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ON THE OXYGEN SUPPLY TO SALMON EGGS

by

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ON THE OXYGEN SUPPLY TO SALMON EGGS

A preliminary study on pre-eyed chum salmon eggs in the gravel at Nile creek

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ABSTRACT

Both field and laboratory experiments have shown lethal effects from the deposition of silt on incubating salmon eggs. Because silting appears to deprive the eggs of sufficient oxygen, theoretical limits of flow and oxygen content of sub-surface water were studied. Data have been gathered on temperature, oxygen content, and rate of flow of water twelve inches below the surface of the gravel at Nile creek. Field determinations of oxygen consumption of pink, chum and coho eggs have been made. In heavily-silted portions of the bed there was an insufficient supply of oxygen for pre-eyed chum salmon eggs. A field method for determining oxygen content and apparent velocity of gravel water is presented.

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I. INTRODUCTION

The Problem

In a study of the freshwater development of the chum salmon (*Oncorhynchus keta*) at Nile creek on Vancouver island, high losses (averaging 70%) have been found in the pre-eyed stage. It is believed that a real part of this loss is due to oxygen deficiency, associated with the presence of silt in the salmon redds. To assess this, it was necessary to obtain basic knowledge of the oxygen requirements of the eggs and of the oxygen available in the stream bed. A technique that may have general application in the field of fishery biology is required for the rapid assessment of oxygen availability in salmon redds.

Literature

Two studies of the natural incubation of salmonoid eggs are of major interest, those of D. Hobbs (1937, 1940, 1948) in New Zealand and W.M. Cameron (1939, 1941) in British Columbia. In both places, pre-eyed losses were greater than eyed losses and were associated with the amount of very fine material in the redds during the development of the ova before eyeing.

In his classic study of the natural reproduction of New Zealand salmonoids, Hobbs recognized an adequate oxygen supply as an important factor influencing egg survival. Mortalities at the various stages of development of eggs and alevins were observed by sampling redds in numerous localities. In New Zealand he concluded "that the extent of losses of fertilized ova in undisturbed redds depended primarily on the amount of very fine material in the redds during the development of ova before eyeing". However, these losses were less than 10%, and other losses were dominant and limited the population size.

He listed seven factors to be considered if anything in the nature of an exact determination of the permeability of a redd were attempted, with a view to ascertaining whether ova receive a sufficient amount of oxygen:

1. The number and size of ova per unit volume of bottom material.
2. Their oxygen requirements.
3. The permeability of the redd material.
4. The contours of the redd.
5. The rate of flow of water over the redd.
6. The amount of available oxygen per unit volume of water.
7. Water temperature.

Hobbs, however, was not able to satisfy his own conditions.

Cameron suggested that for McClinton creek pink salmon there is a definite relation between pre-eyed and total mortalities of eggs and alevins, and that low mortalities are almost invariably associated with medium to coarse gravel, good circulation, and the absence of silt or plant material. This suggests that when pre-eyed losses are high they become dominant, and that conditions conducive to a plentiful supply of oxygen reduce this mortality.

Recent work indicates a direct relation between flow of streams during the period of spawning (which includes the early pre-eyed stage) and chum salmon population size four years later in the Vancouver island district (Neave and Wickett, 1949). The size of particles carried by water is related to the velocity of flow (Mavis, Ho and Tu, 1935). If the flow decreases at spawning time, increasingly fine silt may accumulate on the spawning beds. Silting may reduce the rate of flow of oxygen-bearing water in the gravel since the permeability of a porous medium varies as the square of the diameter of its grains (Mavis and Wilsey, 1936).

Mavis and Wilsey also found that the permeability of sand varied with the fifth or sixth power of the porosity, i.e., degree of consolidation, (page 5). This restriction of flow by consolidation is emphasized by Ellison (1950) who says that deep-sealing of fields may be caused by the infiltration of turbid rainwater, the ground becoming nearly impervious to water within twenty-five years under certain conditions. This process could very well be taking place in stream beds.

A third factor that may also be associated with reduced surface discharge of streams is reduced sub-surface flow through the gravel from the banks of streams, due to the lowering of the water-table, which is one of the primary causes of decreased stream flow. (Hoyt, 1942).

Water transports the oxygen that is consumed by salmon eggs. The oxygen consumption of salmonid eggs has been studied by several workers but none has related his findings to conditions in gravel beds. The oxygen consumption of Atlantic salmon (*Salmo salar*) eggs has been carefully studied by Lindroth (1942) and by Hayes and his associates (Hayes, 1949). Kawajiri (1925) recorded the oxygen consumption of the eggs of *Oncorhynchus masou*, though the temperature of the experiments is not given. Smith and Kleiber (1950) give formulae for the relation of size and oxygen consumption of various fertilized eggs at 25°C. Zeuthen (1947) made a general study of body size and metabolic rate in the animal kingdom.

None of the above give data suitable for present requirements nor are any studies of the oxygen demand of chum salmon eggs known to the writer.

Besides the two authors mentioned previously there is ample evidence to indicate the importance of adequate water flow over incubating eggs in the writings of Schaeperclaus (1933), Hata (1931), Vibert (1950), Hubbs, Greeley, Tarzwell (1932), Shetter, Clark, Hazzard (1946), Hewitt (1931), White (1942) and Moffett (1949). From these authors it is clear that an improvement of the quantity and quality (oxygen content, temperature, freedom from silt and chemicals) of the water supply usually improves the survival of incubating salmonoid eggs.

Shaw and Maga (1943) carried out tests on the deleterious effect of mining silt. One or two points from their paper are of particular importance:

> "Silt added during the initial stages of incubation and continued for either a few days or a longer period, causes severe damage resulting in low yields of fry. The emergence of fry above the gravel is retarded .... (and) .... in general these fry were smaller and weaker than those of the control series and a number of deformities were noted. The larger number of whole eggs remaining in the gravel at the conclusion of this experiment is significant as it shows a tendency for undeveloped eggs to resist decomposition, apparently due to a protective coating of silt."

The same effect has been noted in the "controlled-water" section of Nile creek, where eggs planted the previous year have been found preserved in the gravel after twelve months. The composition of the stream bottom in one such area was of consolidated large stones, sand, silt and small gravel, and the surface flow was good with little surface silting. In another of these areas the gravel was (and still is) heavily silted. On the other hand, excellent incubation was found where there was reduced surface flow, much surface silting but a spring upwelled close by and the gravel was loose. In view of this, silt of itself did not seem to be lethal, but in certain instances it would appear that circulation of the water is so greatly reduced that there is insufficient oxygen for the disintegration of dead eggs in gravel.

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II. FORMULATION OF PROBLEMS

Three main problems present themselves: 1. oxygen requirements of chum salmon eggs; 2. the mechanism of transport of oxygen to eggs in the gravel; 3. a method of evaluating water conditions in the gravel.

In this study the following symbols are used:

A = oxygen demand of the eggs, i.e., the amount of oxygen necessary for normal metabolism, in mg.O_2/egg/hr.

R = radius of egg, in mm.

p = porosity of gravel, i.e., $\frac{\text{total volume of pores}}{\text{bulk volume}}$.

u = component of true velocity in direction of flow, in mm./hr.

v = apparent velocity of water, i.e., $\frac{\text{discharge}}{\text{area}}$.

do = amount of oxygen dissolved in water, in mg.O_2/litre.

C = value of de at which A is sharply reduced.

n = number of eggs in a column in the direction of water flow.

Oxygen requirements of chum salmon eggs

The oxygen demand is assumed to be the same for all eggs of similar past history at a given temperature and at a similar stage of development.

For *Salmo salar* eggs the oxygen demand increases with age and temperature (Hayes, 1949), but is independent of the amount of oxygen dissolved in the water, provided the dissolved oxygen (do) is above a critical value (C). The oxygen demand is abruptly reduced when the amount of oxygen dissolved in the water is reduced below this critical value. For the stages immediately preceding hatching, the critical value is greater than full saturation because the oxygen consumption of the egg is being limited by the rate of diffusion of oxygen through the capsule.

The critical value of dissolved oxygen varies with the oxygen demand of the egg, the square of its radius and the rate of diffusion of oxygen through the egg (Krogh, 1941). It may be expressed in oxygen tension, i.e., partial pressure of oxygen in millimeters of mercury multiplied by the percentage saturation; in atmospheres, i.e., 760 mm. Hg pressure of oxygen; in the degree of oxygen saturation of the water; or simply parts per million at a given temperature.

Values of the oxygen demand (A) of pre-eyed chum salmon eggs are required at temperatures that occur in nature, and at values of dissolved oxygen (do) greater that the critical value (C). In view of the lack of specific knowledge, field determinations are preferable to deductions made from the literature. A and C may be found by recording the reduction of do per unit time in either moving or static volumes of water in which the eggs are immersed.

Oxygen supply in the gravel

The oxygen supply to eggs in water will depend on the volume of water per unit time (Q) delivering oxygen to the eggs, and the oxygen per unit volume (do) dissolved in the water; i.e., gross supply is Qdo. The oxygen available for full metabolism will consist of the dissolved oxygen in excess of the critical oxygen content; i.e., the effective supply is

$$Q(do-C) \qquad (1)$$

The true velocity (u) of fluids in gravel beds is difficult to determine. Nominal or apparent velocity (v) is used in practice and is defined as the volume of discharge per unit time (Q) divided by the total cross section of the area (a) through which the fluid is assumed to flow, just as though this area were filled with water only, i.e.,

$$v = \frac{Q}{a}$$

In the case of a clear area, $v = u$. If a fluid discharges through a porous medium, and discharge (Q) and area of cross-section (a) are the same as for the clear area, then u is greater than v, for Q is coming from only the total area of the pores in a.

v is a quantity capable of calculation and easy observation in a laboratory. If we use it instead of true velocity then an expression of limiting supply of oxygen to an egg is possible. Acceptable conditions for full metabolism will obtain when the weight of oxygen per unit volume, in excess of the critical weight per unit volume, multiplied by the volume per unit time equals or is greater than the weight of oxygen used per unit time, i.e.,

$$A \leq Q(do-C) \quad (2)$$

Whether an egg is in water only, or in gravel of any given porosity does not matter if v is known. Because of variations in speed of flow in different parts of the gravel, measurements of v may have to be made close to the eggs with several replications of v. Even so, estimating v is much simpler than u because v is calculated from a which is a gross area that contains gravel, eggs and pores.

Assume as a first approximation that if the effective area (a_e) presented by an egg to the flow of water is known, then Q may be calculated from

$$Q = va_e$$

For a single egg, if oxygen diffuses from the adjacent 1 mm. of water only, a_e will be a maximum at $\pi(R+1)^2$ and the maximum supply of oxygen is

$$\pi(R+1)^2 v(do-C)10^{-6} \quad mg. O_2/egg/hr. \quad (3)$$

For eggs in an egg mass, the area of egg plus interstitial space per egg presented in one plane was found to be approximately $1.1\pi R^2$ by measuring the area occupied by one layer of eggs, so the maximum supply in this case is

$$1.1\pi R^2 v(do-C)10^{-6} \quad mg. O_2/egg/hr. \quad (4)$$

In expression (4) no allowance is made for a progressive decrease of do as the water passes successive eggs. In order that the last (n) egg of a column in the direction of water flow, shall just receive sufficient oxygen, then the oxygen supply must be equal to n times the demand of one egg or the demand of one egg equals 1/n times the supply. As ten eggs is a reasonable number of eggs to occur naturally in the direction of flow of water in a salmon redd, and is easy to calculate, it may be taken as an arbitrary standard.

If the oxygen demand, the critical value of dissolved oxygen, and the radius of the eggs is known, the sufficiency of the oxygen supply in the gravel may be estimated from the apparent velocity and oxygen content of the water in the gravel, using this formula:

$$nA \leq 11\pi R^2 v(do-C)10^{-7} \qquad (5)$$

Method of evaluating gravel water conditions

The expression above requires data on the water 10 to 12 inches below the surface of a stream bed. Temperature is required so that the oxygen demand of the eggs may be known. The dissolved oxygen content and velocity at that level are required so that the supply of oxygen may be known.

Cole (1932) describes a method of determining the dissolved oxygen content of the mud at the bottom of a pond. A glass tube with a filter on the bottom was forced into the mud and withdrawn when full of water. Tubes set permanently in the gravel would enable water samples to be drawn from the sub-surface water by inserting a suction tube, and temperature could be found by introducing a thermometer into the set pipes.

Rose (1945), who has formulated the laws of fluids through granular materials, notes that exact velocities in a particular part of a bed are virtually impossible to calculate. The possibility of observing velocities, though, is not ruled out.

The observation of true velocity, u, by means of tracers is dependent on the sampling positions being on the line of flow of water. This is not necessarily easy to determine and, it can be shown, would require that the porosity (p) be known. The act of sampling gravel changes the porosity, though a maximum value can be obtained by testing a dried sample of gravel. In view of the difficulties involved, the observation of true velocity will not be attempted.

The observation of apparent velocity would require that the discharge from a given area be known. (In the field, ground water flow is calculated from the observed change in depth of water in wells around a pumped well.) For present purposes, a method is desired that will not change the hydraulic conditions above or below the surface of the bed of a stream and will indicate v where a is small. Further research is required to provide a method fulfilling these conditions (sections IV and V).

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III. DETERMINATION OF OXYGEN REQUIREMENTS OF PRE-EYED CHUM EGGS

Method

Nineteen ordinary glass-top preserving jars of approximately 950 cc. volume were weighed dry and filled with water at 6°C. to determine their volumes to ± 0.5 cc. Each top and bottle was numbered and used together. Eggs were placed carefully in the jars by means of "egg pickers", and the jars were filled with water which was led to the bottom of the jar by a tube from the hatchery head trough (at the Nile creek field station). The jars were capped without air bubbles and placed in the head trough so that they were covered with water. A water seal and a fairly uniform known temperature were thus obtained.

Due to the extreme susceptibility of pre-eyed eggs to shock, the water over these eggs could not be stirred. In most cases, 100 eggs were used as a sample as they formed a single layer on the bottom of the jar, although samples of 50 and 200 eggs were used occasionally.

Oxygen determinations were made on samples of water taken at the time of filling. Procedures and equipment for oxygen determination are described by Tully (1949, 1950). After approximately twelve hours, the jars were opened carefully and water drawn off by siphon from the bottom of the sealer for the final oxygen determination. The oxygen sample bottle was rinsed and the sample for determination was that from the mid-section of the jars.

To find out if excessive amounts of carbon dioxide were being formed, the pH of the water from some of the bottles was taken by a Beckman meter at the end of the experiment. The range found was 6.89 to 7.1, which was within the normal range of the natural waters.

After making the oxygen determination, the eggs were dried by rolling them in cheesecloth and then on filter paper, live and dead were counted, weighed, and their volume determined by displacement. The radius of the eggs (R) was found by measuring a row of ten eggs. The oxygen consumption for later stages of development of chum, pink, and coho eggs were taken as a check on the correct order of magnitude of oxygen demand.

<u>Results</u>

Results are given in Table I and appendix A.

TABLE I

OXYGEN CONSUMPTION OF PRE-EYED CHUM SALMON EGGS DETERMINED IN STATIC WATER AND COMPARATIVE VALUES OF CONSUMPTION AND CRITICAL DISSOLVED OXYGEN FOR OTHER EGGS

State and age of eggs at start (days)	Consumption A (mg/egg/hr.)	Critical DO C (ppm.O_2)	Temp. (°C.)	No. of eggs & replicates
		Oncorhynchus keta		
Pre-eyed 0	.00013		3.7-5.2	100 (11)
" 5	.0003		8.0-8.2	100 (3)
" 12	.0002-.00028		0.1-0.7	100 (9)
" dead	.0003		0.1-0.7	40 (6)
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Faintly eyed 67	.0002		0.1-0.7	100 (5)
" " 85	.00079	<5 (3.7)*	3.6-4.9	50 (13)
10 days before hatching 103	.002	8.6 (9.2)*	5.9-6.1	200 (4)
		O. gorbuscha		
Faintly eyed 28	.0003		6.2-6.9	100 (1)
Eyed 33	.0006		7.9-8.3	100 (3)
7 days before hatching 48	.0007	9.6	7.9-8.3	100 (3)
7 day alevin 62	.01		8.0-8.2	50 (3)
		O. kisutch		
Faintly eyed 67	.0002		0.1-0.7	100 (5)
Hatching 110	.003		4.3-4.9	10 (8)
0 day alevin 110	.009		4.3-4.9	10 (1)
		Salmo salar (Lindroth, 1942)		
"Domed"	.00014	0.76 (0.66)*	5.5	
Brain just)	.00028		4	
developed)	.00068		13	
Nearly hatching	.0039	approx. 5.8	5	
Hatching	.0067	10	17	
		O. masou (Kawajiri, 1925)		
Pre-eyed	.001		?	

* Calculated from Harvey's formula in Krogh (1941)

Oxygen consumption of the eggs was calculated as follows:

$$A = \frac{(V_B - V_F)(DO_1 - DO_2)}{1000\ NT}$$

where A	= oxygen demand of the eggs	mg. O_2/egg/hour
V_B	= capacity of bottle	cc.
V_F	= total volume of eggs	cc.
DO_1	= dissolved oxygen in water at start of experiment	mg./l.
DO_2	= dissolved oxygen in water at end of experiment	mg./l.
N	= number of eggs used	
T	= duration of experiment	hr.

$(DO_1 - DO_2)$ is divided by 1000 to convert mg./l. to mg./cc.

The bio-chemical oxygen demand (BOD) of the water was found to be nil, but the BOD of dead chum eggs at 0.1 - 0.7°C. was found to be about 50% greater than the consumption of living eggs. As the time of death of eggs in the experiment was not known, corrections were not made for the BOD after death of eggs.

Critical values of dissolved oxygen (C) were not found for pre-eyed eggs as the value of do could not be reduced to this limit within the time of the experiment. However it was found for the eyed chum eggs. To obtain an approximate value for pre-eyed eggs, the formula of Harvey (1928) quoted by Krogh (1941) was used, as it gave reasonable checks with both the eyed chum and Lindroth's (1942) data.

It is assumed that the egg is a homogeneous spherical body in which oxygen is used up at a constant rate, the same throughout, and that the oxygen tension at the centre is maintained at zero. (Oxygen tension is the product of percent oxygen saturation and the partial pressure of oxygen in air saturated with water vapour at 760 mm. Hg.).

Harvey's formula is:

$$C_o = \frac{A.r^2}{6D} \text{ atmospheres}$$

where: C_o = critical concentration of oxygen in atmospheres (760 mm. Hg.) at the surface of the egg.

A = oxygen consumption in ml./gm./min.

r = radius of egg in cm.

D = diffusion coefficient of oxygen within the egg in ml./atm/cm./cm.^{2}, assumed to be .000015.

To convert to mm. of Hg., C_o must be multiplied by 760 mm. The partial pressure of oxygen (P_o) (approx. 157 mm.) must be divided into this figure to give the equivalent percentage saturation of oxygen. The critical value of do required is found by multiplying the percentage saturation value by the p.p.m. oxygen (do_{100}) required for full saturation at the given temperature.

The formula given in Tully (1950) is used to get a factor (approx. .7) to convert mg./l. to ml./l. O_2. The critical value of do is expressed thus:

$$C = \frac{760\ A\ r^2\ do_{100}\text{ppm.}}{6DP_o}$$

1. Pre-eyed chum eggs; age 0 days; temp. 3.7°-5°C.; A = .00013 mg./egg/hr.

$$A = .00013 \text{ mg./egg/hr.} = \frac{.00013 \times .71}{.29 \times 60} = .00000394 \text{ ml./gm./min.}$$

$$C = \frac{760 \times 3.94 \times 10^{-6} \times 1.6 \times 10^{-1} \times 12.8}{6 \times 1.5 \times 10^{-5} \times 157.5} = 0.39 \text{ ppm.} O_2$$

2. Pre-eyed chum eggs; age 5 days; temp. 8°C.; A = .0003 mg./egg/hr.

$$A = .0003 \text{ mg./egg/hr.} = \frac{.0003 \times .72}{.29 \times 60} = 0.0000125 \text{ ml./gm./min.}$$

$$C = \frac{760 \times 1.25 \times 10^{-5} \times 1.6 \times 10^{-1} \times 11.9}{6 \times 1.5 \times 10^{-5} \times 157.2} = 1.3 \text{ ppm.} O_2$$

3. Pre-eyed chum eggs; age 12 days; temp. $0.1^{\circ} - .7^{\circ}C.$; A = .0002

$$A = .0002 \text{ mg./egg/hr.} = \frac{.0002 \times .7}{-29 \times 60} = 0.00000805 \text{ ml./gm./min.}$$

$$C = \frac{760 \times 8.05 \times 10^{-6} \times 1.6 \times 10^{-1} \times 14.4}{6 \times 1.5 \times 10^{-5} \times 157.9} = 0.60 \text{ ppm.} O_2$$

Discussion

The results are not precise but are field determinations which establish the order of magnitude. Their general agreement with Lindroth's results lead to the belief that they may be used in the formulae developed previously to establish minimum values of velocity and oxygen content necessary to supply the full demand of the eggs. These values of oxygen consumption are apt to be less than they should be, because the water was not stirred except in the experiment with the 103-day eggs.

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IV. DETERMINATION OF OXYGEN CONTENT AND VELOCITY OF GRAVEL WATER

Method

At Nile creek a side channel has been dammed and a water gate installed so that the water flow may be controlled. In this section freshly fertilized ova have been planted each fall since 1947. Data on gravel conditions were gathered here. The upper quarter was normal loose gravel, free of sand(pipes #1-5), the second quarter consolidated gravel (#6,7), and the lower half covered with a heavy layer of sand and leaf material (#8,9).

Nine $1\frac{1}{2}$" pipe rail fittings, known as "cross with side outlet" were fitted with $\frac{1}{2}$" pipe 24" long in the side outlet, forming a standpipe with a 300 cc. reservoir, having four-4.5 cm. lateral openings at the base (Fig. 1). These pipes were wrapped in wire mosquito netting and set 12 inches into the gravel along the centre of the "controlled-water" planting bed. The third one of the series was modified so that a recording thermometer bulb could be placed in it. A second thermograph was set up to record surface temperature. Temperatures were measured in the other pipes by thermometer. Samples of water were taken by suction for oxygen determinations according to the method outlined previously.

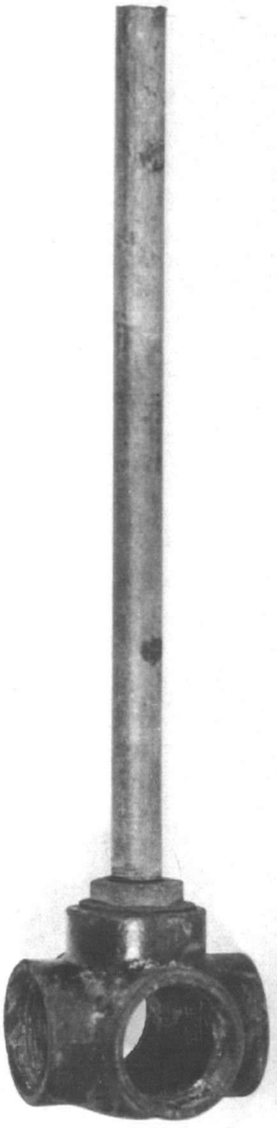

Fig. 1 STANDPIPE

Dye was used to find the rate of sub-surface flow. Both eosin and methylene blue were used, but the methylene blue proved more satisfactory. Dye was added by pipette to the pipe, the water stirred and a sample taken. After several hours a second sample was taken. The samples were compared with standard concentrations to determine dilutions. Each standard was equivalent to the previous one with an equal volume of clear water added to it. The number of volumes added per hour was calculated by dividing the difference on the scale of the two samples by the number of hours the dilution had been taking place.

A photoelectric colorimeter was used as well, but it was not convenient for field work. A more stable dye than methylene blue would be desirable.

Volumes per hour were converted to apparent velocity (v) by calibrating the pipe in a trough of gravel. (See page 20).

In July and in August 1949 the planting bed was dug over and washed by hosing. On February 22-23, 1950 the bed was covered with fine sand experimentally.

Results

Data are shown in appendix B. Thermograph records are filed at the Pacific Biological Station, Nanaimo, B. C.

Oxygen content of gravel water. Average values of oxygen saturation have varied from 56 percent to 88 percent in the normal gravel (#1-5). Low values (less than 8%) were found in consolidated portions (#6,7). Zero and near zero values were found in the permanently silted portion (#8,9).

Rate of sub-surface flow. The rate of flow of the sub-surface water was found to be closely related to the discharge in the main stream when the surface flow was kept constant (Fig. 2). The average apparent velocity varied from 5 to 36 mm./hr. (0.4 to 2.8 ft./day).

Temperature. A comparison of the thermograph records for pipe #3 (normal gravel) and the surface, show that the temperatures tend to be similar between six and nine o'clock in the morning when the surface water is coldest, but the gravel water lags up to eighteen hours in reaching diurnal maxima. Temperature differences between surface and gravel waters were least at the upper end of the planting bed, near the inlet and at the highest level, and greatest in the lower half which is nearly level and

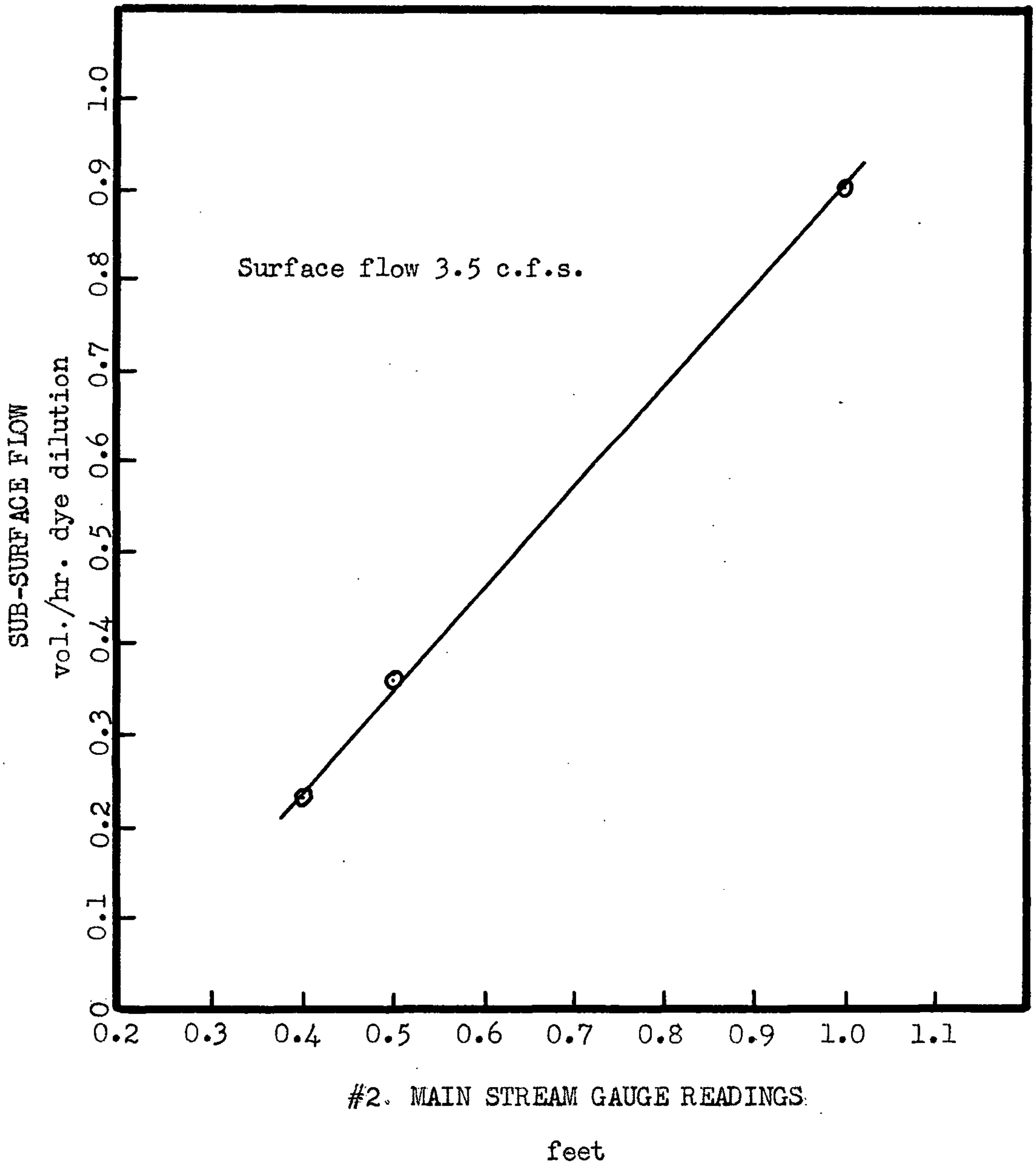

Fig. 2. RELATION BETWEEN SUB-SURFACE WATER FLOW 12 INCHES UNDER "CONTROLLED-WATER" SECTION AND MAIN STREAM GAUGE READINGS

Surface flow on "controlled-water" section was kept constant at 2" on a weir. Sub-surface flows are average readings of all standpipes. They may be converted to apparent velocity using figure 4.

permanently silted (#8,9). Differences in temperature tend to be associated with lowered oxygen saturation, but not with rate of sub-surface flow.

Effect of digging and hosing gravel. Washing the stream bed silted up the pipes at first, but after the pipes were also cleaned out, the average values of dissolved oxygen were raised, particularly in the consolidated area. This previously consolidated area maintained a high saturation value (78-95%) for a year. The silted area was raised from near zero to 45 percent but reverted to low values in two months. The thermograph records show that the lag in diurnal temperature maxima became zero to six hours. This effect lasted for ten weeks.

Experimental silting. Silting the bed experimentally caused no immediate change in the oxygen content of the water but the average apparent velocity was reduced by half, in spite of an increase in surface flow.

Discussion

The data gathered are not complete enough for a clear analysis of ground water hydraulics but indicate that:

The supply of water to gravel one foot below the surface, is derived from surface flow and from sub-surface flow of water, of lowered oxygen content, from the banks. On another portion of the main stream, a spring at the edge of the creek had an oxygen content of 46.6-53.5%. When the main stream rises, there is increased sub-surface flow from the water table on either side of the stream bed (fig. 2). The surface contribution will vary with the depth of the surface water and the permeability of the surface gravel. The permeability of the surface gravel varies with the presence or absence of silt and the degree of consolidation.

Average values are of interest perhaps in comparison of areas within streams, and of streams in different parts of the world, but individual values of dissolved oxygen and velocity are of greater importance in this study in view of Cameron's report (confirmed by the author's observations) that samples of eggs from redds show a preponderance of either high or low survival. Tests of the comparative survivals of eggs placed in certain of the pipes were negated by excessive cold and flooding, but the areas in which dead eggs from the previous year's planting have been found are those of lowered oxygen content.

Some individual values, below the limiting values for survival calculated from expression (5), are shown in fig. 5.

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V. DEVELOPMENT OF GRAVEL WATER SAMPLER

Description

The "railing-pipe" standpipes set in the stream had the advantage of giving a fair size volume of ground water for sampling dissolved oxygen. Dye samples when taken with a glass pipette required the removal of no more than 5 cc. so that the hydraulic disturbance was minimal. For general survey purposes a sampler is required that could be driven into the stream bottom anywhere desired. Ruggedness and simplicity were necessary.

At first a well point, commonly available in hardware stores, was modified by blanking all but the lower inch of the perforations. This pointed perforated pipe was found to break at the threads after being

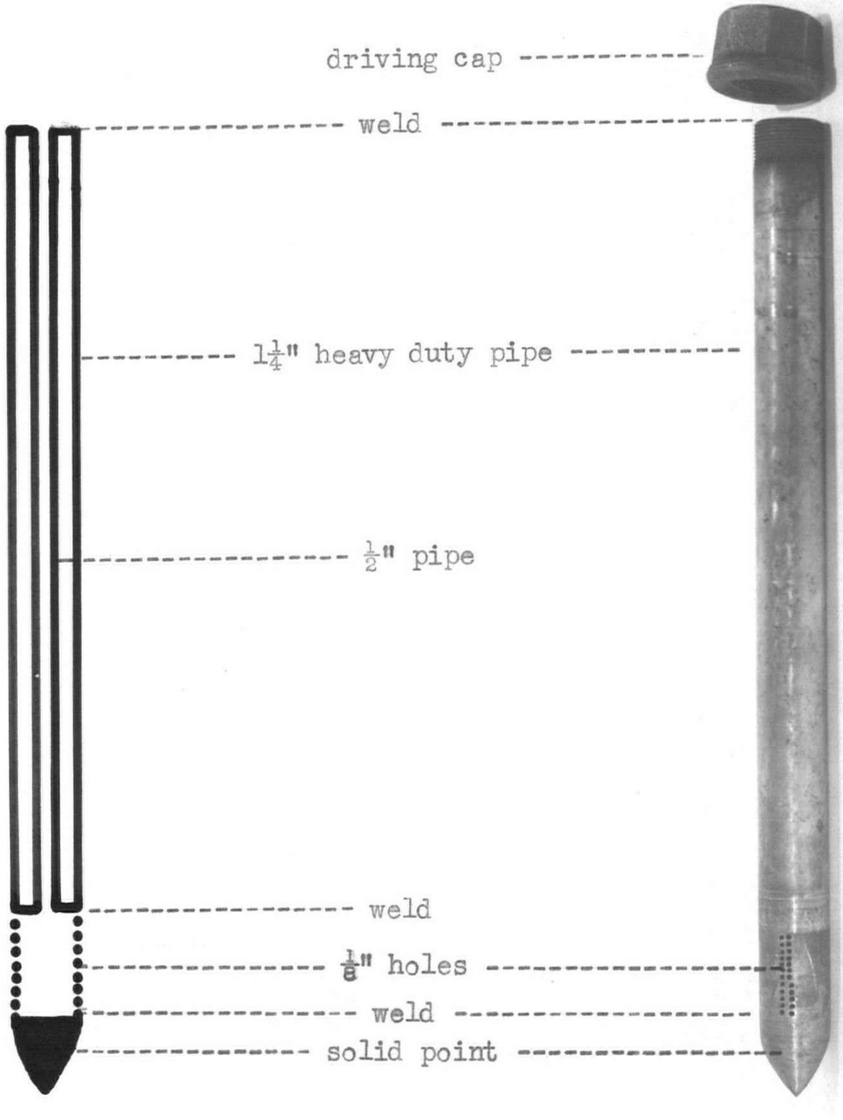

Fig. 3. GRAVEL WATER SAMPLER

After driving the sampler into the gravel to a known depth, a water sample is withdrawn by suction for oxygen determination. Apparent velocity is found by comparing the rate of dilution of a dye, introduced into the chamber, with a standard series of dilutions.

driven into the gravel a few times. After experimentation, the model illustrated (Fig. 3) was made of heavy duty $1\frac{1}{4}$" tube and has been found satisfactory.

A rubber gasket is fitted inside the driving cap to minimize the influx of surface water while the sampler is being driven by sledge-hammer into the gravel. A half-inch pipe liner welded into the tube reduces the stagnant volume of dye when determining apparent velocity of flow. Perforations in the chamber at the bottom allow the sub-surface water to flow through the chamber, diluting the dye.

The sampling procedure suggested is:

1. Rinse sampler free of sand and dye.
2. Screw on driving cap and tighten by hand.
3. Drive the sampler to a standard depth (say 10 inches) keeping the perforations in known direction.
4. If sand is handy, pour it around the pipe to reduce exchange of surface water next to the pipe. Remove the cap and note the time taken for the water to rise to stream level. The ease of driving the sampler and the time for filling may give a general description of the compactness of the gravel.
5. If the water in the sampler is cloudy, draw off by suction several volumes until it clears. Take a sample for oxygen determination and place a thermometer in the sampler.
6. Fix the water sample.
7. Take the temperature.
8. By means of a length of narrow bore (approx. $\frac{1}{8}$") glass tubing, pipette concentrated dye into the sampler. Stir, stop the top of the glass

tube, insert to the bottom and open the top of the tube so as to take a dye sample from the bottom of the sampler.

9. Stop the top of the tube, remove from the sampler and compare the dye sample with a standard series in test tubes made of the same tubing as the pipette. Note the reading.
10. Titrate the oxygen sample or compare with standard series.
11. In an hour take another dye sample from the bottom of the sampler. A longer period or a more finely graduated standard dye series (see below) may be necessary to get a change in the reading.

The use of the results in conjunction with expression (5) is considered in the general discussion (page 22).

Calibration

Dissolved oxygen. The sampler was driven twelve inches into the gravel six inches from each of the set pipes in the "controlled-water" section at Nile creek and dissolved oxygen determinations made on samples from each. The greatest difference noted, 1.9 ppm., was found where the dissolved oxygen in the fixed pipes was less than one part per million. The sampler was left four days and the difference became 0.4 ppm. If the sampler is cleared of clouded water and the dissolved oxygen saturation not very low, oxygen determinations can be made within an hour. The sampler should be left in the gravel for several days if accurate readings are required at points of low oxygen saturation.

Table II gives the results of the test.

Velocity. A trough was made of 2" x 12" x 6' boards. Screens were set in it and the volume between them filled with gravel from Nile creek

TABLE II

CALIBRATION OF SAMPLER FOR DISSOLVED OXYGEN

Water samples were taken by sampler six inches away from standpipes in Nile creek "controlled-water" section.

		Temp. °C.	DO ppm.	Diff.	
1443	June 30, 1950				
	Surface	12.5	10.6		4½ minutes to fill
	* 8B	11.1	0.4		
	Sampler	11.1	2.3	+ 1.9	
1140	July 4, 1950				
	Surface	11.8	10.6		
	8B	11.2	0.13		
	Sampler	10.2	0.54	+ 0.4	
1400	July 4, 1950				
	Surface	12.9	10.4		
	4	12.6	5.2		
	Sampler	12.5	5.3	+ 0.1	2½ minutes to fill
1050	July 5, 1950				
	Surface	11.8	10.9		
	2	11.8	6.7		
	Sampler	11.8	6.25	-0.5	4 minutes to fill
	Surface	11.8	10.9		
	1	11.8	9.8		
	Sampler	11.8	8.9	-0.9	2 minutes to fill
0953	July 6, 1950				
	Surface	11.8	10.8		
	5	11.8	8.5		
	Sampler	12.0	8.5	0	
	Sampler in gravel one hour. Four volumes discarded to clear water.				
1110	July 6, 1950				
	Surface	11.8	10.8		
	6	12.0	10.1		
	Sampler	12.0	10.0	-0.1	
	First sample used; water clear.				
1125	July 11, 1950				
	Surface	11.0	11.0		
	7	10.8	9.6		
	Sampler	10.8	9.8	+ 0.2	

*Standpipe number.

to give a bed 113 cm. x 22 cm. x 25.5 cm. and head and tail water pools at either end of the gravel bed. Water was lead into the head water pool where the water was maintained at a constant level by an overflow set so that there was no surface flow over the gravel. The outflow was a tap set in the centre of the end wall of the tail water pool. Samples of water were collected from the tailwater, measured by volume and timed to determine the rate of flow at the beginning and end of each test.

One of the standpipes was set 12 centimeters into the centre of the gravel bed and the procedure for obtaining the dilution of dye outlined above was followed for various rates of flow. The apparent velocity was calculated by dividing the discharge (cc./hr.) by the cross-section of the bed (561 sq. cm.). Dye dilution is reported in equal volumes of water added per hour (vol./hr.). The standard series of dyes was made up by taking one volume of concentrated dye. An equal volume of water was added and one volume of this diluted dye was used as the first of the series, the remainder had one volume of water added and half of the second dilution became the second of the series, etc. (Dilutions half way between those above may be useful.)

For some of the tests the standpipe was set with two of the openings in line with the direction of flow and in others, forty-five degrees off the line of flow.

The dilution rate appears higher with two openings in line with the flow. Three comparison tests with the sampler and standpipes in the creek bed gave identical results. From figure 4 it appears that the standpipe at 45° from the direction of flow has a dilution rate similar to the sampler. Velocities converted from dilutions at the higher rate

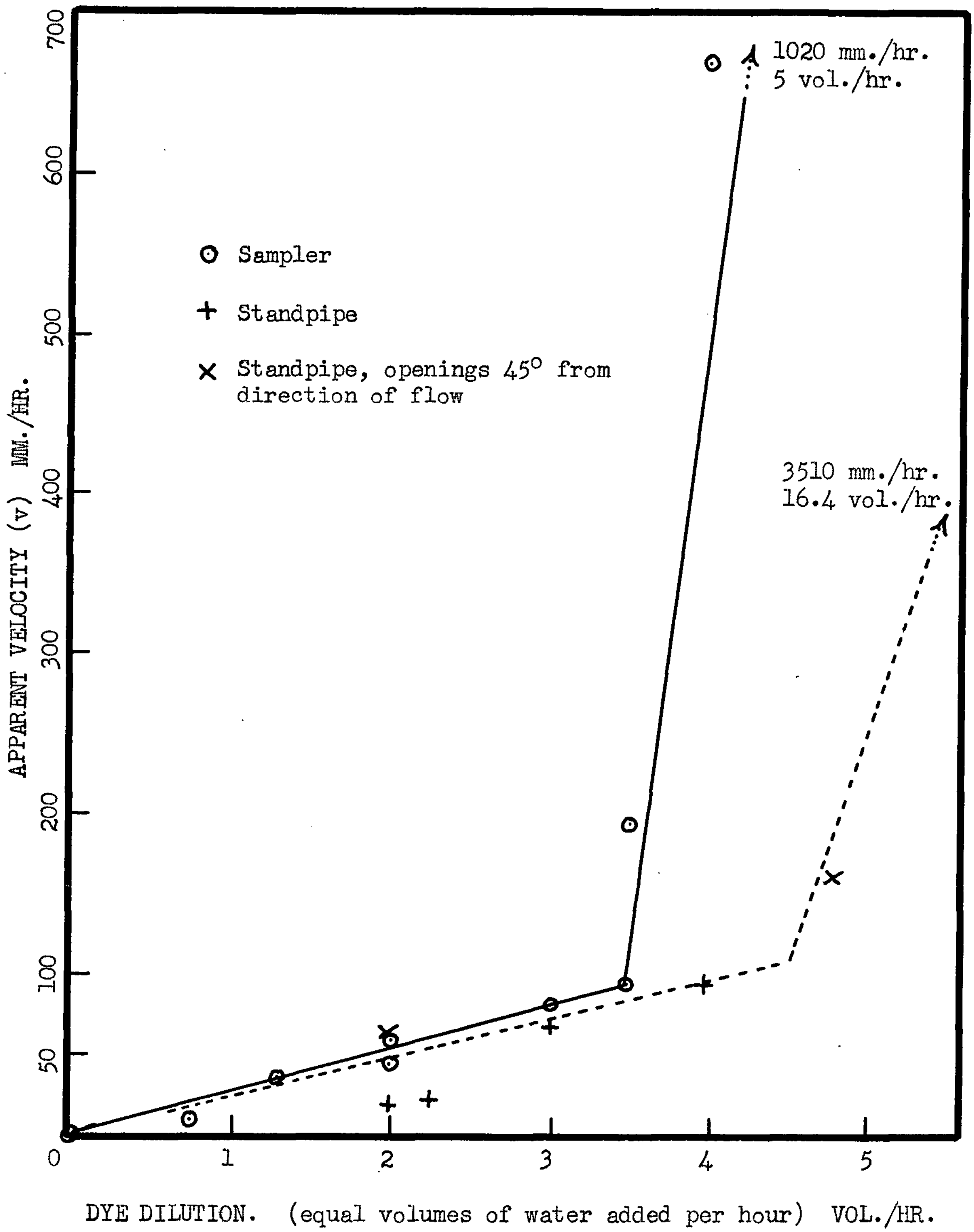

Fig. 4. CALIBRATION OF STANDPIPE AND SAMPLER FOR APPARENT VELOCITY

Velocities were calculated from discharges through a trough of 561 square centimeter cross-section containing gravel. Velocities encountered in nature were below the inflection points. Average maximum porosity was 23%.

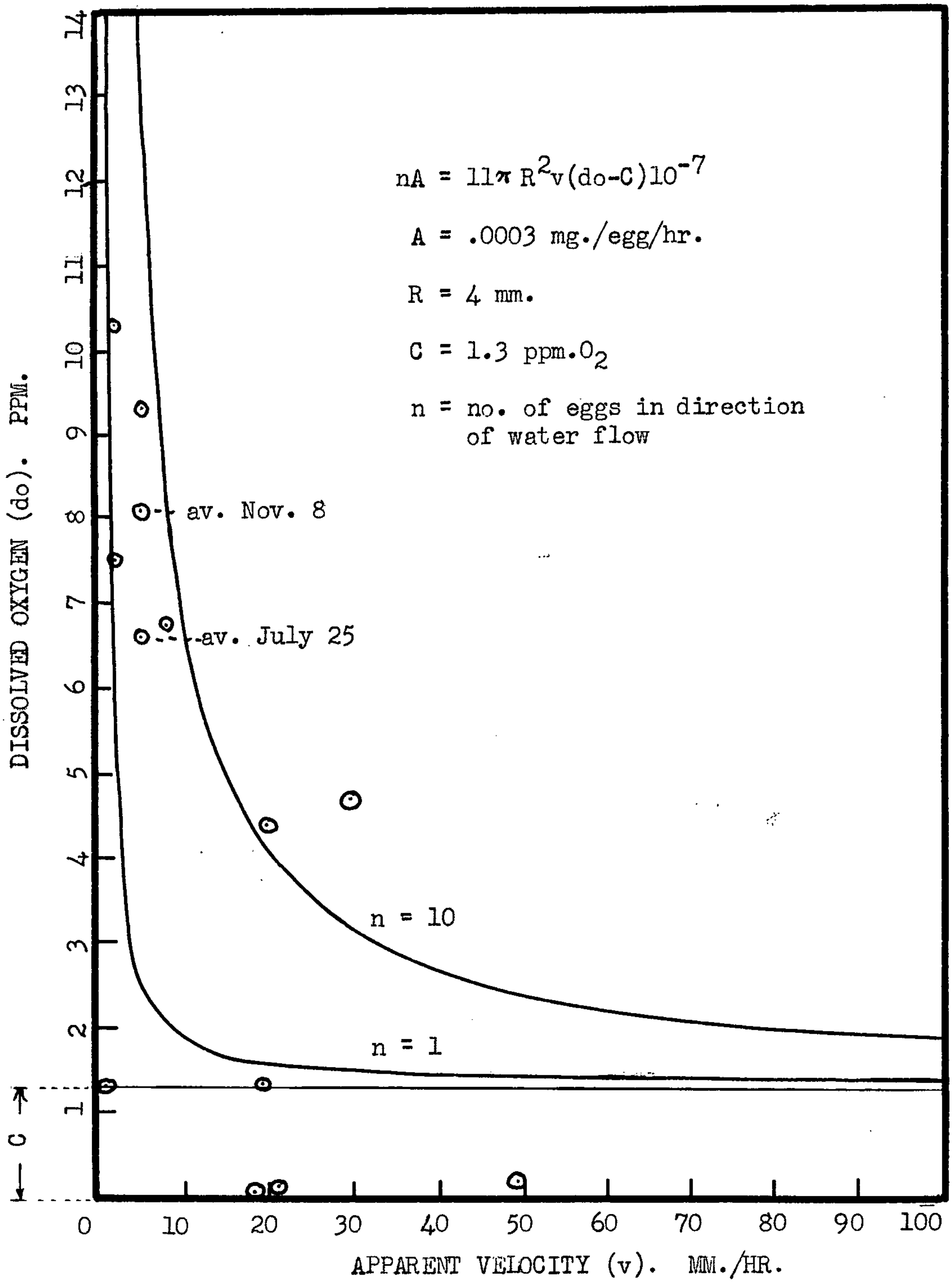

Fig. 5. CURVE OF LIMITING VALUES OF DISSOLVED OXYGEN AND APPARENT VELOCITY OF WATER TO SUPPLY THE FULL OXYGEN DEMAND OF PRE-EYED CHUM SALMON EGGS AT 8°C.

For values to the right and above the curve, supply exceeds demand; below and to the left, supply is less than demand. Some low values found in the gravel of the Nile creek "controlled-water" section are plotted.

when used in expression (5) will give a greater calculated quantity of oxygen being supplied. The maximum porosity of the gravel bed in the trough was 23%. The porosity of samples from Nile creek was 22%.

The sampler gives promise as a means of evaluating the dissolved oxygen content and apparent velocity of gravel water. It should be calibrated in the type of gravel to be sampled.

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VI. EVALUATION OF OXYGEN SUPPLY AT NILE CREEK

The standpipes at Nile creek do not give a full coverage of the controlled water section nor were the readings taken consistently enough to evaluate the entire bed's oxygen supply during the pre-eyed stage, but certain values of dissolved oxygen and apparent velocity are compared with a curve of limiting values that just maintain full metabolism of the pre-eyed eggs (fig. 5).

$nA \leq 11\pi R^2 v(do-C)10^{-7}$ is taken as the expression of the sufficiency of oxygen supply. A,R,C, are constants for eggs of a given age and at a given temperature. v and do are variables. If the oxygen supply just equals the demand, then expression (5) is the equation of the positive values of a curve of the form $x(y-C) = K$ that is the curve of limiting values of v and do. At any point above or to the right of the curve the oxygen supply exceeds the particular oxygen demand being considered. At any point below or to the left, the full demand is not being met, probably with fatal results.

Using the values A =.0003 mg./egg/hr., R = 4 mm., C = 1.3 ppm.O_2, for n = 1, expression (5) reduces to v(do-1.3) = 5.5, and for n = 10 to v(do-1.3) = 55. The asymptotes of these curves are v = 0 and do = 1.3.

In figure 5 there are plotted several points well to the left or below the curve of limiting values. Those points with do < C indicate that there are portions of the "controlled-water" section in which the full oxygen demand of .0003 mg./egg/hr. cannot be met irrespective of velocity. These readings (do < C) were gathered in the heavily silted part of the bed. Thousands of chum eggs, planted there, died after the original silting occurred.

Surveys of the survival of naturally deposited eggs and of gravel water conditions as determined by the gravel water sampler are planned. Low rates of flow in consolidated gravel and low oxygen saturation values in silted gravel are expected. Low rates of flow are also expected in all parts of the spawning beds when the discharge of the stream is low. If the major cause of egg mortality in the gravel is lack of oxygen then high survival rates should be associated with points above and to the right of a curve similar to that in figure 5 and low survival rate associated with points to the left of and below it.

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VII. SUMMARY

1. The oxygen demand of pre-eyed chum salmon eggs was found to be between .00013 and .0003 mg./egg/hr. at temperatures of 0.1-8.2°C.

2. By means of standpipes set in the gravel, the oxygen content and apparent velocity of water was observed twelve inches belowthe surface

of the gravel.

3. Theoretical limits of dissolved oxygen content and apparent velocity that just supply the full oxygen demand of salmon eggs were developed. The oxygen supply to eggs in an egg mass is adequate if:

$$nA \leq 11\pi R^2 v(do-C)10^{-7}$$

4. Portions of the "controlled-water" section at Nile creek were found in which there was an insufficient supply of oxygen to supply the demand of pre-eyed eggs. This may explain the high pre-eyed mortalities found in these areas.

5. A gravel water sampler is described and a field method, using it, presented for determining the oxygen content and apparent velocity of gravel water.

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APPENDIX A

Oxygen consumption data

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Species Age	Date	Time	Period	Temp. °C.	Bottle Thio. cc. F = .624	D.O. p.p.m.	Wt. of water in bottle	pH	D.O. reduced	No. of eggs Live	Dead	Wt. of eggs	Vol. of eggs	Wt. of chorion	mg./egg/hr.
	1949														
Chum eggs 0 days	Dec. 7	(1600 (1700	0 hr.	5.2	18.95	11.84									
		1830			19.43	12.13									
	8	2215	30 hr.	5.0	18.77	11.72	918.0		.41	120	0		33.0		.000101
					17.75	11.09	917.4		.75	107	4		29.4		.000200
					17.92	11.20	920.8		.64	99	0		25.4		.000189
	12	1810	122 hr.	3.7	16.78	10.48	922.5	*6.6	1.36	95	0		25.5		.000105
					16.49	10.29	918.1	6.4	1.55	91	0		25.2		.000117
		1915			16.51	10.31	923.7	6.4	1.53	98	0		25.2		.000115
					16.38	10.23	916.3	6.1	1.61	111	2		28.7		.000109
	13	1700	144 hr.	3.7	16.9	10.5	916.8		1.3	77	0		20.9		.000105
					14.18	8.86	916.9		2.98	89	0		23.8		.000208
					17.95	11.21	916.7		.92	71	0		19.0		.000081
					16.90	10.61	922.6		1.52	74	1		20.0		.000127
								*colorimetric determinations.						Average -	.00013
Chum eggs 5 days	Nov. 22	(0930 (1000	0 hr.	8.2	18.5	11.55									
		2230	13 hr.	8.0	17.66	11.02	916.9		0.53	98	0	25.5	23.0		.00037
	23	0930	24 hr.	8.0	17.71	11.05	923.7		0.50	100	0		25.0		.00019
		2145	36 hr.	8.0	17.05	10.65	918.0		0.90	99	0	26.3	24.2		.00022
														Average -	.0003
	1950														
Chum eggs 12 day	Jan. 23	(1330 (1450	0 hr.	(0.1 (0.7	22.21	13.61									
	28	1500	120 hr.		14.2	8.7	922.5	6.95	4.91	11	89	29.7	27.8	.016	.00038
					16.1	9.88	923.3		3.73	72	28	28.8	26.6		.00028
					15.45	9.48	917.4		4.13	14	86	28.9	27.0		.00031
					16.4	10.05	916.9		3.56	4	96	30.9	28.8		.00028
		1600			15.7	9.63	923.7		3.94	16	84	31.2	29.0		.00029
	29	1015	146 hr.		13.7	8.40	918.0		5.21	18	82	32.3	29.9		.00032
					15.32	9.37	918.1		4.24	40	57	28.7	26.5		.00027
					16.69	10.2	916.7		3.4	56	41	28.8	26.5		.00021
		1400			16.2	9.92	916.3	6.94	3.7	83	20	30.4	28.5		.00022
Chum eggs Dead	Feb. 1	1400	0 hr.	0.7	23.39	14.33									
	6	1400	120 hr.		12.51		260								
					13.2		264								
					13.05		260								
					13.55		261								
					15.0		265								
					13.55		265								
				Average -	13.48	8.26	262.5		6.07	0	40		11		.000317

Species Age	Date	Time	Period	Temp. °C.	Bottle Thio. cc. F = .728	D.O. p.p.m.	Wt. of water in bottle	pH	D.O. reduced	No. of eggs Live	Dead	Wt. of eggs	Vol. of eggs	Wt. of chorion	mg./egg/hr.
	1950														
Chum eggs	Jan. 23	1330		0.1	22.21	12.61									
Eyed		1450													
67 days	29	1155	145 hr.	0.7	17.30	10.60	920.8		2.01	88	12	26.5	25.0	.011	.000124
		1231			16.70	10.22	921.2		2.38	95	2	25.7	24.2		.000153
		1234			13.86	8.50	916.8	6.89	4.11	97	4	26.6	25.0		.00025
					16.11	9.87	921.6		2.75	95	5	26.5	24.9		.00017
		1320			16.13	9.88	922.6		2.73	91	8	26.0	24.8		.00019
														Average -	.0002
Chum eggs	Mar. 7	0900	0 hr.	4.9	17.6	12.81									
85 days	9	(2035	0 hr.	4.3	17.60	12.81									
partly-eyed		(2045													
30 days before	9-10	0901	12½ hr.	4.1	16.88	12.30	917.6		.51	50	0	(14.17)	13.4	.015	.000738
hatching.	9-10	1410	18 hr.	4.1	16.46	11.98	920.8		.83	49	1	14.0	13.3		.000837
	9-10	1450	18 hr.	4.1	16.46	11.98	918.0		.83	50	0	14.35	13.5		.000834
	7-8	0945	24 hr.	4.3	16.00	11.66	920.8		1.15	45	4	14.2	13.0		.000884
	9-11	0811	36 hr.	3.9	15.60	11.35	920.8		1.46	48	2	(14.17)	13.4		.000733
	9-11	0819	36 hr.	3.9	15.36	11.18	922.5		1.63	48	2	(14.35)	13.5		.000822
	7-8	2304	38 hr.	4.3	14.60	10.64	917.6		2.17	52	5	15.7	14.9		.000905
	7-9	0946	48 hr.	4.2	15.10	11.00	920.8		1.81	48	1	13.7	12.8		.000697
	7-9	2107	60 hr.	4.3	14.04	10.23	916.8		2.58	48	4	[illegible]	13.8		.000746
	7-9	2146	60 hr.	4.3	14.18	10.31	916.3		2.50	48	5		14.0		.000710
	7-10	0916	72 hr.	4.1	13.47	9.80	921.6		3.01	46	5		13.7		.000745
	7-13	1608	152 hr.	3.6	7.47	5.44	922.6	6.95	7.37	37	13	13.9	13.2		.000884
	7-13	1626	152 hr.	3.6	9.62	7.00	921.2	6.95	5.81	43	7	14.5	13.9		.000694
Chum eggs	Apr. 6	1015	0 hr.	5.9	16.44	11.98									
Eyed		1415	4 hr.	5.9	13.80	10.12	922.5		1.86	203	0	55.5	51.6		.00196
103 days															
10 days before		1030	0 hr.									calculated for 4-8th hours			.00168
hatching		1830	8 hr.	6.1	11.82	8.61	923.3		3.37	202	0	57.0	53.2	full period	.00182
		1045	0 hr.									calculated for 9th hour			.000242
		1945	9 hr.	6.1	11.10	8.09	917.4		3.89	198	0	56.4	52.5	full period	.00188
		1115	0 hr.									calculated for 10th hour			.000069
		2145	10 hr.	6.1	10.72	7.82	916.9		4.16	203	0	57.4	53.5	full period	.00177

Species Age	Date	Time	Period	Temp. °C.	Bottle Thio. cc. F = .624	D.O. p.p.m.	Wt. of water in bottle	pH	D.O. reduced	No. of eggs Live	Dead	Wt. of eggs	Vol. of eggs	Wt. of chorion	mg./egg/hr.
	1949														
Pink eggs	Oct. 18	1400	0 hr.	6.9	18.8	11.73									
Eyed 28 days	20	0900	43 hr.	6.2	16.25	10.14	919.6		1.59	100	0		19.5	.001	.00033
Pink eggs	Nov. 7	2100	0 hr.	7.85	17.55	10.95									
33 days	8	0900	12 hr.	7.9	16.35	10.20	922.5		0.75	95	6	24.4	23.0		.00055
	8	2130	24 hr.	8.3	15.10	9.43	917.4		1.52	96	4		19.7		.00057
	9	0945	36 hr.	8.2	15.09	9.42	923.7		1.53	95	5		19.7		.00039
Pink eggs	Nov. 7	2100	0 hr.	7.85	17.55	10.95									
48 days	8	0900	12 hr.	7.9	16.10	10.05	923.3		0.90	100	4		21.1		.00067
	8	2130	24 hr.	8.3	15.25	9.51	916.9		1.44	96	4		19.7		.00054
	9	0945	36 hr.		15.61	9.74	918.0		1.21	93	7		19.2		.00032
Pink alevins	Nov. 22	0930	0 hr.	8.2	18.50	11.55									
7 days old		2230	13 hr.	8.0	5.79	3.62	922.5		7.94	62	4	12.0	10.9		1 .0090 2 .0084
	23	0930	24 hr.	8.0	5.05	3.15	923.3		8.40	32	8	7.81	7.0		1 .0103 2 .0080
	* 23	2145	36 hr.	8.0	0.05	0.031	917.4		11.52	34	13	9.3	8.3		1 .0094 2 .0068

* no opercular movement, heart beat 6-13/min., all subsequently died.

1. assumed death took place at beginning
2. assume no death

Species Age	Date	Time	Period	Temp. °C.	Bottle Thio. cc. F = .612	D.O. p.p.m.	Wt. of water in bottle	pH	D.O. reduced	No. of eggs Live	Dead	Wt. of eggs	Vol. of eggs	Wt. of chorion	mg./egg/hr.
	1950														
Coho eggs	Jan. 23	1330													
Eyed		-1450	0 hr.		22.21	13.61									
67 day	29	1455	150 hr.		16.66	10.19	920.8		3.24	98	2	30.4	28.5	0.01	.000204
		1516		0.1	15.31	9.38	917.6	7.1	4.23	95	5	30.3	28.6		.000251
		1501			16.77	10.25	920.2		3.36	83	8	27.2	25.4		.000220
		1514		0.7	16.36	10.00	917.4		3.61	94	3	29.4	27.6		.000220
														average -	.000241
					F = .728										
Coho eggs	Mar. 7	(0830	0 hr.	4.9	17.6	12.81									
hatching		(0955													
	8	0930	24 hr.	4.3	16.45	11.99	916.7		0.82	8 egg	0	2.9	2.65		*1 .00297
										2 al.					2 .00262
Coho eggs	Mar. 7		0 hr.	4.9	17.6	12.81									
nearly	-8	2253	38 hr.	4.3	16.06	11.70	922.5		1.11	10	0	3.0	2.9		1 .00269
hatching															2 --
	9	0931	48 hr.	4.2	15.62	11.38	918.0		1.43	9 egg	0	3.0	2.9		1 .00272
										1 al.					2 .00203
		2048	60 hr.	4.3	12.82	9.34	923.3		3.47	4 egg	0		(2.9)		1 .00532
										6 al.					2..00008
		2135	60 hr.	4.3	14.64	10.66	917.4		2.15	7 egg	0		(2.9)		1 .00328
										3 al.					2 .00090
	10	0950	72 hr.	4.1	15.78	11.49	923.7		1.32	8 egg	0		(2.9)		1..00169
										2 partly hatched			(2.9)		2 . --
		1001	72 hr.	4.1	13.62	9.93	918.1		2.88	6 egg	0	2.8	2.7		1 .00366
										4 al.					2 .00025
		1014	72 hr.	4.1	14.36	10.45	916.9		2.36	6 egg	2	2.9	2.8		1 .00300
										2 al.					2 .00155
Coho alevins	Mar. 8	1050	0 hr.	4.3	17.6	12.81									
just hatched	9	0826	21.6 hr.	4.3	14.76	10.75	916.7		2.06	10 al.	0	2.5	2.3		.00881

*1. Assume no hatching
2. Assume alevins hatched at start.

APPENDIX B

Gravel water data

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WATER CONDITIONS IN GRAVEL

1. Temp. °C.
2. D.O.
3. Vol./hr.
4. pH.

Standpipe numbers:
1-5 normal gravel
6,7 consolidated gravel
8-9 thick sand cover

Standpipe number			1	1^x	2	2^x	3	4	4^x	5	6	7	8	A	B	9
1. Oct. 21/48 Air 13°C., Surface 8.9 #2 gauge 0.3	1445	1	8.8	8.8	8.85	8.65	8.6	8.7								
2. Nov. 14/48 Air 6.1, Surf. 5.4 #2 gauge 2.1	1430	1	5.5	5.5	5.5	5.8	5.6	6.1			5.8	5.7				6.1
3. Nov. 15/48 Air 6.5, Surf. 5.5 #2 gauge 1.6	1030	1	5.4	5.4	5.6	5.8	5.8	5.9			5.8	5.8				5.85
			Water was turned on more and #1 became 5.55.													
4. Nov. 23/48 Air 6.6, Surf. 4.9 #2 gauge 1.6 (Thermograph changed)	1400	1	4.9	4.9	4.9	5.2	5.2	5.6			5.2	5.3				6.2
			Water backed up by blockage below fry fence.													
5. Nov. 23/48 Surf. 5.0	1600		Blockage partially removed, water dropped 1 foot at 9.								5.2	5.2				6.3
6. Nov. 24/48 Air 5.8, Surf. 4.9 #2 gauge 0.9	1540	1	4.9	4.9	4.9	5.1	5.2	5.1			5.1	5.1				6.3
7. Dec. 3/48 Air 1.7, Surf. 3.5 #2 gauge 0.7	1400	1	3.55	3.6	3.5	3.9	4.5	4.6			4.2	4.2				6.2
8. Dec. 6/48 Air 3.5, Surf. 3.8 #2 gauge 0.6	1330	1	3.8	3.7	3.8	4.0	4.5	4.3			4.1	4.0				5.7
9. Dec. 7/48 Air 0.5, Surf. 3.1 #2 gauge 0.55	1948	1	2.9	2.9	2.9	3.2	3.5	3.6			3.6	3.2				5.3
10. Feb. 25/49 Air 5.0, Surf. 3.3 #2 gauge 1.0	1525	1	3.3	3.2	3.2	2.9	2.9				2.8	3.1				3.6
11. Mar. 3/49 Air 7.0, Surf. 3.42 #2 gauge 0.8	14-1500	1					3.5									

WATER CONDITIONS IN GRAVEL

	Standpipe number			1	1^x	2	2^x	3	4	4^x	5	6	7	8	A	B	9
12.	Mar. 8/49 Air 7.3, Surf. 4.0	1400	1	4.0	3.8	4.0	3.6	3.7				3.8	3.7				4.3
13.	Mar. 14/49 Air 2.3, Pool 3.8 #2 gauge 0.5	1330	1	3.7	3.8	3.7	3.7	4.0	3.9		3.7	3.9	3.8				4.0
14.	Mar. 23/49 Air 8.9, Pool 5.0 #2 gauge 0.7	1430	1	5.1	4.6	4.9	4.1	4.1	4.4	4.1	4.1	4.3	4.1	4.6			4.7
15.	Mar. 30/49 Air 6.3, Pool 4.3 #2 gauge 0.4 Stream 4.6	1045	1	4.4	4.6	4.4	4.3	4.4	4.3	4.4	4.3	4.3	(1510 air 6.3°C., stream 5.°C. (4.7	 4.7			 4.8
16.	May 18-19/49 Pool 1"		3	.40								.48					
	2"		3	.31								.42					
17.	July 21/49 Air 17.0, Pool 11.7 #2 gauge 0.38, Pool 1¾" Dipped O_2 sample 10.66 suction O_2 " 11.18	1335	1	11.5	11.2	11.5	11.4	11.5	11.4	11.4	11.4	11.4	11.1	11.1			11.4
			2	10.66	9.01	10.22	8.59										
18.	July 25/49 Air 13.6, Pool 11.3 #2 gauge 0.45, Pool 1¾" D.O. 10.3	1415-1530	1	11.3	11.3	11.2	11.3	10.8	11.2	11.3	11.2	11.8	11.1	10.7	11		11.4
			2	9.97	7.2	9.2	8.6		5.5	6.2	9.6	0.50	2.6	0.2			2.0
			3	.24	.29	.26	.25	.22	.28	.18	.24	.22	.22	.12			.17
19.	July 26/49 Air 12. Pool 10.7 #2 gauge 0.45, Pool 1¾"	0840	1	10.7	10.7	10.7	10.9	10.9	11.0	11.1	10.8	10.9	10.8	10.6			11.1
20.	July 27/49 Air 14.7. Pool 12.1 #2 gauge 0.45, Pool 1¾"	1430	1	11.8	11.7	11.8	11.4	11.1	11.2	11.1	Stream being hosed and dug over.						
21.	July 28/49 Air 14.9, Pool 10.7° Pool gauge 2¼"	1000	1	10.5	10.4	10.8	10.8	10.5	10.9	11.1	10.5		10.5	10.5			11.0
22.	Aug. 2/49 Air 20.4, Pool 13.3 #2 gauge 0.4, Pool 2" D.O. 10.99	1330	1	13.0	12.8	12.9	12.4	12.1	12.4	12.5	13.1	12.1	12.4	12.4			12.0
			2	8.05	8.92	7.8	6.24		6.1+	7.2	8.5	0.26	1.3	0			0
			3	.33	.23	.22	.21		.14	.28	.12	.16	.36	.22			.23
			4	7.4	7.4							6.8	7.0	6.4			7.0 (old reagent)

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Stream hosed and dug over again and standpipes cleaned out.

Standpipe number				1^x	A	B	2^x	3	4^x	A	B	5	6	7	8	A	B	9
23.	Sept. 8/49	1100-1220	1	11.2			11.6	11.1	11.4			11.3	11.4	11.1	11.2			11.8
	Air 15.4, Pool 11.3		2	9.75			6.91		6.75			9.24	8.4	9.15	5.41			5.27
	#2 gauge 0.3, Pool $1\frac{3}{4}$"		4	7.1			6.8		6.8			7.2	7.4	7.3	6.7			6.9
	D.O. 10.5, pH 7.4																	
24.	Nov. 8/49	1430	1	8.1			8.05	8.0	7.4			8.05	8.0	8.0	8.1			7.3
	Pool 8.1		2	9.23			7.52	5.74	7.1			10.29	9.0	8.89	1.29			1.97
	Pool gauge 3", 11.0																	
25.	Nov. 8/49	1600-1610	3	.23			.115		.109			.16	.13	.21	.22			.0006
	Pool 3"																	
	Nov. 9/49	0835	1	7.3			7.5	7.6	7.6			7.2	7.4	7.3	7.8			7.6
	Pool 7.1, #2 gauge 0.7																	
26.	Nov. 16/49	1430-1530	1	7.6			7.5	7.4	7.6			7.6	7.6	7.55	8.1			7.6
	Air 9.2, Pool 7.6		2	10.62			9.60	6.03	10.31			10.1	8.92	9.03	0.8			2.08
	#2 gauge 0.71,																	
	Pool gauge $2\frac{1}{2}$", 11.45																	
27.	Nov. 22/49	1430-1510	1	8.3			8.1	8.0	8.3			8.0	8.1	8.2	8.2			8.0
	Air Pool 8.3		2	10.11			8.65	8.35	10.96			9.83	8.95	8.16	1.37			0.27
	#2 gauge 1.5-2.4																	
	Pool gauge $5\frac{1}{2}$", 11.38																	
28.	Nov. 25/49	1015-1145	1					8.0										
	Pool 8.0		3	.85			.83		1.05			1.67	1.0	.74	.68			.60
	# 2 gauge 2.4																	
	Pool gauge $\frac{1}{4}$-$\frac{1}{2}$"																	
29.	Dec. 3/49	1530	1	5.7			6.5	6.9	6.1			5.8	6.2	6.2	7.7			7.0
	Air 3.4, Pool 5.9, $3\frac{1}{2}$"																	
30.	Dec. 7/49	0950	1	4.7			4.8	5.4	4.8			4.8	5.1	5.1	7.2			6.6
	Pool 4.7		2	11.46			9.41	9.04	9.64			10.40	7.06	8.15	0.23			0.0
	#2 gauge 0.7																	
	Pool gauge 0.7, 12.52																	

1A and 1B, 4A and 4B, 8A and 8B, having wide standpipes, placed to take experimental eggs.

NILE CREEK CONTROLLED SECTION, 1949-50.

Standpipe number		1^x	A	B	2^x	3	Spring	4^x	A	B	5	6	7	8	A	B	9
31. Jan. 20/50	1	1.0	0.9	0.9	1.7	2.0		1.5	1.5	1.5	1.0	1.0	1.1	iced	1.1	2.2	iced up
Air 0.5, Pool 1.0	2	12.3(	-11.5)	9.1				5.8	8.7	11.75	12.3	10.5-		up	7.9	6.4	
#2 gauge 0.35																	
Pool gauge 2", 12.45																	
32. Jan. 21/50 0935	1													2.8		2.7	2.5
Pool 0.7, $2\frac{1}{2}$"																	
33. Feb. 13/50 1510	1						3.0										
#2 gauge 0.8, 2.5°C.	2						10.6										
D.O. 13.4																	
34. Feb. 18/50 0845	1	2.2	2.2	2.2	2.2	2.2	2.8	2.2	2.2	2.3	2.4	2.5	2.5	4.6	2.5*	4.6	--
Pool 2.5, 4",	2		11.73	11.74			11.35	13.41	11.97	11.75					13.5*	4.26	
#2 gauge 1.2														*covered by surface water			
35. Feb. 21/50 0900-1030	1	2.5			2.1	2.3		2.5			2.5	2.5	2.6	4.5			4.5
Pool 3", 2.8°, D.O. 13.35	2	12.02			10.08	7.76		10.48			12.39	12.02	11.48	4.5			0.18
#2 gauge 0.9. 10.30-1100=1530-1600 Vol./hr.	3	1.0	1.2	0.3	1.8	1.0		1.6	0.3	0.4	1.6	2.2	1.6	2	0.4	0.6	1.8
Pool 2.8																	
1530/21 pool set at 2"	1	2.8	2.8	2.9	2.8	2.8	3.0	2.8	2.8	2.8	2.8	2.8	2.9	5.0	3.1	4.5	4.5
36. Feb. 22/50 0900-1030	1	2.9	2.9	2.9	2.8	2.9	3.1	2.9	3.0	2.9	2.9	2.9	2.9	4.5	4.5	4.8	5.9
Pool 2", 3.0°, D.O. 13.51	2	11.61	12.47	14.95	9.96	9.94	9.14	9.56	12.40	11.9	12.34	11.88	11.95	5.04	5.79	4.66	0.19
#2 gauge 1.0, 1030-1515-1545 3.5	3	0.8	1.2	1.2	1.0	0.3		1.2	1.4	1.0	1.4	0.4	0.3	1.2	0.2	1.4	0.6
1600 pool set at 4" which caused bed to be covered with silt during night.	1	3.5	3.3	3.5	3.5	3.0		3.1	3.5	3.3	3.5	3.6	3.6	5.6	4.0	5.0	5.0
37. Feb. 23/50 0900-1030	1	2.8	2.8	2.8	2.8	2.9	2.9	2.9	2.9	2.9	2.8	2.9	2.9	4.2	3.6	4.5	4.9
Pool 2.8, 4", #2 gauge	2	11.81	12.71	12.84	10.04	10.02	11.49	9.72	12.12	12.83	12.88	12.15	11.78	4.67	7.7	4.38	0.166
0.9. 1030-1100 to 1530-1600, 13.10. 1530-1600	3	0.6	0.7		0.4	0.4		1.0	0.5	1.6	0.2	0.5	0.3	1.1	0.2	0.6	0.8
3.0	1	3.0	3.0	3.0	2.9	3.0		3.1	3.0	2.9	3.0	3.0	3.0	4.2	3.9	4.7	5.0
							Bed covered with silt.										
38. Apr. 18/50 1455-1550	1		5.8	5.1					5.7	4.8					5.1	5.3	
Air 9.5, Pool $3\frac{1}{2}$"	2		11.70	10.32					10,85	9.55					3.58	3.97	
Pool 6.2, 12.50																	

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