THE INFLUENCE OF ENVIRONMENTAL CONDITIONS IN REDDS ON THE SURVIVAL OF SALMONID EMBRYOS

by

DANIEL WIGGIN COBLE

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APPROVED:

Redacted for privacy

Associate Professor of Fish and Game Management

In Charge of Major

Redacted for privacy

Head of Department of Fish and Game Management

Redacted for privacy

Chairman of School Graduate Committee

Redacted for privacy

Dean of Graduate School

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Typed by Jeannette Cox

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THE INFLUENCE OF ENVIRONMENTAL CONDITIONS IN REDDS ON THE SURVIVAL OF SALMONID EMBRYOS

INTRODUCTION

A field study of some of the factors affecting the survival of salmonid embryos in spawning gravels was conducted in Lincoln County, Oregon, from November, 1958, to June, 1959, in order to learn more about conditions controlling the production of salmon and trout. Determinations of gravel permeability and of velocity and dissolved oxygen concentration of ground water were made through the use of standpipes buried in artificial redds. The measurements were then compared with the survivals of embryos placed in the gravels. Gravel samples were collected at the study sites to determine the extent of sediment deposition.

The investigation was carried on under the support and direction of the Oregon Cooperative Wildlife Research Unit[1] and the Governor's Committee on Natural Resources.[2] These organizations are conducting studies of the effects of different logging practices upon various watershed values. One study will include several years of investigation on three streams, Needle Branch, Flynn Creek and Deer Creek, which have watersheds that have not been logged. Further studies will be made after logging.

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[1]Oregon State College, Agricultural Research Foundation, Wildlife Management Institute, U. S. Fish and Wildlife Service, and Oregon State Game Commission cooperating.

[2]Comprised of representatives of various state agencies that are concerned with the conservation of Oregon's natural resources.

This coastal area receives a high annual rainfall, about 100 inches per year, most of which falls between October and May. Water levels in the streams fluctuate widely during this eight month period, and considerable movement of stream bed gravels occurs, especially during peak flows. Water temperature and discharge data are given in the appendix. When a watershed is logged, silt often enters the stream and settles in the gravels of the stream bed. The gravels are used by spawning salmonids, and silt is known to have a detrimental effect on salmonid reproduction under some circumstances. This study was designed to provide information on conditions in spawning gravels before the stream bed becomes altered as a result of the logging that is planned.

Several investigations have shown that silt deposited in spawning gravel is harmful to developing salmonid embryos. Hobbs (12, p. 79) in New Zealand found evidence that heavy mortality is a consequence of excessive fine material in the gravel;..."there is the writer's general impression that losses were heaviest in natural redds in which the most turbidity was produced on disturbance of material in the egg pockets;...there is the correlation of measured mortality and measured fine material in natural redds. Circumstances suggest that suffocation may be the immediate cause of death." In California, Shaw and Maga (15, p. 40) introduced mine silt to troughs of gravel in which they had planted silver salmon embryos, *Oncorhynchus kisutch* (Walbaum). "The experiments further show that mine silt deposited on gravel spawning beds during either the early or later stages of incubation results in negligible yields of fry and is therefore a serious menace to natural propagation." A. C. Cooper (5), in his Horsefly River investigations, found evidence that silt deposition in spawning gravel is detrimental to salmon embryonic survival. He also stated that Pyper (unpublished) showed a definite relationship between the flow of water through the gravel and egg and fry survival.

In Canada, Wickett (20, p. 934) found low dissolved oxygen levels in portions of a study stream and thought they may have caused the high mortalities of chum salmon embryos, O. keta (Walbaum) observed. He stated,..."surface silt of itself did not seem to be lethal, but in certain circumstances it would appear that the circulation of water is so greatly reduced that there is insufficient oxygen for the survival of living eggs..." The supply of oxygen to embryos depends not only upon the dissolved oxygen content of the water, but also upon the rate at which it is supplied. Wickett also described a standpipe (later improved by Terhune, 17) which he used to estimate the apparent velocity[3] of the subsurface water, and which provided an access to this water for dissolved oxygen determinations. Alderdice, Wickett and Brett (1) exposed chum salmon embryos to low dissolved oxygen levels. Various concentrations at different

[3]"The apparent velocity sometimes called the superficial or macroscopic velocity, is the rate of seepage expressed as the volume of liquid flowing per unit time through a unit area (of solids plus voids) normal to the direction of flow. The true, or pore velocity is the actual velocity of flow through the interstitial spaces, and differs from pore to pore." Pollard (13, p. 709)

developmental stages resulted in delays in hatching and in mortalities. Monstrosities were produced when embryos at early stages of development were subjected to very low oxygen levels. Advanced stages were stimulated by low levels of oxygen to hatch prematurely. Silver (16), in his work for the Pacific Cooperative Water Pollution and Fisheries Research Laboratories at Oregon State College, exposed steelhead trout embryos, *Salmo gairdnerii gairdnerii* (Richardson), and chinook salmon embryos, *O. tshawytscha* (Walbaum), to various levels of dissolved oxygen and approximately true velocity. Reduced levels of dissolved oxygen or velocity caused delays in hatching. Also, embryos reared at low velocities or oxygen concentrations were smaller in length and volume than those reared at higher levels. All embryos died that were reared in water having a dissolved oxygen concentration of 1.6 milligrams per liter (mg/l).

MATERIALS AND METHODS

Standpipes, which have been utilized for studies of water flowing through gravel, are basically pieces of pipe perforated at one end. When such a pipe is placed vertically in a stream bed, ground water flows through its lower end. The top of the pipe extending above the surface of the stream provides access to the gravel water. The standpipes used in this study (Figure 1) were 15-inch lengths of aluminum pipe having an inside diameter of one and one-quarter inches. The lower end of the pipe itself was sealed by a small plate, and two flat metal bars attached here served to hold it more firmly in the gravel. The bottom two inches of the pipe wall were perforated by 48 evenly spaced holes, one-eighth inch in diameter. Horizontal grooves one-sixteenth inch wide and one-sixteenth inch deep extended between the holes in the outer surface of the pipe wall and reduced the chance of pebbles blocking the openings. A piece of sponge rubber on a handle, the stopper, could be placed in the pipe to prevent water from flowing through it. When a pipe was buried 10 inches in the gravel with the stopper in place, and the top capped, it could be considered a part of the stream bed. When measurements of subsurface conditions were being acquired, the cap and stopper were removed, and a two-foot extension was fitted to the top of the pipe.

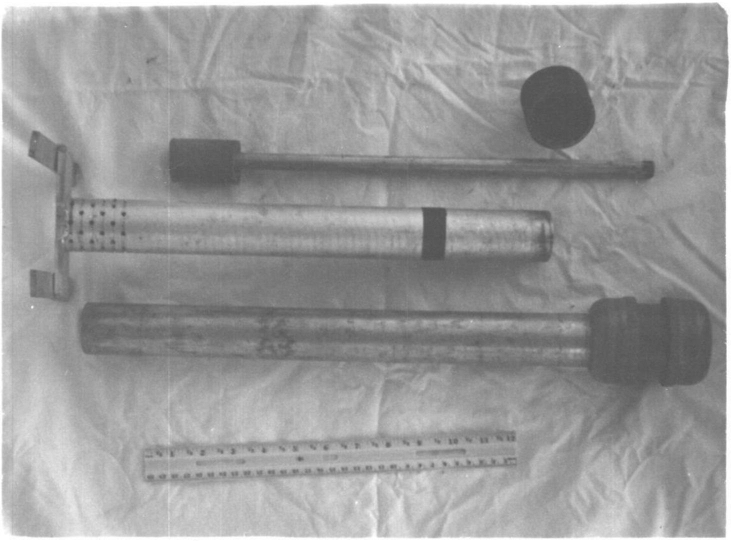

Figure 1. The standpipe assembly showing extension, stopper, and cap.

Figure 2. Standpipe with extension attached.

Figure 3. The gravel sampler, open.

Figure 4. Gravel sampler with door closed.

Gravel permeability[4] is measured by pumping water from the pipe into a graduated cylinder and recording the time taken to remove it. An amount of water per unit time (ml/sec) is thus obtained, and it is a function of the permeability of the gravel surrounding the pipe. Through the relationship between the volume of water removed and the permeability of the gravel, it is possible to estimate the gravel permeability (m/hr).

When a color solution is injected into the standpipe, as time passes, the color of the water in the pipe becomes lighter as it is diluted by the exchange of that water with water from the stream bed. By periodically withdrawing small samples of water from the pipe, it is possible to measure the rate of dilution of the water in the standpipe; the dilution rate is greatly influenced by the velocity of the water flowing through the gravel. Through the relationship between the exchange rate in the pipe and the velocity of the water in the gravel, the apparent velocity (cm/hr) of the ground water flow can be estimated.

The semimicro method of dissolved oxygen determination was used during most of the study. Usually, two 37-milliliter samples of water were drawn from the pipes, one immediately following the

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[4]Permeability is defined as the apparent velocity per unit hydraulic gradient. For our purposes we may define it as the capacity of the gravel to transmit water. A porous medium that transmits either a liquid or gaseous fluid is permeable, and spawning gravels, depending on their nature, transmit water at various rates. In this paper the capacity of gravels to transmit waters at different rates is expressed as meters per hour (m/hr).

other. Frequently the two samples appeared to contain quite different concentrations of dissolved oxygen. Faulty sampling techniques were indicated, since other workers report good results using this sampling method. All attempts to find the cause of the discrepancies were unsuccessful. The only dissolved oxygen concentrations that have been used are those calculated from two semimicro samples containing the same or nearly the same amounts of oxygen.

The standpipe described above incorporates some of the features of the pipe developed by Gangmark and Bakkala (8) and that designed by Terhune (17). In these two papers and that of Pollard (13), one can find a more complete discussion of the theories behind and the problems and limitations involved in the design, calibration, and use of standpipes.

The gravel sampler used for this study was an eight by nine-inch steel box which was open on the top and bottom and which was attached to a two-foot handle. After it was pushed into the stream bed, an arc-shaped piece of steel attached to the box was pushed down through the gravel so that it formed a bottom to the box. The sampler was then lifted from the stream bed to obtain a sample.

Fertilized silver salmon and steelhead trout eggs were obtained from the Oregon Fish Commission hatchery on Fall Creek, a tributary of the Alsea River, and transported directly to the study area, a distance of 65 miles. Holes 10 inches deep and about 14 inches long were dug at arbitrarily selected spawning gravel locations.

Gravel and 100 fertilized eggs were placed in plastic mesh[5] sacks, the tops of which were then secured with nylon cord. A standpipe was placed in the downstream end of the hole, and a sack of fertilized eggs and gravel was put in the upper end about 10 inches away from the pipe. The hole was then filled with gravel to the level of the stream bed. Determinations of gravel permeability and of apparent velocity and dissolved oxygen content of ground water were made at intervals throughout the incubation period in order to evaluate the environment of the planted embryos. A month after calculated hatching times, the sacks and pipes were removed, and the fry in the bags counted and preserved in Bouin's solution.

[5] Nineteen meshes per inch.

RESULTS

In mid-December, 1958, ten study redds were prepared in each of the three streams. Fertilized eggs of silver salmon were used in five redds and "eyed" embryos were buried in the other 25. During December and January, water levels fluctuated widely, as is common in coastal streams, and considerable gravel movement occurred. Holes were dug and sand bars were formed at various locations in the stream beds. Some standpipes and egg sacks were washed out of the gravel and carried downstream, but in many sections the stream beds seemed to be unaffected by the high water.

Successive standpipe readings showed that gravel permeability and the apparent velocity of ground water were continually changing, even in areas where the gravel appeared to be static. Table 1 presents data on the changes in permeability of gravel 10 inches below the surface of the stream bed which occurred in three days in one of the streams. At one station, number five, the permeability varied by more than 400 meters per hour. Evidence that the gravel itself was shifting during this period was discovered when the standpipes and sacks were removed in late January. One sack of embryos and gravel was found a foot away from where it was buried, another could not be located at all. At both stations, the standpipes seemed to be undisturbed.

This experiment did not yield good information on the effects of environmental conditions on salmonid embryos. An inadequate number of determinations of gravel permeability and of apparent velocity and dissolved oxygen content of gravel water were made for accurate assessment of the rapidly and widely changing conditions. Other aspects of the experiment will be discussed in the next section.

Table 1

Gravel permeability in meters per hour (m/hr) at eight locations in Needle Branch, 1959

Standpipe	January 27	January 30
1	220	280
2	550	280
3	220	140
4	150	250
5	700	280
6	350	270
7	220	130
8	450	700

On February 10, 1959, ten study areas in Needle Branch and five in Horse Creek were prepared using fertilized steelhead eggs. The first measurements from the standpipes were taken two days later. A permeability measurement was made each week (except one) for the next 12 weeks, and 10 apparent velocity determinations were obtained in this period. Various numbers of dissolved oxygen determinations were made at different stations. One egg sack was later found exposed, probably uncovered by a spawning fish. The tops of two bags were not tied tightly, and the alevins escaped after hatching. For these and other reasons, the information from five study redds has not been used. The experiment was terminated in May. Complete data from two stations in Horse Creek and eight in Needle Branch are given in Table 2. It can be seen that conditions were quite different in the various redds. Mean permeabilities ranged from 80 to 400 meters per hour, apparent velocities from 5 to 108.5 centimeters per hour, dissolved oxygen concentrations, from 2.6 to 9.25 milligrams per liter. Survival percentages ranged from 16 to 62. Again, the changing gravel permeabilities are apparent.

Figures 5 and 6 were drawn using data from Table 2. It can be seen from Figure 5 that, in general, low embryonic survivals are correlated with low mean apparent velocities, and higher survivals with higher velocities. For example, less than 30 per cent of the embryos survived where mean apparent velocities were less than 10 centimeters per hour. Figure 6 shows that the same sort of relationship holds for the mean dissolved oxygen content of water flowing through the redds and embryonic survivals. This relationship was not evident, however, for permeability and survival; i.e., the low survivals were not correlated with low permeabilities nor the higher survivals with higher permeabilities.

At the beginning and end of this experiment, gravel samples were collected beside two of the pipes in each of the streams. The gravel was placed in buckets and taken to Oregon State College where it was analyzed at the Soils Department. The results of the analysis of the samples are shown in Table 3. Analysis of variance showed that there was no significant increase in the percentages of medium sand, fine sand, or very fine sand, or in the percentages of silt in the gravel, from the beginning to the end of the period that the planted embryos were in the gravel.

Table 2

Permeabilities, apparent velocities, oxygen concentrations of water, and percentages of survival of steelhead embryos in 10 study redds in Needle Branch and Horse Creek, Lincoln County, Oregon, 1959

	Horse Creek 1			Horse Creek 2		
	*Perm. m/hr.	Vel. cm/hr.	D.O. mg/l	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l
February						
12 - 13	100	15		350	20	5.5
19 - 20	100			200		5.1
26 - 27	150	30	9.2	150	20	10.8
March						
5 - 6	60	30	6.0	100	5	6.1
12 - 13	60	20	3.9	150	2.5	
20 - 21	100	15	4.9	150	7.5	5.7
28 - 29	60	12.5		100	7.5	8.5
April						
2 - 3	100	25	4.4	150	12.5	4.1
16 - 17	60	40		150	2.5	
23 - 24	60	45		150	5	
May						
1	70			90		
13	70			200	10	
Mean	82.5	26	5.7	160	9.5	6.5
Range	60 - 150			90 - 350		
Standard deviation		10.3	1.9		6.1	2.1
Percentage of survival	23			24		

Table 2 (cont.)

	Needle Branch 1			Needle Branch 2		
	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l
February						
12 - 13	150	10		60	15	6.8
19 - 20	200		6.1	100		5.5
26 - 27	150	15	6.7	60	20	8.1
March						
5 - 6	150	7.5		100	20	
12 - 13	150	5	4.1	60	20	4.0
20 - 21	150	10		100	12.5	4.9
28 - 29	150	5		100	12.5	9.7
April						
2 - 3	150	5	4.1	60	10	5.8
16 - 17	150	7.5		60	22.5	
23 - 24	150	7.5		100	22.5	
May						
1	150			200		
13	100	7.5		90	12.5	
Mean	150	8.0	5.25	90	16.75	6.4
Range	100 - 200			60 - 200		
Standard deviation		2.9	1.2		4.4	1.7
Percentage of survival	26			17		

Table 2 (cont.)

	Needle Branch 3			Needle Branch 4		
	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l
February						
12 - 13	350	150		200	10	
19 - 20	500		5.2	150		
26 - 27	450	35		200	5	4.1
March						
5 - 6	350	60	8.7	100	7.5	
12 - 13	300	80	7.8	100	5	3.7
20 - 21	150	60		100	5	1.0
28 - 29	150	80		60	5	3.0
April						
2 - 3	100	50	3.8	90	5	1.1
16 - 17	200	50		60	5	
23 - 24	150	55		60	5	
May						
1	150			70		
11	100	30		80	2.5	
Mean	245	65	6.4	105	5.5	2.6
Range	100 - 500			60 - 200		
Standard deviation		32.2	2.0		1.9	1.9
Percentage of survival	49			16		

Table 2 (cont.)

	Needle Branch 5			Needle Branch 6		
	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l
February						
12 - 13	350	60		350	10	
19 - 20	450			450		
26 - 27	300	17.5	9.0	450	10	4.2
March						
5 - 6	300	20	9.6	200	5	5.7
12 - 13	200	10	7.9	200	5	3.3
20 - 21	150	20		150	5	1.4
28 - 29	200	20	11.5	200	5	0.8
April						
2 - 3	150	20	3.6	100	2.5	0.8
16 - 17	500	22.5		500	2.5	
23 - 24	450	17.5		500	2.5	
May						
1	550			350		
6	700	22.5		800	2.5	
Mean	400	23	8.3	355	5	2.7
Range	150 - 700			150 - 800		
Standard deviation		12.8	2.6		2.7	1.8
Percentage of survival	36			22		

Table 2 (cont.)

	Needle Branch 7			Needle Branch 8		
	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l	Perm. m/hr.	Vel. cm/hr.	D.O. mg/l
February						
12 - 13	90	15		350	150	
19 - 20	100			500		
26 - 27	150	30		300	85	
March						
5 - 6	60	30	11.1	300	85	11.4
12 - 13	100	60	7.4	150	85	
20 - 21	60	50		150	100	4.2
28 - 29	60	40		150	100	4.1
April						
2 - 3	60	50		150	130	
16 - 17	100	75		200	110	
23 - 24	60	70		200	110	
May						
1	40			300		
6	50	45		350	130	
Mean	80	46.5	9.25	300	108.5	6.6
Range	40 - 150			150 - 500		
Standard deviation		17.8	1.9		21.1	3.4
Percentage of survival	62			48		

*Means rounded off to nearest half meter per hour.

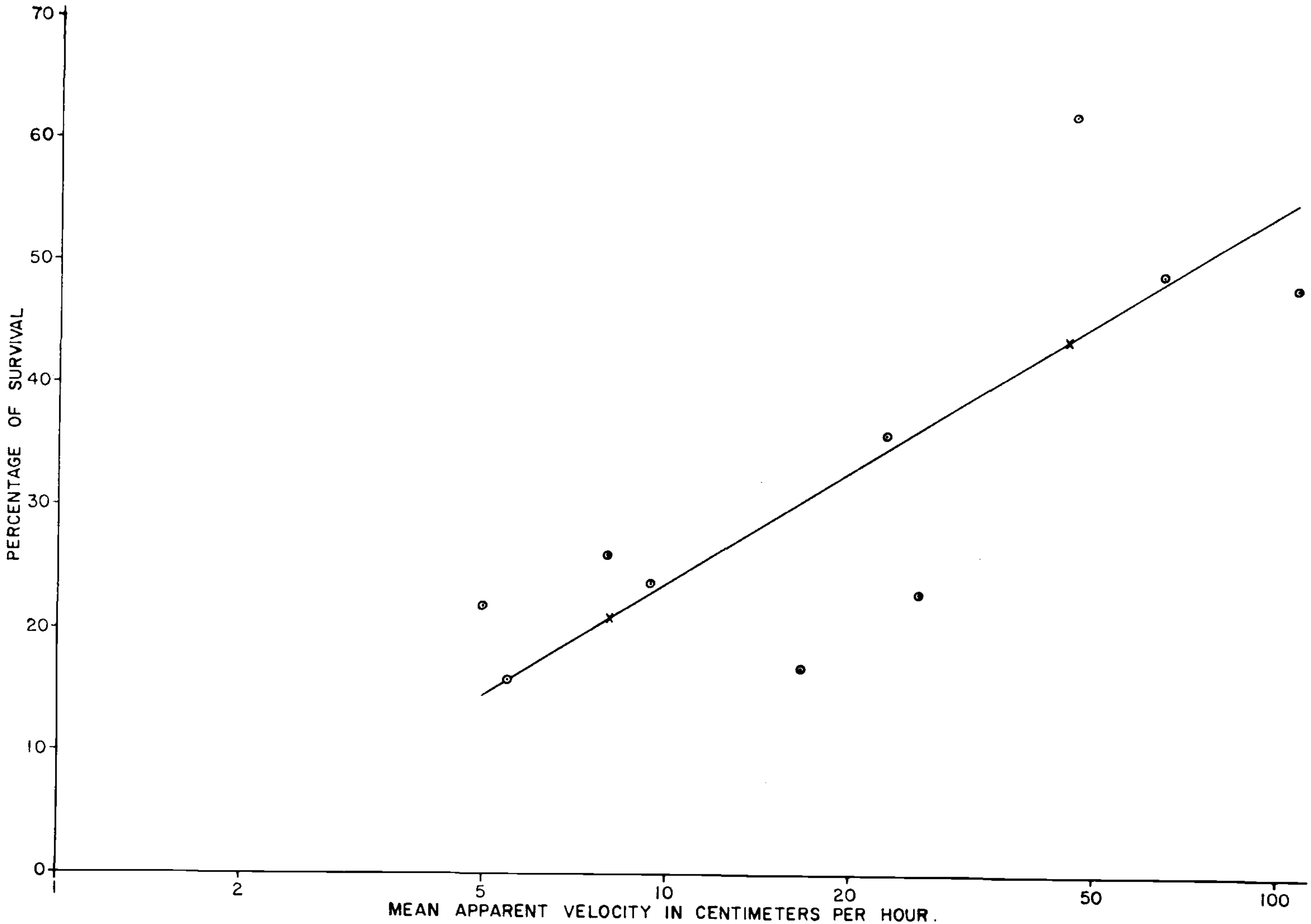

FIGURE 5. THE RELATIONSHIP BETWEEN APPARENT VELOCITY AND EMBRYONIC SURVIVAL.

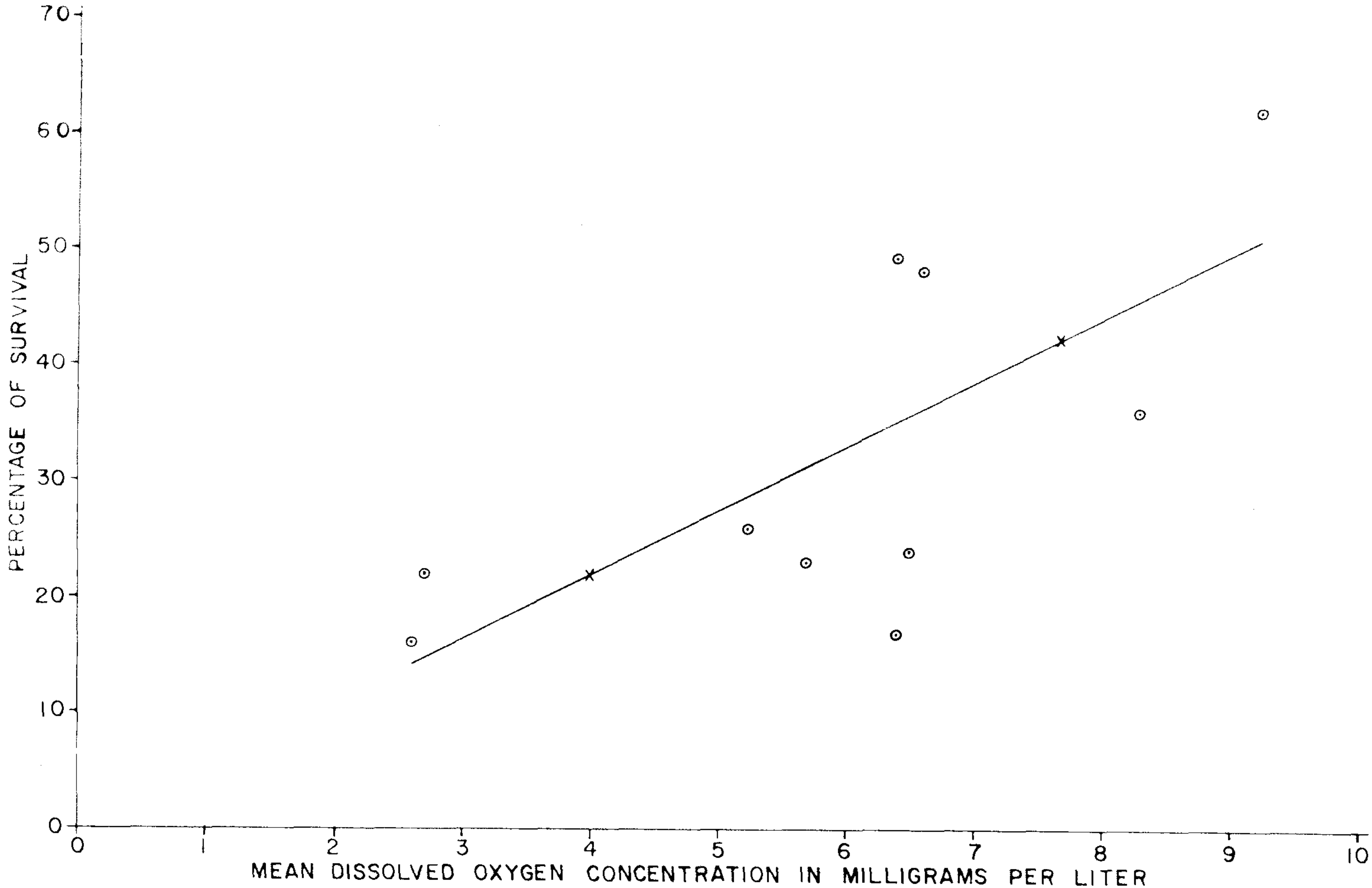

FIGURE 6. THE RELATIONSHIP BETWEEN DISSOLVED OXYGEN CONCENTRATION AND EMBRYONIC SURVIVAL.

Table 3

Percentages of particles less than two millimeters in diameter in gravel samples from Needle Branch and Horse Creek taken at the beginning and end of the period that planted steelhead embryos were in the gravel, 1959

Sample		Fine gravel 1 cm.	Coarse sand 1 mm.	Medium sand 0.5 mm.	Fine sand 0.25 mm.	Very fine sand 0.1 mm.	Total sand	Silt 0.02 mm.	Clay 0.002 mm.
Needle Branch 1									
February 10	a	14.7	31.5	24.4	16.4	6.4	93.0	4.0	3.0
	b	15.4	31.8	24.6	15.5	6.0	93.3	4.3	2.5
May 13	a	15.4	28.2	22.8	19.0	7.0	92.3	4.2	3.5
	b	13.0	27.3	24.0	20.4	7.6	92.3	4.4	3.3
Needle Branch 2									
February 10	a	15.7	40.8	22.4	10.7	4.3	93.8	4.5	1.7
	b	17.7	40.0	22.5	10.3	4.4	95.0	2.6	2.4
May 13	a	12.6	41.0	24.3	12.4	4.4	94.7	2.2	3.2
	b	14.9	41.5	24.1	11.5	3.8	95.8	1.9	2.4
Horse Creek 2									
February 10	a	8.9	12.4	19.9	31.4	15.5	86.4	8.1	5.2
	b	9.0	12.4	18.9	29.5	15.6	85.2	9.0	5.8
May 13	a	14.1	41.0	22.6	12.0	4.8	94.7	3.2	2.1
	b	14.0	40.0	22.2	12.6	5.0	94.0	3.9	2.2
Horse Creek 3									
February 10	a	17.8	43.2	22.5	8.2	3.3	95.1	2.1	2.8
	b	13.8	46.4	24.2	7.8	2.7	95.0	2.1	2.9
May 13	a	13.2	39.9	27.5	10.6	3.6	94.7	3.3	1.9
	b	18.2	42.0	23.2	8.7	3.3	95.4	2.2	2.4

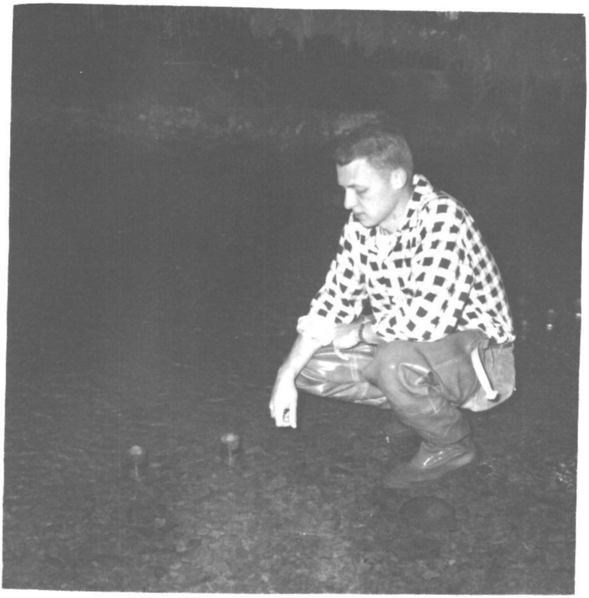

Figure 7. Two standpipes in position in the stream bed.

Figure 8. Obtaining readings of apparent velocity of ground water.

DISCUSSION

The apparent velocity of gravel water is a function of several variables: the head or pressure gradient of the water and its density and absolute viscosity, the diameter of the particles and the porosity of the material, the acceleration of gravity, the roughness of the surfaces of the particles and their shape and size distribution. For practical purposes, all of the factors may be reduced to two variables which most influence the velocity of the ground water: the pressure gradient of the water and the permeability of the gravel. The dilution rate of a color solution in a standpipe actually measures the pressure gradient of the ground water. In order that the data obtained by such a procedure can be converted into the more useful apparent velocity figures, the other variable, gravel permeability, must be known.

The experiment in which salmon embryos were used was designed under the assumption that gravel permeability does not appreciably change during the incubation period. Therefore, no attempt was made to measure permeabilities and apparent velocities on the same or consecutive days. Consequently the velocity determinations in this experiment were inaccurate. Furthermore, because "eyed" embryos were used, the length of exposure of the embryos was relatively short and early developmental stages were not tested. The experiment, then, was of limited value in showing the effects of gravel conditions upon developing embryos.

In the steelhead experiment, when the apparent velocity readings were plotted against the percentage survivals on arithmetic graph paper, a curvilinear relation was apparent. Semi-logarithmic paper was used in Figure 5 so that the relationship could be shown as a straight line. If the various points on the graph are moved along and parallel to this line to 31 centimeters per hour, they will then lie on an imaginary vertical line which passes through 31 centimeters per hour, the mean value of all apparent velocity determinations. Now if the percentages of survival corresponding to these points in their new positions are plotted against the 10 mean dissolved oxygen values, no definite relationship is apparent, as is shown in Figure 9. In the same manner, the various points in Figure 6 can be moved along and parallel to the regression line to six milligrams of oxygen per liter, the mean value of all dissolved oxygen measurements. When the percentages of survival corresponding to these points (which are now lying one above the other) are plotted against the 10 mean apparent velocity figures, no correlation is evident. (See Figure 10)

In this study, the determinations of apparent velocity and of dissolved oxygen are of similar value in appraising the environment of the embryos. In Figure 9 the relationship between apparent velocity and survival has been removed. If a positive correlation were shown here, the dissolved oxygen sampling would be providing more information than the velocity measurements. In Figure 10 the relationship between dissolved oxygen and survival has been

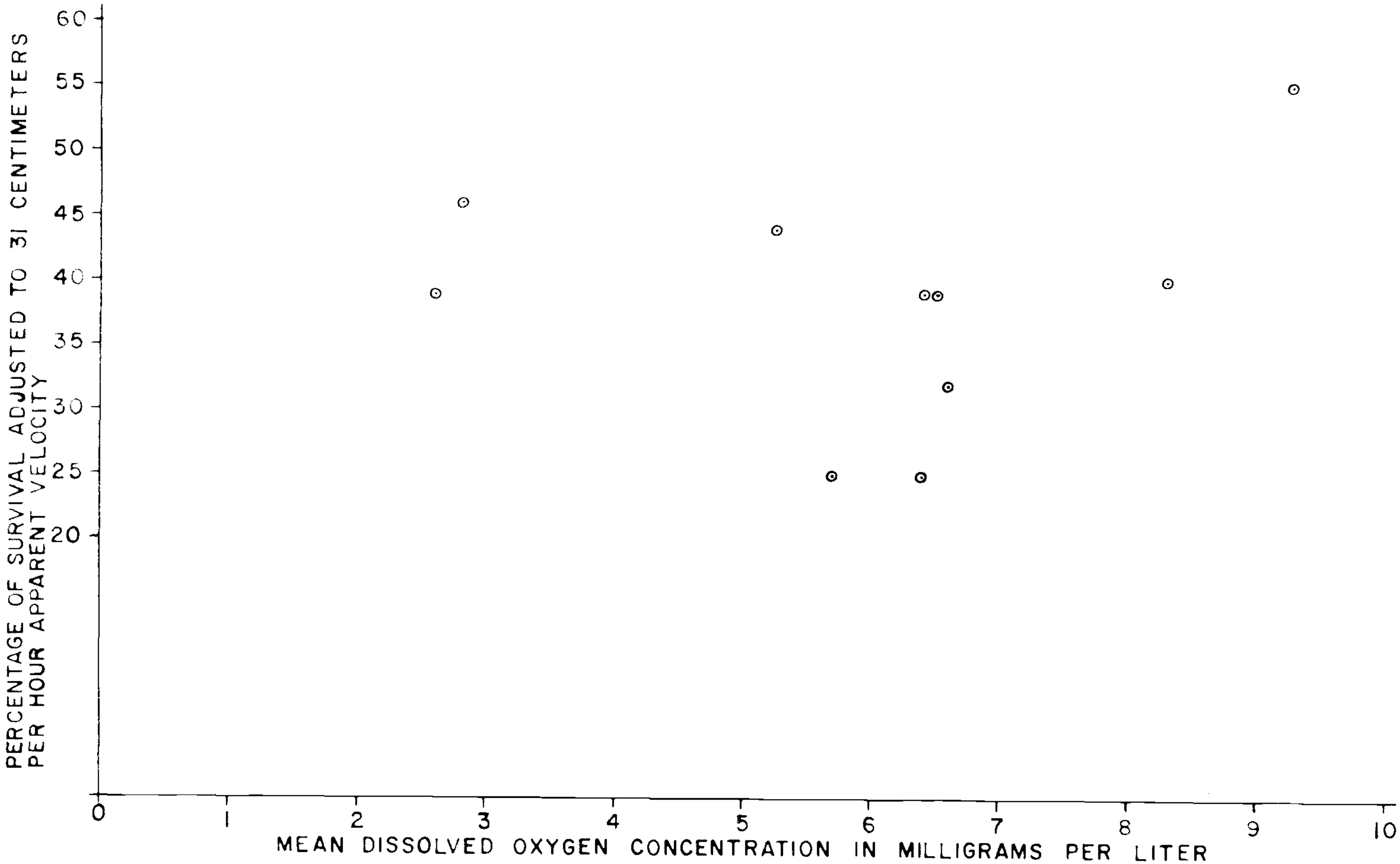

FIGURE 9. THE RELATIONSHIP BETWEEN DISSOLVED OXYGEN CONCENTRATION AND THE PERCENTAGE OF SURVIVAL ADJUSTED TO 31 CENTIMETERS PER HOUR APPARENT VELOCITY.

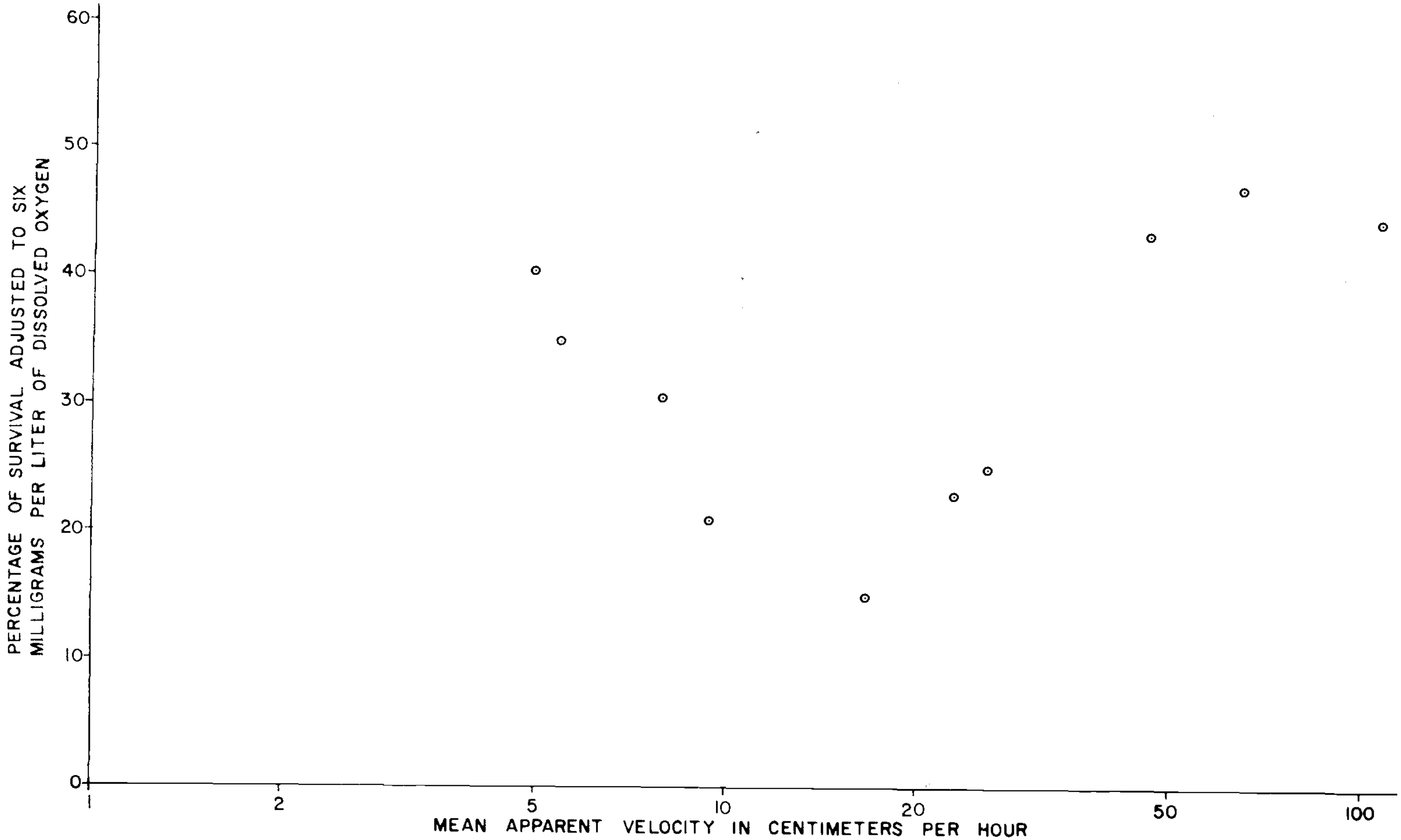

FIGURE 10. THE RELATIONSHIP BETWEEN MEAN APPARENT VELOCITY AND PERCENTAGE OF SURVIVAL ADJUSTED TO SIX MILLIGRAMS PER LITER OF DISSOLVED OXYGEN.

removed. Since no correlation is obvious here, the velocity determinations are not yielding more information than the measurements of dissolved oxygen.

It should be borne in mind, however, that it is oxygen that is essential to the embryo. The function of water movement is merely to deliver oxygen to the embryo and to carry away metabolic waste products. Usually, however, dissolved oxygen concentrations and apparent velocities are closely related in the stream bed; when one is high the other may be expected to be high and when one is low the other may be expected to be low. The effect of these on embryonic survival has already been illustrated in Figures 5 and 6. Recent work by Mr. Dean Shumway for the Pacific Cooperative Water Pollution and Fisheries Research Laboratories at Oregon State College has shown that the embryo's oxygen requirements can be met by very low water velocities and that the influence of velocities ranging from 3 to 750 centimeters per hour on embryonic growth is slight compared to the influence of oxygen levels ranging from 2.5 to 10.4 milligrams per liter.

In most cases, therefore, determinations of the oxygen content of water flowing through the redd provide a satisfactory evaluation of the environment of the embryos. Situations may occur where oxygen levels are low while velocities are high because of the flow pattern in the gravel or because of large amounts of organic matter or large numbers of embryos in the gravel. In two redds receiving waters flowing at different velocities but containing the same concentration of dissolved oxygen, a higher survival may be expected in the area with the higher exchange rate.

Gravel six inches away from a standpipe has little effect on the permeability measurement obtained at the pipe. Furthermore, gravel permeability varies greatly from point to point; standpipes half a foot apart may yield different readings. (Measurements taken one after another at a pipe, however, are the same.) It is not surprising that no apparent relationship was found between gravel permeability and survival. Over a relatively large area, however, in general, a positive correlation between permeability and survival may be expected. Wickett (21, p. 1103) states that, "The density of spawners that produces the greatest numbers of fry is related to the average permeability of the stream bottom."

Gravel and some of the steelhead embryos used in the experiment were placed in a plastic bag and suspended in a five gallon jar as a control. Water from a small spring-fed stream was led through a piece of rubber tubing to the bottom of the container. In the days that followed, the stream supplying water to the jar became turbid, and silt was deposited in the gravel in the egg sack. The bag was removed 22 days later, and the 94 eggs in it were preserved. Embryos were present in 68 of these ova. Of those that did not contain embryos, 17 were covered with fungus; the other 9 were as clean as the good eggs. Either handling or silt could account for the failure of the embryos to develop. An estimate that 72 to 82 per cent of the embryos lived beyond the first 22 days is reasonable. The maximal survival to emergence of water-hardened salmon ova used in the first experiment was 64 per cent. Briggs (4) figured the percentage of emergent fry produced from naturally spawned steelhead eggs in Prairie Creek, California, to be 64.9 per cent. Shapovalov and Taft (14) estimated that 65 to 85 per cent of the embryos deposited at Waddell Creek, California, emerge as fry.

Indications were found that considerable gravel movement occurs at least 10 inches below the stream bed during the period that salmonid eggs are in the gravel. It is conceivable, therefore, that shifting gravel as well as insufficient oxygen is a cause of egg losses. Gangmark (7) found early mortalities corresponding with freshets. Unfortunately, no evidence supporting this theory was acquired in this study.

Needle Branch is a virgin stream; the watershed of Horse Creek has been logged. The gravel sampling data is of general interest, and the analysis of it is statistically sound, but it is not intended to show that there is a difference in sediment deposition in logged and unlogged streams. Such a conclusion is not justified for several reasons, one of which is the lack of sufficient samples.

SUMMARY

1. A study of spawning gravel conditions and their effects upon incubating salmonid embryos was conducted in four small coastal streams in Lincoln County, Oregon.

2. The permeability of spawning gravel in the streams was continually changing during the period that silver salmon and steelhead trout embryos were in the gravel.

3. Movement of gravel 10 inches below the surface of the stream bed was indicated in areas where no disturbance was apparent at the surface.

4. The survival of salmonid embryos in the gravel was related to the apparent velocity and dissolved oxygen content of subsurface water.

5. In this study determinations of the apparent velocity and dissolved oxygen content of ground water were of equal value in evaluating the environment of the embryos.

6. The analysis of gravel samples collected in February and May indicated no increase in the amounts of medium, fine, very fine sand, or silt in the gravel over this period.

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APPENDIXES

APPENDIX A

Discharge, cu. ft. per sec., of Needle Branch, Lincoln County, Oregon, (1958 and) 1959*

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
1	0	0.1	1.0	3.1	4.7	1.1	4.1	1.5	0.4
2	0	.1	1.2	2.4	3.6	1.0	3.7	1.2	.4
3	0	.2	1.9	1.9	2.6	.9	3.1	.9	.4
4	0	.6	1.7	1.7	1.9	.8	2.4	1.1	.6
5	0	11.9	1.4	1.8	1.6	.8	1.9	3.9	.6
6	0	4.7	1.2	1.7	1.6	.7	1.5	3.8	.4
7	0.1	3.0	2.3	2.7	1.8	.6	1.3	2.5	.4
8	.2	6.7	2.1	9.9	1.7	.6	1.1	1.9	.4
9	.1	6.3	1.9	13.0	2.4	.8	.9	1.7	.9
10	.1	4.9	2.3	8.2	4.1	.6	.8	1.5	.8
11	.1	3.2	5.7	6.8	3.8	.6	.7	1.4	.7
12	.1	3.7	4.8	9.2	3.0	.8	.6	1.2	.6
13	.1	7.0	3.8	6.8	4.0	1.2	.6	1.0	.6
14	0	7.2	2.8	5.2	7.8	1.2	.6	1.1	.6
15	.1	5.6	2.1	3.8	6.8	1.1	.5	1.2	.5
16	.1	3.9	1.7	3.2	5.9	1.0	.5	1.0	.5
17	.1	2.8	1.4	2.6	4.7	.9	.5	1.0	.5
18	.2	4.3	1.2	2.4	4.4	1.9	.4	1.1	.4
19	1.3	9.2	1.1	2.2	5.9	2.8	.4	.9	.4
20	.3	9.6	1.6	2.1	5.3	2.0	.4	.9	.4
21	.2	7.2	2.8	1.9	4.0	2.4	.3	.8	.4
22	.2	4.9	2.4	1.8	3.2	2.4	.3	.8	.3
23	.2	3.5	2.0	1.8	2.5	3.0	.3	.7	.3
24	.1	2.5	1.8	3.6	2.0	2.9	.3	.6	.3
25	.1	1.9	1.9	3.4	1.8	3.1	.3	.6	.3
26	.1	1.5	2.8	3.3	1.5	3.7	.3	.6	.3
27	.1	1.2	4.3	11.7	1.4	3.5	.6	.5	.3
28	.1	1.1	5.2	9.0	1.2	3.5	.6	.5	.3
29	.1	1.2	4.4	6.2		3.7	.7	.5	.3
30	.1	.9	4.3	7.8		5.2	1.8	.4	.2
31	.2		3.8	6.3		4.7		.4	
Mean	.14	3.70	2.55	4.76	3.40	1.92	1.05	1.20	.45
Max.	1.3	9.6	5.7	13.0	7.8	5.2	4.1	3.9	.9
Min.	0	0.1	1.0	1.7	1.2	.6	.3	.4	.2

*Data obtained from a stream-gage on Needle Branch operated by the U. S. Geological Survey. There is no such installation on Horse Creek.

APPENDIX B

Maximal water temperature, degrees F., of Needle Branch, Lincoln County, Oregon, (1958 and) 1959

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
1	55	51	48	48	47	48	48	49	50
2	56	51	49	47	47	47	49	48	50
3	57	52	49	45	47	46	49	48	50
4	57	52	49	42	47	46	49	48	52
5	57	53	47	42	47	45	48	48	51
6	56	54	47	43	46	46	48	49	50
7	55	54	47	45	45	46	49	50	51
8	55	53	47	47	44	46	50	50	50
9	54	53	47	48	44	46	51	49	49
10	55	52	49	48	46	45	49	49	49
11	55	50	49	48	46	45	50	49	
12	54	50	49	48	46	46	48	51	
13	56	50	48	48	46	46	48	50	
14	55	49	47	48	46	45	47	50	
15	55	47	47	47	47	46	47	50	
16	55	46	47	48	48	46	46	49	
17	54	46	47	48	48	47	47	49	
18	55	48	48	48	48	47	47	49	
19	54	49	48	48	48	47	49	48	
20	53	49	49	47	48	47	49	48	
21	51	49	49	46	48	47	50	48	
22	50	49	49	47	47	47	50	50	
23	50	49	47	47	47	47	51	51	
24	48	49	47	48	47	47	50	50	
25	48	48	47	48	46	47	49	50	
26	48	46	47	48	46	47	49	49	
27	48	45	47	48	46	47	49	49	
28	48	44	47	48	47	47	49	48	
29	48	45	48	48		47	50	49	
30	49	47	48	47		47	50	50	
31	51		48	47		47		50	
Mean	53	49	48	47	47	46	49	50	50