area 1, September 1959. Upper figure shows increase in water temperature and dissolved oxygen with distance away from bank ground-water source at 10 inches in gravel. Lower figure is temperature and dissolved oxygen data from upper figure plotted to show relationship between water temperature and dissolved oxygen.

longer apparent. The trend of increase shown in figure 8 would have been even better defined except for vertical as well as horizontal variation. Vertical gradations of water temperature and dissolved oxygen were well defined near the bank, but were not nearly as pronounced as near the center of the stream (table 9).

Interchange of Flowing Stream Water with Water in the Gravel of the Streambed

Studies of interchange of flowing stream water with water in the gravel of the streambed were started as soon as it became apparent that ground water was usually low in dissolved oxygen content and that dissolved oxygen levels decreased with depth in the streambed. The extent and method of interchange in salmon spawning riffles had not been thoroughly demonstrated.

Wickett (1954) suggested that intragravel water containing a large amount of dissolved oxygen comes from the stream through percolation. Cooper (1959) reported that interchange is greatly increased by placing a few large rocks on the surface of the streambed. Interchange was indicated by the work of Fisheries Research Institute personnel (unpublished) and of Skud (1954) on changing temperatures and salinities in the gravel of intertidal zones through the tidal cycle.

Interchange of water between stream and streambed was first demonstrated in the Indian Creek spawning riffle in 1958. At that time upwelling of intragravel water was shown by inserting fluorescein dye into standpipes placed at various depths in the gravel and mapping the subsequent appearance of dye-marked water at the surface of the streambed. Descent of surface water was demonstrated by marking flowing stream water masses with dye and capturing dye-marked water in standpipes placed at different depths in the gravel downstream from the point of insertion.

The mechanics of interchange in the Indian Creek riffle were qualitatively studied in more detail in 1959; results of this work appear in a report by Vaux and Sheridan (1960).

Water in Gravel of Streambanks and Gravel Bar

Temperatures of water in the gravel of the main stream channel closely approximated temperatures of the flowing stream (except in areas under ground-water influence discussed previously). Because of interchange, dissolved oxygen levels of water in the gravel

Table 9.--Comparison of dissolved oxygen and temperature gradations at two locations in Indian Creek study riffle, September 1959

Depth in gravel	Near the bank (ground-water seepage)		Near center of stream (no ground-water seepage--interchange)	
	Dissolved oxygen	Temperature	Dissolved oxygen	Temperature
Inches	Mg./l.	° F.	Mg./l.	° F.
5	7.0	51.0	10.1	51.0
10	4.4	50.5	9.9	50.8
15	1.4	48.0	-	-
20	0.5	45.5	9.7	51.0

of the main stream channel also usually approximated dissolved oxygen levels of the flowing stream, except in areas under ground-water influence and during low stream levels when interchange was minimized.

On the other hand, within the gravel of the bar, both temperature and dissolved oxygen content of water varied widely depending on stream level. The bar was covered with water on high stream levels (the bar became a part of the main stream channel at a stream gage reading of 2.20 or more) and uncovered on low stream levels (stream gage reading of 1.90 or less). Dissolved oxygen content of water in the gravel of the bar increased with an increase in stream level. This is shown in figure 9. The shapes of the curves representing the increase of dissolved oxygen with stream level at individual standpipes differ because (1) some of the standpipes were located at points where the gravels were more permeable, hence more interchange occurred, (2) some of the curves represent points closer to ground-water outflows, and (3) standpipes were not all at the same depth below the water table.

When stream level was above 2.2 feet and stream water ran over the bar, there was a fairly good relationship between temperature and dissolved oxygen (upper fig. 10).

At a lower stream level sampling points showed a different temperature-dissolved oxygen relationship (lower fig. 10). First, dissolved oxygen levels were generally lower than they were on a higher stream level. Second, although dissolved oxygen and temperature at points 3, 43, 6, and 66 have remained generally low, the water at points which were previously high in dissolved oxygen (64, 29, 9, 2, 20, 30, 67, and 63) shows a marked decrease in dissolved oxygen content, but either remains the same or increases in temperature.

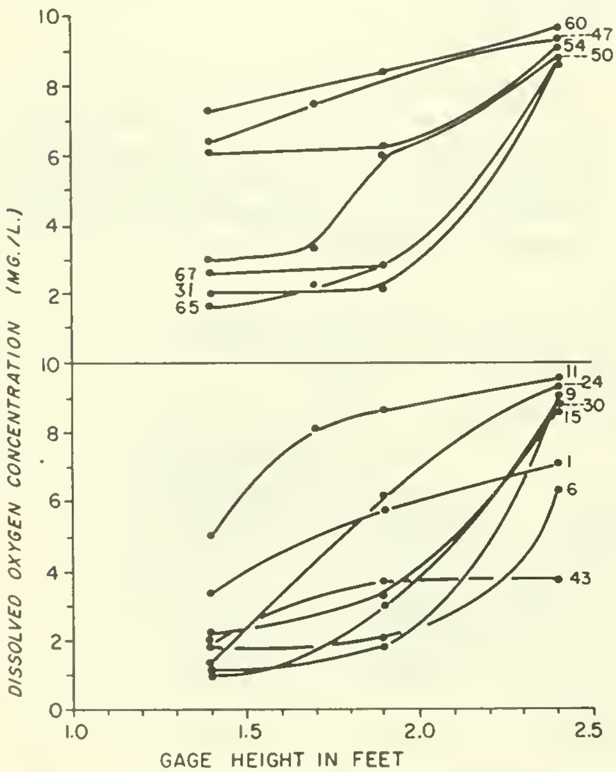

Figure 9.--Increase in dissolved oxygen levels of water in the gravel bar with increase in stream water levels, Indian Creek, August 1958. (Numbers correspond to standpipe locations shown in figure 2. Relative depths of pipes shown in figure 3.)

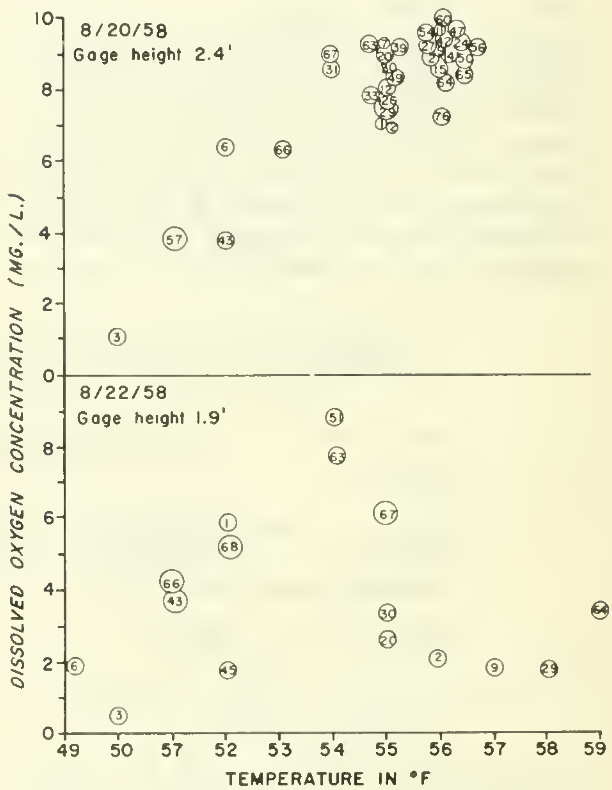

Figure 10.--Dissolved oxygen levels plotted against water temperatures on two different gage heights, Indian Creek, August 1958. (Numbers correspond to standpipe locations shown in figure 2. Relative depths of pipes shown in figure 3.)

I suggest that the reason for a decrease in dissolved oxygen with an increase in temperature (above and beyond decrease due to temperature alone) is that the absence of a layer of water over the bar prevents interchange. Ground-water influence can be ruled out, for the water temperatures are too high to indicate the presence of ground water. Therefore, dissolved oxygen was maintained on a high level as long as surface stream water flowing over the bar permitted interchange to take place. But as soon as the stream level dropped, no interchange occurred, and water flowing through the bar was subject to a continuous oxygen depletion from biochemical oxygen demand.

That such depletion can occur may be indicated indirectly. The range of 27 flow velocity measurements made in the bar in 1956 (by timing the appearance of dye-marked water) was from 2 to 170 feet per day with an average of 37 feet per day. Based on this average velocity and the length of bar, it is possible that high oxygen content water entering the upper end of the bar would be subject to a biochemical oxygen demand for 2 days at a temperature around 55° F. In preliminary studies on the biochemical oxygen demand of Indian Creek gravels, dissolved oxygen content fell from 9.5 to 2.2 mg./l. in 48 hours at an average water temperature of 52.5° F.

DISCUSSION

Ground water in the Indian Creek study riffle was generally low in dissolved oxygen, and dissolved oxygen levels decreased with depth in streambed gravels. Thus, by a process of elimination we can corroborate reports of Royce (1959) and Vaux and Sheridan (1960) that the primary source of high oxygen content intragravel water in salmon streams is the stream itself.

Therefore, if anything interferes with interchange of stream and intragravel water, the amount of dissolved oxygen available to salmon eggs will be decreased, and the rate of flow past embryos will be lowered. Silting of the streambed, by lowering permeability of streambed gravels, can definitely interfere with interchange. An algae cover over the streambed (such as that observed in Indian Creek in September 1957) is another factor that can interfere with interchange.

It is also possible that varying amounts of fine materials in spawning riffle streambeds are responsible for some streams producing more salmon than others. Wickett (1958) found a relationship between permeability of streambed gravels and pink and chum *(Oncorhynchus keta)* salmon fry production in British Columbia streams. If high permeabilities are desirable and a large amount of fines are detrimental to survival of salmon eggs, fines can be removed. This action would increase dissolved oxygen levels and flow rates and enhance survival of salmon embryos.

Low dissolved oxygen levels of Indian Creek ground water during summer and fall months indicate that areas of ground-water effluence may be harmful to salmon eggs. But on the other hand we found that in both Cabin and Indian Creeks ground water was colder than stream water, in summer and warmer in winter. Therefore, as Needham and Jones (1959) point out, ground water may have a tempering effect on stream water and help prevent freezing of streambed gravels. This possibility can easily be investigated, since ground water in salmon spawning riffles can be detected and traced through its distinctive qualities of dissolved oxygen and temperature.

Although ground water has either a harmful or beneficial effect (depending on circumstances) in upstream spawning areas, it is doubtful if it has any direct effect at all in intertidal areas where great numbers of pink salmon spawn in Southeastern Alaska, Prince William Sound, and other regions. Intertidal areas are often underlain by impervious bedrock or a clay layer at relatively shallow depths, and streams meander through extensive tide flats composed mostly of mud. Only main stream channels are kept clean. Since there is no place for ground water to come from, intragravel water in intertidal areas must depend exclusively on interchange for replenishment of dissolved oxygen and on ebb and flow of warmer salt water for protection against freezing.

Because of low ground-water dissolved oxygen, Indian Creek (and probably many other streams in Southeastern Alaska and elsewhere) apparently differs from spawning areas in which the presence of ground water has been reported to affect beneficially spawning of adult salmonids and survival of their eggs and larvae. White (1930), Greeley (1932), Hazzard (1932), and Benson (1953) all stated that the presence of springs and of ground-water seepage determined the location of spawning areas of brook and other species of trout. Benson also said that ground-water seepage affected both sizes and numbers of all age groups of brook and brown trout in the Pigeon River, Mich.

Association of sockeye salmon spawning with ground water has been mentioned by Burgner (1958), and Mathisen (1955) for Bristol Bay, Alaska, and by Krogius (1951), Krokhin and Kurenkov (1954), Krogius and Krokhin (1948), and Kurenkov (1957) for the Kamchatka Peninsula. Royce (1951) found no evidence that lake trout select a lake bottom supplied with spring water for deposition of their eggs.

Results of temperature and dissolved oxygen measurements of water in the gravel bar of the study riffle in Indian Creek furnish indications as to whether or not a gravel bar is a favorable environment for developing salmon eggs. In almost every stream suitable for pink salmon spawning in Southeastern Alaska, there are extensive gravel bars (termed marginal or fringe spawning areas) on which heavy spawning sometimes occurs when stream level and population pressure are high. In Cabin Creek I determined that spawning in a cross section of a riffle increased by 50 percent with a rise in stream level of 1.1 feet (gage height from 0.48 to 1.58 feet). Since salmon eggs and larvae that are developing in marginal spawning areas are subject to fluctuating stream heights and are often exposed to prolonged periods of low air temperatures, their chance for survival would appear to be low. Hunter (1959) reported that in some years spawning in fringe areas showed greater survival ratios than spawning in other areas in Hooknose Creek, British Columbia. He attributed high survival years to relatively constant water levels and absence of persistent freezing temperatures.

Since salmon eggs deposited in certain parts of the marginal spawning area in the Indian Creek study riffle would be subject to intermittent high temperatures and low dissolved oxygen levels, this does not appear to be a favorable environment for survival.

SUMMARY

Part of study conducted by the Fisheries Research Institute on effects of logging in southeastern Alaska salmon spawning streams was an investigation of waterflow through the gravel of a spawning riffle in Indian Creek. This investigation included a determination of (1) dissolved oxygen content and temperature of ground water and the extent of ground-water seepage, (2) variation of dissolved oxygen content of water with depth in the streambed, (3) interchange of flowing stream water and water of the streambed gravel, and (4) flow characteristics of water in the gravel of streambank and gravel bar.

Through tracing flow directions with fluorescein dye and measuring the dissolved oxygen content and temperature of stream and ground water, we found the following:

1. Ground water was low in dissolved oxygen at all times of the year except the winter months when ground-water temperatures were lowest.

2. Ground-water temperatures were lower than stream temperatures during the summer and higher during the winter.

3. Dissolved oxygen content of water within the gravel of the streambed decreased with depth.

4. Ground water flowed from the streambank into the streambed. Its presence was detected by its dissolved oxygen and temperature differences.

5. The major source of water of high oxygen content within the gravels of the riffle was the stream. This was determined by demonstrating large-scale interchange in the main stream and by measuring dissolved oxygen content and temperatures of water in the gravel of a gravel bar with intermittent surface flow.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the foresight of William F. Thompson, who formulated basic concepts of ground-water hydrology and interchange of stream and intragravel water in a salmon stream some years ago. He also wishes to express his appreciation to William F. Royce, Robert L. Burgner, and Ted S. Y. Koo of the Fisheries Research Institute, for helpful suggestions in the preparation of this paper.

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