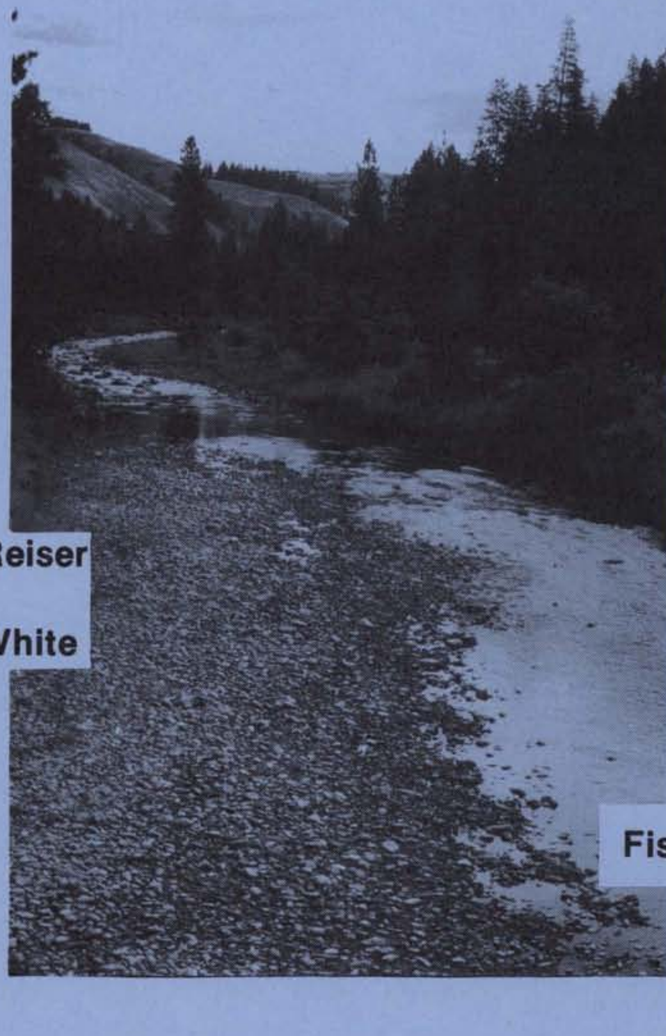
Research Technical Completion Report
Project A-058-IDA

INFLUENCE OF STREAMFLOW REDUCTIONS ON SALMONID EMBRYO DEVELOPMENT AND FRY QUALITY



By

Dudley W. Reiser
and
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Fisheries

Idaho Water & Energy Resources Research Institute
University of Idaho
Moscow, Idaho

March, 1981

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Spring chinook eggs were obtained from Idaho Power's Rapid River Hatchery and Idaho Department of Fish and Game's Hayden Creek Hatchery; cutthroat trout eggs from IDFG's Henry's Lake Hatchery; steelhead trout eggs from U.S. Fish and Wildlife Services, Dworshak National Fish Hatchery.

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ABSTRACT

From 1977-1979 field and laboratory tests were conducted to determine the impacts of streamflow reduction over redds on salmonid embryo incubation and fry quality. Laboratory tests were conducted in artificial stream channels located at the Hayden Creek research station and in incubation chambers installed in the University of Idaho fisheries wet lab. Field tests utilized sections of Big Springs Creek and Bear Valley Creek. Tests were designed to evaluate the effects of reducing depths and velocities over redds on spring chinook salmon (Onchorhynchus tshawytscha) and steelhead trout (Salmo gairdneri) embryo incubation success and resulting alevins. Sediment size and level was incorporated into the test design. Measurements on 104 spring chinook salmon redds, 50 summer chinook salmon redds, and 89 summer steelhead trout redds were taken and spawning criteria developed. Reductions in streamflow over redds containing sediment (<0.84mm) in quantities from 3-13% resulted in increased embryo mortality with greatest increases associated with levels of 7% sediment <0.84 mm. Flow reductions retarded development of embryos resulting in alevins which were shorter and lighter at time of hatching. Flow reductions made during early embryonic development may result in higher mortality than if made after the circulatory system is functional (approximate time of eye-up). Sediment was inversely related to embryo survival but unrelated to alevin quality. Sediment sizes < 0.84 mm were the most deleterious to embryo survival. Water depths and velocities over redds are poor indicators of intragravel velocities and therefore of little use in predicting embryo survival. Artificial redds in Bear Valley Creek having water depths of at least 0.15 m and velocities of at least 0.30 mps did not experience

intragravel freezing. During field tests, empirically measured intragravel velocities were in all cases greater than computed values using the U.S. Fish and Wildlife Services Instream Flow Group technique, although a good correlation existed between the two. Incubation flow recommendations based on the IFG technique should provide for suitable incubation velocities.

INTRODUCTION

Man's increasing domestic, industrial and agricultural use of water has often resulted in reduced streamflows. Such reductions can adversely affect stream biota by the stranding and dessication of adult organisms, or by affecting a particular life stage of the organism.

To circumvent these deleterious effects, fishery biologists have recently begun to investigate the influence of streamflow on fish populations, most notably salmonids. To accomplish this, the life stages of fish species have been empirically evaluated to determine instream flow requirements. Methodologies for recommending streamflows for spawning (Rantz 1964, Thompson 1972, Waters 1976, Bovee and Cochnauer 1977), cover (Wesche 1973), rearing (Nickelson 1976, Bovee and Cochnauer 1977), and passage (Thompson 1972) of salmonids have been developed.

Flow requirements for embryo incubation have not been extensively studied and no methodology has been developed for recommending egg incubation flows. It has been generally assumed that flows sufficient for spawning are adequate for incubation (Washington Department of Fisheries). Oregon Department of Fish and Wildlife have used a combination of judgement and field observations to derive incubation flow recommendations, which are in general equivalent to two-thirds of the spawning flow. Although inextricably tied to spawning, flows which satisfy spawning needs of fish do not automatically satisfy incubation requirements of the deposited embryos.

There are four fundamental requirements for salmonid embryo incubation: (1) water temperatures conducive to development (4-14°C), (2) dissolved oxygen levels at or near saturation, (3) intragravel water velocity (apparent velocity) for transporting oxygen to the embryos and removing metabolites, and (4) high gravel permeability. Many studies (Wickett 1954; Phillips and Campbell 1961; Coble 1961; Silver et al. 1963; Shumway et al. 1964; McNeil and Ahnell 1964; Cooper 1965) have evaluated one or more of these incubation requirements and have established limits for each. These studies focused on intragravel requirements of incubation but did not attempt to relate these to associated extragravel factors. The importance of such a relationship was indicated by Vaux (1962) who noted that the initial source of oxygen in intragravel water was the atmosphere and listed the following steps for transport of oxygen to the intragravel environment:

1) dissolution of oxygen through air-water interface into stream water;
2) transport of oxygenated water to the stream bottom;
3) interchange of oxygenated water from the stream into the porous gravel interior.

Thus, intragravel conditions are influenced by conditions in the extragravel environment.

The possibility of a relationship between intra-and extragravel parameters was suggested in studies by Wickett (1954) and Shelton (1955). Wickett noted that changes in stage resulted in direct changes in intragravel velocity. Shelton found that reductions in mean extragravel velocity resulted in concomitant reductions in intragravel velocity. Recently, Bovee and Cochnauer (1977) theoretically investigated this relationship by an indirect parameter analysis. Their technique related intragravel velocity as defined by Darcy (1856) to mean surface velocity defined using Manning's equation.

Our study was designed to examine effects of streamflow reduction on embryo incubation success, to determine if extragravel parameters could be adequately related to the intragravel environment, and to develop a methodology for recommending embryo incubation flows. If a good relationship could be established between intra- and extragravel parameters, it would be possible to base incubation flow recommendations on easily obtained extragravel measurements. Because of the importance of sediment to the intragravel environment we also investigated the effects of various sediment size classes and quantities on embryo survival and fry quality related to flow. Three important secondary objectives of our study include:

1) comparison of flow requirements of different developmental stages of salmonid embryos (i.e., green versus eyed fertilized eggs);

2) assessment of effects of dewatering, low flow, and flow fluctuation on embryo survival and fry quality;

3) measurement of the physical and hydraulic parameters associated with natural redds.

DESCRIPTION OF LABORATORY TEST FACILITIES

Hayden Creek Research Station

Streamflow incubation tests were conducted in artificial stream channels located at the Idaho Department of Fish and Game's Hayden Creek Research Station near Lemhi, Idaho (Figure 1). Each of four channels measures 20.6 m long x 1.2 m wide x 0.6 m deep and contained two riffle and three pool areas (Figure 2). The lower two channels were connected to the upper two, essentially creating two channels with four riffles each. Riffle substrate was typical of salmonid spawning gravels (1.3-7.6 cm diameter).

Two sources of water supply were available to the channels: Hayden Creek water which varied in temperature diurnally and seasonally; and spring water which had a constant temperature of 12.0 C. Flow into each channel was independently regulated and was measured by two H-flumes located at the head of the channels. Water temperatures were recorded using a Weathermeasure two pen thermograph.

Egg dewatering tests were conducted in two 1.2 m wide x 2.4 m long channels each with eight 1.2 m long x 0.3 m wide x 0.3 m deep independent flow controllable chambers. Water supply to the chambers was from Hayden Creek.

Rearing tests of fry produced from the embryo dewatering tests were performed in four 4.9 m long x .56 wide x .30 m deep fiberglass troughs plumbed with Hayden Creek water. Flow fluctuation tests utilized these same troughs.

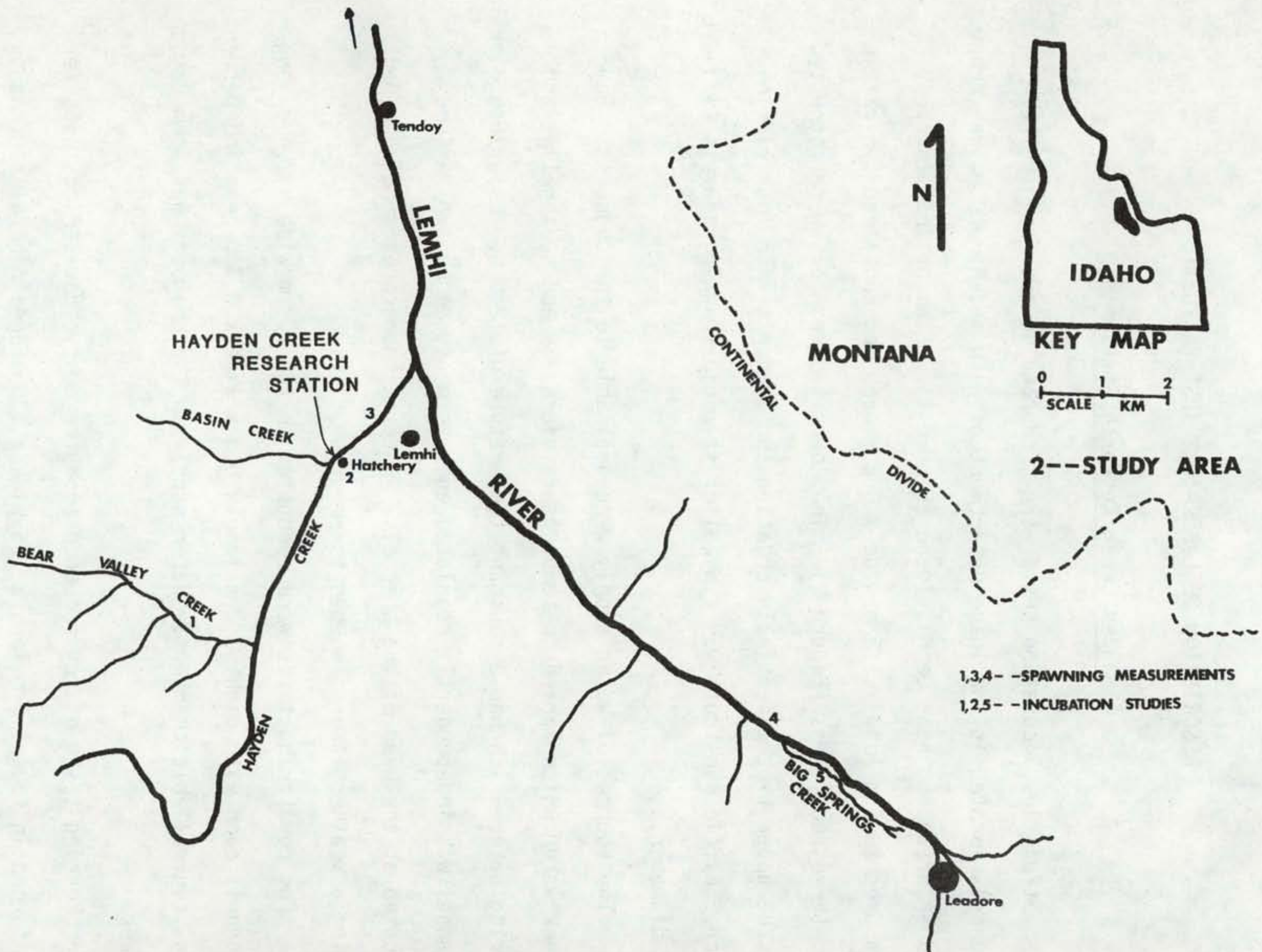


Figure 1. Location map showing study areas used in incubation-flow tests and areas surveyed for spawning measurements. 1977-1979.

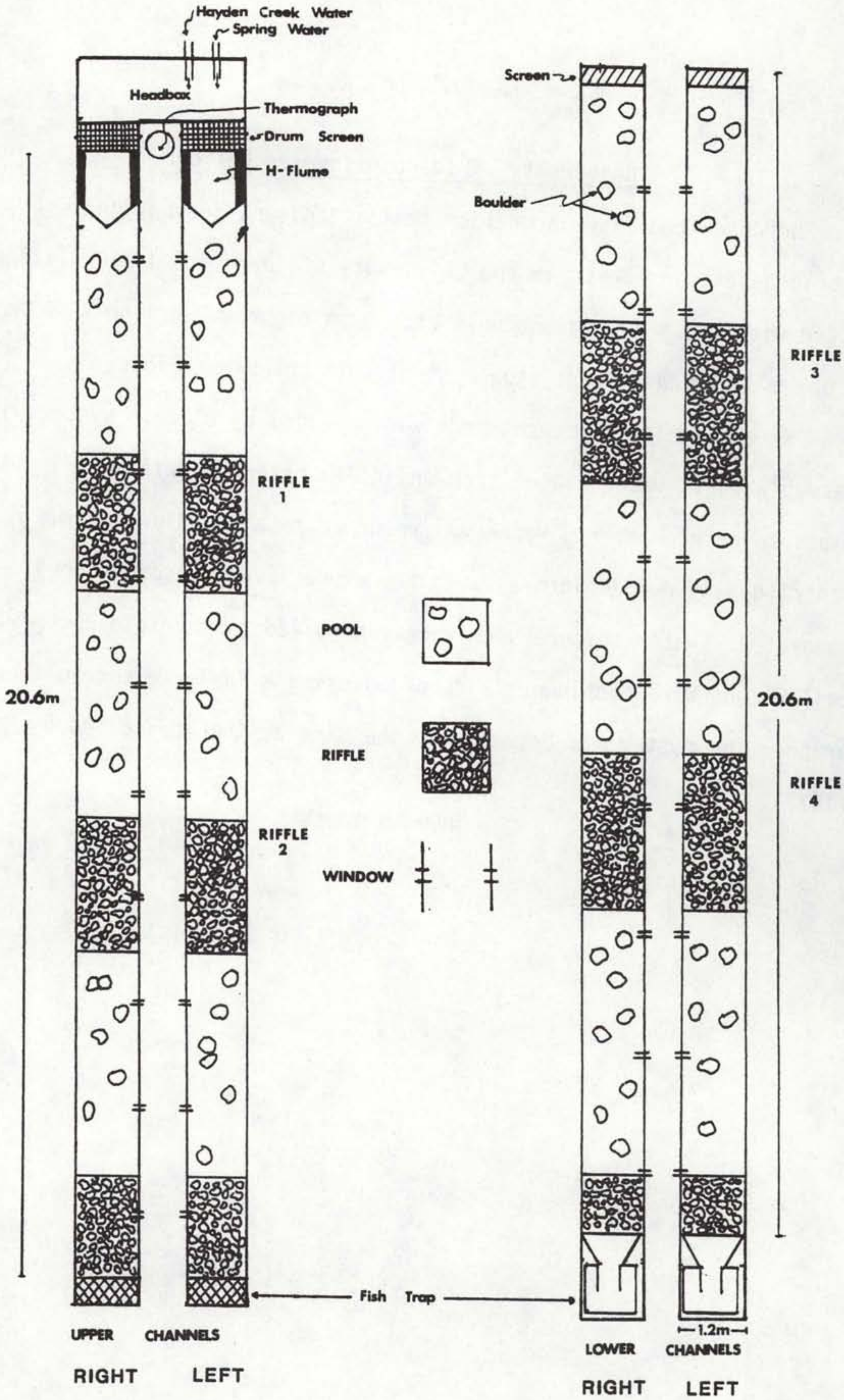


Figure 2. Schematic diagram of the Hayden Creek artifical stream channels used in flow - embryo incubation tests, Hayden Creek Research Station 1977-1979.

University of Idaho Fisheries Wet Lab

We conducted flow-incubation tests, sediment-incubation tests, and embryo dewatering tests in the University of Idaho wet lab utilizing five 1.2 m wide x 2.4 m long channels each with eight 1.2 m long x 0.3 m wide x 0.3 m deep independent flow controllable chambers (Figure 3).

Water supply to the chambers was provided by a reuse system with makeup water. Water exited from an inflow reservoir via distribution pipes to each chamber. Water was returned to an outflow reservoir and centrifugally pumped into a biofilter where it was reconditioned and reaerated. Water temperatures were controlled by a Frigid Units water chiller and were continuously recorded using a Taylor electric thermograph. The system was essentially the same as that described by McCuddin (1977).

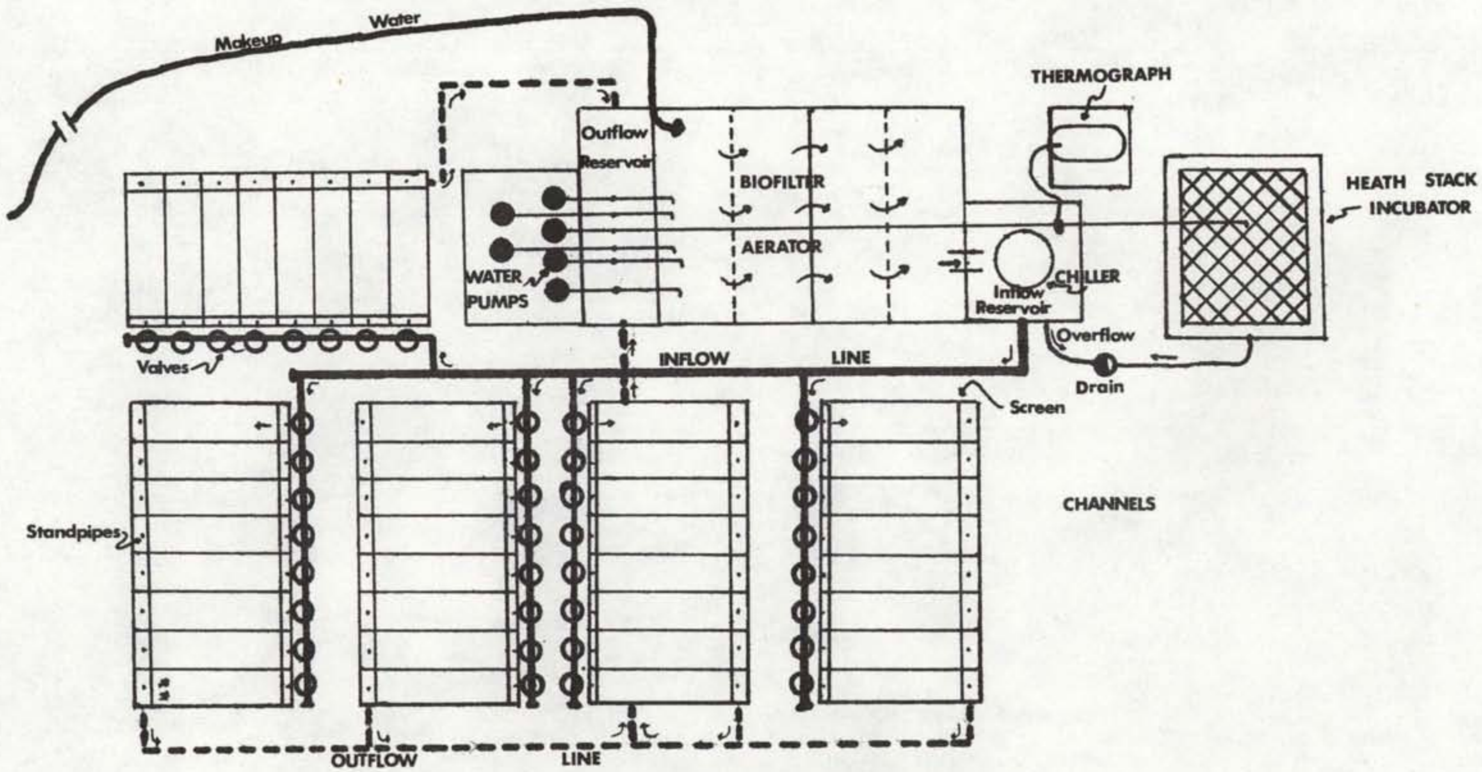


Figure 3. Schematic diagram of the egg incubation test facility located in the fisheries wet lab, University of Idaho, fall 1977-79.

DESCRIPTION OF FIELD STUDY AREAS

Big Springs Creek

We utilized a 115 m section of Big Springs Creek for field streamflow-incubation tests in a low lying productive stream (Figure 1). Big Springs Creek arises from a series of springs approximately 2 kilometers (km) south of Leadore, Idaho. From its origin the stream flows northwesterly for 10 km where it enters the Lemhi River.

Big Springs Creek flows through heavily grazed areas and is bordered by various grasses and willows (Salix sp.). Heavy mats of aquatic vegetation are common during the summer and fall. The substrate composition of riffle areas included a large percentage of fine sediment. Water temperatures have ranged from 9.9-20.2 C in the summer months and from 4.0-11.8 C in the fall (Bjornn 1966). Discharge of Big Springs Creek remains relatively constant owing to the large amount of groundwater inflow. During our tests the flow averaged .595 cubic meters per second (cms) (21 cubic feet per second - cfs).

Bear Valley Creek

We selected a 152 m section of a side channel of Bear Valley Creek for field streamflow-incubation tests in a high mountain stream. The headwaters arise from Bear Valley lakes (elevation 2784 m) and flow in a southeasterly direction for approximately 16 km where it enters Hayden Creek (Figure 1). Discharge in October was .425 cms (15 cfs) for the main channel and .078 cms (2.75 cfs) for the study section. Bear Valley Creek is a typical second or third order stream with steep gradients for much of its length. Our study section was located in a low gradient meadow section which has historically been used by salmon and steelhead for spawning. Riffles contained good spawning gravel with a paucity of fine sediment. Water temperatures declined quickly in the fall with temperatures as low as 0 C by mid-September.

Spawning Measurements

We surveyed sections of eight streams and rivers for locating and measuring salmonid redds (Figures 1 and 4; Table 1). The summer chinook redds from the Salmon River were located in a 0.5 km section known as "Indian Riffle" approximately 8 km below Sunbeam, Idaho.

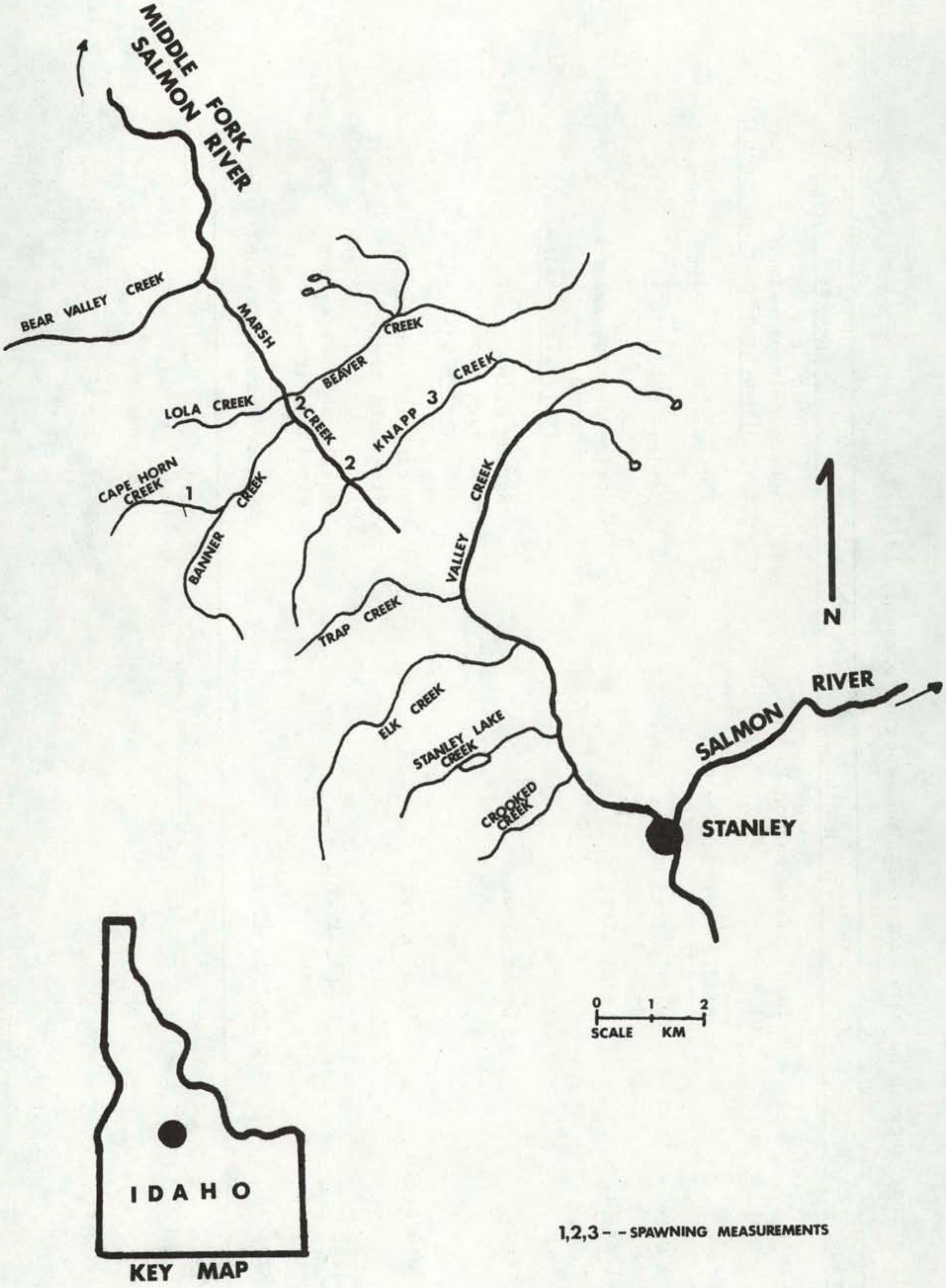


Figure 4. Study streams within the Middle Fork of the Salmon River drainage surveyed for spawning measurements, fall 1977-78.

Table 1. Study streams surveyed for redds and species present, 1977-79.

Stream	Drainage	Species
Marsh Creek	Middle Fork Salmon River	Spring chinook salmon (*Oncorhynchus tshawytscha*)
Knapp Creek	Middle Fork Salmon River	Spring chinook salmon
Capehorn Creek	Middle Fork Salmon River	Spring chinook salmon
Bear Valley Creek	Lemhi River	Spring chinook salmon Bull trout (*Salvelinus malma*)
Hayden Creek	Lemhi River	Spring chinook salmon Steelhead trout (*Salmo gairdneri*)
Big Springs Creek	Lemhi River	Spring chinook salmon Steelhead trout
Lemhi River	Lemhi River	Spring chinook salmon Steelhead trout
Salmon River	Salmon River	Summer chinook salmon

METHODS

Our general approach in attempting to derive a methodology for recommending incubation flows was to relate extragravel parameters to intragravel parameters and embryo survival. To investigate this potential relationship we conducted laboratory flow-incubation tests with and without sediment. Flow requirement comparisons of different embryo developmental stages were integrated into these tests by utilizing both green (newly fertilized) and eyed eggs. Subsequent flow-incubation tests were performed in the field using sections of Big Springs Creek and Bear Valley Creek. Embryo dewatering and flow fluctuation tests were conducted at both the Hayden Creek and University of Idaho research facilities.

We evaluated incubation success of salmonid embryos exposed to a wide variety of physical and hydraulic conditions. Whitlock-Vibert boxes (W-V boxes) were used as egg containers in all tests. The W-V box measures 145 mm long x 90 mm high x 60 mm wide and is slotted on all sides to allow intragravel water flow. Embryos are placed in an upper compartment which serves as the incubator with a lower compartment providing a nursery area for hatched fry. The W-V box allowed us to plant a known number of embryos in the gravel, and to recover these embryos eggs and/or fry.

Incubation Tests Without Sediment

Our initial tests conducted in the fall of 1977 were designed to evaluate effects of various flows on chinook salmon (*Oncorhynchus tshawytscha*) embryo incubation success and fry quality. For these tests we utilized sediment free substrate measuring 6.3 to 76.1 mm in diameter. This substrate composition represented an optimal incubation environment and survival results could therefore be related to changes in one variable, discharge.

Hayden Creek Channels

We planted W-V boxes with 100 eyed chinook embryos per box in artificial redds in each of the eight riffles within the Hayden Creek channels. Fertilized eggs were obtained from Rapid River hatchery near Riggins, Idaho. Nine of the boxes were planted in groups of three, equidistantly spaced across the riffle. The boxes were placed at a depth of 20-25 cm and covered with gravel. A Mark VI standpipe (Terhune 1957) was installed anterior to and at the same depth as the W-V boxes to enable measurements of intragravel dissolved oxygen, water temperature and gravel permeability. The remaining three boxes were buried at the lower ends of each riffle and served as indicators of embryo mortality.

We reduced the flows in all four channels at three 5 day intervals: initial flow - 1257 liters/minute (l/min); mid-flow - 356 l/min; low flow - 7.6 l/min. These flows resulted in 10-15 cm, 1-2 cm and 0 cm of water passing over the riffles during each flow period, respectively. During each flow, the extragravel parameters of depth, mean velocity, dissolved oxygen and temperature were measured, as were the intragravel parameters of permeability, dissolved oxygen, and temperature. We utilized a Marsh-McBirney Model 201 current meter for the velocity measurements and a Yellow Springs Instrument (YSI) Model 54-ARC oxygen meter for the determination of dissolved oxygens and temperatures. Average water velocity of each channel for each flow was determined using fluorescent dye time of travel techniques.

We estimated embryo mortality prior to each flow reduction by counting the number of dead eggs in the indicator boxes. After the final flow reduction period, all boxes were examined and replaced in the substrate.

We tested the ability of fry to emerge in the absence of surface flow across the riffles by maintaining low flows until the fry had buttoned up.

University of Idaho Channels

We equidistantly spaced four W-V boxes, each containing 100 embryos within each of the 40 chambers (eight chambers per channel) and covered them with gravel (Figure 5). The surface configuration of the substrate was molded to resemble typical redds (convex shape). Eight W-V boxes were placed in Heath stack vertical flow incubators to evaluate handling mortality.

We tested flows ranging from 11046 to 512 ml/min in four of the five channels (Table 2). Inflow velocity was measured at the inflow valve with a Marsh-McBirney current meter. The average flow corresponding to this velocity was determined by quantifying the outflow water over a 120 second period. Each of the four flow levels was duplicated in eight chambers. Extragravel velocities were calculated by dividing the flow by the estimated cross sectional area of the flow. Once regulated, flows were maintained throughout the incubation period.

We used the fifth channel to assess impacts of incremental flow reduction. Beginning with an initial inflow velocity of 30 cm/sec, we reduced the flows at four 7 day intervals with the final adjustment resulting in 0.6 cm/sec inflow velocity. Dissolved oxygen and water temperature measurements were taken weekly in each chamber.

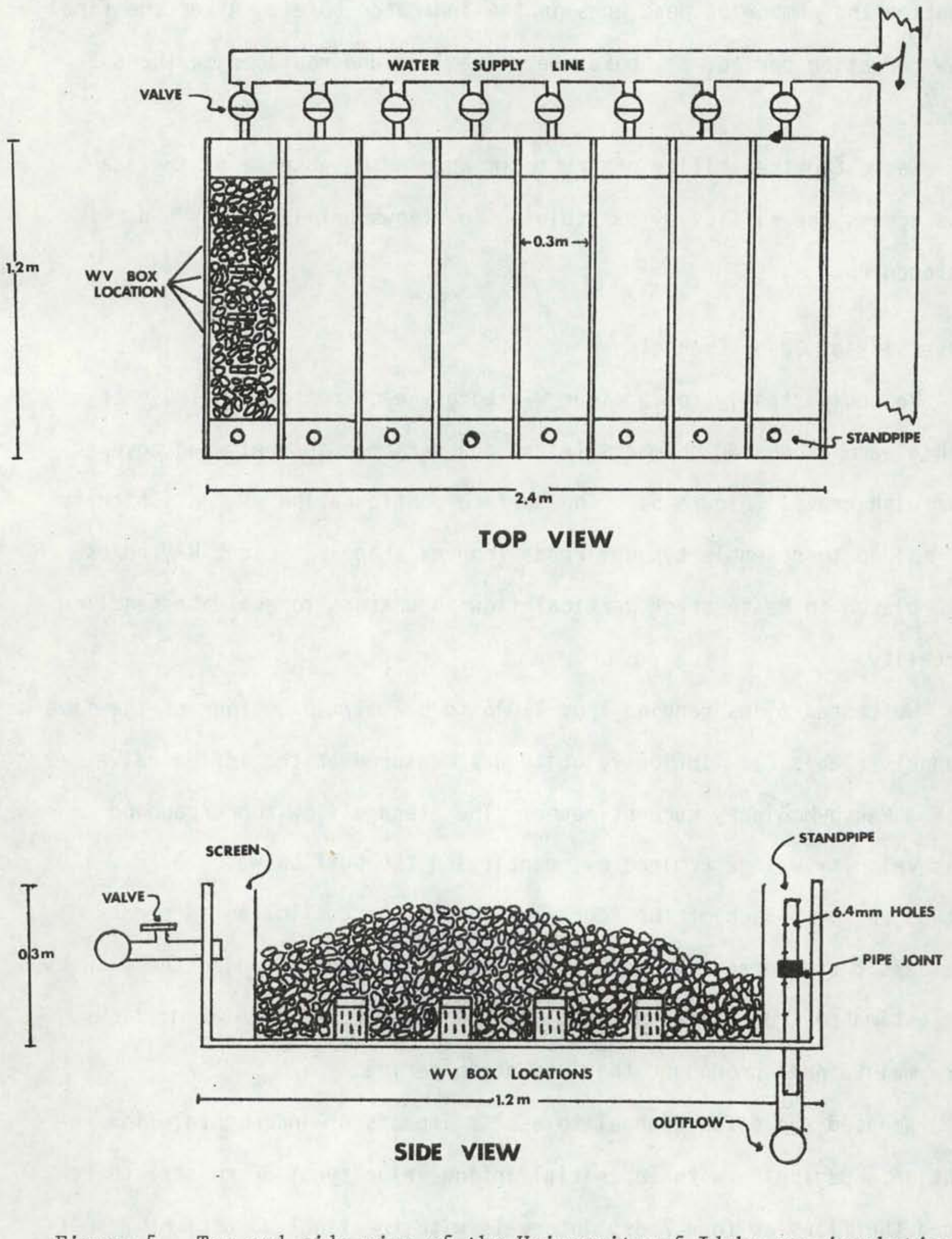


Figure 5. Top and side view of the University of Idaho egg incubation chambers noting the location of the egg filled Whitlock-Vibert boxes, 1977-79.

Table 2. Inflow velocity (cm/sec) average flow (ml/min), estimated cross sectional area (cm^2) and computed apparent velocity (cm/hr) in embryo incubation chambers during nonsediment flow tests, University of Idaho channels, fall 1977.

Chamber	Inflow velocity (cm/sec)	Average flow (ml/min)	Estimated X-sectional area of flow (cm^2)	Apparent[a/] velocity (cm/hr)
1 and 2	30.0	11046	851.6	778.3
3 and 4	10.0	2195	851.6	154.6
5 and 6	5.0	1080	712.3	91.0
7 and 8	0.6	512	572.9	53.6

[a/] Apparent velocity = (average flow ml/min)(60 min/hr)/(X-sectional area cm^2).

When embryos had hatched in the vertical flow incubator, we assessed survival in boxes 1 and 4 of each chamber. To determine fry quality differences resulting from the different flows, we measured total length to the nearest 0.5 mm and weight to the nearest 0.1 mg of a random sample of fry from each chamber. Boxes 2 and 3 were left in each chamber an additional month (12/18/77) to compare quality differences at a later date.

Incubation Tests With Sediment

Our incubation tests conducted in the spring and fall of 1978 incorporated sediment into the design to evaluate effects of flow-sediment interactions on embryo survival.

Hayden Creek Channels

Our spring and fall 1978 tests compared embryo survival and fry quality related to incubation of salmonid embryos under high (control) versus low (test) streamflow conditions and four sediment levels. We utilized granitic sediment typical of streams in the Idaho Batholith. All material added to the riffles was less than 6.4 mm in diameter.

For our spring 1978 tests we used fertilized eggs (both green and eyed) of cutthroat (Salmo clarkii) and steelhead trout. Cutthroat embryos were obtained from the Idaho Department of Fish and Game Henrys Lake Hatchery and steelhead embryos from Dworshak National Fish Hatchery.

Sediment was added by weight to riffles 2, 3, and 4 of each channel in the following amounts: Riffle 2 - 290 kg; Riffle 3 - 370 kg; Riffle 4 - 490 kg. Riffle 1 received no sediment and served as our control. The quantities added resulted in mean sediment levels (< 6.4 mm) ranging from 0 percent in Riffle 1 to 42 percent in Riffle 4.

Three artifical redds were constructed in each riffle with four W-V boxes per redd (Figure 6). We alternately placed cutthroat and steelhead trout embryos in the redds with each redd comprised entirely of embryos of one species. Fertilized green eggs were placed in the anterior two boxes and eyed eggs in the posterior two. Boxes of each were placed in vertical flow incubators. A Mark VI standpipe was centrally positioned in each redd at the level of the embryos (Figure 6).

We regulated flows to provide 7-13 cm depth over control riffles (1730 l/min) and essentially no flow over test riffles with all water passing intragravelly (water flow in upper test channel was 98 l/min). To accomplish this in the lower test channel, with its increased sediment levels, it was necessary to make a second flow reduction to 11 l/min.

We measured both extra- and intragravel parameters (dissolved oxygen, temperature, gravel permeability, and mean surface and intragravel apparent velocity) at each redd at weekly intervals throughout the incubation period. Following a 36 day incubation period we assessed embryo

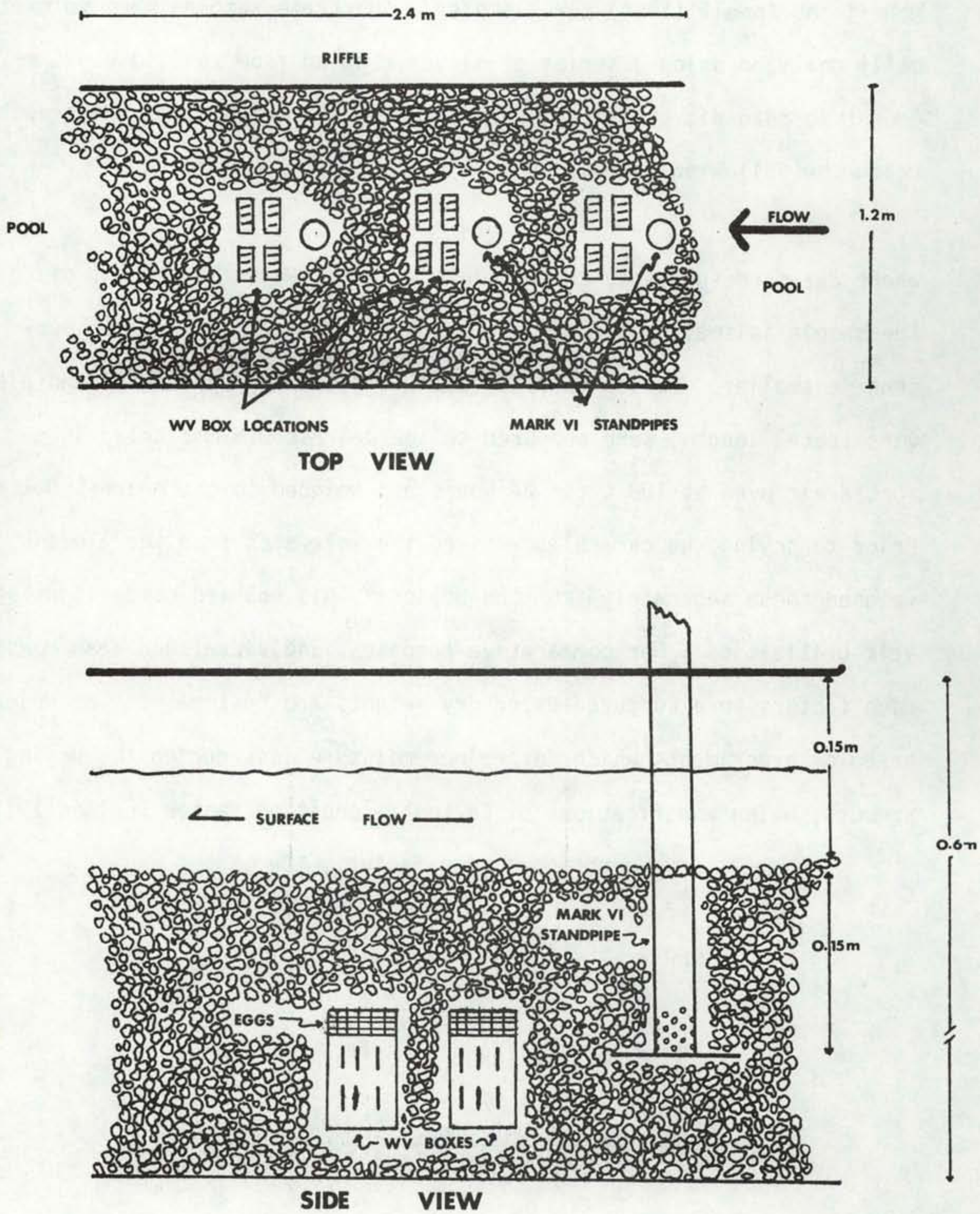


Figure 6. Top and side view of the artificial redds within the Hayden Creek channels and the relative position of the W-V boxes and Mark VI standpipes, spring-fall 1978.

and fry mortality in each box and preserved a representative sample of fry from each redd in 10% formalin. Following fry recovery we collected a substrate core sample directly over each standpipe using a modified McNeil and Ahnell (1964) core sampler. Substrate samples were volumetrically analyzed using a series of sieves ranging from 76.1 to 0.425 mm. Geometric mean diameters (dg) were computed from each sample distribution using the following formula:

$$dg = d_{84} \times d_{16}$$

where d_{84} corresponds to the particle size for which 84 percent of the sample is smaller and d_{16} is the particle size for which 16 percent is smaller. Button up fry (total length and fork length) and alevins (total length) were measured to the nearest 0.5 mm, dried in a forced air oven at 100 C for 24 hours and weighed to the nearest 0.1 mg. Prior to drying, we carefully excised the yolk sacs from the alevins and weighed these separately from the bodies. This enabled comparisons of yolk utilization. For comparative purposes, individual and mean condition factors were computed using dry weights and "estimated" wet weights, based on experiments which determined moisture loss during the drying process, using modifications of Fulton's condition factor (Fulton 1911):

dry weight condition factor: KDW

$$KDW = \frac{\text{dry weight (mg)} \times 10^3}{\text{fork length}^3\ \text{(mm)}}$$

and wet weight condition factor: KWW

$$KWW = \frac{\text{wet weight (mg)} \times 10^2}{\text{fork length}^3\ \text{(mm)}}$$

Bams' (1970) developmental index was also computed to allow comparisons of developmental stage. This index, KD, is computed as:

$$KD = \frac{10 \sqrt[3]{\text{wet weight (mg)}}}{\text{fork length (mm)}}$$

Values larger than 2.0 indicate early developmental stage; values = 1.95 indicate yolk absorption complete; values of 1.90 or less mean the fry is completely buttoned up and is resorbing body tissue at the expense of growth.

Fry quality comparisons were made by first computing the means and range of each variable using the PROC MEANS procedure from the Statistical Analysis System (SAS) on file at the University of Idaho computer facility. The general linear model procedure (PROC GLM) of the the form:

$$\begin{aligned} Y_{ij} &= u + F_i + R_j + FR_{ij} + e_{ij} \text{ with} \\ F_i &= \text{effect of flow} \\ R_j &= \text{effect of riffle sediment level} \\ FR_{ij} &= \text{interaction of flow x riffle} \\ e_{ij} &= \text{error} \end{aligned}$$

This procedure was used to determine if significant differences in the variables were present between the control and test channel, and among the four riffles. Duncan's multiple range test was used to pinpoint differences. Tukey's (W) procedure (Ott 1977) was used to compare means from a particular riffle and its counterpart in the opposite channel.

We used fertilized eggs (green and eyed) of spring chinook salmon during our fall tests which followed the same basic design as in our spring tests. We attempted to create more marginal incubation conditions with respect to sediment by adding 125 kg of sediment less than 0.84 mm in diameter to the number 4 riffles. Flows were 1270 l/min and 6.6 l/min in the test and control channel, respectively.

With the following exception, alevin and fry quality analysis and comparisons were the same as for the spring 1978 tests. Total wet weights were computed for alevins and fry using regression equations based on fry which had been wet weighed prior to drying. Computed wet weights were then used in computing wet weight condition factors (KWW) and developmental indices (KD). The model used in the comparison was the form:

$$Y_{ijk} = u + F_i + S_j + FS_{ij} + R{:}FS_{ijk} + e_{ijk}$$

where F_i = effect of flow

S_j = effect of sediment level

FS_{ij} = interaction of flow x sediment

$R{:}FS_{ijk}$ = effect of k redd on ijth FS subclass

(considers egg developmental stage)

$_{ijk}$ = error.

University of Idaho Channels

Our tests conducted at the University of Idaho were designed to investigate effects of various sediment size classes and quantities on intragravel flow, embryo survival and fry quality. Based on previous sediment incubation tests (McNeil and Ahnell 1964, Koski 1966, Hall and Lantz 1969, Bjornn 1969, Targart 1976, McCuddin 1977, Platts et al., 1979) we selected two size classes of material: sediment ranging from 4.6 to 0.84 mm in diameter, and sediment less than 0.84 mm in diameter. Size grouping was achieved by wet sieving through a number 4 (4.6 mm) and a number 20 (0.84 mm) 0.3 m x 0.3 m Gilson screen. We tested 16 sediment mixes with two replicates of each (Table 3). All chambers were filled with material to a depth of approximately 16 cm resulting in a cross sectional area/chamber of 488 cm^2 (30.48 cm wide x 16 cm deep). We regulated flow in each chamber so that all water passed through the substrate with no surface flow.

In each chamber we alternately positioned W-V boxes containing fertilized green eggs with boxes containing eyed eggs (100 eggs/box) with each chamber containing a total of four boxes (Figure 6). We used steelhead trout embryos from Dworshak National Fish Hatchery for our spring tests and spring chinook salmon embryos from Rapid River Hatchery for our fall tests. Embryos were placed in the lower chambers of the W-V box to maximize gravel cover. We placed several W-V boxes with embryos in vertical flow incubators as controls and as a means for determining when the embryos had hatched. When hatching was complete, we uncovered all boxes, assessed survival and preserved a representative sample of fry from each chamber for fry quality evaluation.

Because of the possible influence of accumulations of sediment in W-V boxes during spring and fall 1978 tests, we duplicated the spring test in 1979 but placed clean gravel in the W-V boxes prior to adding the embryos.

Field Incubation Tests

Our field studies attempted to determine whether differences in embryo survival would result from differences in the extragravel parameters of depth and velocity. The general approach was to plant embryos in artificial redds in areas of varying water depth and velocity. Substrate composition within these areas typified gravel utilized by spawning fish. A substrate core sample was collected from each redd and a

Table 3. Chamber numbers and associated percent sediments levels and sizes(mm) used in the egg incubation tests conducted at the University of Idaho. Spring-fall 1978, spring 1979.

Percent sediment and size (mm)	Chamber number
0%	16 and 32
10% < 4.6 > 0.84	15 and 31
20% < 4.6 > 0.84	14 and 30
30% < 4.6 > 0.84	13 and 29
50% < 4.6 > 0.84	12 and 28
10% < 0.84	10 and 26
20% < 0.84	1 and 17
30% < 0.84	4 and 20
50% < 0.84	8 and 24
5% < 4,6 > 0.84; 5% < 0.84	11 and 27
10% < 4.6 > 0.84; 10% < 0.84	9 and 25
10% < 4.6 > 0.84; 20% < 0.84	3 and 19
20% < 4.6 > 0.84; 10% < 0.84	2 and 18
20% < 4.6 > 0.84; 30% < 0.84	7 and 23
30% < 4.6 > 0.84; 20% < 0.84	6 and 22
40% < 4.6 > 0.84; 10% < 0.84	5 and 21

Mark VI standpipe installed anterior to the W-V boxes. Substrate samples were analyzed volumetrically using sieves ranging from 76.1-0.425 mm.

At various intervals during the incubation period we measured depth, mean velocity, dissolved oxygen (extra- and intragravel), water temperature (extra- and intragravel) and gravel permeability.

During the fall tests for both Big Springs Creek and Bear Valley Creek, we established cross channel transects in front of selected standpipes. Depths and velocities (measured at 0.6 of the depth) were measured at specified intervals across the transect, making sure a measurement was taken over each artifical redd. Water surface slopes were measured over each redd using an Abney level. We measured intragravel velocities within each standpipe using the techniques developed by Terhune (1958). Theoretical intragravel velocities were computed for each redd using the equation:

$$Va = \frac{Vs^2\ n^2\ k}{2.22\ R^{4/3}} \quad \text{(Bovee and Cochnauer 1977)}$$

where: Vs = mean extragravel velocity
n = roughness coefficient (assumed to equal 0.035)
R = hydraulic radius = cross sectional area A divided by the wetted perimeter WP.
k = gravel permeability

We then compared the computed values with those empirically determined and evaluated the reliability of the equation.

Big Springs Creek

During both the spring and fall of 1978, we constructed 15 artificial redds within the 115 m study section (Figure 7). We planted four W-V boxes per redd in both tests. In the spring, each redd contained two

W-V boxes with green cutthroat trout embryos and two with green steelhead trout embryos; in the fall, the redds contained two boxes of green and two boxes of eyed spring chinook embryos. Survivals were assessed for the two tests following 61 and 95 day incubation periods, respectively.

Bear Valley Creek

We constructed 13 artifical redds in a side channel of Bear Valley Creek and two in the main channel (Figure 8). Three W-V boxes, each containing 100 eyed spring chinook embryos, were positioned in each redd along with a Mark VI standpipe. Prior to planting the embryos we collected a substrate sample from each redd and volumetrically analyzed them as previously described. We placed four 3 ml vials filled with water posterior to and at the same level as the embryos to determine if intragravel freezing occurred.

At the time of planting (9/26/78) we augmented the flow in the side channel via a small diversion dam and measured the extra- and intragravel parameters of water depth, velocity, temperature, dissolved oxygen, and permeability. On 12/5/78 we reduced the side channel flow .078 cms (2.7 cfs) and maintained this low level throughout the winter. During the spring, we reregulated the flows and measured intragravel velocities and extragravel velocities and depths along established transects for flows of .814 and .979 cms (6.5 and 34.6 cfs). On 5/26/79 we recovered all boxes and assessed embryo and fry survival and obtained a substrate sample from each redd. Fry samples were preserved for later fry quality analysis.

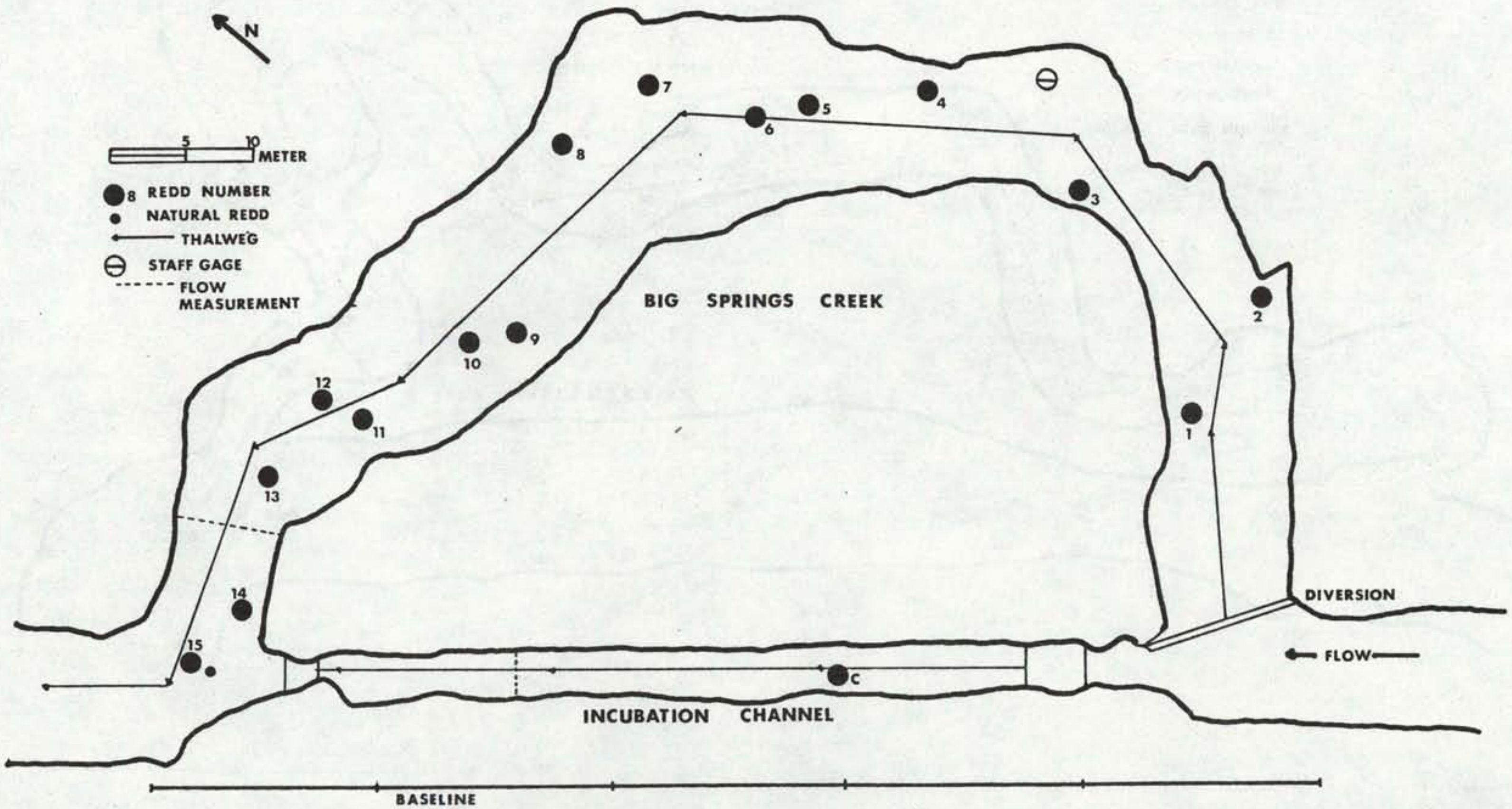


Figure 7. Big Springs Creek study area map showing the location of 15 artificial redds, spring-fall 1978.

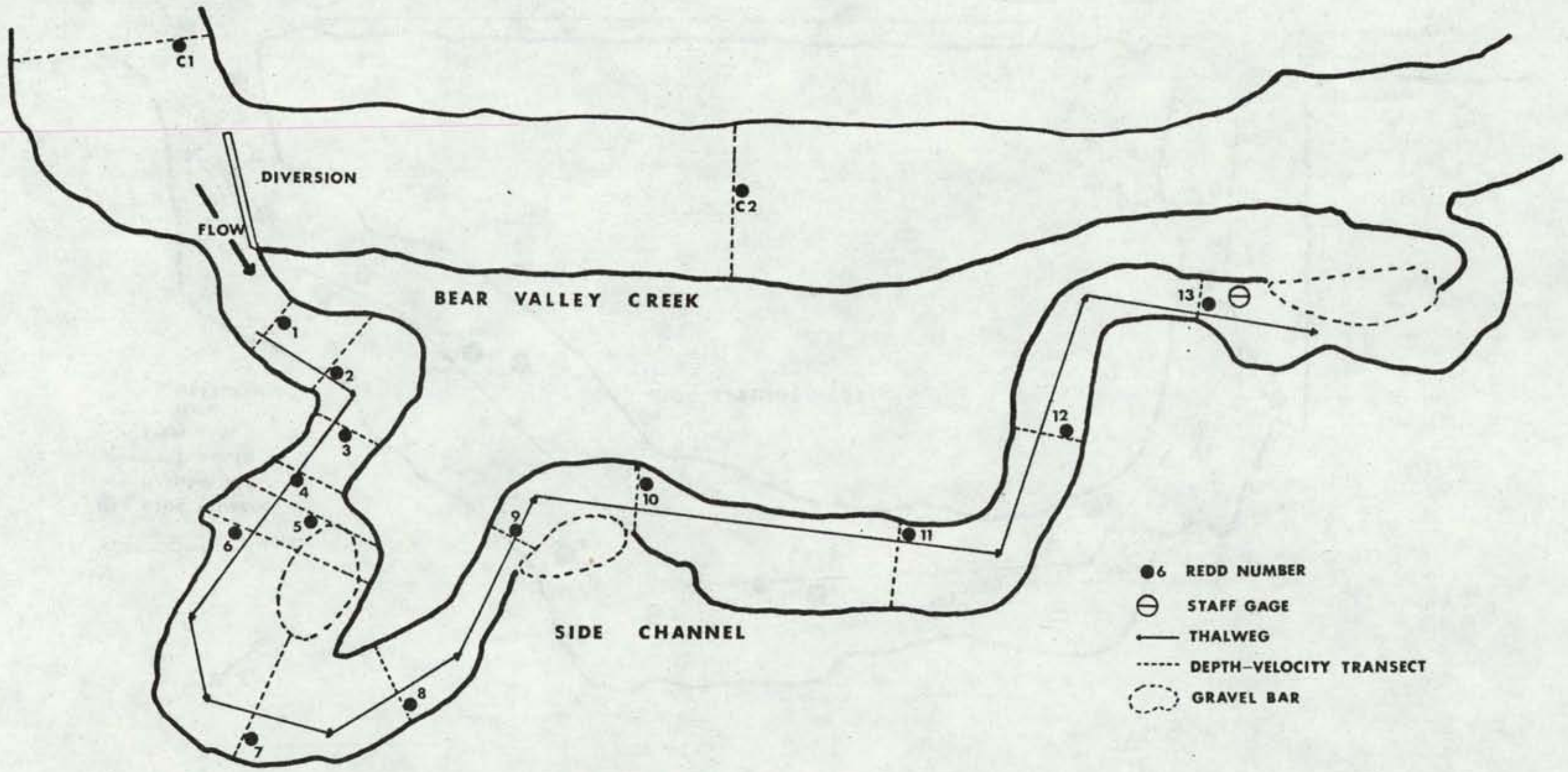


Figure 8. Bear Valley Creek study area map showing the location of 15 artificial spring chinook salmon redds.

Embryo Dewatering Tests

We conducted several tests to determine the impact of varying periods of complete dewatering on salmonid embryo survival and fry quality. We defined dewatering as the absence of flow over and within salmonid redds, with embryos having no contact with either standing or moving water.

Drip Incubation Tests

To determine the extent of the ability of salmonid embryos to withstand periods of dewatering, our initial tests, conducted in the spring and fall 1978, monitored development and hatching success of embryos which were incubated in a moist environment without submergence in water. For these tests we utilized Heath stack incubator screens lined with cotton cloth to retain moisture. We used fertilized eggs of steelhead trout in spring tests and chinook in fall tests.

Our first test, spring 1978, utilized three 300 embryo lots (steelhead) which were covered with cotton cloth and moistened each day. We placed one 300 lot in a Heath stack vertical incubator as a control. The screens were stacked on top of each other and placed in a 12.2 C temperature controlled room at the University of Idaho. After 26 days, we evaluated eyeup and hatching success.

Similar tests were conducted in the fall 1978 using chinook embryos at both the University of Idaho and Hayden Creek Research Station. For these tests we employed a cotton wick siphon which "dripped" water (315 ml/hr) continuously onto the trays to maintain their moisture.

Redd Dewatering

Redd dewatering tests were conducted during fall 1978 at the Hayden Creek Research Station and University of Idaho. Both tests employed the independently flow controllable chambers previously described. Based on our spring 1978 sediment tests we selected four gravel-sediment mixes for our Hayden Creek tests (Figure 9). Adjacent chambers within each channel were filled with the same mixture (Figure 9). We planted one channel (chambers 1-8) with fertilized green spring chinook eggs (four W-V boxes; 100 embryos/box) from the Hayden Creek Hatchery; in the other (chambers 9-16) we alternated eyed and green eggs. We adjusted flows in all chambers to provide approximately 2.5 cm of water depth over the substrate (≈300 ml/sec flow). After 3 days, flow in one chamber of each sediment mixture was reduced so that water levels were below embryo pockets. A small inflow was maintained in these chambers to simulate groundwater flow. At weekly intervals we uncovered one W-V box per chamber, noted survival and replaced it in the gravel. Dead embryos were removed from the boxes to prevent fungus (Saprolegnia sp.) induced mortality. Prior to hatching, the flows in chamber 1-8 were restored, while flows in chambers 9-16 were maintained as regulated to determine if embryos could complete development in moist gravel. Upon hatching, samples of yolk sac fry were preserved in 10% formalin.

The remaining fry from each chamber were placed in separate vertical flow incubators until buttonup and then transferred to rearing troughs. Each trough was divided into three equal rearing compartments. We placed fry resulting from watered versus dewatered conditions for a given sediment mix in the same relative positions within the troughs (Figure 9). Fry were placed on a programmed feeding schedule. When the fry attained a size of 35-40 mm, final survival was assessed and a sample of fry preserved in 10% formalin.

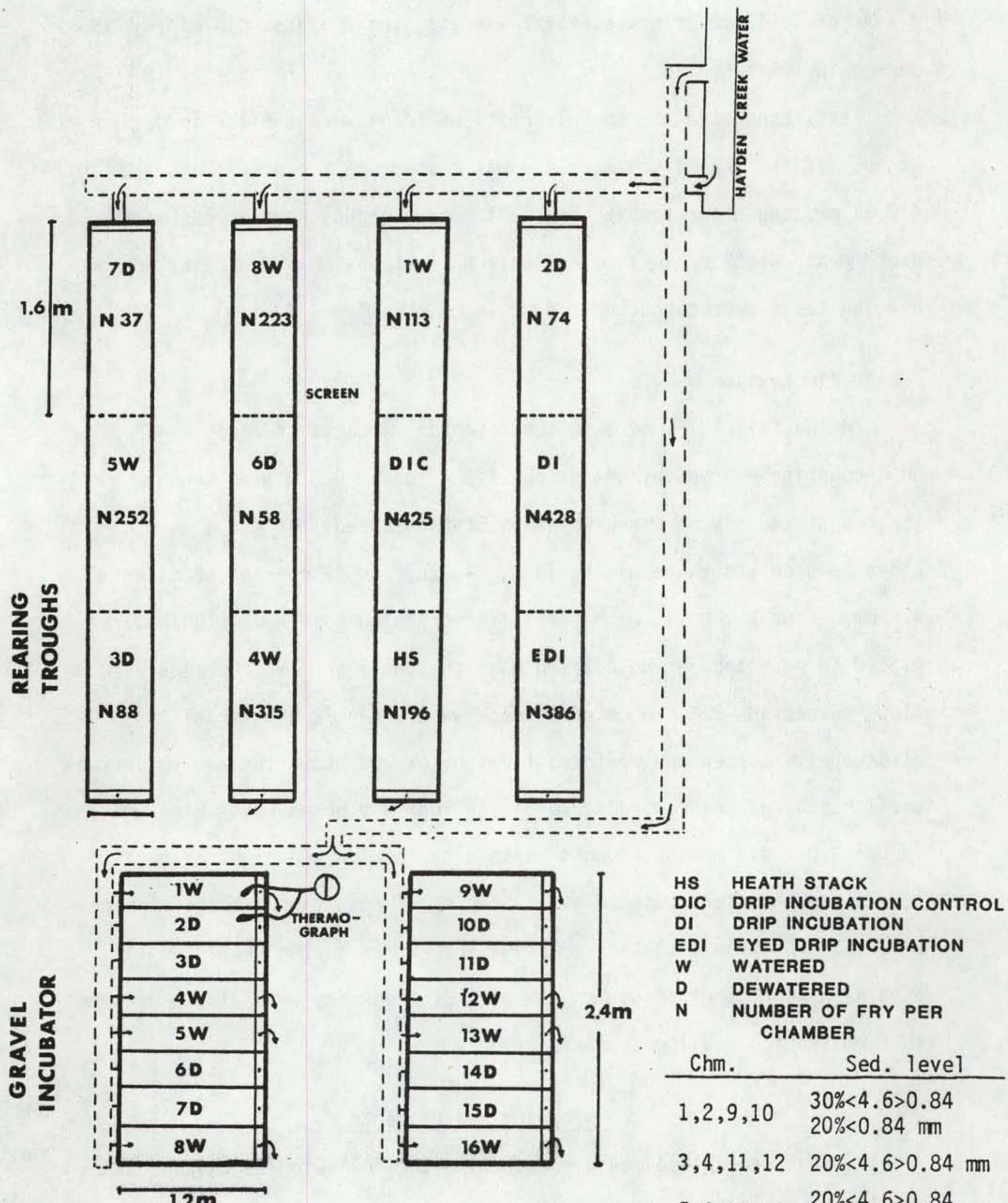
Tests conducted at the University of Idaho were similar in design except a fifth gravel-sediment mix was tested - 20% < 4.6 > 0.84 and 30% < 0.84 mm; and prior to hatching, all embryo groups were moved to separate Heath stack drawers to evaluate ultimate hatching success; and no rearing tests were conducted.

Flow Fluctuation

In the fall 1978, we assessed potential impacts of fluctuating flows on incubating embryos by using four 4.9 m long x 0.3 m wide troughs located at the Hayden Creek Research Station. Sediment < 6.4 mm was added to each trough resulting in 0, 24, 20, and 37 percent of material < 4.6 mm. Four W-V boxes with fertilized green chinook eggs (100/box) were placed in each trough and covered with the sediment mix. We regulated flows to provide 2.5-5.0 cm of surface water. At 72 h intervals we alternately reduced and restored flows below and above the embryo pockets until hatching. As controls, we placed four W-V boxes containing embryos in two 3.0 x 0.3 m wide troughs containing the low and high sediment levels, and constant water flows. Samples of resulting alevins were preserved in formalin with the remaining fry reared in the troughs until attaining lengths of 35-40 mm. Samples of these fry were also preserved in formalin for quality comparisons.

Spawning Measurements

We measured all salmonid redds using the following techniques as described by Reiser and Wesche (1977). Measurements of water depth, mean velocity (0.6 of the depth) and point velocity (on the substrate surface) were taken at the upper edge, pit and tailspill of each redd. Water



Chm.	Sed. level
1,2,9,10	30%<4.6>0.84 20%<0.84 mm
3,4,11,12	20%<4.6>0.84 mm
5,6,13,14	20%<4.6>0.84 10%<0.84 mm
7,8,15,16	10%<0.84 mm

Figure 9. Schematic diagram of the Hayden Creek Research Station incubation and rearing facilities utilized during egg dewatering tests, Fall 1978.

depth (nearest 0.01 m) was measured with a top setting rod, while mean velocities were measured with either a Price AA or Marsh-McBirney current meter. We measured the length (nearest 0.01 m) of each redd from the upper edge to the lowermost portion of the tailspill and three equidistantly spaced width measurements (nearest 0.01 m) (Figure 10). From these measurements, we estimated the surface area per redd by using the following formula:

$$A = 1/2\ L \cdot W_t + 1/3\ L \cdot W_p + 1/6\ L \cdot W_u$$

where: A = redd area in m^2

L = length of redd

W_t = width of redd across the tailspill

W_p = width of redd across the pit

W_u = width of redd across the upper edge.

The equation solves for three rectangles corresponding to areas representing the upper edge, pit, and tailspill, and sums all three to get the total area (Figure 10). The fractional components of length assigned to each area were largely determined by field observations on several hundred redds and the shape of typical redds.

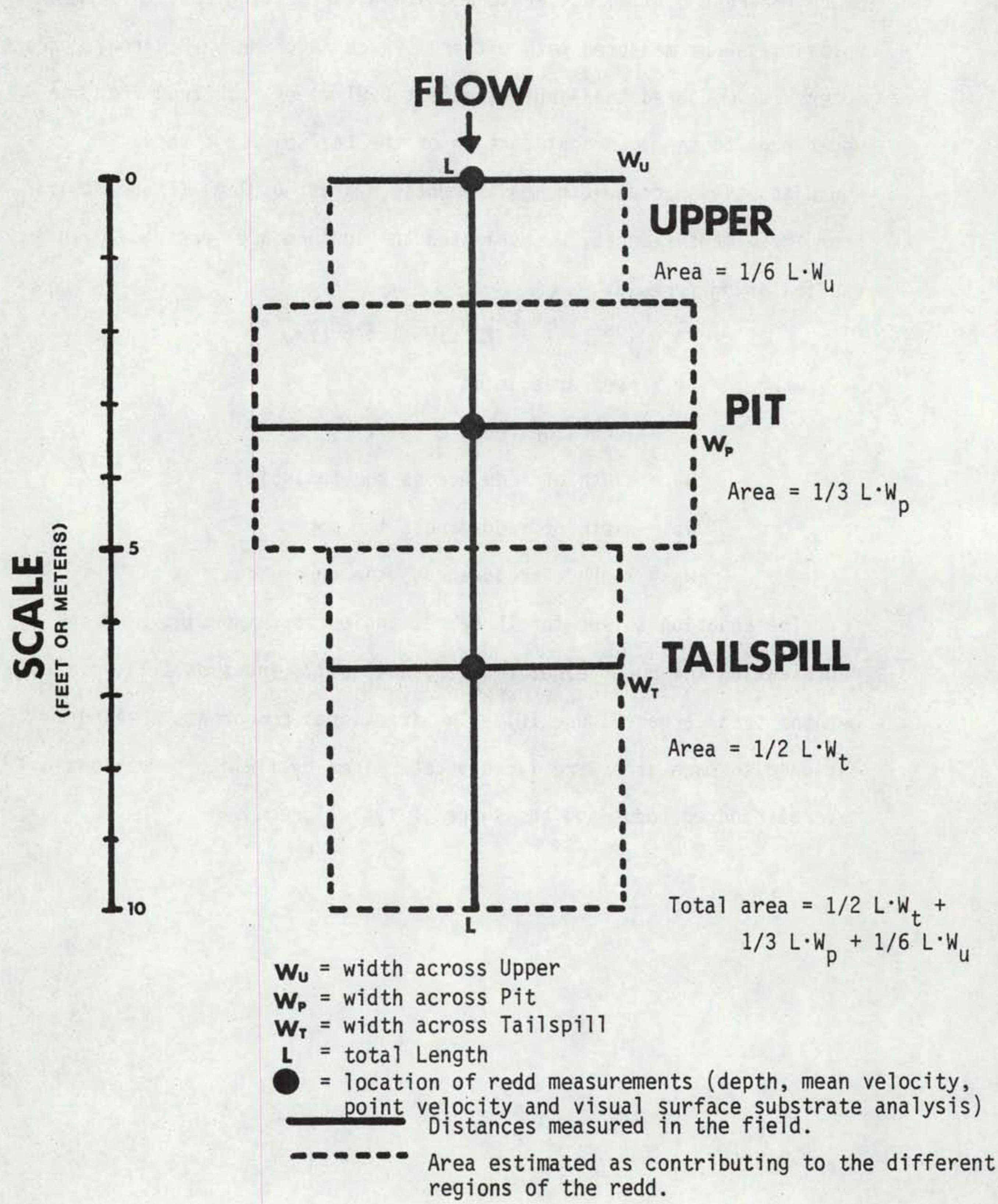


Figure 10. Redd area computation and location of redd measurements.

RESULTS

Incubation Tests Without Sediment

Flows tested in the Hayden Creek and University of Idaho channels had no observed affect on chinook embryo survival within sediment free gravel. However, the low flow conditions in the U of I tests did result in significantly smaller alevins than those from the high flow conditions.

Hayden Creek Channels

Average survival to hatching of eyed chinook embryos subjected to flow reductions in sediment free gravel was high ($\overline{X}$ = 99.3%) even though the lowest flow resulted in all water being channeled intragravelly (Table 4).

Table 4. Spring chinook salmon embryo survival to hatching resulting from flow reduction tests [a/] in sediment free gravel, Hayden Creek channels, fall 1977.

Channel	Riffle	Embryo Survival (%) Mean	Range	% of fry remaining in W-V box
1(Right)	1(Upper)	99.9	99-100	47.6
2(Left)	1	100	100	35.0
1	2	99.6	97-100	46.1
2	2	99.6	96-100	44.8
1	3	100	100	58.2
2	3	98.4	96-100	18.5
1	4(Lower)	98.9	96-100	49.8
2	4	98.2	91-100	38.8
Overall Total		99.3	91-100	42.4

[a/] Flows reduced from 1257 l/min (10/14/77) to 356 l/min (10/20/77) to 7.6 l/min (10/25/77).

Mean water velocities in the four channels ranged from 8.6 to 12.0 cm/sec for the 1257 l/min flow, 3.1 to 4.0 cm/sec for the 356 l/min flow and 1.5 to 2.6 cm/sec for the 7.6 l/min flow (Table 5). During the tests, dissolved oxygens (extra- and intragravel) ranged from 5.2 to 7.8 mg/l, while permeabilities were all in excess of 5000 cm/hr.

Fry emergence assessed in April 1978 showed that 11.5% of the total number of hatched fry had emerged, although 42.4% were still within the W-V boxes (Tables 4 and 6). Ten predatory fish were found in various pools and had likely consumed some fry; pools with no predators usually had more fry. Fry emerged in approximately equal numbers up and downstream from the artificial redds (Table 6).

University of Idaho Channels

Average chinook embryo survival ranged from 97.3 to 99.7% in each of the four flows tested as well as in the flow reduction tests (Table 7). During the tests, dissolved oxygen levels ranged from 7.6 to 10.2 mg/l in the inflow and from 7.4 to 10.1 mg/l in the outflow.

Average fry length decreased with decreased flow (Table 8). For both sampling dates, fry produced in low flow tests (1.0 cm/sec) were significantly smaller in length than those from the high flow (30 cm/-sec)(date, 11/16/77, $p \leq 0.001$; date, 12/18/77, $p \leq 0.001$). Fry length was positively correlated with apparent velocity but no significant relationship was found between apparent velocity and fry weight (Figure 11). Fry produced from the flow reduction tests exhibited average lengths similar to those from the 5-10 cm/sec inflow, and average weights similar to those from the 1030 cm/sec inflow (Table 8).

Table 5. Discharge and average velocities in Hayden Creek channels during the fall 1977, spring 1978 and fall 1978 incubation tests.

Date/Channel	Flow reduced	Discharge liters/min	Average velocity cm/sec	Average velocity cm/hr
Fall - 1977				
Upper Right	10/14	1257	8.90	32040
	10/20	356	3.06	11016
	10/25	7.6[a]	1.71	6156
Upper Left	10/14	1257	11.6	41760
	10/20	356	3.63	13068
	10/25	7.6[a]	2.55	9180
Lower Right	10/14	1257	12.0	43200
	10/20	356	3.87	13932
	10/25	7.6[a]	1.54	5544
Upper Left	10/14	1257	8.60	30960
	10/20	356	4.0	14400
	10/25	7.6[a]	2.50	9000
Spring - 1978				
Test		98[a]	0.94	3384.00
Control		1729	16.60	59760.00
Test		10.6[a]	< 0.67[b]	< 2397.33[b]
Control		1729	11.99	43164.00
Fall - 1978				
Test		6.6[a]	< .96[c]	< 3456
Control		1264	19.68	34848.00
Test		6.6[a]	< .99[c]	< 3564
Control		1264	13.32	47952.00

[a] Essentially all water passing intragravelly.

[b,c] Estimate - greatest concentration of dye had not reached sampling point after 45 minutes (b/) and 30 minutes (c/).

Table 6. Number of chinook fry emerging from dewatered riffles in Hayden Creek channels, fall 1977.

Channel	Riffle	Pool	Number fry recovered	Percent fry recovered/pool	Percent of total fry recovered	Number predators observed in pool
1	3-4	Lower	76	32.6	3.2	1
		Middle	137	58.8	5.7	0
		Upper	20	8.6	0.8	3
			233			
2	3-4	Lower	179	35.5	7.5	0
		Middle	169	33.5	7.0	1
		Upper	156	31.0	6.5	0
			504			
1 (Right)	1-2	Lower	18	8.7	0.8	1
		Middle	166	80.6	6.9	0
		Upper	22	10.7	0.9	2
			206			
2 (Left)	1-2	Lower	46	28.2	1.9	0
		Middle	80	49.1	3.3	0
		Upper	37	22.7	1.5	2
			163			
Total		All	1106		11.5	10

Table 7. Average percent survival of spring chinook embryos subjected to four different continuous flows in the University of Idaho incubation test facility, fall 1977.

Inflow velocity (cm/s)	Average flow (ml/min)	Average Percent Survival[a/] Box #1	Box #2	Box #3	Box #4
30.0	11046	99.4	98.9	98.8	99.3
10.0	2195	99.3	99.0	99.7	99.3
5.0	1081	99.1	99.3	98.5	99.1
1.0.	512	98.7	98.6	98.6	97.3
Flow reduction test		99.1	99.0	98.8	98.6

[a/] Averages based on eight W-V boxes.

Incubation Tests With Sediment

Hayden Creek Channels

We found no significant difference ($p \leq 0.05$) in survival of fertilized green or eyed eggs between control and test flows with sediment < 0.84 ranging from 1.4 to 13. 8% (Table 9). In addition, there was little variation in embryo survival between the different sediment levels for a given flow (Figure 12). Overall, percentage survival was higher in the test channel (61.1%), than in the control (57.1%). A large amount of silt and organic material was carried in the control channel during spring runoff. This resulted in the deposition of a high percentage of material < 0.84 mm within the gravel interstices of riffle one and a concomitant reduction in average permeability (Figures 12 and 13; Table 1 Appendix 1). The test channel was unaffected by runoff because of its low flow. Mean intragravel velocities in the control closely paralleled permeability values while velocities in the test channels decreased from riffles 1-4 even though permeabilities remained constant (Figure 13).

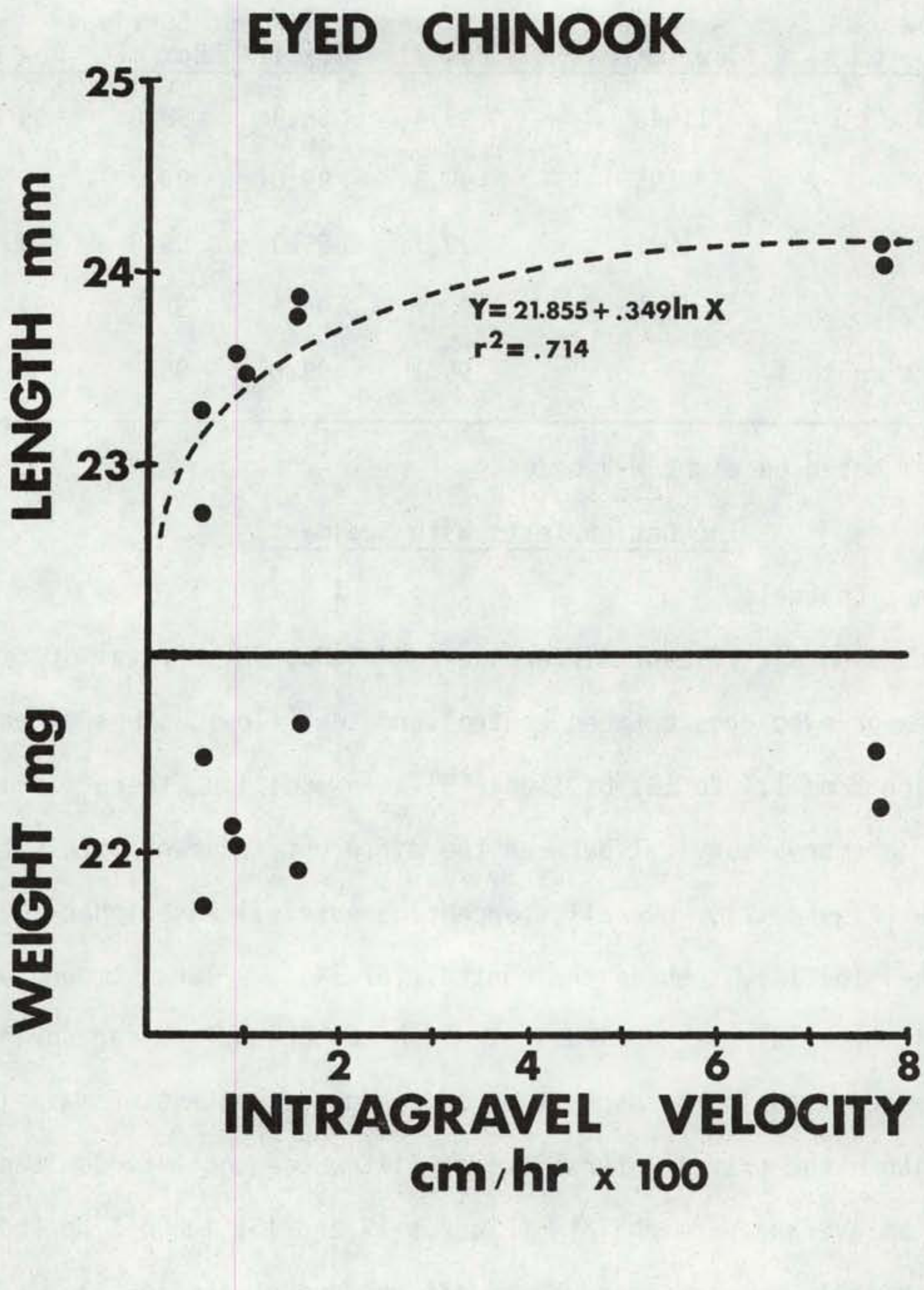


Figure 11. Relationship of spring chinook salmon alevin length and weight to intragravel water velocity. Tests were conducted in the University of Idaho incubation facility using sediment free gravel, fall 1977.

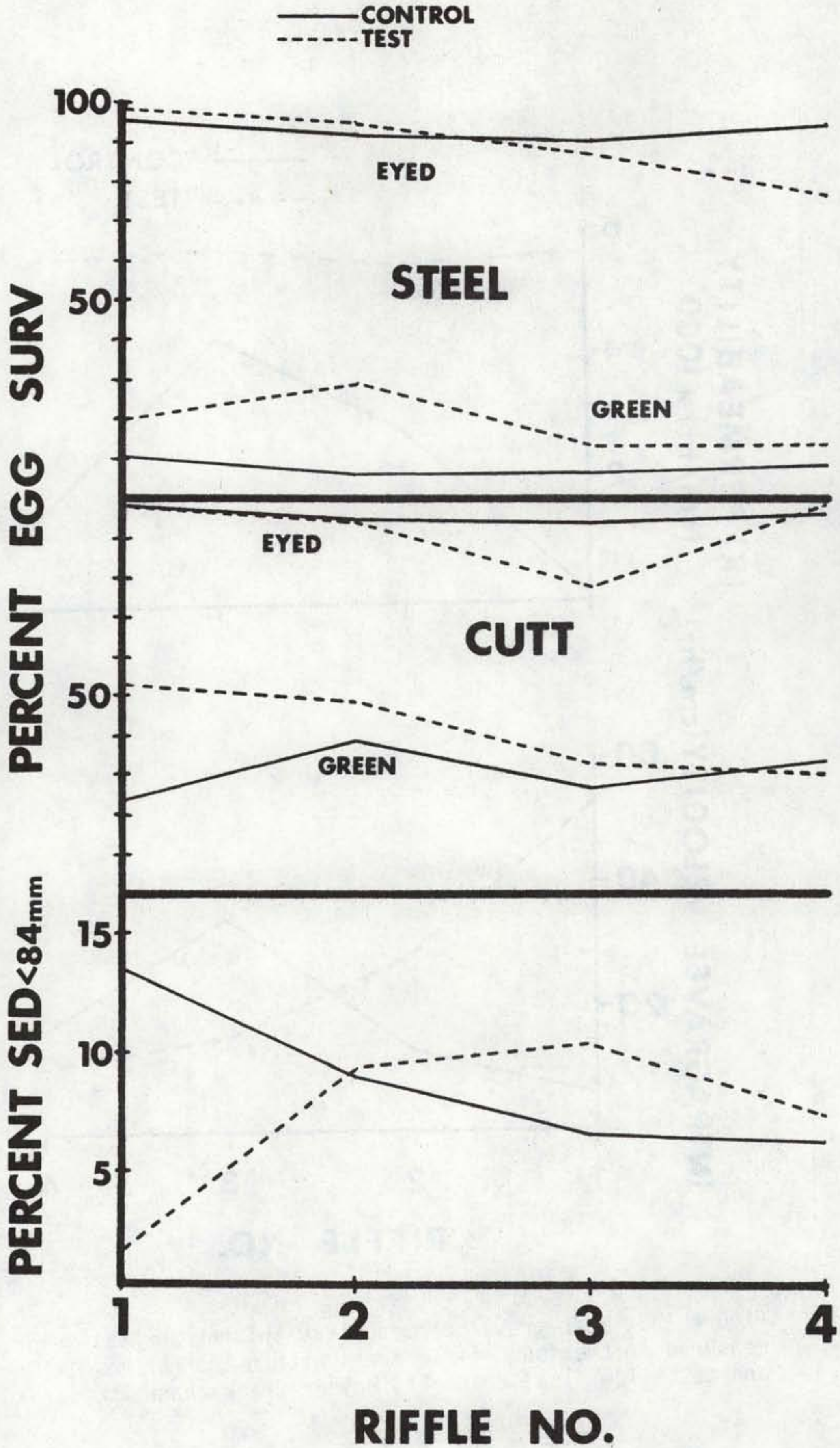


Figure 12. Mean percent steelhead and cutthroat trout green and eyed egg survival and associated percent sediment < 0.84 mm in the four riffle areas within the control (high flow) and test (low flow) channels, Hayden Creek channels, spring 1978.

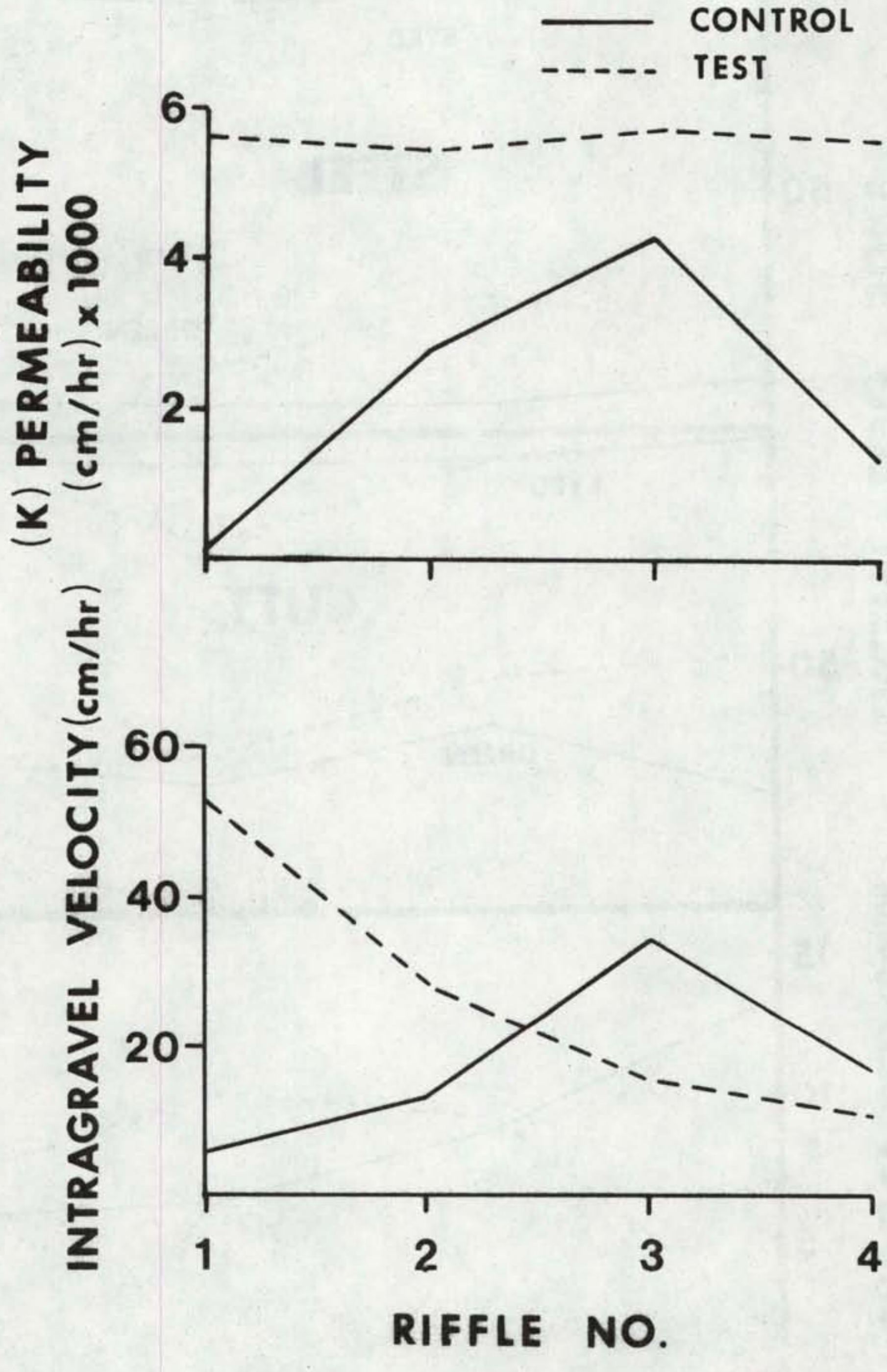


Figure 13. Mean gravel permeability and intragravel velocity as measured in the four riffle areas within the control (high flow) and test (low flow) channels, Hayden Creek channels, spring 1978.

Table 8. Average length (mm) and weight (mg) of spring chinook fry resulting from four different continuous flows, and weekly flow reductions in sediment free gravel in the University of Idaho incubation test facility, fall 1977. Box #1 is closest and box #4 the farthest from inflow water.

Inflow velocity (cm/s)	Average flow (ml/min)	Average[a/] length (mm) of 15 fry - 11/16/77 Box #1	Box #4	Average[a/] weight (mg) of 50 fry - 11/16/77 Box #1	Box #4
030.0	11046	24.05	24.08	22.2	22.5
010.0	2195	23.87	23.81	22.6	22.0
005.0	1081	23.50	23.57	22.1	22.0
001.0	512	22.76	23.28	21.7	22.5
Flow reductions		23.58	23.80	22.2	22.3
		12/18/77		12/18/77	
		Box #2	Box #3	Box #2	Box #3
030.0	11046	31.11	31.33	28.0	28.3
001.0	512	30.07	30.09	27.7	27.7

[a/] Averages based on eight W-V boxes.

Table 9. Percent sediment < 0.84 permeability of artificial redds, and percent survival of cutthroat and steelhead trout eggs resulting from flows of 1730, 98, and 11 l/m in Hayden Creek channels, spring 1978. Chi-square values are comparison of survival between control and test flows.

Channel/riffle	Flow l/m	Average % sediment < 0.84 mm	Average permeability cm/hr[a]	Average % survival CT green	Average % survival CT eyed	Average % survival SH green	Average % survival SH eyed
Control/1	1730	13.8	157.2	22.5	99.0	10.5	96.5
Test/1	98	1.4	> 5637.5	52.7	98.5	24.0	98.5
Control/2	1730	8.7	2832.42	38.8	95.0	6.0	93.0
Test/2	98	9.3	> 5569.2	48.5	95.0	28.7	96.7
Control/3	1730	6.8	4305	27.0	96.5	7.0	92.0
Test/3	11	10.1	> 5740.0	32.5	78.0	13.7	88.2
Control/4	1730	6.3	1329.1	30.5	96.0	8.5	94.0
Test/4	11	7.3	> 5603.3	33.7	97.2	12.5	78.5
Average survival Control				29.7	96.6	8.0	93.9
Average survival Test				41.9	92.2	19.7	90.5
Chi-square, df = 3, $\alpha = 0.05$				5.79	1.55	3.93	1.32

[a] Based on final set of permeability measurements.

Intragravel dissolved oxygen measure 12 days prior to survival assessment ranged from 6.3-7.6 mg/l in the test and 1.1-6.7 mg/l in the control. The low dissolved oxygen values reflected the high organic and sediment content accumulated in the control channel. Mean velocities during spring 1978 tests, for the control ranged from 11.9-16.6 cm/sec, and for the test, less than 0.67-0.94 cm/sec (Table 5).

Because of high embryo mortality, we were unable to recover sufficient numbers of cutthroat alevins to evaluate fry quality. We did, however, analyze steelhead alevin quality. Average length and body weight were in general higher in the control channel while yolk weight tended to be higher in the test (Figure 14; Table 10). Because yolk weight accounts for the major portion of total weight, and test channel fry were shorter in length, their dry weight condition factors were greater than those from the control. There was no significant difference, however, in fry quality between the two channels when all four riffles were considered ($p \leq .05$). Likewise, where were no significant differences between riffles when the channels were combined. On a per riffle basis, only riffle 4 showed significance, with control (C) > Test (T) for total length; T > C for total weight and T > C for condition factor ($p \leq .05$). Control fry from riffle 4 averaged longer than all others while riffle 1 fry were next to the smallest.

In fall 1978 tests, green embryo survival was significantly higher in the control versus test channel ($p = .05$) while eyed embryo survival differences were not significant (Table 11). Overall average green embryo survival was 68.4% (range, 33-88.4) for the control and 50.1% (range, 27-97.5) for the test (Table 11). In all riffles except number

Table 10. Steelhead alevin quality evaluated by mean (range) . length, yolk weight, body weight, total weight and condition factor resulting from control (high flow) and test (low flow) flow conditions, Hayden Creek Channels, spring 1978.

Redd numbers	Channel	Flow	N	Mean length (mm)	Range length (mm)	Mean yolk weight (mg)	Range yolk weight (mg)	Mean body weight (mg)	Range body weight (mg)	Mean total weight (mg)	Range total weight (mg)	Dry mean condition factor KDW
1	Control[a/]	High[c/]	47	23.90 (1.13)	21.5-26.5	23.61 (36.61)	13.3-32.3	19.77 (5.73)	15.4-25.0	43.38 (52.43)	33.1-53.6	3.178
1	Test[b/]	Low[d/]	25	23.96 (.348)	22.5-25.0	21.60 (46.24)	13-31.5	20.40 (2.56)	18.2-23.5	42.00 (53.29)	32.5-54.2	3.053
2	C	H	25	24.54 (.723)	22-26	20.30 (33.64)	13.6-30.4	22.40 (6.25)	17.1-29.3	42.80 (51.84)	32.5-54.6	2.896
2	T	L	25	24.12 (.941)	22-26.5	25.30 (36.00)	15.3-33.3	20.60 (5.29)	17.2-24.8	45.90 (50.41)	34-55.4	3.271
3	C	H	38	24.96 (1.343)	21.5-27	24.04 (50.03)	12.2-36.5	20.66 (11.93)	9.0-26.7	44.70 (51.48)	32.7-53.9	2.875
3	T	L	36	24.00 (.800)	22-25.5	22.92 (43.66)	12.4-35.4	19.83 (5.28)	14.5-24.5	42.76 (50.36)	32.4-52.8	3.093
4	C	H	41	25.75 (.776)	23-27.5	20.85 (27.62)	12.6-29.6	23.56 (4.21)	17.8-27.7	44.50 (40.09)	34.8-53.0	2.60
4	T	L	25	23.22 (1.323)	20-25	29.20 (42.25)	15.7-40.4	19.00 (68.89)	11.4-31.7	48.30 (46.24)	35-61.9	3.858

[a/] C = Control

[b/] T = Test

[c/] H = High flow

[d/] L = Low flow

Table 11. Physical, hydraulic, and chemical parameters associated with green and eyed chinook egg survivals resulting from control (C) (high flow) and test (T) (low flow) flow conditions, Hayden Creek Channels, fall 1978.

Redd number	Channel	Percent sediment <0.84 mm	Geometric mean diameter (mm)	Water depth (cm)	Water velocity (cm/s) at 0.6 depth	Mean intragravel dissolved oxygen (mg/l)	Green eggs survival (%)			Eyed eggs survival (%)		
							Box 1	Box 2	$\bar{X}$	Box 1	Box 2	$\bar{X}$
1	C	0.53	34.46	12.19	13.72	7.72	78	88	83	98	100	99
2	C	0.32	34.29	9.14	12.19	7.65	75	85	80	100	99	99.5
3	C	0.13	41.95	6.10	24.38	7.80	91	86	88.5	99	100	99.5
Mean		0.33	36.90	9.14	16.76	7.72			83.8			99.3
1	T	1.86	33.82	6.09	0	2.83	98	97	97.5	100	97	98.5
2	T	0.80	35.92	0	0	7.88	87	90	88.5	98	97	97.5
3	T	0	34.32	0	0	8.03	73	82	77.5	99	98	98.5
Mean		0.89	34.69	2.03	0	6.25			87.8			98.2
4	C	--	--	9.14	19.81	7.65	90	85	87.5	97	99	98
5	C	7.1	12.96	6.10	13.72	7.75	74	70	72.0	98	95	96.5
6	C	7.3	11.81	7.62	15.24	7.58	71	82	76.5	99	100	99.5
Mean		7.2	12.39	7.62	16.26	7.66			78.67			98.0
4	T	3.1	12.61	3.04	0	8.02	54	11	32.5	94	99	96.5
5	T	8.1	9.61	1.52	0	8.33	99	65	82	99	96	97.5
6	T	4.1	13.86	0	0	8.23	44	10	27	35	99	67.0
Mean		5.1	12.03	1.52	0	8.19			47.17			87.0

Table 11. Continued.

Redd number	Channel	Percent sediment <0.84 mm	Geometric mean diameter (mm)	Water depth (cm)	Water velocity (cm/s) at 0.6 depth	Mean intragravel dissolved oxygen (mg/l)	Green egg survival (%)			Eyed egg survival (%)		
							Box 1	Box 2	X	Box 1	Box 2	X
7	C	9.4	7.69	10.66	10.66	8.20	73	54	63.5	97	98	97.5
8	C	8.0	8.02	7.62	9.14	8.15	80	85	82.5	97	94	95.5
9	C	8.6	8.80	9.14	10.66	8.05	52	35	43.5	97	98	97.5
Mean		8.7	8.17	9.14	10.15	8.13			63.17			96.83
7	T	9.6	7.71	6.10	0	9.17	29	50	35	98	96	97
8	T	7.1	6.29	0.76	0	8.77	52	15	33.5	96	95	95.5
9	T	6.1	10.45	3.05	0	8.80	62	0	31	94	96	95
Mean		7.4	8.15	3.30	0	8.91			33.17			95.83
10	C	14.0	7.38	7.62	7.62	8.07	75	55	65	100	96	98
11	C	13.3	6.56	3.05	4.57	8.30	11	55	33	97	97	97
12	C	9.8	6.84	6.10	9.14	8.22	41	51	46	100	97	98.5
Mean		12.4	6.93	5.59	7.11	8.20			48.0			97.83
10	T	13.2	8.93	1.52	0	9.35	53	27	40	99	98	98.5
11	T	17.6	5.22	0	0	9.33	21	37	29	98	100	99
12	T	13.2	6.55	1.52	0	9.03	31	24	27.5	99	100	99.5
Mean		14.7	6.90	1.01	0	9.24			32.17			99.0
Overall mean	C								68.42			98.0
	T								50.08			95.0

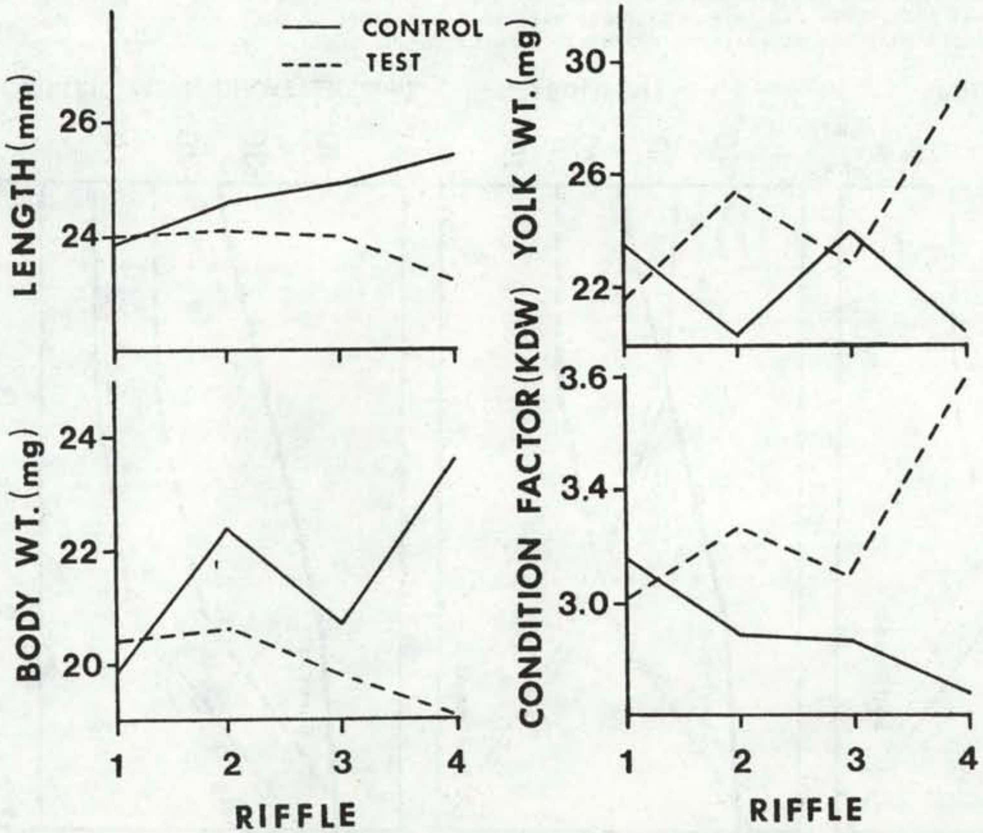


Figure 14. Mean total length, body weight, yolk weight and condition factor of steelhead alevins recovered from the four riffle areas within the control (high flow) and test (low flow) channels. Hayden Creek channels, spring 1978.

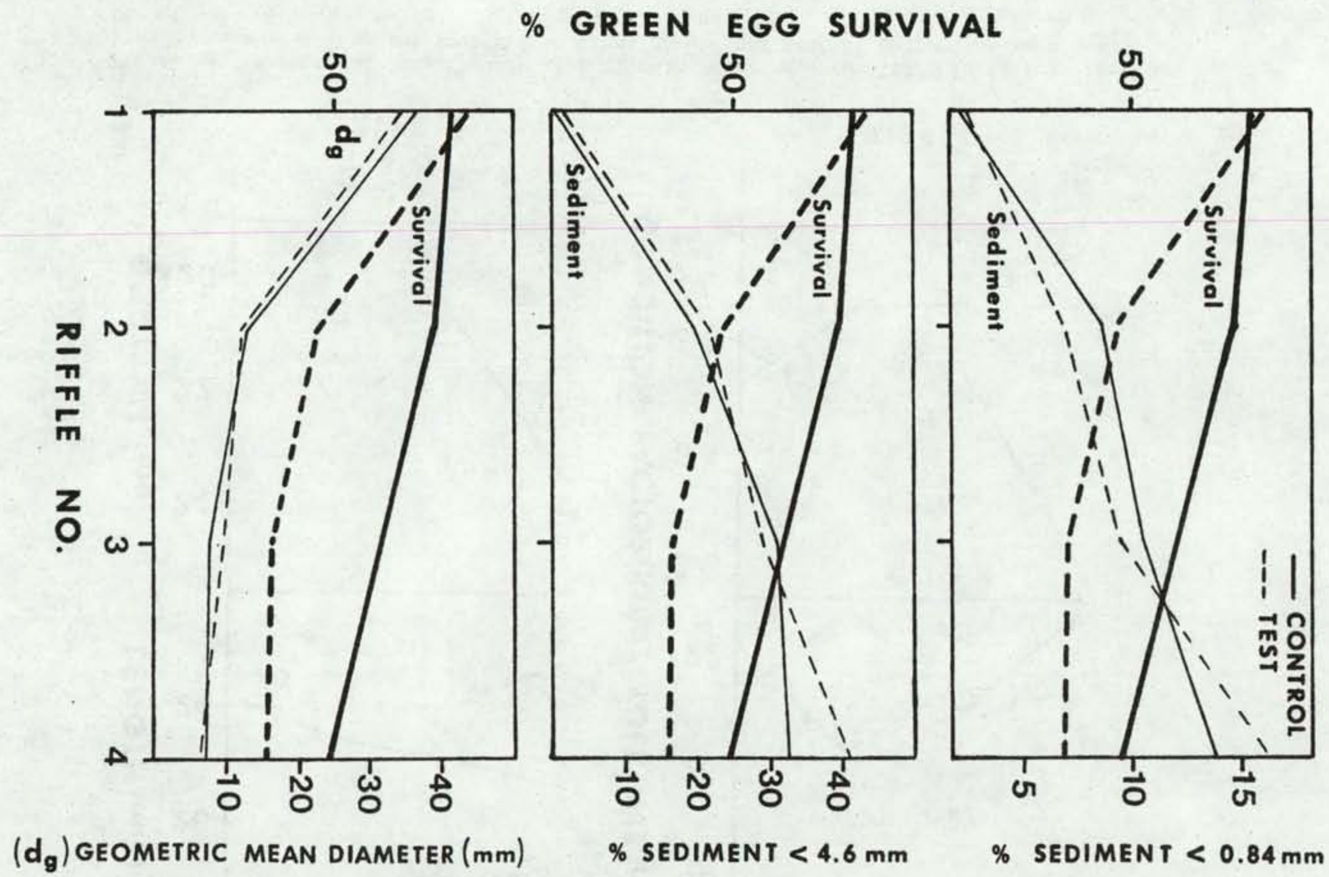


Figure 15. Average percent spring chinook green egg survival in the four riffle areas within the control (high flow) and test (low flow) channels, and associated levels of sediment < 0.84 mm (top) sediment < 4.6 mm (middle) and geometric mean diameters (bottom). Hayden Creek channels, fall 1978.

1, embryo survival was higher in the control versus test, even with approximately equal sediment levels and sizes (geometric mean diameter) (Figure 15; Table 2 Appendix I).

In evaluating embryo survival from a sediment standpoint, the greatest difference between control and test channels occurred at the level of 7% < .84 mm (Figure 16). This difference decreased as sediment level increased. Mean intragravel dissolved oxygen ranged from 7.7 to 8.2 mg/l for the control channel and from 6.25 to 9.24 mg/l for the test (Table 11). Control and test channel water depths and velocities over riffles averaged 7.87 cm and 12.5 cm/sec, and 1.97 cm and 0 cm/sec, respectively. With the exception of redds 10 and 11 in both channels, gravel permeability exceeded 5500 cm/hr. In these redds, permeability averaged 3116 cm/hr and intragravel velocity 19.5 cm/hr for the test and 2643 cm/hr and 24 cm/hr for the control channel.

Control channel alevins and fry were generally significantly longer and heavier than test channel fry, while alevin yolk weights from the test channel were significantly heavier than from the control (Tables 12 and 13; Figure 17). Test channel fry had condition factors and developmental indices which were significantly higher in a number of cases. This was not unexpected since there were few differences in total weight of fry between channels while length differences were common (C > T).

In conjunction with our fall 1978 tests, we investigated the impacts of adverse environmental conditions associated with low streamflow incubation. These tests were continued into January before egg survival assessment. Water and air temperatures decreased steadily throughout the incubation period with air temperatures remaining at or below 0 C by 9 November. When eggs were recovered, air temperature was -31 C. The low

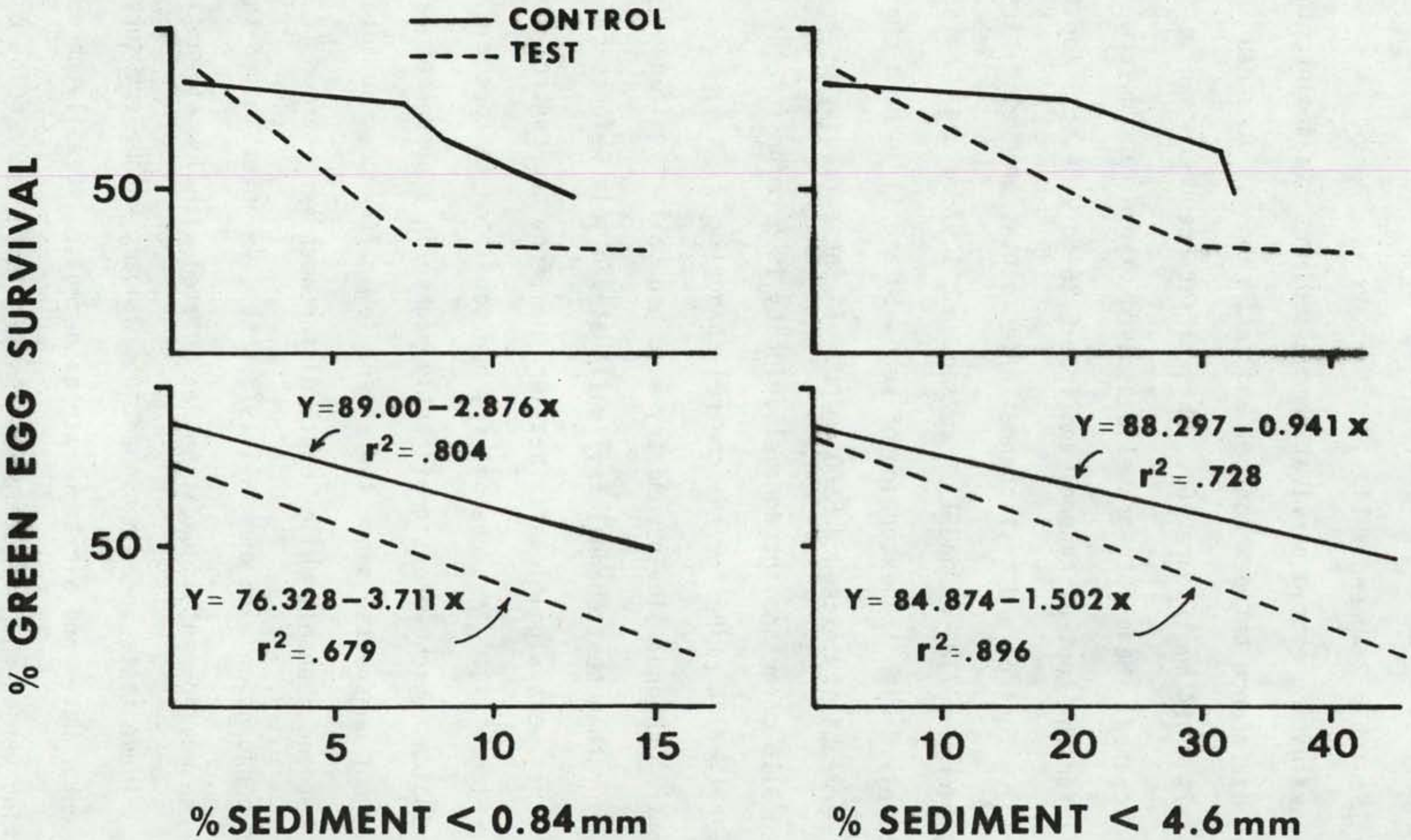


Figure 16. Relationship of average percent spring chinook salmon green egg survival to percent sediment < 0.84 mm and percent sediment < 4.6 mm in the control (high flow) and test (low flow) channels. Hayden Creek channels, fall 1978.

Table 12. Comparison of mean and range chinook buttonup fry quality variables between control (high flow) and test (low flow) channel for the four riffle areas, Hayden Creek Channels, fall 1978.

Variable	Riffle	Control		Test		Tukey's W Procedure
		Mean	Range	Mean	Range	significance ($p \leq 0.05$)
Total length (mm)	1	36.321	33-83.5	35.369	33.5-37.5	C > T
	2	35.306	30.5-38	34.327	30.5-38	C > T
	3	34.740	30.5-37	34.164	30-37	C > T
	4	35.373	31.5-37.5	33.605	32-36.5	C > T
Fork length (mm)	1	35.038	33-38.5	34.109	32.5-36.5	C = T
	2	33.888	29.5-36	33.207	29.5-37	C > T
	3	33.352	30-36	33.182	29.5-35	C = T
	4	34.127	30.5-37	32.395	30-35	C > T
Total dry weight (g)	1	68.755	41.6-86.5	66.524	47.6-81.7	C = T
	2	62.828	40-84.6	65.027	38.2-84.3	C = T
	3	63.811	40.5-83.3	65.031	35.8-87.7	C = T
	4	62.291	36.3-82.0	57.873	33.1-91.7	C > T
Total wet[a/] weight (mg)	1	408.223	280.34-491.79	397.718	308.60-469.18	C = T
	2	380.315	272.81-482.84	390.671	264.33-481.43	C = T
	3	384.942	275.16-476.72	390.687	253.03-497.44	C = T
	4	377.786	255.38-470.60	356.981	240.32-516.28	C > T
Wet weight condition factor	1	0.948	.763-1.125	1.001	.844-1.190	T > C
	2	.974	.732-1.266	1.066	.906-1.387	T > C
	3	1.038	.768-1.524	1.064	.891-1.266	C = T
	4	.946	.794-1.175	1.077	.864-1.504	T > C
Dry weight condition factor	1	1.593	1.183-1.933	1.672	1.324-2.051	T > C
	2	1.603	1.118-2.142	1.770	1.428-2.380	T > C
	3	1.716	1.132-2.635	1.765	1.262-2.231	C = T
	4	1.553	1.138-1.997	1.751	1.288-2.529	T > C
Developmental index	1	5.756	5.130-6.247	5.838	5.323-6.315	C = T
	2	5.736	5.025-6.369	5.941	5.456-6.664	T > C
	3	5.868	5.035-6.874	5.936	5.215-6.560	C = T
	4	5.676	5.040-6.288	5.886	5.258-6.717	T > C

[a/] Computed from regression of total dry weight (X) on total wet weight (Y) using data from redd 3 (test flow); $Y = 84.44 + 4.709X$; $r^2 = .908$.

Table 13. Comparison of mean and range of chinook alevin quality variables between control (high flow) and test (low flow) channel for the four riffle areas, Hayden Creek Channels, fall 1978.

Variable	Riffle	Control		Test		Tukey's W Procedure
		Mean	Range	Mean	Range	significance ($p \leq 0.05$)
Total length (mm)	1	25.853	22-28	25.019	23-27	C = T
	2	25.849	21-28	24.114	20-27	C > T
	3	25.558	19-28	23.926	22-27	C > T
	4	25.632	21-28.5	22.666	19.5-24.5	C > T
Total dry weight (mg)	1	55.129	40.9-68.1	53.769	37.2-66.4	C = T
	2	53.351	39.1-64.5	54.206	43.6-69.9	C = T
	3	53.283	39.8-65.4	57.322	46.2-67.7	T > C
	4	54.454	42.3-68.4	55.166	35.4-61.8	C = T
Yolk weight (mg)	1	34.994	20.4-51.9	37.311	20.6-52.3	C = T
	2	32.782	17.7-49.6	39.633	31.2-56.0	T > C
	3	32.906	19.1-43.3	41.952	31.5-53.7	T > C
	4	38.689	27.4-55.4	41.347	28-45.8	C = T
Body weight (mg)	1	20.135	10.8-35.6	16.551	7.5-28.9	C = T
	2	20.568	12.6-30.3	14.572	9.6-20.7	C > T
	3	20.377	12-37.5	15.370	10.5-27.0	C > T
	4	15.765	8.8-28.9	13.820	7.4-19.4	C = T
Total wet weight (mg)[a]	1	263.828	218.2-339.5	246.293	202.0-306.7	C = T
	2	265.946	226.9-313.5	236.617	212.3-266.6	C > T
	3	265.010	224.0-348.7	240.519	216.7-297.4	C > T
	4	242.449	208.4-306.7	232.934	201.5-260.3	C = T
Wet weight condition factor	1	1.552	1.250-2.514	1.575	1.308-1.837	C = T
	2	1.572	1.221-2.545	1.664	1.349-2.179	C = T
	3	1.618	1.087-3.266	1.768	1.422-2.151	C = T
	4	1.463	1.133-2.424	2.044	1.603-2.788	T > C
Dry weight condition factor	1	3.255	2.392-5.672	3.452	2.207-4.832	C = T
	2	3.167	2.062-6.716	3.827	2.788-5.145	T > C
	3	3.266	2.209-6.429	4.232	3.123-6.179	T > C
	4	3.312	2.306-6.543	4.809	3.882-7.112	T > C
Developmental index	1	6.292	5.893-7.686	6.268	5.832-6.736	C = T
	2	6.325	5.794-7.470	6.334	5.841-7.079	C = T
	3	6.384	5.517-7.877	6.485	6.026-7.186	C = T
	4	6.083	5.531-7.369	6.754	6.229-7.467	T > C

[a] Computed from regression of body weight (X) on total wet weight (Y) using data from redd 3 (test flow); $Y = 165.32 + 4.891X$; $r^2 = .576$.

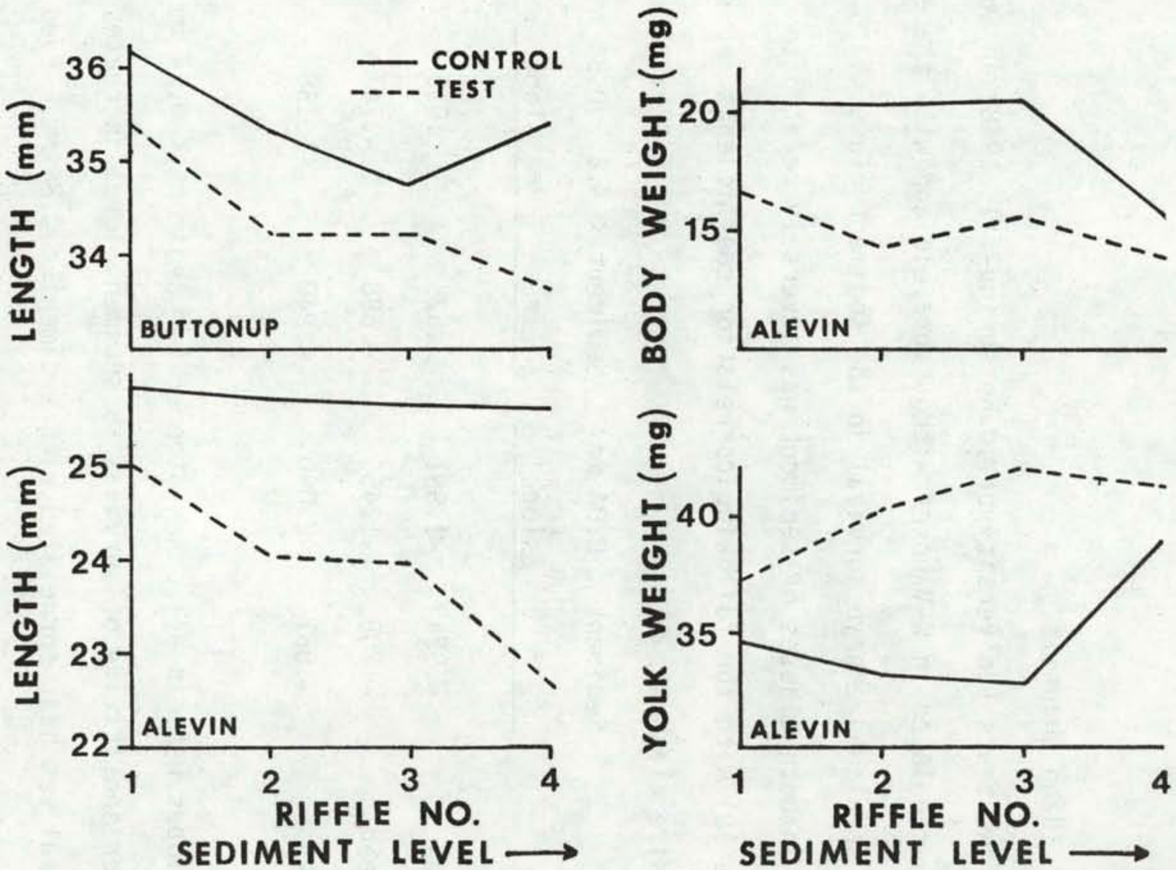


Figure 17. Mean total length of spring chinook salmon button up fry and alevins and mean body weight and yolk weight of spring chinook alevins recovered from the four riffle areas within the control (high flow) and test (low flow) channels. Hayden Creek channels, fall 1978.

flow within the test channel had allowed the freezing of the artificial redds while the flow in the control channel had effectively insulated them. Sheet ice was present in all pool areas of the test channel while no ice was present in control pools. We found gross fry mortality in riffles with frozen substrate with many boxes over one-half full of intragravel ice.

University of Idaho Channels

For the two tests (University of Idaho spring-fall 1978) in which the embryos were placed in W-V boxes without gravel, and with the exception of eyed steelhead embryo survival in the sediment class < 4.6 > 0.84 mm, survival in both classes of sediment was inversely related to percent level (Figure 18) with the following correlation coefficients and slopes for the two size classes:

	Sediment < 0.84 mm		Sediment < 4.6 > 0.84 mm	
	r	slope	r	slope
Eyed steelhead	-.924	-1.991	.525	.016
Green steelhead	-.809	-1.459	-.698	-.743
Green chinook	-.861	-2.090	-.940	-1.158

Regression slopes were in all cases steeper for sediment < 0.84 mm indicating greater sensitivity of survival to sediment level increase. Embryo survival was best correlated with sediment < 0.84 mm. Eyed steelhead embryo survival was essentially unaffected by the different levels of sediment < 4.6 > 0.84 mm. Even with sediment levels of this mix as high as 50%, green steelhead embryo survival averaged higher than 50% while green chinook survival averaged approximately 15%. Comparable

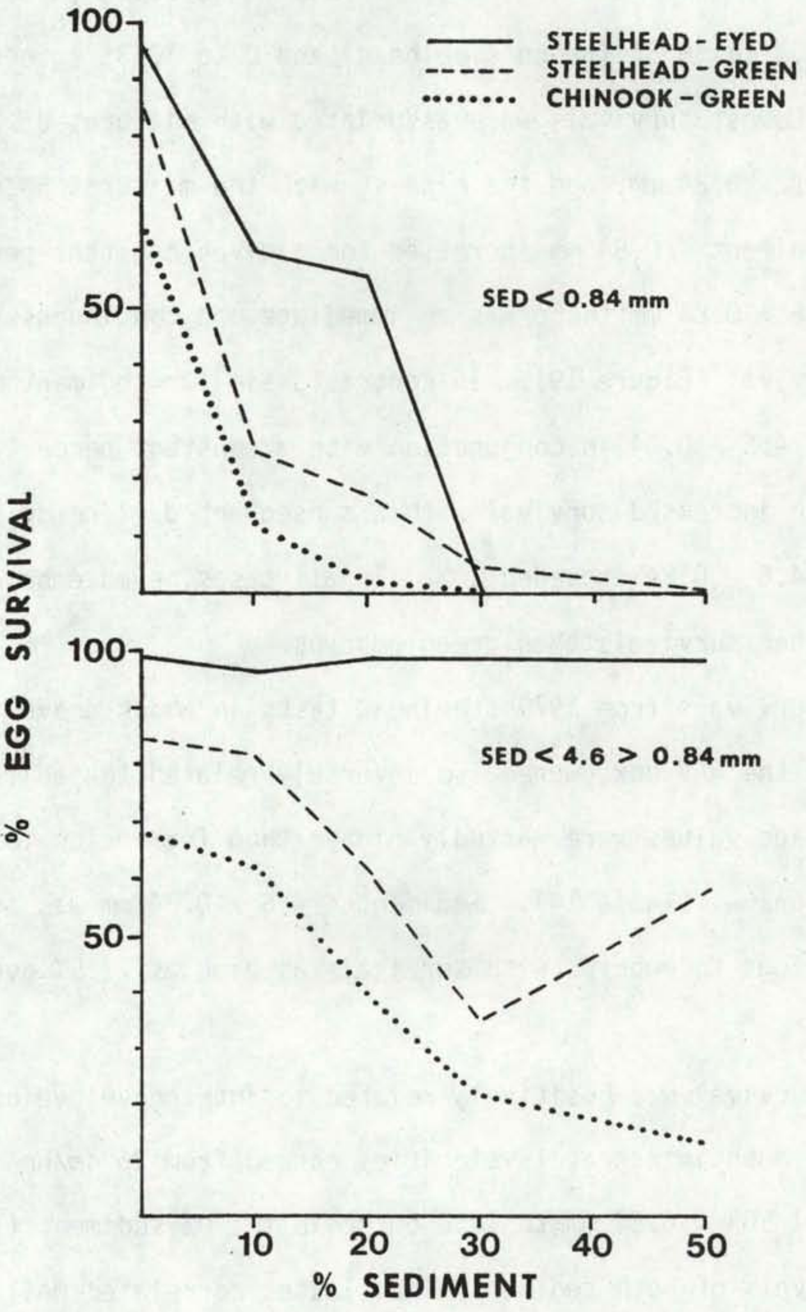


Figure 18. Relationship of percent green and eyed steelhead trout and green chinook salmon egg survival to sediment < 0.84 mm and sediment < 4.6 > 0.84 for conditions of no surface flow. University of Idaho incubation channels, spring-fall 1978.

levels of sediment < 0.84 mm resulted in 0% survival for both steelhead and chinook embryos.

Embryo survivals resulting from the chambers containing various combinations of each size class ranged from 24.0 to 97.5% (eyed steelhead); 1.3 to 56.5% (green steelhead) and 0 to 33.3% (green chinook) (Table 14). Lowest survivals were associated with mixtures of 20% < 4.6 > 0.84 and 30% < 0.84 mm, and the highest with the mixtures 5% < 0.84 mm. As percent sediment < 0.84 mm increased for a given constant percent material < 4.6 > 0.84 mm there was an immediate and continuous reduction in embryo survival (Figure 19). In contrast, similar sediment increases of material < 4.6 > 0.84 in conjunction with a constant percentage < 0.84 mm resulted in increased survival with a subsequent decline in survival as percent < 4.6 > 0.84 exceeded 20%. In all cases, eyed embryos exhibited higher survivals than green embryos.

Embryo survivals from 1979 steelhead tests in which gravel was placed within the W-V box, were also inversely related to sediment level, although average values were markedly higher than from prior tests utilizing no gravel (Table 14). Sediment < 4.6 > 0.84 mm was again the least deleterious to embryos with survivals as high as 77.5% even in the 50% level.

Embryo survival was positively related to intragravel velocity (Figure 20). Mean intragravel velocities ranged from 36 cm/hr in the sediment level 50% < 0.84 mm to 1550 cm/hr in the 0% sediment (Table 14). Percentage levels of both sediment size classes correlated well with intragravel velocity; r = -.946 (sediment < 4.6 > 0.84 mm). Average intragravel velocities were slightly higher in association with the size

Table 14. Average (percent) survival of green and eyed steelhead eggs and green chinook eggs resulting from 16 sediment levels with surface flow, University of Idaho incubation channels, spring-fall 1978, spring 1979.

Sediment level	Average flow (ml/sec)	Average intragravel velocity (cm/hr)	Steelhead No surface flow (5/14/78 Average % Surv. (green)	Average % surv. (eye)	Chinook No surface flow (10/22/78) Average % surv. (green)	Steelhead (with gravel) Average % (6/14/79) surv. (green)
0	210	1550	85.7	97.0	67.2	93.5
5% < 4.6 > 0.84; 5% < 0.84	115	850	56.5	97.5	33.3	89.0
10% < 4.6 > 0.84; 10% < 0.84	103	757	47.3	90.0	25.8	89.5
10% < 4.6 > 0.84; 20% < 0.84	83	610	14.3	86.0	6.8	46.2
20% < 4.6 > 0.84; 10% < 0.84	32	446	48.6	94.3	37.2	90.7
20% < 4.6 > 0.84; 30% < 0.84	5	37	1.3	24.0	0	33.2
30% < 4.6 > 0.84; 20% < 0.84	8	60	8.3	50.5	0	51.5
40% < 4.6 > 0.84; 10% < 0.84	15	107	15.0	79.0	3.66	64.0
10% < 4.6 > 0.84	117	862	84.8	97.3	63.3	89.2
20% < 4.6 > 0.84	130	962	63.0	98.5	34.3	94.3
30% < 4.6 > 0.84	38	277	36.5	98.0	23.0	86.2
50% < 4.6 > 0.84	16	118	58.5	97.8	14.6	77.5
10% < 0.84	118	872	23.2	60.0	11.6	81.5
20% < 0.84	143	1054	16.0	57.3	4.2	75.2
30% < 0.84	75	467	4.5	2.8	0	64.0
50% < 0.84	5	36	0	0	0	0
Control (Heath stack)	112		91.8	98.5	79.5	--

a/ Based on a cross-sectional area of 487.68 cm^2.

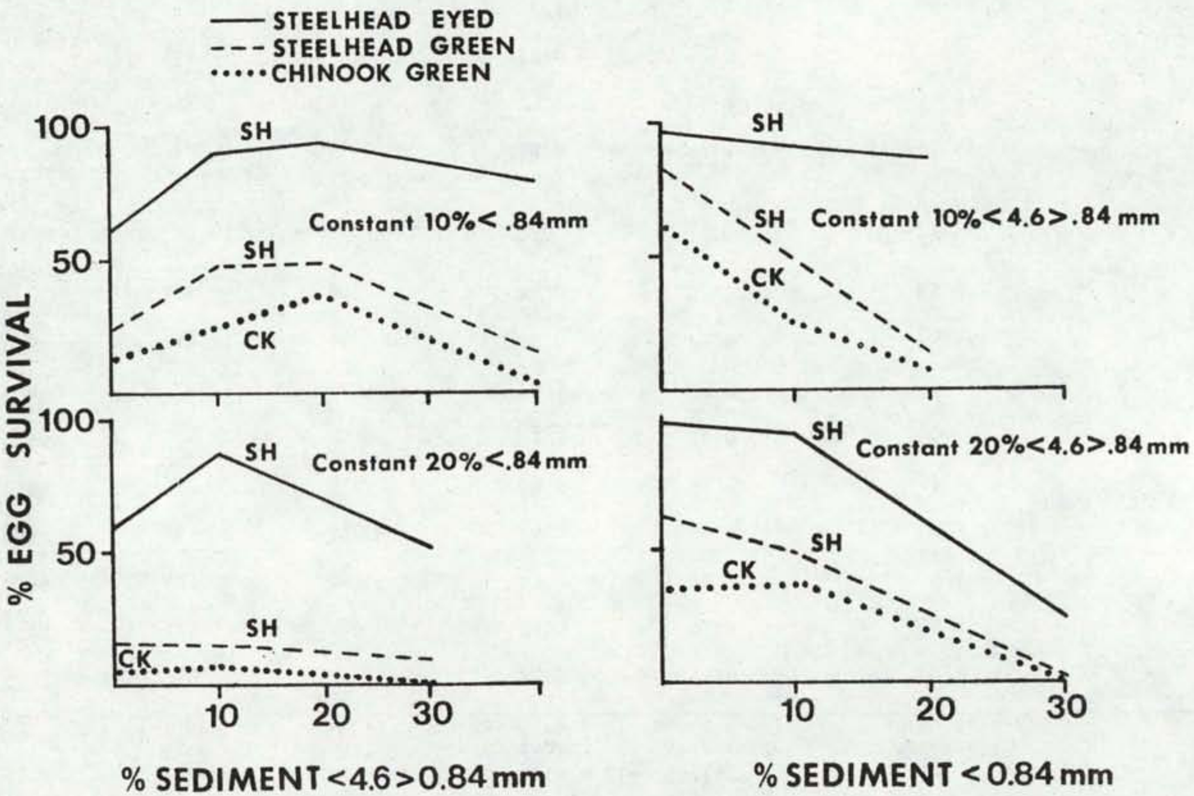


Figure 19. Relationship of green steelhead trout and chinook salmon egg survival to combinations of sediment < 4.6 > 0.84 mm and sediment < 0.84 mm. Egg survival on the left resulted from the addition of sediment < 4.6 > 0.84 mm to constant levels of sediment < 0.84 mm, on the right, from the addition of sediment < 0.84 mm to constant levels of sediment < 4.6 > 0.84 mm. University of Idaho incubation channels, spring-fall 1978.

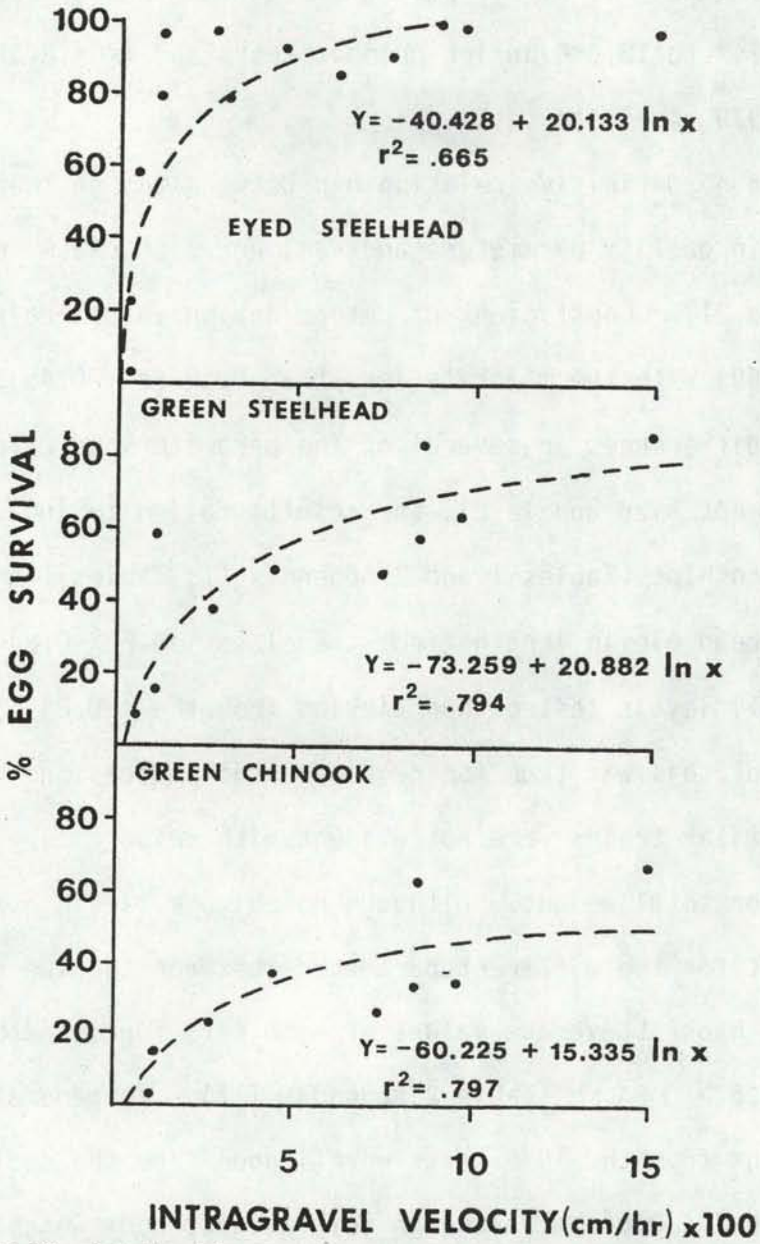


Figure 20. Relationship of green and eyed steelhead trout and green chinook salmon to intragravel velocity. University of Idaho incubation channels, spring-fall 1978.

class < 0.84 mm. This occurred because of the settling out of material < 0.84 mm thereby increasing permeability in the overlying gravel.

Dissolved oxygens during tests ranged from 6.2 to 7.7 mg/l. Water temperature ranged from 5.7 to 14.8 C during the spring 1978 steelhead tests; from 7.2 to 18.3 C during chinook tests and from 8.3 to 10.5 C during the 1979 steelhead tests.

We found no definitive relationship between any of the steelhead or chinook alevin quality parameters and sediment size class or sediment level (Figure 21). Coefficient of determination values never exceeded 0.47 (r = 0.69) with the majority less than 0.20 (r = 0.45). Although significant differences in several of the parameters were found with respect to sediment size and level, the results failed to indicate any specific relationships (Tables 1 and 2 Appendix II, Tables 1 and 2 Appendix III). Steelhead alevin lengths from the class < 4.6 > 0.84 mm averaged longer for all levels tested than alevins from the < 0.84 class, while the reverse of this was true for developmental indices and both condition factors. Similar trends were not evident with respect to yolk weight, body weight or total weight. Although no chinook alevin quality trends were apparent for the different parameters between the two sediment classes, the highest average values of each were found in the class of sediment < 4.6 > 0.84 mm (Table 2 Appendix III). In general, steelhead alevin lengths from the 1979 tests were longer from the sediment class < 4.6 > 0.84 than < 0.84 mm, although yolk weight, body weight, total weight, and condition factors tended to be higher in the latter (Table 1 Appendix III). The longest average lengths were found in the combination of sediment mixes. In the 1978 steelhead and chinook tests, Heath stack incubator produced alevins exhibited mean lengths, yolk weights, body

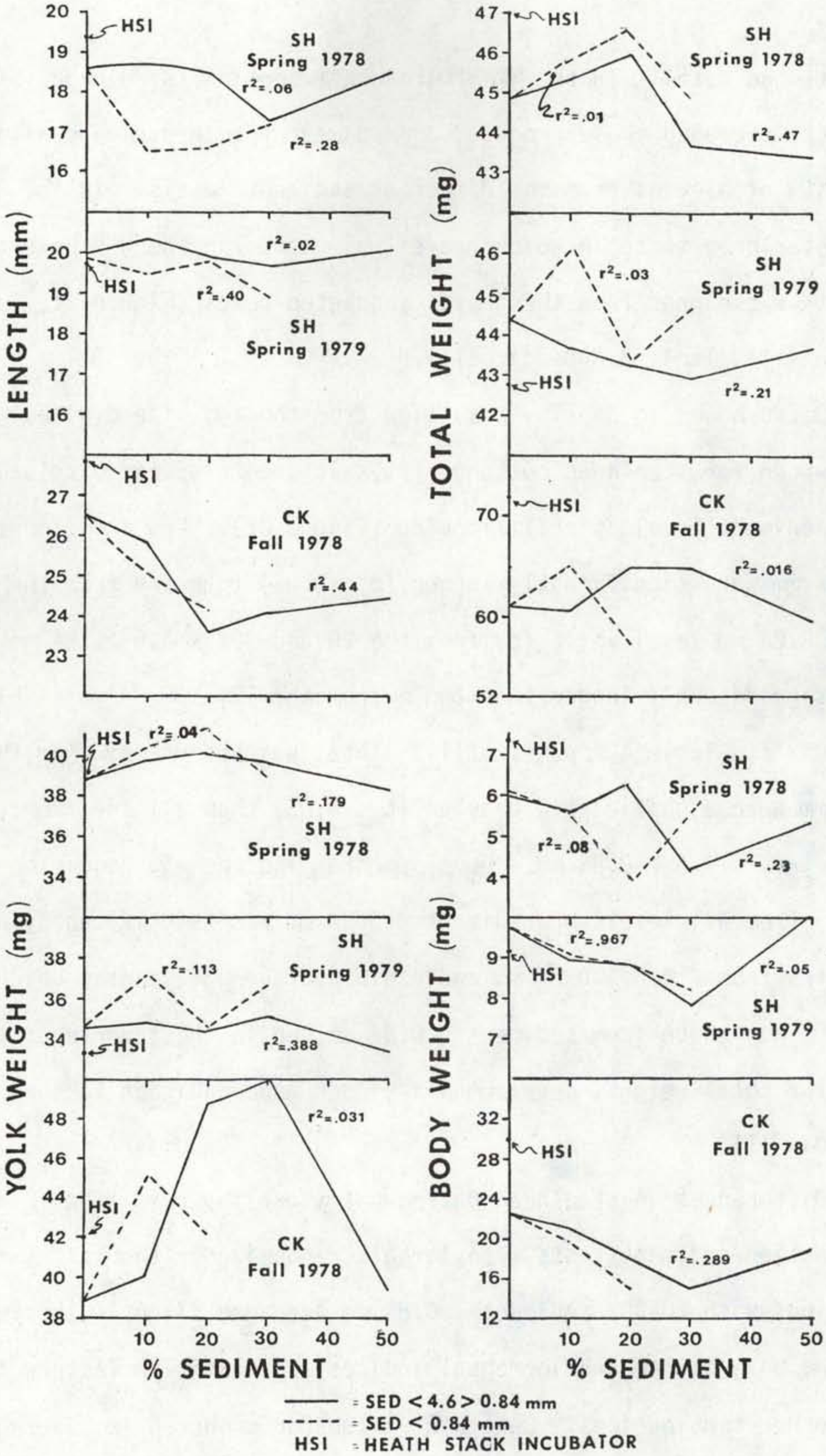


Figure 21. Mean total length, yolk weight, total dry weight and body weight of steelhead trout and spring chinook salmon alevins resulting from egg incubations in levels of sediment < 4.6 > 0.84 mm, sediment < 0.84 mm and in Heath stack incubators. University of Idaho incubation channels, spring-fall 1978.

weights and total weights which with one exception (steelhead yolk weights) exceeded those produced in sediment free gravel and also the majority of alevins from the different sediment levels. In the spring 1979 steelhead tests in which gravel was placed in the W-V boxes, alevin quality was higher from the gravel incubated boxes (Figure 21, Table 3 Appendix II, Table 3 Appendix III).

Differences in quality resulting from the two size classes were more pronounced for steelhead buttonup fry, although a specific relationship with sediment level is still lacking (Figure 22). Fry from the 10% < 4.6 > 0.84 mm were significantly longer ($p \leq 0.05$) than fry from the 10 and 20% < 0.84 mm level while fry from the 20 and 30% < 4.6 > .84 mm level were significantly longer than those from the 10% < 0.84 mm (Table 4 Appendix II, Table 4 Appendix III). Total weights of fry from the 10% < 0.84 mm were significantly heavier ($p \leq 0.05$) than all fry from the sediment class < 4.6 > 0.84 mm. Developmental indices and condition factors of fry from all levels of sediment < 0.84 mm were significantly higher than fry from < 4.6 > 0.84 mm and exhibited average lengths which were longer than those from sediment < 0.84 mm, while the reverse of this was true for total weight, developmental index and condition factors (Table 4 Appendix III).

Differences in steelhead buttonup fry quality resulting from the combination sediment tests were largely randomized although fry from combinations with 20-30% sediment < 0.84 mm averaged slightly shorter, heavier and with higher developmental indices and condition factors than fry from other combinations. Length of incubator produced fry averaged shorter than fry from nine of the sediment mixes while average weights

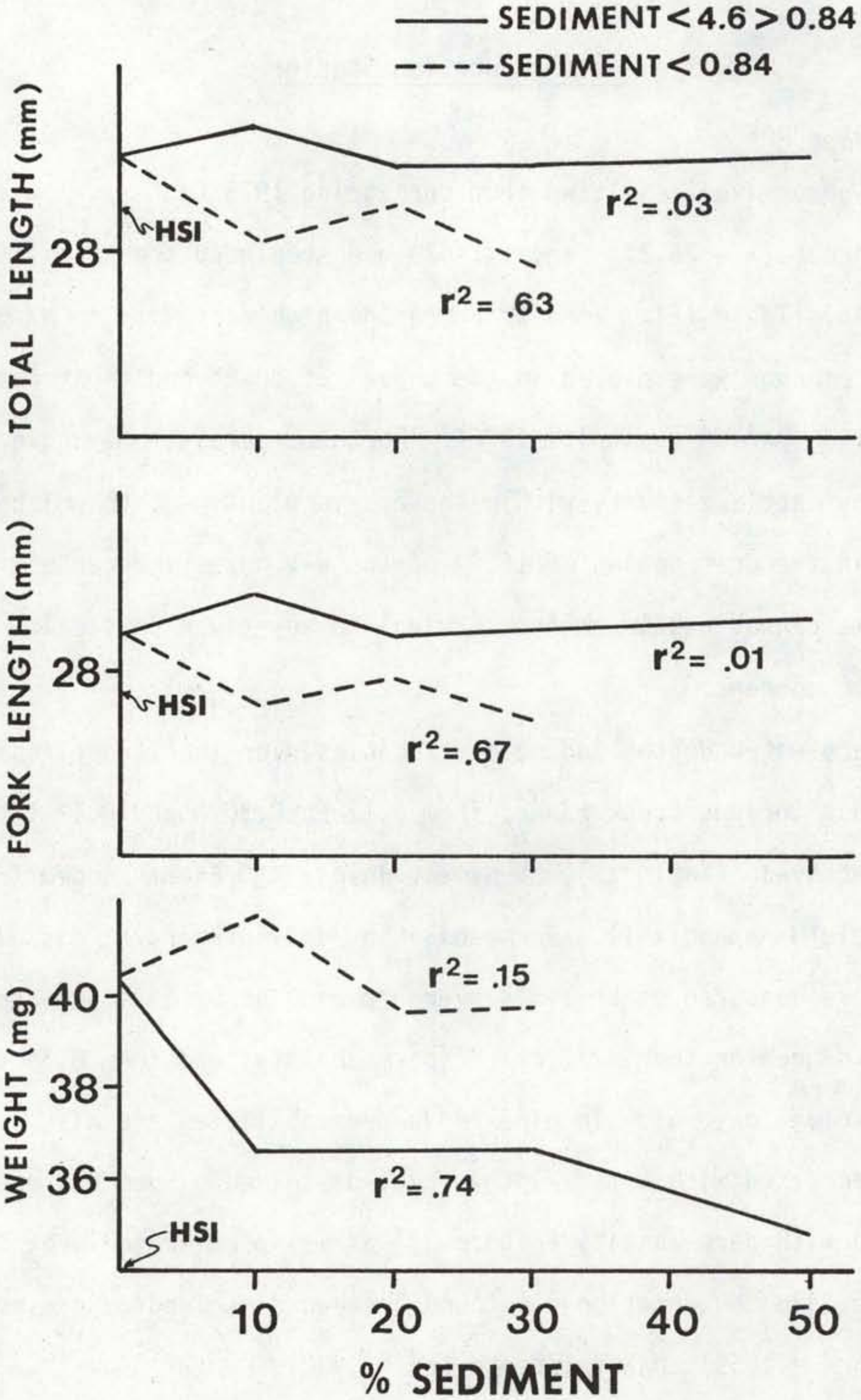


Figure 22. Mean total length, fork length and total dry weight of steelhead trout button-up fry resulting from egg incubations in levels of sediment < 4.6 > 0.84 mm, sediment < 0.84 mm and Heath stack incubators. University of Idaho incubation channels, spring 1978.

(dry and wets) were significantly lighter ($p \leq 0.05$) than all mixtures (Table 4 Apppendix II, Table 4 Appendix III).

Field Incubation Studies

Big Springs Creek

Embryo survival resulting from our spring 1978 test was low for both cutthroat ($\overline{X}$ - 26.1%; range, 1-67) and steelhead trout (X = 8.4%; range, 0-46) (Table 15). We attributed the high mortality to handling, since the embryos were placed in the gravel at or beyond the recommended 48 h handling period (Leitritz 1976). Further mortality may have been imparted by cattle activity within the embryo planting site which resulted in the destruction of 16.7% of the W-V boxes. Because of these problems we cannot equate embryo survival to any given physical or hydraulic component.

Surface water depths and mean velocities over the 16 artificial redds in Big Springs Creek ranged from 0.11 to 0.30 m and 0.12 to 0.56 mps, respectively (Table 15). Sediment levels < 0.84 mm ranged from 0 to 28.8% (Table 3 Appendix I). Permeabilities and intragravel dissolved oxygens were measured eight times over a period of 57 days and ranged from 260 to greater than 6270 cm/hr (permeability) and from 3.55 to 9.30 mg/1 (dissolved oxygen). In nine redds permeabilities and dissolved oxygens decreased with time. Intragravel dissolved oxygen was positively correlated with permeability (Figure 23) as was percent sediment < 0.84 mm (Figure 24). No relation was found between dissolved oxygen and water velocity (r^2 = .059) or water depth (r^2 = .232).

For our fall 1978 tests, survival of fertilized green chinook eggs ranged from 39.5 to 100% while eyed egg survival ranged from 99.5 to 100%

Table 15. Physical, chemical, and hydraulic characteristics of 16 artificial redds constructed in Big Springs Creek, spring 1978.

Redd number	Water depth (m)	Average velocity (mps)	Average sediment 0.85 (mm)	Permeability cm/hr and (dissolved oxygen mg/1) for dates indicated 5-29	6-9	6-12	6-19	6-27	7-10	7-17	7-24	Average $\overline{X}$	(green cutthroat) Percent Egg Survival Box #1	Box #2	(green steelhead) Percent Egg Survival Box #1	Box #2
1	0.24	0.35	9.1	6460[a] (8.50)	3654 (7.3)	2160 (4.65)	1176[b]	1092 (5.3)	700 (6.4)	1235 (7.0)	1620 (7.95)	2262 (6.7)	c/	c/	14.0	33.0
2	0.12	0.31	18.1	1330 (5.55)	6090[a] (5.5)	3240 (5.8)	4620[b]	5040[a] (7.1)	5250[a] (8.4)	4370 (8.7)	5400[a] (8.8)	4417 (7.1)	c/	c/	46.0	c/
3	0.27	0.12	8.3	4560 (6.8)	2262 (7.45)	5940[a] (8.0)	5544[ab]	5040[a] (7.6)	5775[a] (8.6)	6270[a] (8.85)	5400[a] (9.2)	5098 (8.1)	20	33	1	5
4	0.30	0.37	9.1	5940 (8.0)	5742[a] (7.99)	5400[a] (7.8)	5040[ab]	6720[a] (7.7)	5775[a] (8.5)	6270[a] (8.8)	5400[a] (9.1)	5660 (8.3)	67	16	3	4
5	0.30	0.39	12.8	2185 (7.1)	783 (6.48)	738 (6.2)	260[b]	462 (6.1)	613 (3.55)	855 (8.2)	2160 (8.65)	1007 (6.6)	39	33	7	3
6	0.20	0.48	15.7	4465 (8.0)	2871 (7.69)	1170 (4.75)	462[b]	294 (6.3)	820 (6.65)	1235 (6.8)	2160 (8.4)	1684 (6.9)	36	26	0	8
7	0.21	0.51	16.6	2470 (8.0)	1218 (7.65)	5400[a] (7.5)	1512[b]	1092 (7.9)	1575 (8.25)	3325 (8.4)	1890 (8.75)	2310 (8.1)	15	1	0	6
8	0.17	0.17	16.0	4370 (7.85)	1827 (6.75)	6120[a] (8.05)	5544[ab]	4620 (7.9)	5775[a] (8.3)	5700[a] (8.75)	5400[a] (8.95)	4919 (8.1)	d/	20[e]	4[e]	d/
9	0.15	0.13	17.4	3420 (5.9)	1827 (6.0)	1620 (4.9)	756[b]	756 (4.75)	1225 (4.70)	779 (5.40)	1350 (5.50)	1466 (5.3)	d/	24[e]	1	5
10	0.23	0.32	12.0	3420 (8.0)	3045 (6.30)	3240 (6.9)	2940[b]	1512 (5.1)	2188 (5.6)	6270[a] (8.8)	5310[a] (9.15)	3490 (7.1)	8	30	0	0
11	0.11	0.17	13.5	4370 (7.65)	2001 (7.30)	2520 (5.6)	5880[ab]	5040[a] (8.1)	5250[a] (8.2)	5700[a] (8.7)	5400[a] (8.95)	4520 (7.8)	23	16	11	6
12	0.21	0.54	28.7	2185 (8.05)	1218 (6.35)	2340 (5.65)	504[b]	1176 (4.3)	1313 (4.0)	1995 (4.15)	1800 (5.30)	1566 (5.4)	27	21	4	7
13	0.21	0.56	10.2	5605[a] (8.1)	1566 (7.3)	3600 (5.75)	2100[b]	2016 (6.4)	3500 (7.15)	3420 (4.6)	1890 (6.05)	2962 (6.5)	23	17	0	0
14	0.18	0.44	22.1	5700[a] (8.15)	2001 (8.0)	2070 (7.4)	1680[b]	2184 (6.6)	2188 (8.1)	2470 (8.0)	3150 (8.8)	2680 (7.9)	24	16	0	10
15	0.18	0.21	28.8	5700[a] (8.10)	5220[a] (8.2)	5940[a] (7.8)	3528[b]	4368 (7.85)	4550 (8.4)	6650[a] (8.75)	3240 (9.3)	4899 (8.3)	47	28	17	44
Control	0.15	0.27	0	6650[a] (8.2)	5916[a] (8.3)	5400[a] (8.0)	5040[ab]	5544[a] (7.5)	5775[a] (8.65)	6270[a] (8.9)	3240 (9.10)	5479 (8.4)	29	40	4	8
Mean $\overline{X}$													29.83	22.92	7.0	8.50
Overall $\overline{X}$													26.11		8.36	

a/ Permeability was greater than value given.

b/ Not measured.

c/ Eggs decomposed.

d/ Destroyed by cattle.

e/ W-V box damaged by cattle; values based on eggs remaining.

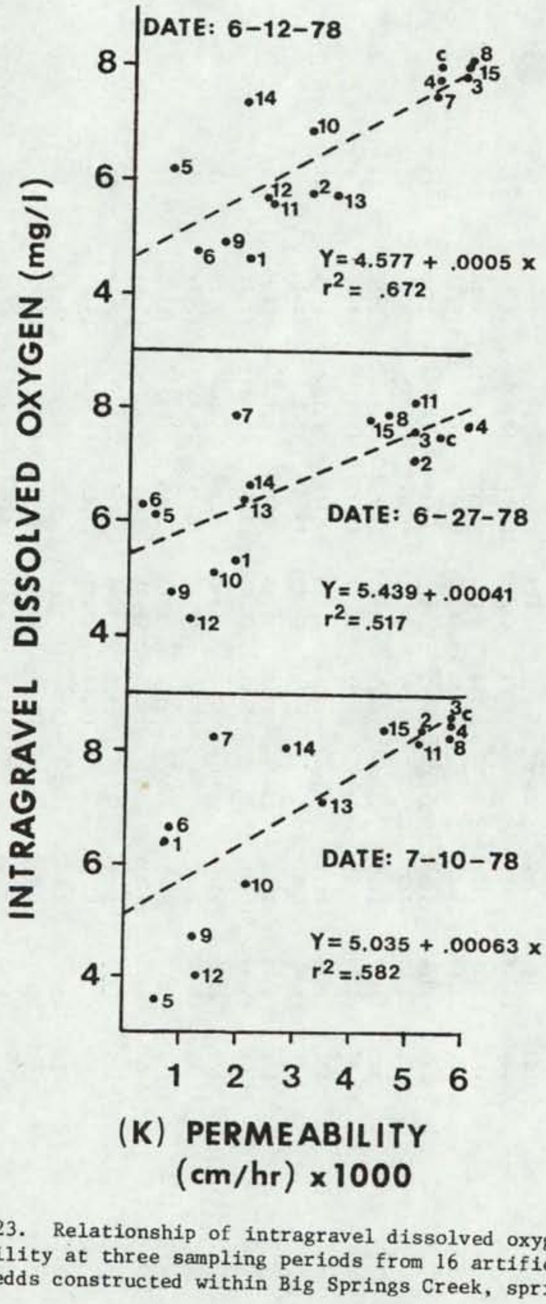


Figure 23. Relationship of intragravel dissolved oxygen to gravel permeability at three sampling periods from 16 artificial steelhead trout redds constructed within Big Springs Creek, spring 1978.

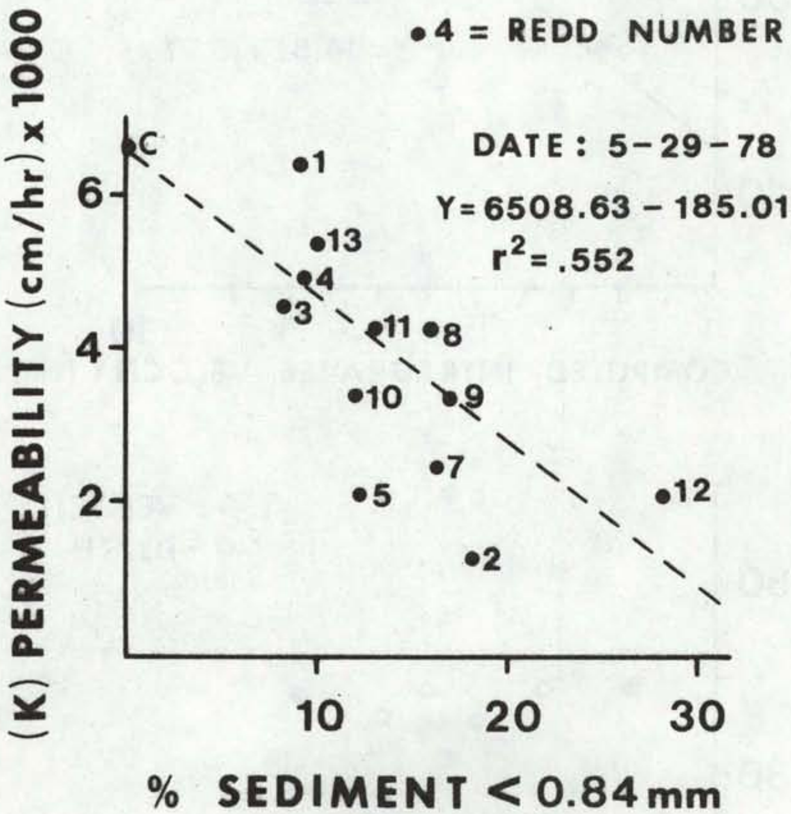


Figure 24. Relationship of gravel permeability to percentage sediment < 0.84 mm from within 14 artificial steelhead trout redds within Big Springs Creek, May 29, 1978.

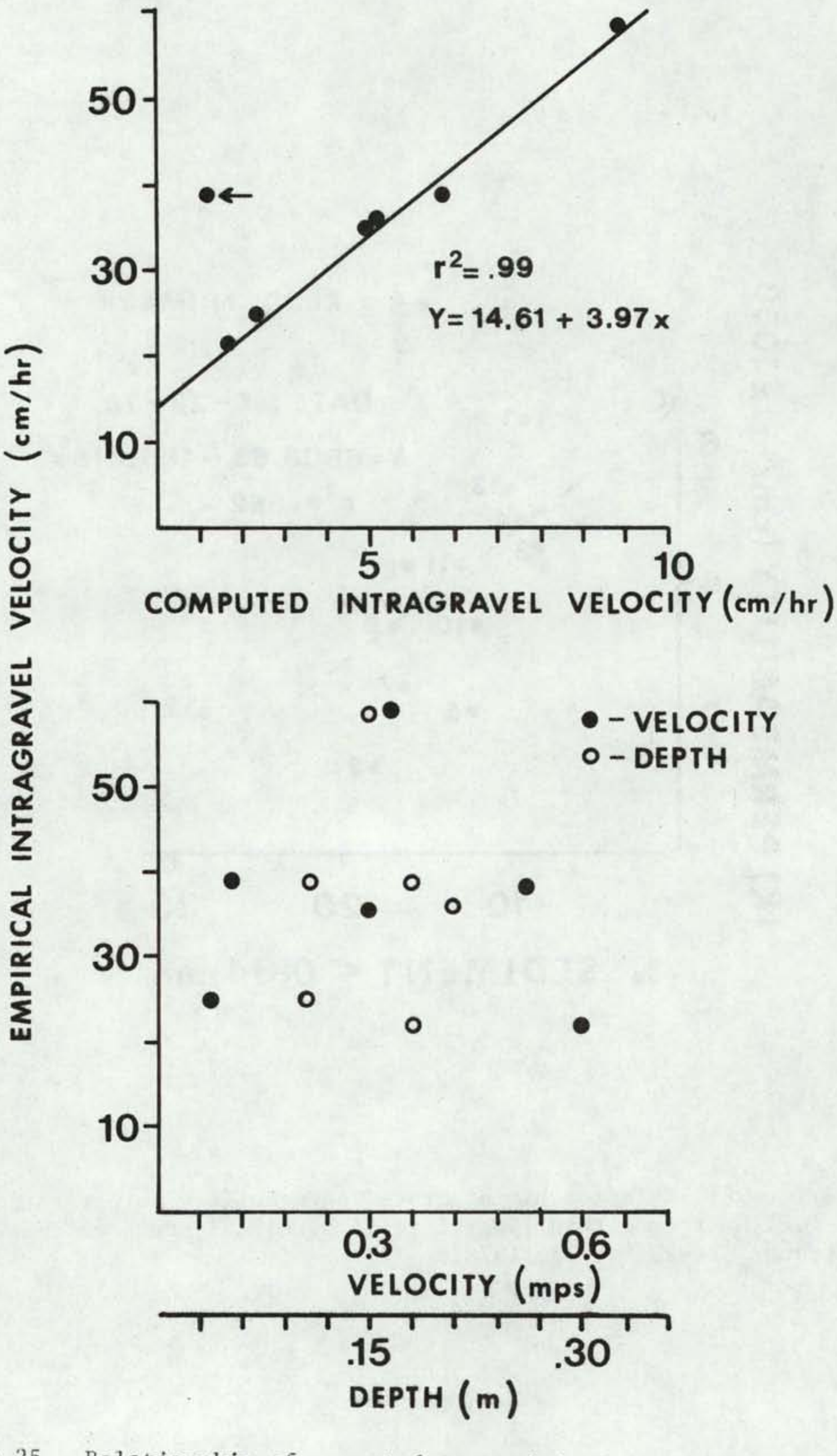


Figure 25. Relationship of computed to empirical intragravel velocity, and water velocity and depth over redds to empirical intragravel velocity for 6 artificial chinook redds in Big Springs Creek, Idaho, fall 1978. Arrow denotes measurement not used in regression calculation.

(Table 16). Cattle activity in the embryo planting sites resulted in damage to 66.1% of the W-V boxes and 59 percent of the standpipes. This precluded meaningful comparisons between survival and parameters monitored.

Permeability and intragravel oxygen values ranged from 555 to > 5487 cm/hr and 2.0 to 9.0 mg/1, respectively; no correlation was found between them (r^2 = .07). Sediment levels < 0.84 mm ranged from 8.2-27.6 percent (Table 4 Appendix I). Measurements of intragravel velocity were taken for six of the standpipes not impacted by the cattle activity. Intragravel velocities were computed using the theoretical equation of Bovee and Cochnauer (1977). This allowed us to make comparisons between the computed and empirical values and test the reliability of the equation. Although we only had six empirical values for comparison, computed values were underestimated by an average of 88% (Table 17). We did find a very good correlation between the computed and empirical values (r^2 = .99) (Figure 25). Changes in computed intragravel velocities may be good indicators of the relative change in velocity occurring within the redd. We found no correlation between intragravel velocity and water depth or mean velocity over the redd, however, water surface slope was at least marginally related (r^2_{slope} = .44).

Bear Valley Creek

Percentage embryo survival to hatching was high for all artificial redds ($\overline{X}$ = 98.4; range, 88.7-100) while fry survival was somewhat less ($\overline{X}$ = 73.8; range, 0-100) (Table 18). The reduction in fry survival was affected in four of the 132 artifical redds. Redds 6 and 7 had excessive accumulations of interstitial fine sediment in the W-V boxes causing

Table 16. Physical, chemical and hydraulic characteristics and percent egg survival to hatching of 17 artificial chinook redds constructed in Big Springs Creek, fall 1978.

Redd number	Water depth (m)	Average velocity (mps)	Percent sediment 0.85	Permeability cm/hr and (dissolved oxygen mg/l) for dates indicated 9-27	10-4	10-13	10-30	Percent[a] survival green	Percent survival eye
1	0.26	0.66	9.4	[b] (7.15)	[b] (8.30)	[b]	[b]	39.5	100
2	0.09	0.24	13.4	1203 (5.8)	1209 (5.75)	1267 (6.6)	1792 (5.5)	79.0	100
3	0.15	0.56	18.6	[b] (7.45)	[b]	[b]	[b]	55.0[c]	[d]
4	0.12	0.24	13.0	555 (2.70)	[b] (2.0)	[b] (3.5)	840 (3.40)	low[e]	low[e]
5	0.27	0.44	11.4	[b] (7.0)	[b]	[b] (5.90)	[b] (6.3)	66.5	100[c]
6	0.30	0.30	14.1	[b] (7.05)	[b] (7.20)	[b]	[b]	100[c]	100[c]
7	0.27	0.29	18.1	[b] (7.30)	[b]	[b]	[b]	100[c]	100
8	0.21	0.55	20.5	[b] (5.80)	[b]	[b]	[b]	100[c]	100[c]
9	0.18	0.58	23.0	[b] (5.55)	1953 (7.3)	[b] (9.0)	2240 (9.0)	low[e]	[d] high fry mort.
10	0.12	0.34	18.3	[b] (7.05)	[b] (7.25)	[b] (8.70)	[b] (6.1)	[f]	[f]
11	0.12	0.14	14.7	3330 (7.3)	4836 (6.35)	5070 (8.3)	2352 (8.3)	[d]	[d]
12	0.27	0.49	11.6	[b] (7.45)	[b]	[b]	[b]	69.0	99.5
13	0.20	0.17	8.2	3885 (6.4)	5487 (6.85)	4095 (6.70)	4928 (6.70)	93.5	100[c]
14	0.21	0.24	27.5	3330 (8.35)	3348 (8.60)	4485 (9.15)	2016 (8.35)	61.5	100
15	0.18	0.56	13.3	1387 (7.95)	763 (5.05)	4290 (8.95)	918 (7.13)	94[c]	100 high fry mort.
C1	0.27	0.61	18.9	[b]	[b]	[b]	[b]	[d] high fry mort.	100[c]
C2	0.21	0.21	12.8	[b]	[b]	[b]	[b]	high[e]	[d]

[a] 66.1 percent of W-V boxes were damaged by cattle activity.

[b] Unable to analyze due to cattle destruction.

[c] Survival based on one of two boxes.

[d] Unable to analyze due to W-V box destruction by cattle.

[e] W-V box damaged by cattle; values based on eggs remaining.

[f] Unable to locate.

Table 17. Empirical and computed intragravel velocities of six artificial chinook salmon redds located in Big Springs Creek, Idaho. Flow = 17.6 cfs, fall 1978.

Redd number	Percent water surface slope	Permeability K (cm/hr)	Width (ft) W	X-Sect area A_2 (ft^2)	Mean depth D (ft)	Mean velocity $\overline{V}$ (fps)	Wetted[a/] perimeter WP (ft)	Hydraulic radius R (ft)	Computed intragravel velocity (cm/hr)	Empirical intragravel velocity (cm/hr)	$\overline{V}$ over redd (fps)	Depth over redd (ft)	Percent difference computed vs. empirical (>or<)
2	.39	1596	28.75	16.18	0.56	1.09	29.87	0.54	2.37	25	0.25	0.35	90.5 <
9	.46	2660	43.75	23.6	0.54	0.75	44.83	0.53	1.92	22	2.00	0.60	91.3 <
11	.37	6170	36.25	19.37	0.53	0.91	37.31	0.52	6.73	39	0.35	0.35	82.7 <
13	.78	6915	37.0	17.45	0.47	1.01	37.94	0.46	10.93	59	1.10	0.50	81.5 <
14	.25	4042	29.25	16.88	0.58	1.04	30.41	0.56	5.22	36	1.00	0.70	85.5 <
15	.57	957	23.25	15.99	0.69	1.10	24.63	0.65	1.13	38	1.75	0.60	97 <

a/ WP = Width + 2 (mean depth).

b/ R = A/WP.

mortality of fry (Table 18). This accumulation is thought to have occurred gradually since the fry were in the buttonup stage when they died. Water filled vials in redds 1 and 5 were broken, indicating freezing was the cause of the 100 % mortality of alevins. Water depth over redds was 9.1 cm and 4.6 cm, respectively (Table 19).

During the incubation period, intragravel dissolved oxygen levels remained adequate (range, 5.65-9.0 mg/1). Low water temperatures (0 C) persisted during a long portion of the incubation period, increasing the time to emergence of hatched fry. Water depths over redds ranged from 4.57-24.38 cm, velocities from 13.72-62.48 cm/s; and water surface slopes from .14-2.76 percent (Table 18). Overall, there was a reduction in fine sediment between the two substrate sampling times with an increase in the average geometric mean diameter from 11.5 to 14.2 mm (Table 5 Appendix I). This was probably a result of redd construction and associated dislodgement of fine materials.

As in our Big Springs Creek tests, we empirically measured the intragravel velocity from six standpipes and compared the results to computed values obtained from cross-channel transects. Two sets of measurement were made corresponding to flows of 1.85 and 9.80 cubic meters/-second (cms) (6.53 and 34.63 cfs). This allowed us to monitor intragravel velocity changes with respect to changes in flow. Computed values were usually smaller than empirical, averaging 47.8 % less (Table 19). No correlation was found between computed and empirical values for the 1.85 cms (6.5 cfs) measurements (r^2 = .03) but a good relationship existed for the 9.80 cms (34.63 cfs) values (r^2 = .755) (Figure 26). Computed values agree precisely with empirical values as to the relative increase or decrease in intragravel velocity following a change in flow

Table 18. Physical, hydraulic, and chemical parameters associated with chinook egg and fry survivals from 15 artificial redds constructed in Bear Valley Creek, Idaho, 25 May 1979.

Redd number	Percent sediment 0.84 (mm)	Geometric mean diameter (mm) dg	Water surface slope (%)	Water depth (cm)	Water velocity (cm/s) at 0.6 depth	Mean intragravel dissolved oxygen (mg) (Range)	Percent Hatch (Percent fry survival) Box 1	Box 2	Box 3	Mean percent survival	Water vial condition
1	7.0	11.04	2.17	9.14	39.62	8.24 (8.0-8.65)	97 (0)	97 (0)	100 (0)	98.0 (0)	B[b]
2	0	19.48	2.01	16.76	62.48	8.35 (8.05-8.80)	100 (100)	100 (100)	100 (100)	100 (100)	NB[c]
3	5.5	11.80	1.35	13.72	32.00	8.18 (7.85-8.50)	100 (100)	100 (100)	99 (99)	99.7 (97.7)	NB
4	27.4	3.56	1.43	15.24	25.91	6.93 (5.85-7.50)	100 (100)	98 (98)	100 (100)	99.3 (99.3)	NB
5	10.0	8.92	2.22	4.57	45.72	7.85 (5.65-8.80)	93 (0)	85 (0)	88 (0)	88.7 (0)	B
6	9.6	10.52	2.76	9.14	38.10	7.77 (5.70-8.85)	100 (18)	99 (13)	100 (64)	99.7 (31.7)	NB
7	14.8	5.99	.26	21.34	15.24	7.69 (6.20-8.35)	98 (98)	100 (0)	100 (5)	99.3 (34.3)	NB
8	3.2	23.80	.34	15.24	19.81	8.25 (7.7-8.60)	100 (100)	98 (98)	100 (100)	99.3 (99.3)	NB
9	9.6	9.20	.14	15.24	50.29	8.17 (7.5-8.80)	100 (100)	100 (100)	100 (100)	100 (100)	NB
10	3.1	17.32	.52	12.19	38.10	8.36 (7.5-8.90)	99 (99)	97 (97)	100 (100)	98.7 (98.7)	NB
11	7.8	8.25	.68	10.67	16.76	8.29 (7.2-9.0)	99 (99)	99 (99)	99 (99)	99 (99)	NB
12	9.4	9.65	.40	12.19	22.86	8.27 (7.3-9.0)	99 (99)	99 (99)	100 (100)	99.3 (99.3)	NB
13	6.0	10.39	.14	15.24	13.72	8.28 (7.9-8.95)	97 (97)	99 (99)	99 (99)	98.33 (98.33)	NB
C1	1.3	23.2	.40	22.86	32.00	8.16 (7.95-8.55)	a/	a/	a/	--	NB
C2	0	7.87	1.22	24.38	32.00	8.09 (7.95-8.3)	a/	a/	a/	--	NB

a/ Egg survival assessed 7/17/79 - eggs and fry badly decomposed.

b/ B = broken

c/ NB = not broken

Table 19. Empirical and computed intragravel velocities of six artificial chinook salmon redds located in Bear Valley Creek, Idaho for flows of 6.5 and 34.6 cfs fall 1978.

Redd number	Stage (ft)	Flow (cfs)	Permeability K (cm/hr)	Width (ft) W	X-Sect Area A (ft^2)	Mean depth D (ft)	Mean velocity $\overline{V}$ (fps)	Wetted[a] perimeter WP (ft)	Hydraulic[b] radius R (ft)	Computed intragravel velocity (cm/hr)	Percent change (+ or -)	Empirical intragravel velocity (cm/hr)	Percent change (+ or -)	Percent difference computed vs. empirical (> or <)
3	1.10	6.53	791	14.75	4.70	0.319	1.39	15.388	0.305	4.10	19.5 +	5.00	50.0 +	28.0 <
3	1.55	34.63	791	15.00	12.35	0.823	2.80	16.646	0.742	5.09		10.00		49.0 <
5	1.10	6.53	2185	16.00	4.70	0.294	1.39	16.588	0.283	12.53	28.0 +	8.00	73.3 +	36.0 >
5	1.55	34.63	2185	17.50	12.20	0.697	2.84	18.894	0.646	17.41		30.00		42.0 <
6	1.10	6.53	667	16.00	3.10	0.194	2.12	16.388	0.189	15.24	74.1 -	12.00	58.3 -	21.0 >
6	1.55	34.63	667	21.50	14.38	0.669	2.41	22.838	0.630	3.95		5.00		21.0 <
10	1.10	6.53	4140	7.00	4.40	0.628	1.48	8.256	0.533	11.58	72.1 +	93.00[c]	11.4 +	88.0 <
10	1.55	34.63	4140	8.00	8.90	1.112	3.89	10.224	0.870	41.62		105.00[c]		60.0 <
11	1.10	6.53	1695	20.00	7.40	0.370	0.88	20.74	0.357	2.87	51.0 +	21.00	0	86.0 <
11	1.55	34.63	1695	22.75	17.34	0.762	2.00	24.27	0.714	5.86		21.00		72.0 <
12	1.10	6.53	1650	14.00	5.41	0.386	1.21	14.77	0.366	5.08	23.2 +	7.50	42.3 +	32.0 <
12	1.55	34.63	1650	18.50	15.38	0.831	2.25	20.16	0.763	6.62		13.00		49.0 <
Mean $\overline{X}$	1.10	6.53								8.57	36.0 +	24.42	20.0 +	47.8
	1.55	34.63								13.43		30.67		

[a] WP = Width + 2 (mean depth).

[b] R = A/WP

[c] Standpipe loose - water slippage ground pipe possible during field measurements.

(Table 19). With one exception, an increase in flow resulted in increase intragravel velocities ($\overline{X}$ = 36% increase). For redd 6, the increased flows actually reduced intragravel velocities owing to the larger wetted perimeter and cross sectional area with little change in mean velocity. In contrast to our Big Springs Creek results, we found a relationship between mean water velocity and intragravel velocity (Figure 27). No correlation between intragravel velocity and water depth or water surface slope was found (r^2 = .009).

Fry quality analysis revealed some significant differences in length and weight resulting from the individual redds, although no explanation for the differences could be found based on correlation of mean velocity, depth, or geometric mean diameter (r^2 values ≃.001) (Table 5 Appendix II, Table 5 Appendix III).

Embryo Dewatering Tests

Drip Incubation

Mean survival to hatch from our steelhead tests was 3.0%. Embryo survival to eyeup ranged from 2-58%, averaging 35%. Air temperatures during the incubation period ranged from 10-14.7 C. The longest time interval between tray waterings was 96 h at which time the moisture content of the cotton cloth was extremely low.

Our Hayden Creek chinook tests resulted in hatching survivals ranging from 28.4-77.4% (average 55.1% compared to control embryo survival of 98.4%. Because hatching continued over a 19 day period and trays were checked at 1 or 2 day intervals, many alevins died (32.5%)

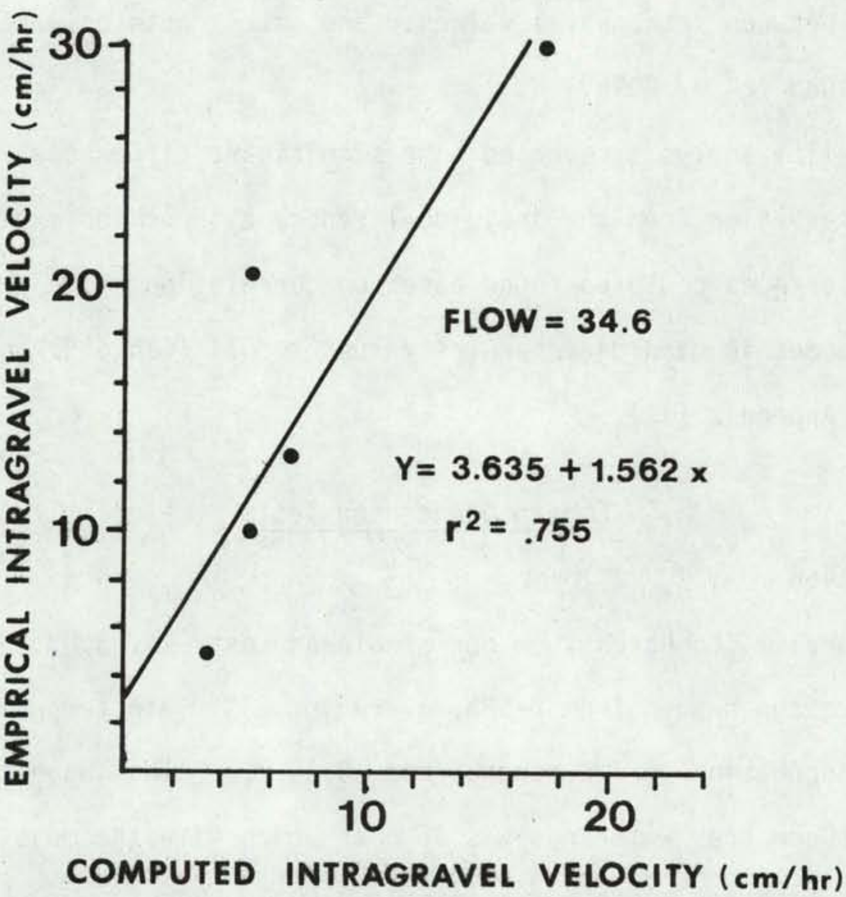


Figure 26. Relationship of computed to empirical intragravel velocity measurements for 5 artificial chinook redds in Bear Valley Creek, Idaho, fall 1978.

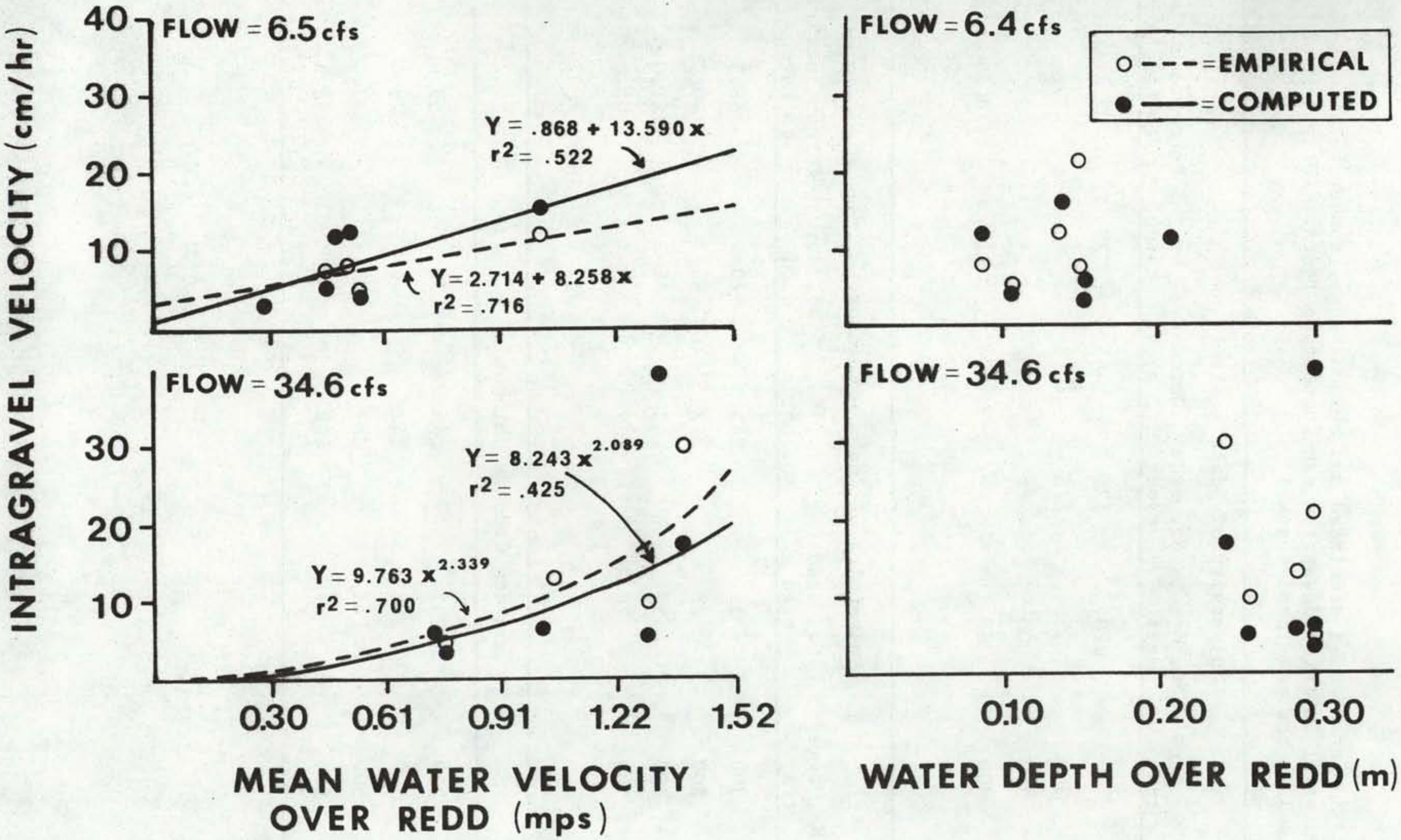


Figure 27. Relationship of empirical and computed intragravel velocities to mean extragravel velocity and water depth over artificial spring chinook redds within Bear Valley Creek at flows of 6.5 and 34.6 cfs, fall 1978.

Table 20. Number of dead steelhead and chinook eggs, number hatch and percent survival in three dewatered egg incubation tests. (Drip siphon was not used in the steelhead tests.)

University of Idaho - Steelhead

Tray #	No. eggs/ tray	No. dead eggs	No. eggs eyed	Percent eyed	No. hatch	Percent survival to hatch
1	300	278	135	45	22	7.3
2	300	295	175	58	5	1.7
3	300	300	6	2	--	0
Control	300	88	--	--	212	70.7

University of Idaho - Chinook

Tray #	No. eggs/ tray	No. dead eggs	No. hatch	No. dry dead	Percent survival to hatch
1	300	35	265	70	88.3
2	300	28	272	65	90.7
3	300	57	243	94	81.0
Control	300	28	272	0	90.7

Hayden Creek - Chinook

1	500	202	298	70	59.6
2	500	358	142	44	28.4
3	500	113	387	155	77.4
Control	500	8	492	--	98.4

before being transferred to water. Peaks in hatching occurred after the accumulation of approximately 928 Temperature Units (T.U.). Cloth temperatures during the incubation period ranged from 5-15 C.

A similar test conducted at the University of Idaho resulted in good embryo survivals (range, 81-90.7%; $\overline{X}$ = 87%), with control survival averaging 90.7% (Table 20). Of the 87% test embryos which hatched, 29.4 percent of the alevins died before being transferred to water. Temperature ranged from 8.5 to 17.0 C during the tests with peaks in hatching occurring at an average of 1091 T.U.

Redd Dewatering Tests

Dewatered embryo survival in the first channel averaged 32.9% and ranged from 24.7 to 40.5% (Table 21). Survival within the watered chambers averaged 68.8%, range 37-90 percent. The majority of the embryo mortality occurred after week 6 when flows had been restored to the dewatered chambers (Figure 28). It is possible that restoration of flows may have imparted thermal shock to the embryos, although results of other tests (e.g., flow fluctuations) suggest this was not the case. The lowest survival in the dewatered chambers occurred in the sediment level 10% $<$ 0.84, while for the watered this occurred in sediment 30% $<$ 4.6 $>$ 0.84 and 20% $<$ 0.84 mm. Overall, survivals resulting from fertilized eggs incubated with water were approximately two times higher than from dewatered eggs and were significantly higher for all levels of sediment tested. Air temperatures during the incubation period ranged from -3.4 to 23.5 C, while water temperatures ranged from 2.2 to 13.4 C. A snowstorm on 18-19 September deposited 0.3 m of snow on the dewatered riffles

Table 21. Average percent chinook egg survival to hatching from dewatered vs. watered artificial redds with five levels of sediment. Hayden Creek and University of Idaho incubation channels, fall 1978.

Sediment levels	Hayden Creek (1st 4 x 8 channel) Average survival - percent		Hayden Creek (2nd 4 x 8 channel) Average survival - percent		University of Idaho Average survival - percent	
	Dewatered[a/]	Watered	Dewatered[b/]	Watered	Dewatered[c/]	Watered
10% < 0.85	24.7	69.5	0	43.5	28.1	11.7
20% < 4.6 > 0.85; 10% < 0.85	40.5	78.3	0	26.5	26.7	37.2
20% < 4.6 > 0.85	29.2	90.0	0	28.5	3.4	34.3
30% < 4.6 > 0.85; 20% < 0.85	36.7	37.7	0	0	0	0
20% < 4.6 > 0.85; 30% < 0.85	--	--	--	--	0	0
Overal $\overline{X}$	32.9	68.8	0	24.6	11.6	16.6
Combined Hayden Creek tests (percent survival)	16.4 dewatered		46.8 watered		--	
Heath stack control (percent survival)	79.0		--		72.2	

a/ Dewatered 42 days before flows restored.

b/ Dewatered 58 days.

c/ Dewatered 38 days when hatching commenced.

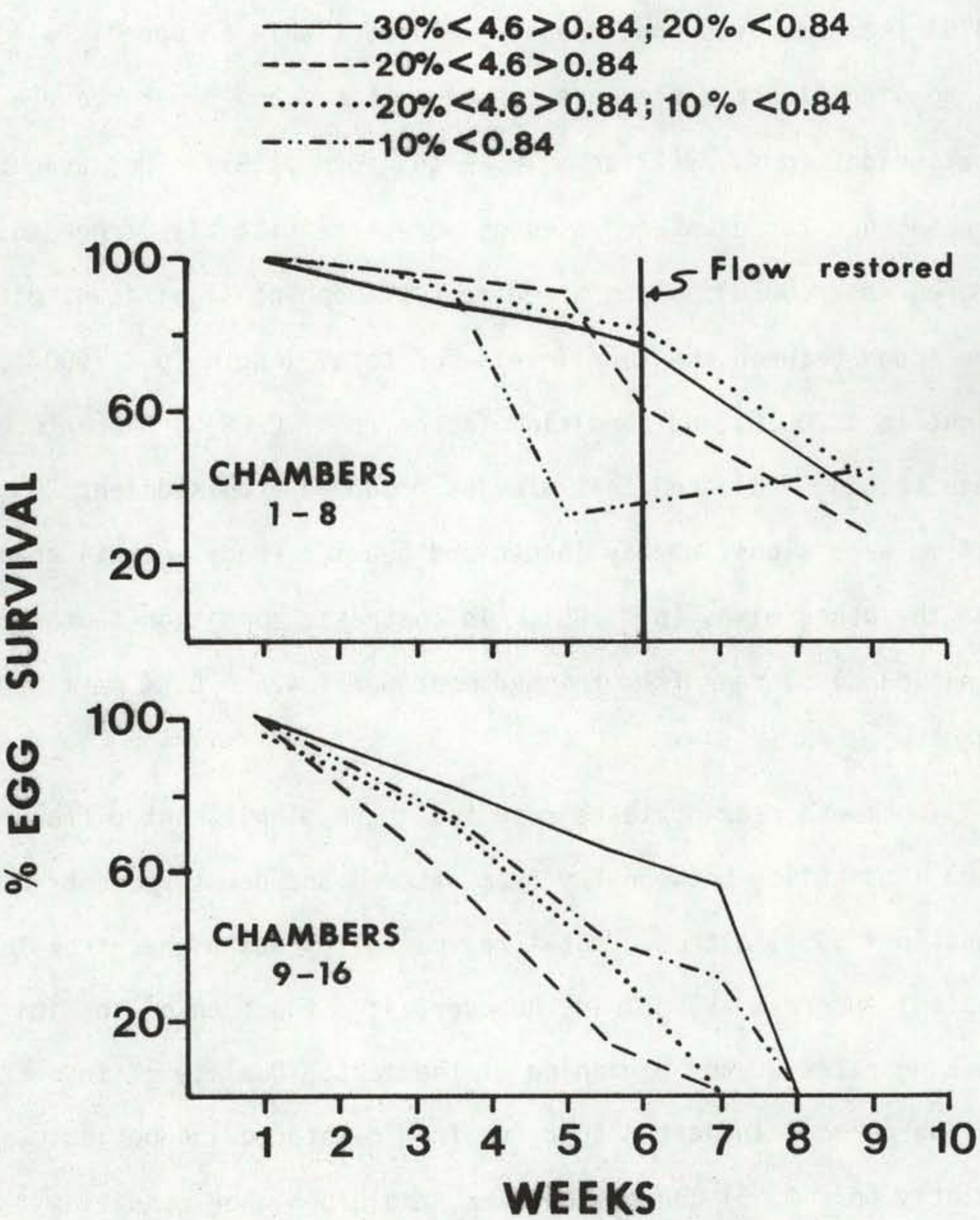


Figure 28. Mean percent spring chinook egg survival resulting from dewatered incubation in four sediment mixtures. Water flow was restored to some incubating eggs after 6 weeks of dewatering (top) while others (bottom) were continuously dewatered. Hayden Creek incubation channels, fall 1978.

insulating them from accompanying cold temperatures. Water flow in the watered and restored chambers averaged 300 ml/sec with dissolved oxygens ranging from 7.2 to 8.9 mg/l.

Alevins were significantly longer ($p < .0001$) and heavier ($p < .0470$) from embroyos continuously watered (Table 6 Appendix III). There was no significant difference between watered and dewatered alevins for total weight ($p < .3917$) or yolk weight ($p < .1199$). Dry weight condition factors for dewatered alevins were significantly larger than for watered ($p < .0020$). From a sediment standpoint significant differences were found between the four levels for total length ($p < .0007$), body weight ($p < .0030$) and condition factor ($p < .0208$). Duncan's multiple range testing indicated that alevins produced from sediment 20% < 4.6 > 0.84 mm were significantly longer and heavier (body weight) than alevins from the other mixes ($p \leq .05$). In contrast, condition factors were significantly larger from the sediment 30% < 4.6 > 0.84 mm mixture ($p \leq .05$).

Two month rearing tests resulted in no significant differences in overall mortality between fry from watered and dewatered embryo incubations ($p \leq .05$), although total fry mortality was higher from the watered (Table 1 Appendix IV). This, however, is a function of the initial stocking rates at the beginning of the test. Quality of fry after the rearing period, indicated that fry from dewatered incubations were significantly ($p \leq 0.05$) longer, heavier, and had higher condition factors than fry from watered incubations (Table 7 Appendix III).

No embryos survived in the second set of dewatered chambers which were dewatered continuously for 58 days to determine if they would complete their embryogenesis out of water. Watered embryo survival ranged from 0 to 43.5% (Table 21). Embryo mortality was most pronounced after 3.5 weeks of dewatering although some embryos survived until the 7th and 8th weeks (Figure 28).

Combining the results of both Hayden Creek tests, overall survival of dewatered and watered embryos was 16.4 and 46.8%, respectively.

When incubated in the thermally controlled environment (temperature 12-15 C) at the University of Idaho, dewatered embryos began hatching after 38 days. Dewatered embryo survival ranged from 0 to 28.1% while watered embryo survivals ranged from 0 to 37.2% (Table 21). Embryo survival was significantly higher ($p \leq 0.05$) in the watered chambers for all levels of sediment tested.

Flow Fluctuation

Hatching success of embryos subjected to 3 day flow fluctuation tests (cumulative dewatering = 28 days) was lowest for embryos incubated in 0% sediment ($\overline{X}$ = 2.75%) followed by 37% sediment < 4.6 mm ($\overline{X}$ = 77.5) (Table 22). At the time of sampling, only four alevins had hatched from the control troughs while as many as 98 had hatched from the flow fluctuation troughs; embryos incubated in 20% sediment < 4.6 mm had the greatest percentage hatch (95.0%). The overall high percentage embryos survivals indicate that the sudden temperature changes (as a consequence of flow restoration) to the dewatered embryos had little or no adverse effect on their development. We estimate changes in temperature to be as great as 5 C averaging approximately 2-3 C. During the tests, water temperatures and dissolved oxygens remained within acceptable incubation limits (Table 22).

Alevin quality between the four sediment levels and 3 day peaking tests was significantly different for total length ($p < .0001$), total

Table 22. Survival of chinook salmon eggs (in lots of 100) incubated in four sediment compositions and subjected to day flow fluctuations, and associated water temperatures and dissolved oxygens. Survival measured at time of sampling. Hayden Creek Research Station, fall 1978.

Trough No.	Percent sediment < 4.6 mm	Number hatched	Number dead eggs	Number dead fry	Number live eggs	Percent survival	Average percent survival	Water temperature C range	Dissolved oxygen mg/l range
1	0	0	100	---	0	0	2.75	5.3-13.5	6.15-7.8
		0	100	---	0	0			
		10	90	1	0	10			
		1	99	1	0	1			
2	24	34	20	6	46	80	90.75	5.5-13.5	6.0-8.5
		48	14	1	28	86			
		37	0	3	63	100			
		69	3	20	28	97			
3	20	95	3	92	2	97	96.50	7-13	5.15-7.0
		92	5	30	3	95			
		95	5	95	0	95			
		98	1	75	1	99			
4	37	63	32	48	5	68	77.50	6-13	5.25-7.25
		83	8	10	9	92			
		56	29	21	15	71			
		74	21	50	5	79			
C1 constant flow	0	0	0	---	100	100	98.50	4-13.8	5.0-7.9
		0	2	---	98	98			
		0	1	---	99	99			
		0	3	---	97	97			
C2 constant flow	~35	4	2	0	94	98	98.75	5-13.5	6.4-8.2
		0	0	---	100	100			
		0	2	---	98	98			
		0	1	---	99	99			

Duration of fluctuations 9/1/78 to 10/25/78 (55 days).

Total duration of dewatering - 28 days.

Total duration with water - 27 days.

weight ($p < .0277$); yolk weight ($p < .0737$); body weight ($p < .0003$) and condition factor ($p < .0001$). If we exclude the 0 sediment incubation results from analysis (due to sample size of 4) mean total length decreases as sediment level increases, while total weight, yolk weight, body-weight, and condition factor increases with increased sediment (Table 8 Appendix III). Results of Duncan's multiple range test indicate that alevins incubated in 37% sediment < 4.6 mm were significantly smaller in length than alevins incubated in other sediment levels tested, yet heavier than alevins from the 0 and 20% levels, and with larger condition factors than those from 0, 24 and 20% levels ($p \leq .05$). This suggests the alevins from trough 4 were less developed.

Fry from both control troughs were smaller (length, weight, condition) at the end of the rearing tests than test fry (Table 8 Appendix III). Significant differences in quality were found for total length ($p < .0001$), fork length ($p < .0001$), total weight ($p < .0001$), and condition factor ($p < .0001$) with fry incubated in troughs containing 20% sediment < 4.6, significantly larger than all others ($p \leq .05$).

Spawning Measurements

We measured physical characteristics of 104 spring chinook salmon, 50 summer chinook salmon, 89 steelhead trout and 4 bull trout (*Salvelinus malma*) redds (Table 1 Appendix IV). Summer chinook salmon redds measured were in deeper water with higher water velocities than spring chinook or steelhead redds (Figure 29 and 30, Tables 23 and 24). Most summer chinook redds were located in water velocities of 0.85-1.00 mps while those for spring chinook and steelhead were found in 0.3-0.55 mps and 0.35-0.80 mps, respectively (Figure 30). The predominant water depth interval for summer

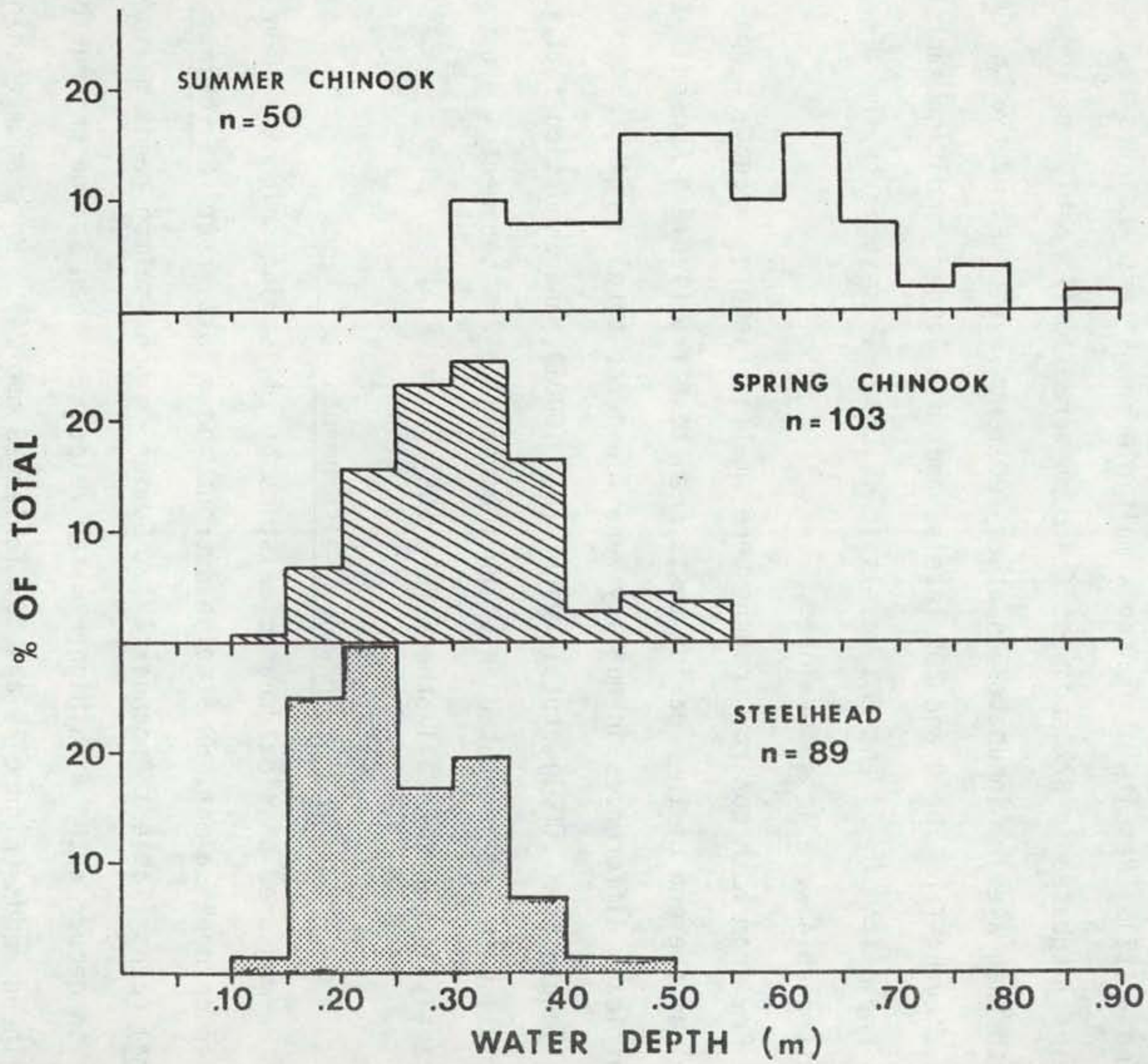


Figure 29. Frequency distribution of water depth over redds of summer chinook and spring chinook salmon and steelhead trout measured from eight study streams in central Idaho, 1977-78.

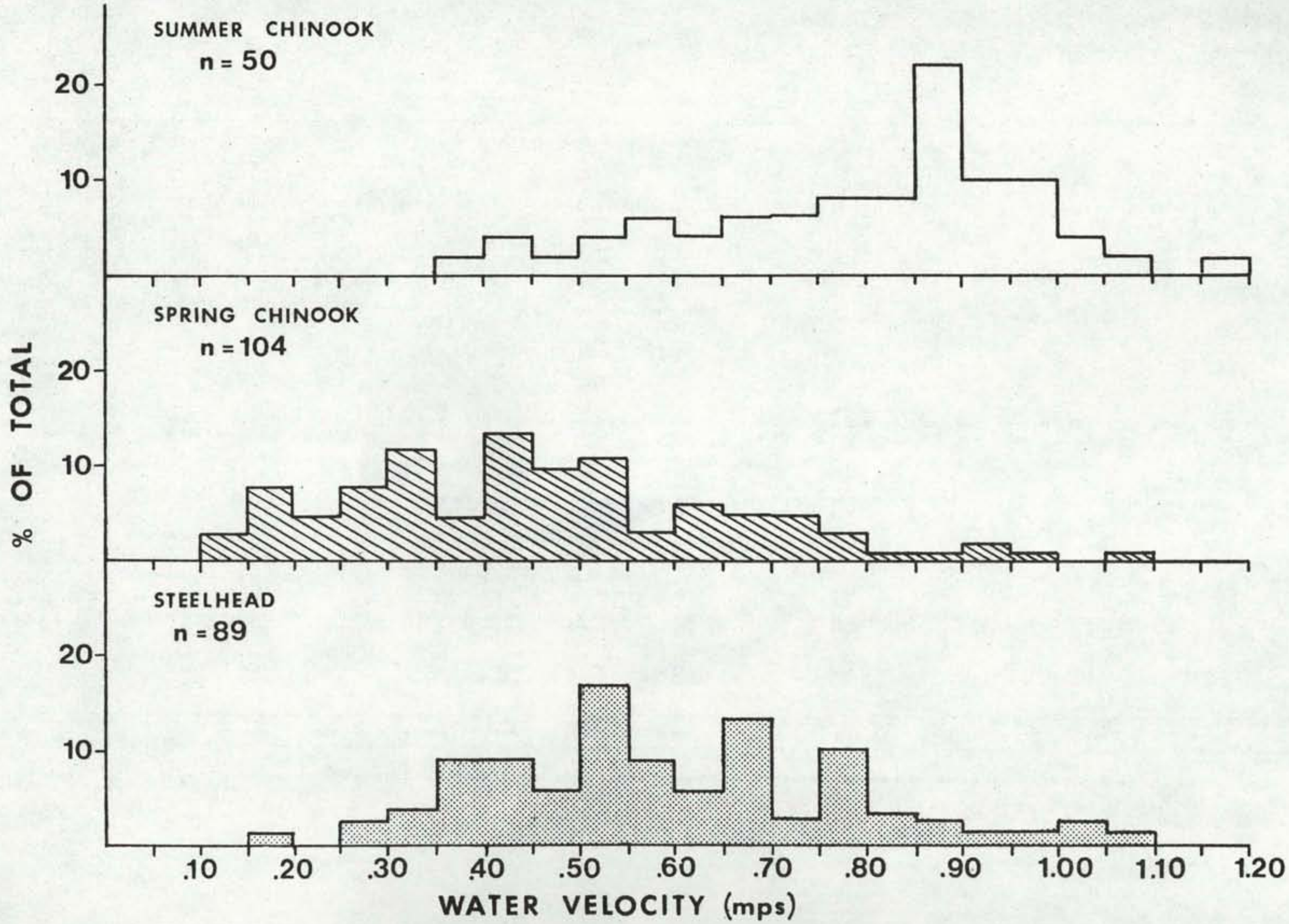


Figure 30. Frequency distribution of mean water velocity (0.6 depth) over redds of summer chinook and spring chinook salmon and steelhead trout measured from eight streams in central Idaho, 1977-78.

Table 23. Mean and (range) of physical and hydraulic characteristics offspring chinook, summer chinook, steelhead and bull trout redds from eight study streams in central Idaho, 1977 and 1978.

Species location	No.	Length m	Width m up	Width m pit	Width m tail	Area m^2	Depth m up	$\bar{V}$ mps up	Pt V mps up	Depth m pit	$\bar{V}$ mps pit	Pt V mps pit	Depth m tail	$\bar{V}$ mps tail	Pt V mps tail
Spring Chinook															
Big Springs Creek	1	3.66 (3.66)	0.61 (0.61)	2.74 (2.74)	1.22 (1.22)	5.95 (5.95)	0.30 (0.30)	0.29 (0.29)	—	0.15 (0.15)	0.49 (0.49)	--	0.09 (0.09)	0.39 (0.39)	--
Knapp Creek	4	4.22 (3.96-5.49)	1.26 (1.22-1.40)	1.51 (1.40-1.83)	1.49 (4.83-9.64)	6.55 (0.26-0.35)	0.31 (0.26-0.35)	0.23 (0.14-0.41)	--	0.26 (0.21-0.35)	0.26 (0.12-0.41)	--	0.17 (0.12-0.21)	0.27 (0.15-0.34)	--
Marsh Creek	12	4.42 (2.90-5.49)	2.10 (1.22-3.05)	2.68 (1.83-3.66)	1.89 (1.10-3.35)	9.89 (5.54-15.42)	0.30 (0.24-0.44)	0.37 (0.17-0.55)	0.20 (0.08-0.34)	0.33 (0.12-0.53)	0.40 (0.21-0.66)	0.16 (0-0.52)	0.15 (0.09-0.30)	0.65 (0.46-0.91)	0.51 (0.30-0.76)
Capehorn Creek	32	3.58 (2.44-6.10)	1.11 (0.61-2.13)	1.56 (0.91-2.59)	1.67 (0.91-2.74)	5.69 (2.11-14.09)	0.31 (0.14-0.52)	0.51 (0.26-0.75)	--	--	--	--	--	--	--
Hayden Creek	37	3.61 (1.37-7.01)	0.79 (0.30-1.83)	1.42 (0.46-2.74)	1.39 (0.61-3.05)	5.16 (0.70-18.52)	0.31 (0.15-0.72)	0.38 (0.14-0.69)	0.17 (0-0.44)	0.36 (0.24-0.52)	0.36 (0.12-0.75)	0.06 (0-0.21)	0.14 (0.03-0.35)	0.57 (0.08-1.07)	0.40 (0.08-0.85)
Bear Valley Creek	9	3.22 (2.13-4.88)	0.95 (0.61-1.83)	1.47 (0.91-2.44)	1.51 (0.61-2.74)	4.99 (2.12-12.14)	0.35 (0.18-0.55)	0.44 (0.14-0.67)	—	--	—	--	--	--	--
Lemhi River	9	4.27 (2.74-6.10)	1.05 (0.61-1.37)	1.68 (1.22-2.13)	1.62 (1.22-2.13)	6.56 (4.04-8.67)	0.35 (0.24-0.49)	0.83 (0.53-1.10)	0.30 (0.11-0.52)	0.47 (0.37-0.64)	0.60 (0.30-1.04)	0.10 (0-0.46)	0.21 (0.15-0.30)	1.12 (0.91-1.43)	0.70 (0.41-0.98)
Summer Chinook															
Salmon River	4	4.57 (3.05-6.10)	1.30 (0.91-1.52)	1.07 (1.83-2.44)	2.29 (1.83-2.44)	9.37 (5.42-12.54)	--	--	--	--	--	--	--	--	--
Salmon River	50	--	--	--	--	--	0.53 (0.30-0.85)	0.79 (0.38-1.28)	--	--	--	--	--	--	--
Steelhead															
Hayden Creek	1	3.05 (3.05)	1.52 (1.52)	1.22 (1.22)	1.07 (1.07)	3.64 (3.64)	0.49 (0.49)	0.69 (0.69)	--	0.27 (0.27)	0.87 (0.87)	--	0.24 (0.24)	0.80 (0.80)	--
Lemhi River	88	3.09 (1.68-6.71)	0.92 (0.46-2.44)	1.26 (0.61-2.44)	1.67 (0.76-3.35)	4.38 (1.58-13.63)	0.25 (0.15-0.41)	0.59 (0.15-1.06)	--	0.32 (0.16-0.53)	0.51 (0.15-0.94)	--	0.13 (0.03-0.35)	0.65 (0.21-1.07)	--
Bull Trout															
Bear Valley Creek	4	1.34 (0.76-2.44)	0.52 (0.24-0.91)	0.61 (0.30-0.91)	0.57 (0.30-1.07)	0.93 (0.28-2.42)	0.27 (0.09-0.40)	0.33 (0.20-0.41)	--	--	--	--	--	--	--

Table 24. Mean and (range) of upper edge depths, velocities and redd area utilized by spring chinook, summer chinook, steelhead and bull trout measured from eight study streams in central Idaho, 1977, 1978.

Species	N	Depth m	Velocity mps	Redd area m^2
Spring chinook	104	0.32 (0.14-0.72)	0.45 (0.14-1.10)	6.00 (2.11-15.42)
Summer chinook	50	0.53 (0.30-0.85)	0.79 (0.38-1.28)	9.37 (5.42-12.54)
Steelhead	89	0.25 (0.15-0.49)	0.59 (0.15-1.06)	4.38 (1.58-13.63)
Bull trout	4	0.27 (0.09-0.40)	0.33 (0.20-0.41)	0.93 (0.28-2.42)

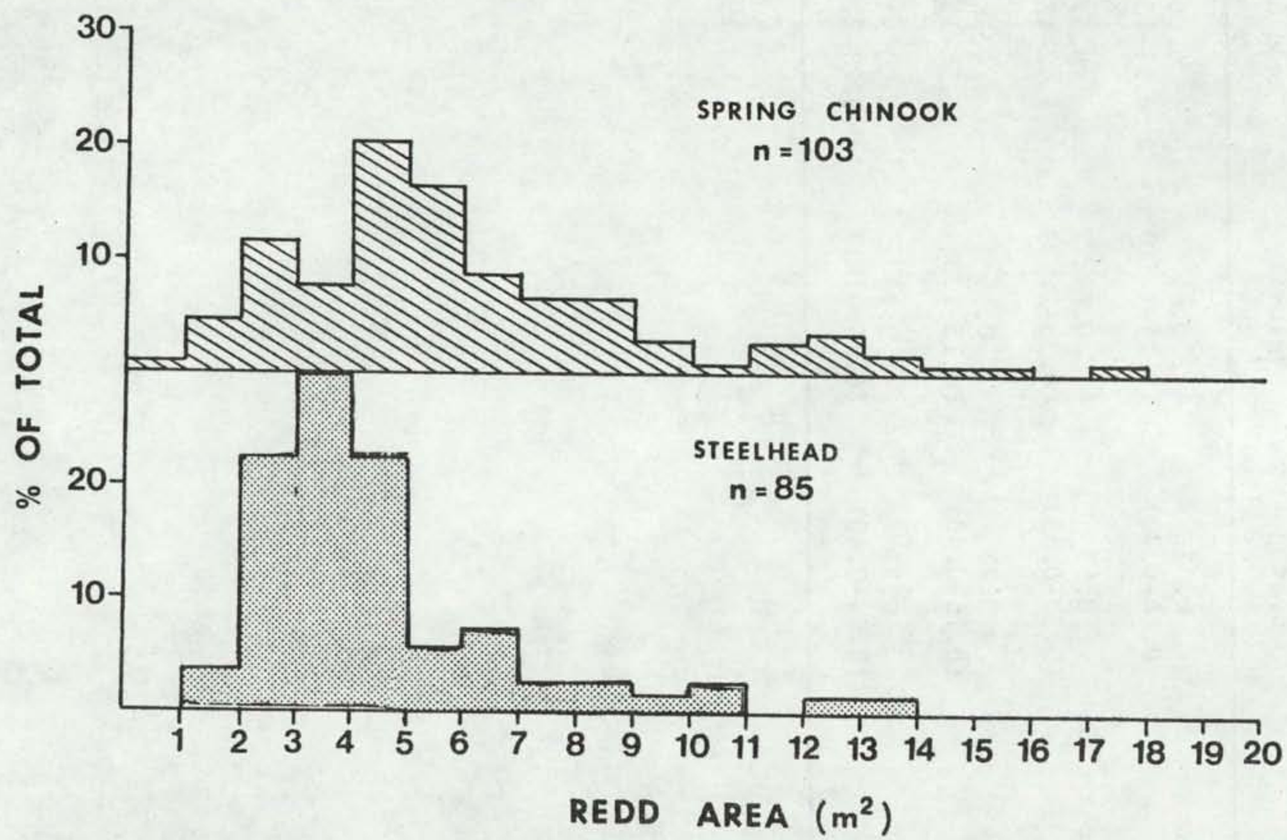


Figure 31. Frequency distribution of spring chinook salmon and steelhead trout redd area utilized during spawning measured from seven study streams in central Idaho, 1977-78.

chinook was 0.45-0.7 m; for spring chinook 0.2-0.40 m and for steelhead 0.15-0.35 m (Figure 29). Area of most spring chinook and steelhead redds ranged from 2.0 to 9.0 m^2 and 2.0 to 7.0 m^2, respectively (Figure 31). Physical characteristics associated with redds of a species or stock varied with the size of the spawning stream. For example, mean velocities selected by spring chinook ranged from 0.23 mps in Knapp Creek to 0.83 mps in the Lemhi River and mean depths ranged from 0.30 m in Marsh Creek to 0.35 m in the Lemhi River (Table 23). Many spring chinook and steelhead redds located in the Lemhi River were adjacent to useable cover (e.g., undercut banks, deep pools).

Spawning Criteria

We developed depth, velocity, substrate, and area spawning criteria for spring chinook and summer chinook salmon, and steelhead trout (Table 25). We used the middle 80 percent of the upper edge velocity measurements as the velocity criteria, and the depth at the upper edge of the redds which 90 percent of the measurements were greater than or equal to. Criteria were developed in this manner to eliminate the low and high "outlier" values from the velocity range and low values from the depth range. Visual substrate analysis of the areas selected for spawning revealed a predominance of coarse and fine gravel (approximately 1.6 to 6.4 cm) in spring chinook and steelhead redds, and rubble and coarse gravel (3.21-25 cm) in summer chinook redds. Spatial needs for spawning spring chinook, summer chinook and steelhead averaged 6.0 m^2, 9.37 m^2, and 4.38 m^2, respectively, although the summer chinook values are based on only four measurements.

Table 25. Depth, velocity, substrate, and area spawning criteria for spring chinook and summer chinook salmon and summer steelhead trout developed from measurements taken in eight streams in central Idaho, 1977-78.

Species/Stock	Depth (m)	Velocity (mps)	Substrate (cm)	Area m^2
Spring chinook	$\geq$0.22	0.20-0.72	1.6-6.4	6.0
Summer chinook	$\geq$0.41	0.52-0.95	3.2-2.5	9.4
Summer steelhead	$\geq$0.16	0.37-0.81	1.6-6.4	4.4

DISCUSSION

Flow Reduction

Our tests conducted in the Hayden Creek channels indicate that within a range of sediment levels (3-13% < 0.84 mm) reductions in streamflow during the incubation of salmonid embryos may result in reductions in hatching success and alevin quality. The greatest difference in chinook embryo survival between the control and test flow conditions (~ 40% difference) occurred at a sediment level of 7% < 0.84 mm. The differences began to diminish as sediment levels increased suggesting that sediment level is the factor governing suitable incubation flow and that above a certain level of sediment, streamflow augmentation will no longer positively influence egg survival.

Intragravel Velocity

The extragravel hydraulic parameter influenced the most by flow reduction is velocity (Kraft 1968, Wesche 1973, 1974). Because of the relationship of stream velocity to the intragravel environment, intragravel velocity may also be diminished following a reduction in surface flow (Bovee and Cochnauer 1977). Empirical evidence to support this is provided in studies by Shelton (1955) and Wickett (1954) as well as our Bear Valley Creek investigations. In our study, both computed and empirical values agreed as to the relative change in intragravel velocity following a change in flow. In all but one instance, streamflow reductions resulted in decreased intragravel velocities. Mean water velocity appeared to be directly related to intragravel velocities, although we found no evidence for such a relationship in our Big Springs Creek tests. If we consider 7 cm/hr (Wicket 1960) as being suitable for embryo incubation the Bear Valley Creek relationship indicates, a mean extragravel velocity of approximately 0.83 mps is needed over the redd. However, actual embryo survivals in our Hayden Creek and Bear Valley Creek tests were high in redds with mean velocities as low as 0.10-0.15 mps provided sediment was not limiting. A study by Hoppe and Finnell (1970) on the Fryingpan River in Colorado suggested that mean water velocity was a major factor influencing intragravel velocity. Their analysis indicated that a velocity of 0.46 mps was needed to ensure brown trout embryo survival. Subsequent reductions in streamflow decreased water velocities to 0.30 mps and caused suffocation of approximately one half of the embryos in surrounding redds. Corning (1969) planted fertilized rainbow trout in four artificial redds and monitored survival in conjunction with flow reductions. Survivals ranged from 88.7% in a redd with suitable flows to 0% in an exposed redd. The remaining redds had 2.5 to 5.0 cm of water covering the gravel, imperceptible velocities, and survivals ranging from 8.9 to 12.3 percent.

Intragravel velocities in our University of Idaho tests were dictated by the various sediment mixes. Consequently, we found good correlation between embryo survival and intragravel velocity for both steelhead and chinook. In general, the greatest decrease in survival occurred in conjunction with velocities < 100 cm/hr. Velocities as high as 1500 cm/hr continued to positively affect embryo survival. In a chinook embryo planting experiment conducted in artificial channels, Shelton (1955) found that intragravel velocities as low as 109 cm/hr proved satisfactory for hatching. Other studies relating apparent velocity to embryo survival include Cooper (1965) working with sockeye salmon (<u>Oncorhynchus</u>

nerka), Coble (1961) with steelhead trout, Peters (1962) with rainbow trout, Gangmark and Bakkala (1960) with chinook, Wickett (1960) with pink salmon (Oncorhynchus gorbuscha) and Phillips and Campbell (1961) with coho salmon (Oncorhynchus kisutch) and steelhead. The intragravel velocities found to provide high embryo survivals in these studies were much lower than indicated by our work (e.g., Wickett > 7 cm/hr, Phillips and Campbell > 20 cm/hr; Peters > 60 cm/hr). However, velocity in the above studies was measured at a given point within the streambed, while our values are average velocities based on cross sectional area and flow. Our field measured velocities more closely approximate those reported in the literature.

Dissolved Oxygen

The actual limiting factor in the successful development of embryos is dissolved oxygen. Because of lowered intragravel velocities, the delivery of oxygen to, and removal of metabolic wastes from embryos may also be reduced. Wickett (1958) and McNeil (1962, 1966) suggested that flow reductions may be accompanied by reductions in intragravel dissolved oxygen as a result of the postive influence surface velocity has on the hydraulic phenomenon of downwelling currents into the substrate (Vaux 1962, 1968). However, high oxygen levels do not necessarily gaurantee high embryo survival. As noted by Coble (1961), in two redds with similar dissolved oxygen levels but different intragravel velocities, development may be better in the redd with the higher exchange rate.

Fry Quality

In our Hayden Creek tests, differences were found in chinook alevin quality between the control (high) and test (low) flows, with total length and body weight greater in the control, and yolk weight greater in the test. These differences indicate that alevins produced from the test flow were at the time of sampling, less developed than control alevins. This developmental retardation probably resulted from lowered intragravel velocities and concomitant reduction in oxygen and metabolic waste transfer associated with the low flow conditions in the test channel. If these differences are developmental rather than morphological, fry produced from the test channel should ultimately emerge from the gravel at approximately the same size as control fry. Silver et al. (1963) stated that abnormally small alevins resulting from the incubation of eggs in low dissolved oxygens, cannot be expected to survive under natural conditions. Brannon (1965), however, described a stream situation in which sockeye salmon embyros were successfully incubated in low dissolved oxygens although resulting alevins were of reduced size. Subsequent sampling from the redds revealed the alevins survived and ultimately emerged. Brannon suggests that alevin quality is not necessarily a good index of their ability to survive.

In most tests conducted at the University of Idaho, we found no difference in fry quality resulting from the different intragravel velocities observed. Only in the test without sediment were significant differences observed in chinook length between high (778 cm/hr) and low (53 cm/hr) intragravel velocities. In similar studies, Silver et al. (1963) and Shumway et al. (1964) found that reductions in water velocity during the incubation period resulted in reductions in steelhead trout and coho salmon fry length. Silver's study indicated that fry length was influenced by water velocities as high as 740-1350 cm/hr. In contrast, a study by Brannon (1965) showed no difference in alevin size from embryos exposed to velocities between 180 and 27000 cm/hr. In our tests, mean intragravel velocities ranged from 1550 cm/hr (0% sediment) to 36 cm/hr (50% < 0.84 mm), although incubation was unsuccessful at velocities less than 118 cm/hr. Evidently, above this rate, oxygen transfer and waste removal were maximized and hence, did not adversely effect development. Bams and Simpson (1977) in their discussion of substrate incubators recommend minimum velocities of 200 cm/hr., but concede that under the right conditions flows of 100 cm/hr or less may be satisfactory. The right conditions are determined by a combination of temperature and dissolved oxygen.

Permeability

Gravel permeability can also be influenced by flow reductions, since stream competency is decreased precipitating the settling out of fine material. Sams and Pearson (1963) noted that permeabilities were much higher in stream areas that remained wet all year than in areas that were at times dry. Reduction in permeability may affect both intragravel velocity and dissolved oxygen transport. Redd permeabilities may decrease with time irrespective of flow reductions. Wickett (1960) noted similar temporal reductions in permeability during a study with pink salmon embryos. In our studies on Big Springs Creek, both permeability and dissolved oxygen levels decreased with time. Owing to the high percentage of fines comprising the substrate in Big Springs Creek, permeability and oxygen levels decreased rapidly (within days). In contrast, virtually no differences were noted for these ame parameters over a 60 day interval in Bear Valley Creek which contains low percentage fines. In many of our ig Springs Creek artificial redds, we found a positive correlation between dissolved oxygen and permeability. Tagart (1976) found an inverse correlation between dissolved oxygen and percentage fines suggesting a similar effect. Reductions in permeability (k) and its effects on intragravel velocity (Va) can, within limits be compensated for by increasing stream velocity(Vs) as suggested by the equation $Va = \frac{Vs^2 n\ k.}{2.222\ R}$ Thus, in streams containing high percentage fines, flow augmentation may be warranted.

Freezing

Reductions in flow during the fall and winter may expose redds to freezing conditions (Neave 1953, McNeil 1966). Evidence of intragravel freezing was present in the two shallowest redds in Bear Valley Creek and in two redds in our Hayden Creek test channels. In the latter situation freezing occurred in areas containing the highest sediment levels. Harshbarger and Porter (1979) found that embryos in Vibert boxes containing sediment were more susceptible to freezing than those without. Reiser and Wesche (1979) found evidence that although streamflow reductions increase the chances for freezing it is not a prerequisite for its occurrence. They observed intragravel freezing in three artificial brown trout redds which met established spawning criteria. In our Bear Valley Creek tests, water depths averaging 0.15 m and velocities averaging 0.30 mps were not affected by intragravel freezing.

Flow Requirements and Developmental Stage

Survivals in both our flow reduction and sediment tests were in all cases higher for eyed than for green fertilized eggs. No differences in chinook eyed egg survival between control and test flows were observed in the Hayden Creek tests. Although a certain amount of green egg mortality can be attributed to handling, this was minimized in several of our tests by obtaining eggs from fish spawned at the test facility and immediately placing them in the gravel. Survival from these eggs which were placed in vertical flow incubators often exceeded 90 percent.

Because the oxygen demand of embryos increases with development (Hayes et al. 1951), intuitively eyed eggs should be affected the most by flow reductions. Wickett (1954) has shown, however, that with respect to development, the embryonic stage just prior to the establishment of the circulatory system is the most critical, since up to this point, the larvae is wholly dependent on diffusion for its oxygen needs. Once the circulatory system is functional approximately at the eyed stage oxygen transport to the embryo becomes more efficient. Alderdice et al. (1958) indicated that early developing embryos have a "plasticity" which compensates for hypoxial conditions by reducing developmental rate. Evidence for this compensatory mechanism in our flow reduction tests manifested itself in differences in alevin yolk weight, body weight, and length between low and high flow tests. Alderdice et al. (1958) found that embryos were most sensitive to hypoxial conditions between 200-390 T.U. Extremely low oxygen levels during early development resulted in fry deformities. In our flow tests, there was no difference in the frequency of anomalies between control and test conditions. Alderdice indicated that embryos subjected to low oxygen levels just prior to hatching may hatch prematurely. Support for this contention in our study is found in comparisons of chinook fry length (fertilized eggs eyed at planting) in which mean length of control channel fry were in all cases longer than test channel fry.

The above evidence suggests that in general, reductions in flow made during early development of the embryos may result in higher mortalities than if made after the circulatory system is functional (approximately at eyeup).

Fry Emergence

Fry emergence from artificial redds having no surface flow posed no problem in sediment free substrate. Although we did not specifically quantify lateral emergence for the cutthroat, steelhead tests in which sediment was present, at the time of survival assessment 121 fry were observed from the low flow channel containing exposed redds and 166 from the control channel. Most fry were found in pools below riffles which contained the most sediment, suggesting some lateral movement was possible. A study of emergence by Bams (1969) indicated that the primary emergence response is geotactically induced and that only in the event of blockage of this mechanism does a secondary water flow oriented mechanism come into play. Bams cited such things as darkness, light or physical barrier as blocking the primary mechanism. The absence of surface flow could also act as a barrier and initiate the secondary response. Both Bams (1979) and Dill (1979) presented evidence for positive rheotaxis of laterally moving fry. Approximately one half of our emerged fry exhibited this behavior as evidenced by their recovery in pools above exposed redds. Provided sediment levels are not limiting, fry apparently have the ability for lateral movement in seeking successful emergence from within exposed redds. The extent of this ability was not determined.

The results of our tests and others noted above, contrasts with the common assumption expressed by Savage (1962) and restated in Stalnaker and Arnette (1976) that reductions in surface water from spawning levels will not reduce incubation potential provided redds are covered by some water and oxygen is sufficient.

Short-term reductions in flow, however, may be less deleterious to embryos since accompanying reductions in intragravel velocity and oxygen transport can be at least partially compensated for by natural convection processes (O'Brien et al. 1978). Bevan (1963) reported that relatively high survivals were obtained in tests conducted in the Soviet Union whereby chinook embryos were incubated in a refrigerator in petri dishes covered by 0.8-1.0 cm of standing water. Water was replaced every 2 or 3 days. Under these conditions, natural convection would be the only mechanism of oxygen transport to the embryos.

Flow Fluctuation

Our limited tests indicate that fluctuations in streamflow, (alternately watering and dewatering embryo) may not adversely affect incubation or resulting fry quality provided; temperature differentials between the intragravel dewatered environment and water temperature are within acceptable limits preventing thermal shock to the embryos, and incubating embryos remain moist during the period of redd dewatering. Moisture retention within a dewatered redd is largely a function of sediment level and sediment size. In our tests, survival of embryos incubated in substrate containing no fine sediment was only 2.7% compared to 77.5% to 96% in substrate containing various levels of sediment. Clearly, "some" sediment within the gravel is important to successful incubation of embryos which may periodically be dewatered.

Flow Cessation

Streamflow reductions and/or cessation may completely dewater salmonid redds. Results of our laboratory tests indicate that dewatered embryos can remain viable and continue embryogensis for a substantial period of time. Even after 6 weeks without water, chinook embryo survival averaged 32.9 percent. Although alevins were significantly smaller, their final size at the end of rearing tests at least equalled the fry from embryos continuously watered during incubation. Differences in alevin size may have been time related developmental differences rather than environmentally induced. Tests whereby we incubated embryos in moist cotton cloth resulted in hatching survivals ranging from 28 to 91% ($\overline{X}$ = 70.9). Water was "dripped" onto the embryos at a rate of 0.01 ml/min/embryo which was approximately 1.1% of that recommended by Bams and Simpson (1977) (0.89 ml/min/embryo) for chinook embryo incubation coincident with mean saturation levels of oxygen.

The role of fine sediment becomes even more important for embryos which are dewatered for long periods of time, in that sediment retards moisture loss from the surrounding embryos and provides an insulating layer to buffer temperature fluctuations associated with the external environment. The level of fine sediment is exceedingly important as it must also allow atmospheric oxygen infiltration to the embryos. In our first series of tests conducted at Hayden Creek, the sediment combination of 20% < 4.6 > 0.84 mm and 10% < 0.84 mm resulted in the highest survival while the level 10% < 0.84 mm had the least. The University of Idaho tests in contrast showed the highest survival in the 10% < 0.84 mm mixture followed closely by the combination noted above. This disparity can be partially explained by considering air temperatures. Hayden Creek tests were conducted outside and were thus subjected to temporal and diurnal fluctuation in temperature which on more than one occasion was lower than 0 C. In comparison, because of the controlled environment at the University of Idaho, air temperatures were held relatively constant (12-14 C). Results of the Hayden Creek tests are more applicable to natural situations.

Both Hobbs (1937) and Hardy (1963) have located brown trout (*Salmo trutta*) redds in the Selwyn River, New Zealand, in which water flow was below egg pockets. Hobbs found that even though water had not passed over the surface for 5 weeks, approximately 83% of the ova from a typical redd were alive. Hardy found healthy brown trout ova in redds dewatered from 2 to 5 weeks. Hawke (1978) in another study in New Zealand, found viable chinook salmon ova in redds which had been dewatered for 3 weeks. Substrate analysis revealed there was a high proportion of sand above the embryo pockets. In comparison, Thompson (1974) planted fertilized eyed steelhead eggs in artificial redds below Hells Canyon Dam and monitored survival under various flows. He noted that after a brief period of dewatering the eggs displayed significant mortality. This mortality may have resulted from the removal of sediment during the egg planting operation, with subsequent dewaterings of redds resulting in egg dessication. Our results support the findings of the former studies; that dewatered embryos can remain viable for a substantial period of time. A study by Reiser and White (1981 In Press) has specifically evaluated dewatering tolerances of chinook salmon and steelhead trout embryos.

Sediment

The effects of sediment on embryo incubation and fry emergence have been extensively studied. Stuart (1953), Koski (1966), Peters (1962), Bjornn (1969), Hall and Lantz (1969), Phillips et al. (1975), McCuddin (1977), and others have found inverse relationships between quantity of fine sediment, embryo survival and emergence. Meehan and Swanston (1977) suggest that sediment accumulation may be influenced by the shape of the gravel, with angular gravel tending to accumulate sediment faster than round gravel.

It is well known that incubating embryos are adversely affected by excessive amounts of sediment. Studies are now attempting to define the critical size and limits of sediment most deleterious to embryos and alevins. Sizes most often mentioned in this respect include 6.4 mm (Bjornn 1969, McCuddin 1977), 3.3 mm (Koski 1966, Tagart 1976), and 0.84 mm (McNeil and Ahnell 1964, Hall and Lantz 1969, Tagart 1976). Our studies using sediment mixes with and without the fraction of material < 0.84 mm, indicate that sediment < 0.84 mm is the most detrimental to incubating embryos. Survival was drastically reduced when sediment < 0.84 reached the 10% level while survivals resulting from sediment < 4.6 > 0.84 mm were not greatly affected until the 20% level. Even with sediment levels of material < 4.6 > 0.84 mm as high as 50%, steelhead eyed egg survival was 98% while green egg survival was 59 percent. Emergence from within such heavy concentrations of sediment, however, would be reduced or prevented. Embryo survivals resulting from specific combinations of both sizes of fine sediment tested were also more influenced by the fraction < 0.84 mm. Our results suggest that ambient levels of sediment < 0.84 mm should be less than 10% for successful embryo incubation and hatching.

Cloern (1976) reported coho salmon embryo survival of less than 2% when associated with fine sediment (< 0.84 mm) levels of 15% or greater. McNeil and Ahnell (1964) related gravel permeability to sediment < 0.84 mm. They considered permeabilities to be high and, therefore, conducive to embryo survival when the bottom materials contained less than 5% sediment < 0.84 mm, and low when materials contain more than 15 percent.

Using the permeability-sediment relationship we developed from Big Springs Creek tests, our 10% value would provide permeabilities of approximately 4600 cm/hr. Based upon the literature, Reiser and Bjornn (1979) recommended permeabilities in excess of 1300 cm/hr for salmonid embryo incubation.

Recently, there has been an added interest to formulate a reliable and standardized method for characterizing spawning gravels. To date, the most promising method is the use of the geometric mean diameter (dg), described by Platts et al. (1979), Shirazi and Seim (1979). Shurazi and Seim have shown a good relationship between embryo survival and geometric mean diameter using the results of several studies. Our chinook embryo survival results from the Hayden Creek tests follow a similar pattern when plotted on the same graph (Figure 32). Geometric mean diameters of approximately 17 mm appear to provide 90% or greater embryo survival.

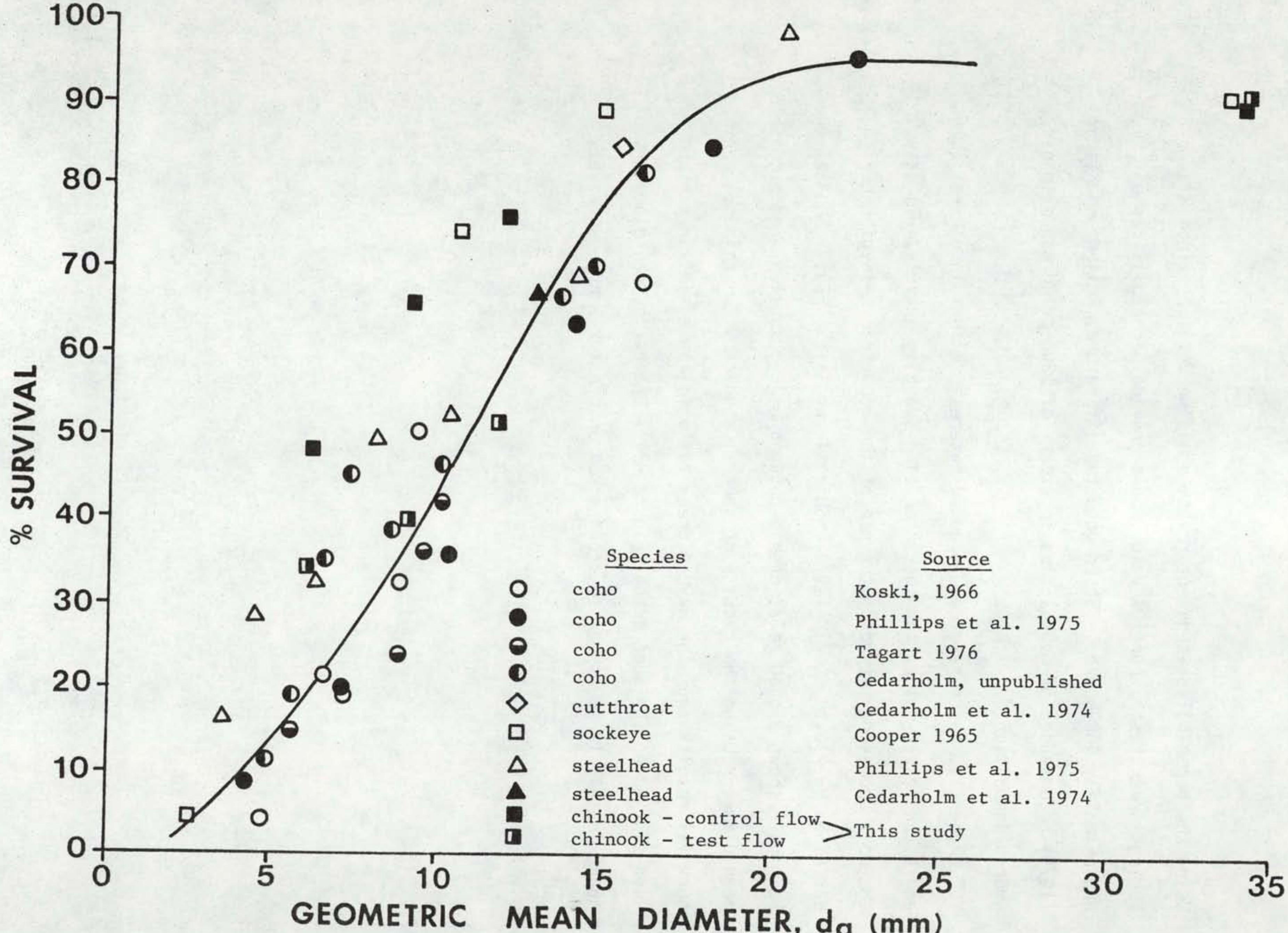


Figure 32. Relationship of egg survival to geometric mean diameter as indicated by previous investigations and this study. (Diagram modified from Shirazi and Siem 1979.)

Embryo Incubation Flow Methodology Development

Our approach to developing an incubation flow methodology was to relate intragravel parameters to extragravel parameters, and extragravel parameters to embryo survival. A good correlation would enable incubation flow recommendations to be based on easily measured extragravel parameters.

In our experiments, we found no consistently good correlation between embryo survival and extragravel flow parameters. Water depth and velocities over redds were of little value in predicting expected embryo-survival.

Sediment size and level were the key intragravel parameters for predicting embryo survival related to changes in flow with r^2 values ranging from 0.56 to 0.90. Our results show that severe reductions in flow may adversely affect embryo survival and development when sediment < 0.84 mm comprises approximately 3 to 13% of the substrate, with the greatest impacts potentially occurring at the 7% level. At this level, surface flows appear to have their greatest influence on embryo survival (Figure 33). At sediment levels greater than 13%, embryo survival is governed more by sediment than by surface flow. In our Hayden Creek tests, control channel (high flow) survival was 40% higher than in the test channel (low flow) with survival differences tapering off as sediment levels increased and decreased from 7 percent.

Because of the longevity of the incubation period, we were only able to test the extreme in flow reduction on embryo survival (i.e., no or little surface flow). To thoroughly describe the relationship of

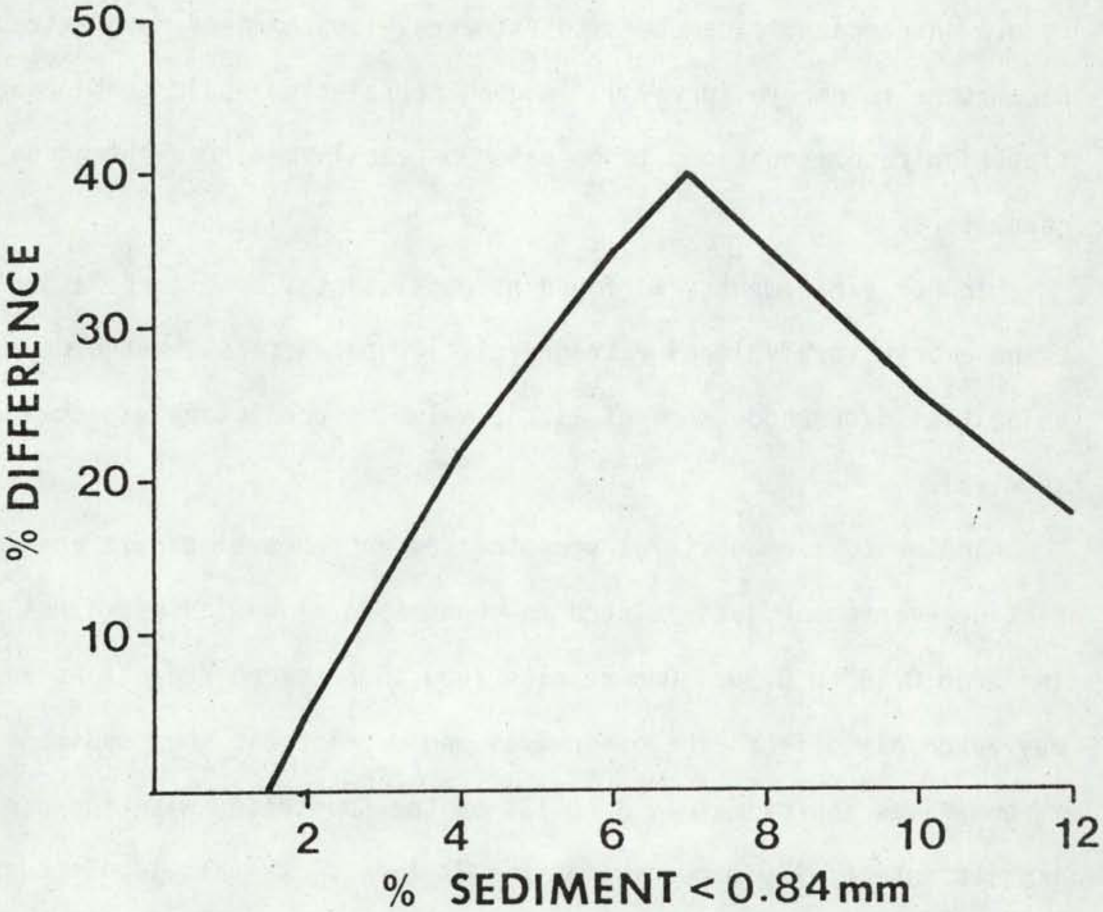


Figure 33. Percentage difference in spring chinook green egg survival between the control and test channel for a given percent sediment < 0.84 mm. Embryo survival was higher in the control channel. Control = high flow; Test = low flow, Hayden Creek Channels, fall 1978.

sediment-flow-embryo survival, other trials should be conducted using specified flow intervals in excess of the low flow.

Because sediment < 0.84 mm appears to be a primary factor in determining embryo survival, it is necessary to assess the amount present in spawning gravels before flow reductions are made. This necessitates the collection and analysis of several substrate samples from the spawning areas. To adequately describe spawning gravels, Shirazi and Seim (1979) recommended collection and analysis of a minimum of three substrate samples from riffle areas. For our tests, we utilized a modified core sampler designed by McNeil and Ahnell (1964). Samples should be analyzed using a series of 20.3 cm diameter sieves ranging in size from 75 mm to 0.425 mm. These series should include a number 20 sieve (0.84 mm diameter). If sediment < 0.84 mm comprises between 3-13% (most notably 7%), embryo survivals may be reduced following severe flow reductions. If flow reductions are to be made, they should occur after the time of eyeup when oxygen uptake mechanisms become more efficient. To prevent intragravel freezing, we recommend water depths $\geq$ 0.15 m and water velocities $\geq$ 0.30 mps over redds during the winter incubation period. These values are based on results of our Bear Valley Creek tests.

After thoroughly reviewing the literature on embryo incubation requirements, Reiser and Bjornn (1979) recommended intragravel velocities greater than 20 cm/h for suitable incubation. This value is dependent on other intragravel parameters (e.g., permeability) previously described. The technique described by Bovee and Cochnauer (1977) for computing intragravel velocity from extragravel parameters underestimated the point intragravel velocity as determined using field analysis. We did find good correlations between computed values and empirical values indicating sensitivity to change was similar. Because computed intragravel velocities appear to be conservative, we believe that flow recommendations based on this technique would provide for suitable intragravel velocities and therefore we recommend its use for determining incubation flows.

Empirical evaluation of sediment levels and theoretical determination of intragravel velocities should provide the necessary information for prescribing salmonid embryo incubation flows. This, however, assumes that both dissolved oxygen levels and temperatures are within acceptable limits.

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APPENDICES

APPENDIX I

Table 1. Substrate Composition for 23 Artificial Cutthrout and Steelhead Trout Redds From Control (High Flow) and Test (Low Flow) Channels - Samples were Collected after Assessment of Egg Survival. Hayden Creek Channels - Spring 1978.

		Percent of Substrate Passing Through Designated Sieve Size (mm)								dg Geometeric Mean
Redd No.	Channel	76.1	50.8	25.4	12.7	6.3	2.0	1.0	0.84	Diameter
1	Control	85.20	85.20	24.90	23.70	23.70	22.00	20.80	20.80	4.54
	Test	75.30	75.30	0.50	0.50	0.50	0.50	0.50	0.50	50.08
2	C	100	100	18.10	17.40	17.40	16.60	14.20	13.90	7.80
	T	100	100	0.70	0	0	0	0	0	34.20
3	C	100	85.80	12.60	12.10	12.00	10.80	6.90	6.60	37.04
	T	100	93.30	3.70	3.70	3.70	3.70	3.70	3.70	37.82
4	C	100	94.0	28.40	25.00	21.10	14.30	10.90	10.30	11.49
	T	100	92.20	29.30	23.30	18.30	9.50	6.00	6.00	14.54
5	C	100	100	29.30	25.80	19.10	10.40	5.20	4.20	13.42
	T	100	93.70	47.00	44.70	36.10	18.00	11.70	10.60	8.52
6	C	100	100	35.30	31.20	25.90	16.00	12.10	11.60	9.17
	T	100	94.90	21.70	18.40	14.60	7.00	3.70	2.80	19.67
7	C	100	100	48.30	42.10	30.60	13.10	7.60	7.60	10.23
	T	100	100	68.50	61.20	45.30	15.90	9.60	8.60	8.37
8	C	100	90.80	41.40	34.90	25.70	10.30	5.70	5.20	12.0
	T	100	100	56.40	51.40	36.50	17.50	11.10	10.60	8.05
9	C	100	100	53.60	50.80	37.90	16.50	8.70	7.40	8.72
	T	100	100	65.40	59.10	45.20	19.20	12.00	11.30	7.50
10	C	100	100	46.70	41.20	28.40	8.90	4.60	3.10	11.60
	T	100	100	45.40	42.50	31.90	9.30	6.10	6.10	10.89
11	C	100	100	43.20	38.80	30.70	15.70	9.90	9.10	9.06
	T	100	100	59.90	48.80	35.60	15.50	9.00	7.90	8.59
12	C	100	100	39.30	32.60	24.00	11.90	6.70	6.40	11.10
	T	100	100	52.80	46.40	33.80	14.90	9.10	8.00	8.84

Table 2. Substrate Composition of 12 Artificial Spring Chinook Salmon Redds From Control (C) (High flow) Test (t) Low Flow Channels - Hayden Creek Channels - Fall 1978.

		Percent of Substrate Passing Through Designated Sieve Size (mm)										
Redd No.	Channel	76.1	50.8	25.4	12.7	6.3	4.75	3.35	1.70	0.84	0 .425	Geometeric Mean Diameter (mm)
1	C	100	100	4.10	4.10	4.10	1.46	1.02	0.76	0.58	0.40	34.46
	T	100	100	12.60	4.40	4.40	4.40	3.28	2.54	1.80	1.06	33.82
2	C	100	94.0	2.90	2.90	1.60	1.03	0.84	0.52	0.33	0.20	34.29
	T	100	94.0	0.80	0	0	0	0	0	0	0	35.92
3	C	100	76.60	1.30	0.54	0.45	0.32	0.23	0.19	0.15	0.11	41.95
	T	100	100	0	0	0	0	0	0	0	0	34.32
4	C	-	-	-	-	-	-	-	-	-	-	-
	T	100	100	35.4	31.20	23.70	17.60	11.20	8.60	3.10	1.30	12.61
5	C	100	100	38.2	32.20	23.40	18.40	14.10	10.90	7.10	3.30	12.96
	T	100	97.70	50.6	43.80	35.00	27.50	21.60	13.70	8.10	3.41	9.61
6	C	100	94.50	35.30	31.40	25.70	20.90	17.80	10.70	7.40	2.00	11.81
	T	100	88.90	37.20	33.10	23.30	18.10	14.00	8.30	4.00	1.20	13.86
7	C	100	100	50.60	47.20	32.20	27.60	23.20	18.00	9.60	2.80	7.69
	T	100	100	53.60	48.20	38.90	32.40	26.10	15.70	9.00	5.70	7.71
8	C	100	100	62.90	56.40	43.50	35.40	28.90	17.60	7.90	3.10	8.02
	T	100	100	54.70	47.00	35.30	28.60	22.50	13.50	7.20	2.40	6.29
9	C	100	95.10	52.90	49.60	38.90	32.50	26.80	15.90	8.50	2.80	8.80
	T	100	100	49.20	41.10	30.80	25.20	18.70	10.60	5.90	1.60	10.45
10	C	100	89.00	54.60	48.00	35.60	28.40	20.60	17.70	14.20	5.50	7.38
	T	90.20	90.20	67.80	63.90	53.20	45.90	38.60	26.10	13.40	3.10	8.93
11	C	100	94.90	53.50	45.90	34.30	31.90	26.30	21.30	13.50	7.50	6.56
	T	100	100	62.40	55.60	44.30	40.00	33.40	25.00	17.60	5.40	5.22
12	C	100	100	57.50	52.30	41.90	36.70	30.50	19.10	9.80	1.50	6.84
	T	100	97.20	56.00	50.70	42.90	37.20	30.70	21.60	13.20	4.50	6.55

Table 3. Substrate Composition of 15 Artificial Steelhead and Cutthroat Trout Redds in Big Springs Creek, Idaho - 5/25/1978.

Percent of Substrate Passing Through Designated Sieve Size (mm)

Redd No.	76.1	50.8	25.4	12.7	6.3	2.0	1.0	0.84
1	100	69.90	46.40	33.90	24.10	13.40	9.50	9.10
2	100	100	79.90	67.70	50.50	29.30	19.20	18.00
3	100	80.90	60.90	44.80	31.90	16.90	9.40	8.50
4	100	91.70	65.30	47.30	34.30	17.50	10.40	9.10
5	100	80.50	63.50	49.30	33.80	19.40	13.60	12.70
6	100	88.70	65.80	51.00	41.40	26.70	17.20	15.70
7	100	80.80	62.50	47.00	36.50	25.40	17.40	16.60
8	100	100	81.90	65.80	50.00	31.90	17.20	16.00
9	100	100	81.80	61.00	43.90	28.90	19.80	17.40
10	100	94.00	81.60	61.40	44.40	23.00	13.20	12.10
11	100	81.50	67.50	55.50	44.90	28.20	15.50	13.50
12	100	100	84.40	72.90	61.80	48.30	29.9	28.80
13	78.5	74.80	64.50	49.00	38.70	24.20	10.80	10.20
14	100	94.50	77.50	56.10	42.80	30.80	23.60	22.10
15	100	91.20	65.50	43.30	29.20	17.60	10.90	10.00

Table 4. Substrate Composition of 17 Artificial Chinook Salmon Redds in Big Springs Creek, Idaho - 9/ 1/1978

Percent of Substrate Passing Through Designated Sieve Size (mm)

Redd No.	76.1	50.8	25.4	12.7	6.3	4.75	3.35	1.70	0.84	0.425
1	85.10	71.60	57.70	45.00	32.50	27.90	21.70	14.10	9.50	4.70
2	100	97.90	83.80	63.50	45.00	39.60	33.40	24.20	13.50	4.00
3	82.60	78.60	59.50	45.10	39.90	34.70	30.20	26.20	18.50	8.80
4	100	89.10	69.00	54.70	41.10	35.20	29.70	20.10	13.00	6.90
5	100	88.90	65.80	52.10	41.00	35.70	30.40	19.60	11.40	7.00
6	100	85.80	57.30	45.40	34.40	30.10	25.60	20.40	14.10	10.10
7	100	95.80	81.00	65.80	50.60	44.60	37.10	27.50	17.90	7.30
8	100	100	78.50	60.70	47.70	43.20	38.70	33.00	20.40	10.90
9	100	92.90	83.60	63.30	53.30	49.60	44.10	34.30	23.10	16.00
10	100	100	74.60	58.00	42.80	39.10	34.00	26.10	18.20	10.90
11	100	89.90	64.40	49.60	38.10	34.10	29.40	23.10	14.70	8.40
12	100	100	74.30	40.80	29.10	25.70	21.70	18.10	11.70	6.00
13	100	100	74.10	45.00	31.90	26.40	21.80	13.30	8.20	3.60
14	100	100	80.30	68.20	59.20	53.90	48.60	36.00	27.60	8.20
15	100	100	63.80	43.40	32.10	28.30	24.50	18.70	13.20	5.90
C1	100	100	78.30	50.50	39.40	35.00	31.70	25.60	18.90	10.60
C2	100	93.00	67.30	49.30	34.80	29.20	24.60	18.60	12.80	7.00

Table 5. Substrate Composition of 12 Artificial Chinook Salmon Redds in Bear Valley Creek, Idaho as Determined from Samples Taken During Egg Planting (9/26/1978) and Fry Recovery (5/25/1979)

Redd No.	(Date)	Percent of Substrate Passing Through Designated Sieve Size (mm) 76.1	50.8	25.4	12.7	6.3	4.75	3.35	1.70	0.84	0.425	dg Geometeric Mean Diameter
1	9-26-78	100	94.0	59.30	40.20	27.50	23.30	17.50	11.50	7.10	0.10	11.0
	5-25-79	100	60.68	48.52	29.79	14.68	11.01	7.85	2.93	1.58	1.01	19.8
2	9-26-78	100	81.70	51.00	27.90	13.90	10.30	6.30	2.50	0.10	0	19.5
	5-25-79	65.38	50.53	29.78	16.55	8.94	7.42	6.22	4.24	3.04	1.38	33.9
3	9-26	100	72.90	57.70	40.0	27.8	23.30	18.80	10.00	5.50	2.10	11.8
	5-25	100	82.89	60.08	29.00	11.97	8.28	4.59	2.74	1.94	1.46	18.6
4	9-26	100	100	82.80	64.30	46.40	41.30	35.40	32.80	27.40	13.60	3.6
	5-25	100	91.74	79.81	51.06	37.21	34.89	33.03	28.75	17.62	10.07	5.3
5	9-26	100	91.40	61.90	43.30	28.90	24.90	21.10	15.70	9.90	2.90	8.9
	5-25	100	83.52	62.10	36.44	21.37	18.50	13.51	8.94	5.93	2.35	14.4
6	9-26	100	80.80	58.8	40.60	28.50	24.20	21.20	14.10	9.60	5.10	10.5
	5-25	100	93.12	59.4	32.00	20.30	18.50	14.30	10.50	7.00	3.80	13.7
7	9-26	100	93.80	68.10	47.30	34.40	29.70	24.70	20.20	14.80	6.90	6.0
	5-25	100	92.61	81.25	58.73	41.19	35.97	30.80	23.60	17.37	7.07	4.9
8	9-26	100	73.90	41.60	22.40	9.10	7.50	5.90	3.20	3.20	3.20	23.8
	5-25	100	88.96	54.61	28.96	19.22	17.08	16.50	14.62	12.41	8.25	12.0
9	9-26	100	87.40	58.50	36.30	29.90	25.30	20.70	14.50	9.60	3.90	9.2
	5-25	100	94.29	58.43	36.86	23.62	18.90	16.63	11.85	7.65	2.23	11.5
10	9-26	100	76.40	49.80	33.10	20.30	15.60	11.10	6.40	2.90	1.00	17.3
	5-25	100	83.67	51.75	35.54	22.89	17.98	13.38	7.00	3.62	1.59	14.5
11	9-26	100	86.50	69.30	52.90	37.30	32.0	27.30	17.90	7.90	3.40	8.2
	5-25	100	94.95	49.94	34.99	22.75	19.29	16.00	10.73	6.61	2.93	10.1
12	9-26	100	94.40	66.80	46.90	31.20	23.20	19.80	13.40	9.20	4.60	9.6
	5-25	100	87.93	66.12	43.92	31.38	23.59	18.14	9.88	4.74	0	11.5
13	9-26	100	100	77.40	49.10	28.10	21.50	15.10	9.80	6.00	0	10.4
	5-25	100	100	76.19	33.05	15.16	12.43	9.63	4.69	3.39	1.05	14.5

APPENDIX II

Table 1. Results of Duncan's Multiple Range Test for Steelhead Alevin Quality Parameters Resulting from Intragravel Flow Incubation Tests Within 16 Sediment Mixes[a/].
Spring 1978 - University of Idaho

Parameter	Smallest														Largest
Total Length (mm)	12	2	3	10	4	11	13	7	15	9	1	8	6	5	16
Total Weight (mg)	10	8	7	13	15	1	4	5	16	2	6	3	12	11	9
Yolk Weight (mg)	8	16	1	4	13	7	5	10	6	15	2	11	3	9	12
Body Weight (mg)	10	3	12	7	15	13	8	5	2	11	4	6	1	16	9
Total Wet Weight (mg)	10	8	7	13	15	1	4	5	16	2	6	3	12	11	9

*note - Sed 14 (20% < 4.6 > 0.84)
30% < 0.84

Note used in comparison owing to small sample size, N=4

Table 1. (Cont.)

Parameter	Smallest-----------------------------------Largest														
Wet Weight Condition Factor KWW	16	8	5	1	6	13	15	7	4	11	9	10	2	3	12
Dry Weight Condition Factor KDW	16	8	1	5	6	13	15	7	4	11	9	10	2	3	12
Developmental Index KD	16	1	8	5	6	7	13	15	4	11	10	9	3	2	12

KEY

No.	SED%
1	0
2	10%<0.84
3	20%<0.84
4	30%<0.84
5	10%<4.6>0.84
6	20%<4.6>0.84
7	30%<4.6>0.84
8	50%<4.6>0.84
9	5%<4.6>0.84;5%<0.84
10	10%<4.6>0.84;10%<0.84
11	20%<4.6>0.84;10%<0.84
12	10%<4.6>0.84;20%<0.84
13	30%<4.6>0.84;20%<0.84
14	20%<4.6>0.84;30%<0.84
15	40%<4.6>0.84;10%<0.84
16	Incubators

Means are in increasing order from left to right. For specific values See Table 1, Appendix II.
Means not underlined by a common line are significantly different from each other ($\alpha = 0.05$).

a/ * Sed 14 - (20%<4.6>0.84; 30%<0.84) was not used in comparisons due to its small sample size (N=4).

Table 2. Results of Duncan's Multiple Range Test for Chinook Alevin Quality Parameters Resulting from Intragravel Flow Incubation Tests Within 12 Sediment Levels.
Fall 1979 - University of Idaho

Parameter	Smallest											Largest
Total Length (mm)	5	9	10	60	3	7	11	2	4	18	1	12
	___	___	___	___	___	___	___	___				
								___	___	___	___	
												___
Total Weight (mg)	8	9	3	7	4	1	5	2	6	10	11	12
	___	___	___	___	___	___	___	___	___	___	___	
							___	___	___	___	___	___
Yolk Weight (mg)	8	1	4	7	12	3	9	2	5	6	11	10
	___	___	___	___	___	___	___	___				
				___	___	___	___	___	___	___	___	
					___	___	___	___	___	___	___	___
Body Weight (mg)	9	10	6	3	5	11	7	2	4	8	1	12
	___	___	___	___	___	___						
		___	___	___	___	___	___					
						___	___	___				
								___	___	___	___	
												___
Dry Wet Condition KDW Factor	8	1	12	4	7	3	2	9	11	6	10	5
	___	___	___	___	___	___	___	___				
					___	___	___	___	___	___	___	
							___	___	___	___	___	___

Means are in increasing order from left to right. For specific values See Table 2, Appendix II.
Means not underlined by a common line are significantly different from each other ($\alpha = .05$)

KEY

No.	SED%
1	0
2	10%<0.84
3	20%<0.84
4	10%<4.6>0.84
5	20%<4.6>0.84
6	30%<4.6>0.84
7	50%<4.6>0.84
8	5%<4.6>0.84;5%<0.84
9	10%<4.6>0.84; 10%<0.84
10	10%<4.6>0.84;20%<0.84
11	20%<4.6>0.84; 10%<0.84
12	Incubators

Table 3. Results of Duncan's Multiple Range Test for Steelhead Alevin Quality Parameters Resulting from Intragravel Flow Incubation Tests Within 16 Sediment Levels. Eggs placed in Lower Chamber of WV Box Containing Gravel. Spring 1979 - University of Idaho

Parameter	Smallest															Largest
Total Length (mm)	12	4	2	10	7	16	9	6	1	11	3	8	5	15	13	14
	—	—														
		—	—	—	—	—										
			—	—	—	—	—	—	—	—	—	—				
				—	—	—	—	—	—	—	—	—	—			
														—		
															—	—
Total Weight (mg)	15	16	11	7	9	12	13	6	14	3	5	8	1	4	10	2
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
													—	—	—	—
Yolk Weight (mg)	14	13	15	8	16	9	11	6	1	3	5	7	10	4	12	2
	—	—														
		—	—	—	—											
			—	—	—	—	—									
				—	—	—	—	—	—	—	—	—	—			
								—	—	—	—	—	—	—		
													—	—	—	—
Body Weight (mg)	12	7	4	6	3	5	2	16	11	9	10	1	8	15	13	14
	—															
		—	—	—	—	—	—	—								
			—	—	—	—	—	—	—	—	—	—				
							—	—	—	—	—	—	—			
										—	—	—	—	—		
														—	—	
																—
Dry Weight Condition Factor KDW	14	13	15	5	11	3	16	9	6	8	1	7	10	2	4	12
	—	—	—													
			—	—	—	—	—	—	—	—	—					
				—	—	—	—	—	—	—	—	—				
					—	—	—	—	—	—	—	—	—	—	—	
													—	—	—	—

KEY

No.	SED%
1	0
2	10%<0.84
3	20%<0.84
4	30%<0.84
5	10%<4.6>0.84
6	20%<4.6>0.84
7	30%<4.6>0.84
8	50%<4.6>0.84
9	5%<4.6>0.84;5%<0.84
10	10%<4.6>0.84;10%<0.84
11	20%<4.6>0.84;10%<0.84
12	10%<4.6>0.84;20%<0.84
13	30%<4.6>0.84;20%<0.84
14	20%<4.6>0.84;30%<0.84
15	40%<4.6>0.84;10%<0.84
16	Incubators

Means are in increasing order from left to right. For specific values See Table 3, Appendix.
Means not underlined by a common line are significantly different from each other ($\alpha = .05$)

Table 4. Results of Duncan's Multiple Range Test for Steelhead Buttonup Quality Parameters Resulting from Intragravel Flow Incubation Tests Within 16 Sediment Levels.[a/]

Parameter	Smallest-------------------------------------Largest														
Total Length (mm)	2	13	12	14	16	3	15	11	10	6	7	1	9	8	5
Fork Length (mm)	13	12	2	14	16	3	15	11	10	6	7	1	9	8	5
Total Weight (mg)	16	8	15	11	6	7	5	10	13	14	9	3	12	1	2
Total Wet Weight (mg)	16	8	15	11	6	7	5	10	13	14	9	3	12	1	2

Table 4. (Cont.)

Parameter	Smallest														Largest
Wet Weight Condition Factor KWW	5	8	16	6	7	15	11	10	9	1	3	14	13	12	2
Dry Weight Condition Factor KDW	8	16	5	6	7	15	11	10	9	1	14	3	13	12	2
Developmental Index KD	8	5	16	6	7	15	11	10	9	1	14	3	13	12	2

Means are in increasing order from left to right. For specific values See Table 4, Appendix II.
Means not underlined by a common line are significantly different from each other ($\alpha = .05$)

a/ Sed 4 (30%<0.84) was not used in comparisons due to its small sample size N=4.

KEY

No.	SED%
1	0
2	10%<0.84
3	20%<0.84
4	30%<0.84
5	10%<4.6>0.84
6	20%<4.6>0.84
7	30%<4.6>0.84
8	50%<4.6>0.84
9	5%<4.6>0.84;5%<0.84
10	10%<4.6>0.84;10%<0.84
11	20%<4.6>0.84;10%<0.84
12	10%<4.6>0.84;20%<0.84
13	30%<4.6>0.84;20%<0.84
14	20%<4.6>0.84;30%<0.84
15	40%<4.6>0.84;10%<0.84
16	Incubators

Table 5. Results of Duncan's Multiple Range Test for Chinook Buttonup Fry Quality Parameters Resulting from Artificial Redds in Bear Valley Creek Incubation Tests. Fall 1978

Parameter	Smallest-----------------------------------Largest										
Total Length (mm)	3	10	13	4	11	8	2	12	9	7	6
Fork Length (mm)	4	13	3	10	11	2	8	12	9	6	
Total Weight (mg)	6	7	8	9	10	11	2	4	12	3	13
Dry Weight Condition Factor KDW	6	8	9	12	2	11	10	3	13	4	

Means are in increasing order from left to right. For specific values See Table 5, Appendix II.
Means not underlined by a common line are significantly different from each other ($\alpha = .05$)

APPENDIX III

Table 1. Sediment Level and Resulting Steelhead Alevin Quality (Mean and Range Length, Yolk Weight, Body Weight, Total Weight, Wet Weight, Developmental Index KD and Condition Factors) From Intragravel Flow Egg Incubation Tests. Eggs Placed in Lower Chambers of WV Box Without Gravel. University of Idaho - Spring 1978.

Sediment Level	N	Mean Length (mm)	Range	Mean Yolk Weight (mg)	Range	Mean Body Weight (mg)	Range	Mean Total Weight (mg)	Range	Mean Total Wet Weight (mg)	Range	Mean Dev. Index KD	Mean Wet Condition KWW	Mean Dry Condition KDW
0	34	18.59	14.5-20.5	38.76	32.80-52.1	6.08	1.5-10.5	44.84	37.6-59.4	129.09	110.9-165.7	5.99	2.00	6.95
10%<0.84	24	16.50	13.5-19.0	40.42	35.7-48.1	5.54	2.2-11.0	45.96	40.5-53.6	131.91	118.2-151.1	7.00	3.07	10.69
20%<0.84	15	16.66	13.0-18.5	42.14	33.6-50.7	3.81	1.3-6.2	46.29	38.6-53.2	132.72	113.4-150.9	6.97	3.07	10.72
30%<0.84	11	17.23	15.5-19.0	39.04	35.9-41.8	5.88	3.6-8.1	44.92	41.1-48.0	129.29	119.7-137.0	6.62	2.59	9.02
10%<4.6 >0.84	25	18.70	17.5-19.5	39.74	32.0-48.2	5.44	4.0-8.2	45.18	38.3-52.3	129.9	112.6-147.8	6.10	2.00	6.96
20%<4.6 >0.84	27	18.61	16.5-20.0	39.95	35.7-51.7	6.06	4.1-7.7	46.01	40.5-59.2	132.04	118.2-165.1	6.18	2.07	7.23
30%<4.6 >0.84	32	17.36	14.0-20.0	39.52	32.1-45.3	4.17	1.10-6.30	43.69	36.9-49.4	126.21	109.1-140.5	6.51	2.51	8.67
50%<4.6 >0.84	42	18.59	16.5-21.0	38.17	32.6-47.6	5.32	2.50-9.70	43.49	37.7-51.8	125.70	111.2-146.6	6.04	1.98	6.87
5%<4.6 >0.84+ 5%<0.84	44	17.56	12.5-20.0	42.32	33.9-52.1	7.19	2.0-17.8	49.51	38.4-61.8	140.81	112.9-171.7	6.80	2.75	9.66
10%<4.6 >0.84+ 10%<0.84	42	16.69	13.0-19.5	39.87	34.6-50.5	3.39	0.3-5.1	43.26	39.0-52.0	125.11	114.4-147.0	6.76	2.85	9.87
20%<4.6 >0.84+ 10%<0.84	49	17.28	15.0-19.0	41.48	35.6-51.8	5.74	2.3-8.2	47.22	41.4-57.3	135.07	120.4-160.4	6.75	2.68	9.37
10%<4.6 >0.84+ 20%<0.84	27	16.18	12.5-19.0	42.56	36.2-54.2	3.88	1.5-5.9	46.44	39.9-59.4	133.12	116.7-165.7	7.22	3.41	11.91
30%<4.6 >0.84+ 20%<0.84	7	17.36	16.0-18.5	39.04	35.7-46.3	5.10	3.7-7.0	44.14	41.4-50.8	127.34	120.4-144.1	6.52	2.48	8.61
20%<4.6 >0.84+ 30%<0.84	4	18.12	17.0-19.0	43.72	41.0-47.2	7.92	7.0-9.3	51.65	48.4-54.2	146.19	138.0-152.6	6.68	2.49	8.78
40%<4.6 >0.84+ 10%<0.84	37	17.40	15.0-19.5	40.07	35.4-48.5	4.76	2.2-7.6	44.83	39.5-53.2	129.06	115.7-150.1	6.54	2.49	8.64
Incubators	43	19.38	18.0-21.0	38.76	34.1-46.4	7.02	4.5-10.2	45.77	40.0-52.9	131.43	116.9-149.3	5.92	1.82	6.32

Table 2. Sediment Level and Resulting Chinook Alevin Quality (Mean and Range Total Length, Yolk Weight, Body Weight, Total Weight and Dry Condition Factor KDW) for Intragravel Flow Egg Incubation Tests. Eggs Placed in Lower Chambers of WV box Without Gravel. University of Idaho - Fall 1978.

Sediment Level	N	Mean Length (mm)	Range	Mean Yolk Weight (mg)	Range	Mean Body Weight (mg)	Range	Mean Total Weight (mg)	Range	Mean Dry Condition KDW
0	24	26.50	24.5-28.5	38.80	18.8-62.1	22.52	14.9-30	61.33	38.8-83.2	3.26
10%<0.84	6	25.00	24-26	45.2	24.4-71.3	19.93	15.6-24.9	65.13	40.1-86.9	4.23
20%<0.84	13	24.12	19-28	42.17	25.9-59	14.93	6.5-24.3	57.1	42.8-79.3	4.19
10%<4.6>0.84	39	25.85	22.5-28.5	40.02	16.9-62.8	20.74	10.5-30.7	60.61	35.8-86.6	3.55
20%<4.6>0.84	27	23.52	17.5-28.5	48.80	20.1-80.6	15.54	4.8-26.7	63.34	36.1-99.3	5.48
30%<4.6>0.84	13	24.08	21-26.5	50.58	22.9-78.1	14.77	6.1-24.3	65.36	41.6-93.9	4.79
50%<4.6>0.84	21	24.43	22-27	41.02	24.9-60.4	18.16	11.2-26.1	59.18	40.4-83.7	4.13
5%<4.6>0.84+ 5%<0.84	17	25.97	23-28	33.85	19.8-61.3	21.99	17.7-29.3	55.84	38.8-79.0	3.21
10%<4.6>0.84 10%<0.84	7	23.64	22-26	43.10	26.3-67.0	12.87	6.9-19.7	55.97	39.2-76.2	4.35
10%<4.6>0.84 20%<0.84	13	23.96	20.5-28	53.37	23.4-85.2	13.81	5.6-17.7	67.05	40.7-99.9	5.24
20%<4.6>0.84 10%<0.84	18	24.55	21-27	50.82	30.6-74.8	16.56	9.8-25.4	67.98	44-90.8	4.72
Incubators	20	27.97	26.5-29	42.04	27.3-53.7	30.81	25.8-35.9	72.81	54.4-83.7	3.33

Table 3. Sediment Level and Resulting Steelhead Alevin Quality (Mean and Range Length, Yolk Weight, Body Weight, Total Weight and Dry Condition Factor) From Intragravel Flow Egg Incubation Tests.
Eggs Placed in Lower Chamber of WV Box With Gravel.
University of Idaho - Spring 1979.

Sediment Level	N	Mean Length (mm)	Range	Mean Yolk Weight (mg)	Range	Mean Body Weight (mg)	Range	Mean Total Weight (mg)	Range	Mean Dry Condition KDW
0	20	19.92	17.5-21	34.54	30-39.3	9.77	5.9-12.5	44.32	39.4-49.2	5.65
10%<0.84	34	19.41	17.5-22	37.14	30.9-43.7	9.06	5.1-14.9	46.21	39.7-52.2	6.45
20%<0.84	35	20.84	15-22	34.67	27.4-44.0	8.82	4.8-12.9	43.50	37.1-51.0	5.56
30%<0.84	29	18.93	14-21	36.58	27.9-46.2	8.12	2.5-13.4	44.70	33.9-52.3	6.98
10%<4.6>0.84	41	20.32	18.5-21.5	34.71	29.3-42.1	8.89	5.6-11.8	43.68	38.8-49.2	5.25
20%<4.6>0.84	39	19.88	17-21.5	34.39	30-43.2	8.82	5-12.1	43.21	37.6-48.3	5.60
30%<4.6>0.84	44	19.74	15-21.5	35.09	30-44.2	7.82	3.1-12.4	42.91	34-52.6	5.80
50%<4.6>0.84	42	20.06	15-23.5	33.30	27.2-42.8	10.39	3.3-16.1	43.70	36.8-50.1	5.62
5%<4.6>0.84+ 5%<0.84	42	19.77	17.5-21.0	33.59	28.8-39.0	9.44	4.6-14.2	43.03	35.5-49.3	5.60
10%<4.6>0.84+ 10%<0.84	42	19.68	11.5-21.5	35.24	28.8-48.4	9.52	3.3-13.8	44.76	36.6-56.2	6.41
20%<4.6>0.84+ 10%<0.84	42	20	16.5-22	33.60	27-41.7	9.36	3.6-13.4	42.84	36.5-51.0	5.47
10%<4.6>0.84+ 20%<0.84	39	18.68	13-21.5	37.10	15.4-48.9	5.96	0.4-9.90	43.06	18.2-50.7	7.07
30%<4.6>0.84 20%<0.84	43	21.71	16.5-26.5	31.38	18.4-43.8	11.71	5.7-22.1	43.10	24.4-50.4	4.40
20%<4.6>0.84 30%<0.84	45	22.14	16-25	29.90	17.2-48.7	13.50	3.5-21.8	43.39	33.9-65.2	4.17
40%<4.6>0.84 10%<0.84	39	21.06	15.5-23	31.91	23.5-44.4	10.83	2.8-17.6	42.79	37.6-51.1	4.73
Incubators	21	19.76	18-21	33.38	29.2-40.5	9.16	4.6-12	42.82	38-48.9	5.59

Table 4. Sediment Level and Resulting Steelhead Buttonup Fry Quality (Mean and Range Total Length, Fork Length, Total Weight, Total Wet Weight, Developmental Index KD and Condition Factors) for Intragravel Flow Egg Incubation Tests. Eggs Placed in Lower Chambers of WV Box Without Gravel. University of Idaho - Spring 1978.

Sediment Level	N	Mean Total Length (mm)	Range	Mean Fork Length (mm)	Range	Mean Total Weight (mg)	Range	Mean Total Wet Weight (mg)	Range	Mean Dev. Index KD	Mean Wet Condition KWW	Mean Dry Condition KDW
0	30	29.02	27-30.5	28.43	25.5-30	40.21	32.2-47.6	234.75	206.4-260.9	5.39	1.02	1.75
10%<0.84	46	28.12	26-30	27.69	25.5-30	41.71	31.2-52	240.04	202.9-276.4	5.59	1.13	1.97
20%<0.84	38	28.50	25.5-30.5	27.93	25-30	39.66	31-51.3	232.80	202.2-273.9	5.47	1.08	1.83
30%<0.84	4	27.87	27-29	27.50	26.5-29	39.97	37.8-43	233.92	226.2-244.6	5.56	1.13	1.92
10%<4.6>0.84	43	29.37	27.5-31.5	28.84	26.5-30.5	36.70	27.1-44.8	222.36	188.4-250.9	5.17	1.53	1.45
20%<4.6>0.84	42	28.92	27-30.5	28.37	26.5-30	36.58	29.1-46.8	221.93	195.5-258.0	5.25	0.97	1.60
30%<4.6>0.84	42	28.98	26.5-31.0	28.40	26.5-31	36.62	30.8-45	222.09	201.5-251.7	5.25	0.97	1.51
50%<4.6>0.84	46	29.09	27.5-31.0	28.55	27-31	34.87	27.8-41.3	215.9	190.9-238.6	5.15	0.93	1.50
5%<4.6>0.84+ 5%<0.84	34	29.05	26-31	28.5	25.5-30	39.32	33.6-46.7	231.61	211.4-257.7	5.34	1.01	1.71
10%<4.6>0.84 10%<0.84	41	28.72	27-31	28.19	25-30.5	37.19	30.3-46.9	224.08	199.7-258.4	5.31	1.01	1.67
20%<4.6>0.84 10%<0.84	45	28.71	27-30.5	28.15	26.5-30	36.54	29.2-53.6	221.79	195.8-282.1	5.28	1.00	1.64
10%<4.6>0.84 20%<0.84	46	28.27	26.5-30	27.66	26-29.5	39.77	32.1-48.1	233.22	206.1-262.6	5.52	1.10	1.88
30%<4.6>0.84 20%<0.84	47	28.13	25.5-30	27.56	25-29.5	38.26	29.8-45.6	227.86	198.0-253.8	5.48	1.09	1.84
20%<4.6>0.84+ 30%<0.84	40	28.31	25-30.5	27.72	24.5-30	38.60	29.8-44.6	229.90	198.0-250.3	5.46	1.08	1.83
40%<4.6>0.84+ 10%<0.84	43	28.58	25-30.5	28.07	24-30	35.76	28.3-42.3	219.04	192.6-242.1	5.28	1.00	1.62
Incubators	41	28.49	26.5-31.0	27.88	26.5-30	32.62	27.3-38.7	207.9	189.1-229.4	5.18	0.96	1.51

Table 5. Hydraulic Parameters and Associated Chinook Buttonup Fry Quality (Total Length, Fork Length, Total Dry Weight and Dry Weight Condition Factor) From 15 Artificial Redds Constructed in Bear Valley Creek, Idaho - 5/25/79.

Redd No.	Water Depth(cm)	Water Velocity (cm/s) at 0.6 depth	N	Mean Total Lgth.(mm) s^2	Range Tot. Length	Mean Fork Lgth.(mm) s^2	Range Fork Length (mm)	Mean Total Dry Wt.(mg) s^2	Range Total Wt.(mg)	Mean Dry Wt Condition Factor Kdw
1	9.14	39.62	0 1/	-	-	-	-	-	-	-
2	16.76	62.48	14	34.07 (.2640)	33.5-35.0	32.50 (.1150)	32-33	56.50 (3.158)	53.9-59.8	1.646
3	13.72	32.00	23	33.22 (.4733)	32-34	32.22 (.2460)	31-33	56.80 (7.486)	51.8-62.7	1.698
4	15.24	25.91	19	33.37 (.6623)	31.5-35	31.92 (.3684)	30.5-33	56.63 (9.893)	52.7-63	1.741
5	4.57	45.72	0 1/	-	-	-	-	-	-	-
6	9.14	38.10	14	36.86 (.3242)	36-38	35.68 (.4849)	34.5-37	47.94 (4.200)	45.5-51.8	1.053
7	21.34	15.24	23	35.65 (.8508)	33.5-37	-	-	48.07 (31.140)	27.9-58.1	1.061 2/
8	15.24	19.81	19	33.68 (.4225)	32.5-35	32.68 (.3114)	32-34	52.13 (12.606)	44.3-55.8	1.494
9	15.24	50.29	20	33.95 (.0037)	32-35	32.83 (.4809)	31-34	55.10 (10.240)	59.6-60.6	1.557
10	12.19	38.10	19	33.26 (.2047)	32.5-34	33.24 (.2325)	31.5-33	56.00 (10.141)	51.3-64.8	1.525
11	10.67	16.76	14	33.64 (.7850)	32-35	32.39 (.3919)	31-33	56.10 (8.41)	49.9-60.6	1.651
12	12.19	22.86	19	34.08 (.6184)	32-35	32.79 (.5365)	31-34	56.63 (7.116)	49.4-60.3	1.606
13	15.24	13.72	16	33.31 (.2958)	32-34	32.06 (.3292)	31-33	57.06 (20.23)	43.4-63.7	1.732
Control 1 3/	22.86	32.00	20	34.80 (.7225)	33.5-36	33.45 (3600)	32-34.5	32.70 (20.25)	26-45.4	.8737
Control 2	24.38	32.00	0 3/	-	-	-	-	-	-	-

1/ 0% survival of fry; redd exposed to freezing temperatures

2/ Computed using Total Length

3/ Egg survival assessed 7/17/79 - fry in poor condition

Table 6. Sediment Level and Resulting Sample Mean (Range) Length, Yolk Weight, Body Weight, Total Weight and Condition Factor (Kdw) for Chinook Alevin From Watered Versus Dewatered Artificial Redds and From Drip Incubation Tests. Hayden Creek Research Station - Fall 1978.

Chinook Alevin - Dewatering Tests HCRS <u>Eggs planted 8/24/78</u>
- Drip Incubation Tests

Chamber #	Condition (Duration)	Date1/ Sample	N	Sediment Content	Mean Lgth (mm) (S^2)	Range Length(mm)	Mean Yolk Wt.(mg) (S^2)	Range Yolk Wt.	Mean Body Wt.(mg) (S^2)	Range Body wt.	Mean Total Wt. (mg) (S^2)	Range Total Wt. (mg)	Dry Mean Condition Factor Kdw
1	Watered	2/		30%<4.6>0.84									
2	Dewatered	10/28/78	13	and	16.58	15.5-17.5	45.79	39.5-52.3	4.02	2.8-5.9	49.81	42.8-55.1	11.035
	(42 days)			20%<0.84	(.4102)		(13.54)		(.61)		(13.91)		
3	D	10/28/78	13		17.35	16.0-18.5	45.18	40.5-52.1	4.18	2.0-6.3	49.37	44.5-56.2	9.578
	(42 days)			20%<4.6>.084	(.5994)		(10.50)		(1.44)		(8.82)		
4	W	11/2/78	14		19.50	18-20.5	41.65	40.4-51.8	6.03	3.6-7.8	47.68	40.4-51.8	6.474
					(.5000)		(13.10)		(1.85)		(13.10)		
5	W	11/2/78	19		16.97	15-19.5	45.65	39.8-51.2	3.41	1.4-6.9	49.06	44.3-54.7	10.267
				20%<4.6>0.84	(1.3465)		(8.53)		(1.99)		(9.42)		
				and									
6	D	11/2/78	18	10%<0.84	17.89	17-20	43.81	36.8-51.7	4.73	3.2-7.5	48.54	40.1-57.1	8.572
	(42 days)				(.7811)		(14.52)		(1.54)		(15.92)		
7	D	10/26/78	18		17.22	12-18	45.1	38.2-51.0	3.38	1.7-4.8	48.44	39.9-54.0	10.044
	(42 days)				(2.2710)		(12.96)		(.69)		(14.36)		
8	W	11/2/78	17	10%<0.84	18.471	17.5-20	43.19	30.5-50.1	4.34	2.1-8.3	47.62	34.2-54.1	7.638
					(.5147)		(26.32)		(3.72)		(22.28)		
Drip Incubated	3/	10/26/78	17	-	21.59	18-23.5	58.2	51.3-69.5	6.88	4.4-10.6	65.08	57.5-79.3	6.467
					(1.7261)		(42.90)		(3.10)		(43.69)		
Control	3/	10/26/78	19	-	20.61	20-21.5	54.8	49.7-65.8	6.82	4.5-9.2	61.58	54.9-72.8	7.034
Heath Stack					(.2660)		(18.06)		(1.23)		(20.25)		

1/ Sampling times differ due to variation in hatching time
2/ Eggs unhatched at last sampling time
3/ Differenct egg source used

Table 7. Chinook Fry Quality (Mean Total Length, Fork Length, Total Weight and Condition Factor) Resulting from a 71 Day Rearing Period Using Fry from Watered Versus Dewatered Artificial Redds and From Drip Incubation Tests. Hayden Creek Research Station - Spring 1979.

Chinook Fry Rearing Tests 3/21/79 - 6/1/79

Chamber #	Condition	N	Sediment Content	Mean Total Lgth (mm) (S^2)	Range Total Length(mm)	Mean Fork Lgth.(mm) (S^2)	Range Fork Length(mm)	Mean Total Wt. (mg) (S^2)	Range Total Wt. (mg)	Dry Mean Condition Factor Kdw
1	Watered	25	30%<4.6>0.84	38.76	34.5-46.5	36.92	33-44.5	72.50	36.6-164.4	1.380
				(7.544)		(7.118)		(1017.49)		
2	Dewatered	25	20%<0.84	42.86	34-48	40.26	32-45	116.55	46.8-180.0	1.734
				(9.490)		(8.648)		(1127.25)		
3	D	23		43.35	35.5-51	40.91	34-48.5	132.49	43-263.9	1.837
			20%<4.6>.084	(17.828)		(14.287)		(2805.05)		
4	W	25		40.52	34.5-45.5	-	-	94.26	45.1-155.9	-
				(9.593)				(865.77)		
5	W	25		41.02	36-46	38.92	34.5-43	100.79	56.3-157.7	1.669
			20%<4.6>0.84	(7.593)		(6.368)		(752.36)		
6	D	25	10%<0.84	43.54	35-49	41.26	33-46.5	137.49	54.9-202.3	1.867
				(13.915)		(13.252)		(2340.46)		
7	D	24		43.94	32-48.5	41.27	31-45.5	109.70	31.4-177.0	1.492
			10%<0.84	(14.789)		(11.869)		(1305.17)		
8	W	25		39.00	32-47.5	37.02	31-44.5	82.60	34.5-166.7	1.535
				(15.312)		(12.239)		(1546.04)		
Drip	Green	25	-	38.74	35.5-47.5	35.96	34-46	77.12	35.2-260.8	1.326
Incubation	Eggs 2/			(9.648)		(8.394)		(2483.05)		
D.I. Control	G.E. 2/	25	-	39.22	36.5-45.5	-	-	76.27	24.9-154.7	1.506 1/
(Heath Stack)				(5.981)				(895.22)		
D.I.	Eyed Eggs 2/	29		37.53	31-52	35.86	30-49	64.59	22.1-244.6	1.222
				(23.088)		(19.105)		(2965.12)		

1/ Different eggs source used.

Table 8. Sample Mean Range Total Length, Fork Length, Yolk Weights, Body Weight, Total Weight, Estimated Wet Weight, Condition Factor and Developmental Indices for Chinook Salmon Alevins and Buttonup Fry From the 3 Day Flow Fluctuation Tests.

Trough #	Percent Sed.<4.6mm	Develop. Stage	Date Sampled	N	% Sed. <0.84	Mean Total Lgth.(mm) (S^2)	Range Tot. Lgth.(mm)	Mean Fork Lgth.(mm) (S^2)	Range Fork Lgth(mm)	Mean Yolk Wt. (mg) (S^2)	Range Yolk Wt.(mg)	Mean Body Wt. (mg) (S^2)	Range Body Wt. (mg)	Dry Mean Total Wt.(mg) (S^2)	Range Tot. Wt.(mg)	Wet Mean Total Wt. (mg) 1/	Mean Index KD	Wet Mean Condition Factor KW	Dry Mean Condition Factor Kdw
Control 1	0	Alevin	-	-		-	-	-	-										
Control 2	37	Alevin	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-
	0	Alevin	10/26/78	4		19.88 (1.792)	18.5-21.0	-	-	52.10 (4.41)	50-54.8	3.90 (1.21)	2.4-4.9	56.03 (3.24)	54.6-58.6	-	-	-	7.131
	20	Alevin	10/26/78	16		20.40 (.573)	19.5-22.5	-	-	56.28 (61.50)	47.8-76.0	4.96 (0.75)	2.8-6.8	61.25 (62.49)	52.7-81.0	-	-	-	7.23
	24	Alevin	10/26/78	20		19.00 (1.184)	15-20.5	-	-	60.49 (104.61)	49.7-80.9	5.67 (1.18)	4.0-8.1	66.165 (107.20)	54.8-86.3	-	-	-	9.82
	37	Alevin	10/26/78	17		15.76 (1.380)	13.5-17.5	-	-	63.83 (143.88)	51.1-87.2	6.26 (1.35)	3.7-8.3	70.10 (155.01)	54.8-95.5	-	-	-	18.42
Control 1	0	Button up	3/5/79	26		37.27 (12.145)	34-48	35.21 (8.685)	32-44	-	-	-	-	68.3 (1849.0)	28.0-202.4	433.81	2.1500	.9938	1.319
Control 2	37	Button up	3/5/79	25		37.02 (10.949)	31.5-44	35.04 (8.67)	30-41.5	-	-	-	-	70.6 (895.79)	32.2-144.4	445.34	2.2434	1.1291	1.391
	0	Button up	3/5/79	-		-	-	-		-	-	-	-	-	-	-	-	-	-
	20	Button up	3/5/79	9		46.83 (51.44)	37-62.5	43.66 (40.69)	35-57.5	-	-	-	-	198.8 (13876.84)	79.1-479.1	1088.11	2.3558	1.3074	1.936
	24	Button up	3/5/79	25		39.30 (12.750)	35-52	36.86 (9.49)	34-48.5	-	-	-	-	89.71 (1395.02)	57.1-236.6	541.5	2.2108	1.0806	1.478
	37	Button up	3/5/79	23		441.52 (68.19)	31.5-62	38.57 (54.67)	28-57.5	-	-	-	-	126.4 (11968.36)	32.7-482	725.11	2.3293	1.2637	1.7659

1/ Computed from regression of Total Dry Wt. (x) on Total Wet Wt.(y) Using Data From Trough #3
$Y = 91.37 + 5.0137x$; $r^2 = .9869$; $R = .99343$.

APPENDIX IV

Table 1. Total Percent Mortality and Remaining Fry Resulting from 71 Day Rearing Tests of Chinook Fry Produced from Eggs Incubated in Watered Versus Dewatered Artifical Redds and Drip Incubation. Hayden Creek research Station. Fall 1978

Chamber Number and/or Incubation Condition

	1-W		2-D		3-D		4-W		5-W		6-D		7-D		8-W		DIC		DI		EDI		H.C.	
Date	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts	Alive	Morts
3-21 (Begin)	113		74		88		315		252		58		37		223		425		428		386		196	
		1		0		1		1		4		2[1/]		2[1/]		4		1		3		13		13
3-27	112		74		87		314		248		56		35		219		424		425		373		193	
		1		0		0		0		0		0		0		0		0		0		3		1
3-31	111		74		87		314		248		56		35		219		424		425		370		192	
		0		0		1		0		0		1		0		0		0		0		2		0
4-4	111		74		86		314		248		55		35		219		424		425		368		192	
		0		0		0		0		0		1		0		2		1		0		5		4
4-6	111		74		86		314		248		54		35		217		423		425		363		188	
		0		0		3		2		6		1		0		3		0		0		7		14
4-10	111		74		83		312		242		53		35		214		423		425		356		174	
		4[1/]		1		9[1/]		17		32[1/]		1		0		2		2		1		6		19[1/]
4-15	107		73		74		295		210		52		35		212		421		424		350		155	
		3		2[1/]		2		28[1/]		16		2[1/]		0		9[1/]		2		14		152[1/]		17
4-18	104		71		72		267		194		50		35		203		419		410		198		138	
		4[1/]		0		2		14		6		0		0		4		5[1/]		40[1/]		48		10
4-22	100		71		70		253		188		50		35		199		414		370		150		128	
		4[1/]		1		0		2		0		0		0		0		1		19		24		10
4-25	96		70		70		251		188		50		35		199		413		351		126		118	
		1		0		0		0		0		0		0		2		0		0		8		3
4-30	95		70		70		251		188		50		35		197		413		351		118		115	
		1		0		0		0		0		1		0		0		1		6		6		1
5-6	94		70		70		251		188		49		35		197		412		345		112		114	
		0		0		0		1		0		2[1/]		0		1		2		1		10		0
5-10	94		70		70		250		188		47		35		196		410		344		102		114	
		1		0		0		0		1		0		0		0		0		1		5		0
5-16	93		70		70		250		187		47		35		196		410		343		97		114	
		0		0		0		1		0		0		0		2		0		4		2		1
5-20	93		70		70		249		187		47		35		194		410		339		95		113	
Total Alive 5/20	93		70		70		249		187		47		35		194		410		339		95		113	
Total Morts.		20		4		18		66		65		11		2		29		15		89		291		81
%Mortality		17.70		5.40		20.45		20.95		25.79		18.96		5.40		13.00		3.53		20.79		75.39		42.35

1/ Indicates maximum number of morts for a given chamber.

W - watered
D - dewatered
DIC - drip incubation control
DI - drip incubation
EDI - eyed drip incubation
H.C.- Heath Stack Inc. Cont.

Sediment Level in Chambers

1 and 2 - 30%<4.6>0.84
20%<0.84 mm
3 and 4 - 20%<4.6>0.84mm
5 and 6 - 20%<4.6>0.84
10%<0.84mm
7 and 8 - 10%<0.84mm

APPENDIX V

APPENDIX 5

Table 1. Spring chinook and summer chinook salmon, summer steelhead trout and bull trout redd measurements from eight streams in central Idaho, 1977-78.

Spring Chinook Redd Measurements

Date Location	Redd #	Length	Width upper (ft)	Width mid (ft)	Width lower (ft)	Redd area (ft^2)	Depth upper (ft)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
Big Springs Creek	1	12.0	2.0	9.0	4.0	64.0	1.0	0.98	--	0.5	1.60	--	0.30	1.28	--
Mean $\overline{X}$		12.0	2.0	9.0	4.0	64.0	1.0	0.98	--	0.5	1.60	--	0.30	1.28	--
Range		--	--	--	--	--	--	--	--	--	--	--	--	--	--
10/4/77															
Knapp Creek	1	13.0	4.0	4.6	6.0	67.60	0.85	1.35	--	0.80	1.35	--	0.40	1.0	--
	2	13.0	4.0	4.6	3.6	52.0	1.10	0.65	--	0.80	0.80	--	0.70	0.90	--
	3	14.0	4.0	4.6	4.0	58.8	0.95	0.60	--	1.15	0.40	--	0.60	0.50	--
	4	18.0	4.6	6.0	6.0	103.8	1.15	0.45	0.25	0.70	0.80	0.55	0.55	1.10	0.75
Mean $\overline{X}$		14.5	4.15	4.95	4.90	70.5	1.01	0.76	0.25	0.86	0.84	0.55	0.56	0.88	0.75
Range		13.0-18.0	4.0-4.6	4.6-6.0	3.6-6.0	52.0-103.8	0.85-1.15	0.45-1.35	--	0.70-1.8	0.40-1.35	--	0.40-0.70	0.50-1.10	--
Marsh Creek	1	17.6	6.0	9.6	6.9	134.6	0.80	0.55	0.25	0.40	1.20	0.85	0.40	1.50	1.25
	2	16.0	5.0	12.0	5.8	123.7	0.80	0.70	0.35	0.85	0.85	0	0.30	1.55	1.45
	3	9.5	9.0	7.0	6.0	64.9	1.00	1.00	0.50	0.55	1.35	1.0	0.40	2.05	1.65
	4	12.0	8.0	8.0	5.0	78.0	1.0	1.35	0.60	1.10	1.15	0.35	0.60	1.85	1.00
	5	12.6	5.6	6.0	3.6	59.6	1.0	1.75	0.80	0.50	2.15	1.70	0.50	2.4	1.70
	6	17.0	7.6	11.0	6.0	134.9	0.8	1.35	0.55	0.90	1.05	0.65	0.30	1.95	1.95
	7	11.0	4.0	8.0	7.0	75.2	1.10	1.20	0.95	1.30	0.70	0	0.50	1.65	1.35
	8	16.6	9.0	9.0	11.0	166.0	0.95	1.15	0.70	1.30	1.20	0.5	0.30	2.15	1.90
	9	12.0	8.0	6.0	5.0	70.0	1.20	1.30	0.55	1.35	1.45	0.50	0.50	3.0	2.50
	10	17.0	10.0	11.0	6.0	141.7	1.20	1.25	0.75	1.65	0.75	0	0.50	1.55	1.40
	11	18.0	4.0	9.5	6.0	123.0	0.85	1.80	1.10	1.40	1.65	0.40	0.75	2.90	2.00
	12	--	--	--	--	--	1.45	1.40	0.90	1.75	2.05	0.15	1.00	2.95	1.90
Mean $\overline{X}$		14.5	6.9	8.8	6.2	106.5	1.00	1.23	0.67	1.09	1.30	0.51	0.50	2.13	1.67
Range		9.5-18.0	4.0-10.0	6.0-12.0	3.6-11.0	59.6-166.0	0.80-1.45	0.55-1.80	0.25-1.10	0.40 1.7	0.70-2.15	0-1.70	0.30-1.00	1.50-3.0	1.0-2.5
10/4/77															
Capehorn Creek *	1	20.0	6.0	8.5	7.5	151.7	1.35	1.65	0.75	1.00	0.60	0	0.35	2.10	1.55
	2	14.0	7.0	7.0	9.0	112.0	1.10	1.05	0.75	1.15	1.25	0.10	0.50	2.70	2.40
9/14/78	3	12.0	3.0	5.0	5.0	56.0	1.10	2.35	--	--	--	--	--	--	--
	4	13.0	4.0	5.0	6.0	69.3	0.90	1.50	--	--	--	--	--	--	--
	5	8.0	2.0	3.0	3.0	22.7	1.30	1.10	--	--	--	--	--	--	--
	6	10.0	2.5	3.5	4.0	35.8	0.9	1.50	--	--	--	--	--	--	--
	7	9.5	4.0	5.0	6.0	50.7	1.0	1.50	--	--	--	--	--	--	--
	8	12.0	4.0	5.0	6.0	64.0	1.25	1.85	--	--	--	--	--	--	--
	9	8.0	4.0	4.0	5.0	36.0	1.5	1.40	--	--	--	--	--	--	--
	10	10.0	4.0	5.0	4.0	43.3	0.95	1.75	--	--	--	--	--	--	--
	11	10.0	3.0	4.5	5.0	45.0	0.90	1.0	--	--	--	--	--	--	--
	12	13.0	3.5	5.0	5.0	61.8	0.50	1.45	--	--	--	--	--	--	--
	13	16.0	3.0	6.0	6.0	88.0	1.05	1.35	--	--	--	--	--	--	--
	14	15.0	2.0	4.0	4.0	55.0	0.75	1.70	--	--	--	--	--	--	--
	15	13.0	3.0	4.0	6.0	62.8	0.50	1.10	--	--	--	--	--	--	--
	16	12.0	4.0	8.0	8.0	88.0	1.70	2.60	--	--	--	--	--	--	--

Appendix 5, Table 1. Continued.

Spring Chinook Redd Measurements (Continued)

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (ft)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
9/14/78															
Capehorn (Cont'd)	17	16.0	4.0	5.0	8.0	101.3	1.25	1.35	--	--	--	--	--	--	--
	18	8.0	3.0	5.0	4.0	33.3	0.45	1.65	--	--	--	--	--	--	--
	19	14.0	3.0	6.0	4.0	63.0	0.90	2.50	--	--	--	--	--	--	--
	20	14.0	5.0	5.0	6.0	77.0	0.90	1.50	--	--	--	--	--	--	--
	21	8.0	3.0	5.0	5.0	37.3	0.70	0.85	--	--	--	--	--	--	--
	22	11.0	3.5	4.0	6.0	54.1	0.95	1.55	--	--	--	--	--	--	--
	23	14.0	5.0	6.0	7.0	88.7	1.20	2.30	--	--	--	--	--	--	--
	24	12.0	4.0	6.0	6.0	68.0	1.20	2.10	--	--	--	--	--	--	--
	25	10.0	4.0	5.0	5.0	48.3	1.10	1.55	--	--	--	--	--	--	--
	26	12.0	4.0	6.0	6.0	68.0	1.0	2.35	--	--	--	--	--	--	--
	27	11.5	4.0	6.0	6.0	65.2	1.45	1.0	--	--	--	--	--	--	--
	28	13.0	4.0	5.0	5.0	62.8	0.90	1.40	--	--	--	--	--	--	--
	29	8.0	4.0	7.0	7.0	52.0	1.0	0.90	--	--	--	--	--	--	--
	30	8.0	2.0	3.0	3.0	22.7	0.85	2.15	--	--	--	--	--	--	--
	31	11.0	2.0	4.0	5.0	45.8	0.90	2.90	--	--	--	--	--	--	--
	32	10.0	3.0	3.0	3.0	30.0	0.85	2.15	--	--	--	--	--	--	--
Mean $\overline{X}$		11.75	3.64	5.11	5.48	61.24	1.01	1.66	0.75	1.08	0.93	0.05	0.43	2.40	1.98
Range		8.0-20.0	2.0-7.0	3.0-8.5	3.0-9.0	22.7-151.7	0.45-1.70	0.85-2.90	n=2	1.0-1.15	0.6-1.25	0-0.10	0.35-0.50	2.1-2.7	1.55-2.4
8/23/78															
Hayden Creek	1	12.0	3.0	5.0	4.0	50.0	1.15	1.95	0.80	1.05	1.0	0	0.50	1.85	1.30
	2	10.0	2.0	3.0	3.0	28.3	1.00	2.00	1.25	1.25	2.45	0.20	1.0	2.65	1.25
	3	15.0	1.5	3.5	3.0	43.8	0.85	0.80	0.30	1.0	1.35	0.40	0.40	1.35	0.60
	4	15.0	2.0	3.5	3.0	45.0	0.70	0.45	0	0.90	0.45	0	0.25	1.20	1.20
	5	7.0	1.5	4.0	2.5	19.8	0.90	2.05	0.70	1.10	1.05	0.15	0.55	3.5	1.25
	6	11.5	1.0	4.0	5.0	46.0	1.25	1.60	0.80	1.20	1.45	0.60	0.60	2.8	1.8
	7	9.0	2.0	4.0	3.5	30.8	1.50	0.90	0.25	1.25	0.60	0	0.80	0.9	0.65
	8	7.0	1.5	3.5	4.0	23.9	0.80	0.90	0.45	0.95	1.50	0.15	0.20	1.40	1.40
	9	15.0	3.0	3.0	4.0	52.5	1.20	0.50	0.35	1.25	0.15	0	0.30	1.40	1.40
	10	14.0	4.0	7.0	6.0	84.0	1.30	0.80	0.10	1.50	1.0	0.10	0.20	1.50	1.50
	11	10.0	2.0	3.0	2.0	23.3	1.05	1.20	0	1.45	0.90	0.05	0.70	2.25	1.50
	12	14.0	3.0	5.0	4.0	58.3	0.70	1.15	0.75	1.50	2.00	0.50	0.30	3.0	2.80
	13	14.0	3.0	4.0	3.0	46.7	0.50	1.20	0.70	0.80	1.30	0.20	0.60	2.0	1.60
	14	6.0	1.5	2.5	3.0	15.5	1.20	1.50	0.70	1.50	1.20	0	1.15	1.65	0.65
	15	11.0	2.0	5.0	4.0	44.0	0.90	1.10	0.65	1.00	0.50	0	0.30	1.20	0.95
	16	10.0	1.0	3.0	4.0	31.7	0.60	1.25	0.55	1.15	0.90	0.10	0.40	1.65	1.30
	17	10.0	1.5	4.0	6.0	45.8	1.20	2.25	0.60	1.50	2.35	0	0.50	2.65	0.50
	18	10.0	2.0	5.0	5.0	45.0	0.80	2.00	1.45	1.20	0.70	0	0.60	1.45	0.70
	19	5.0	1.0	4.0	2.0	12.5	0.80	2.0	0.85	0.90	1.60	0.9	0.50	2.65	1.65
	20	11.0	5.0	6.0	6.0	64.2	2.35	0.85	0.35	1.70	1.05	0.5	0.45	1.25	0.75
	21	19.0	1.5	5.0	6.0	93.4	1.20	0.75	0.55	1.15	0.40	0.10	0.10	0.25	0.25

Appendix 5, Table 1. Continued.

Spring Chinook Redd Measurements (Continued)

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (ft)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
8/26/78															
Hayden Creek	22	12.0	4.0	6.0	6.0	68.0	0.85	0.90	0.50	1.30	1.15	0	0.40	1.45	0.40
	23	23.0	6.0	8.0	10.0	199.3	1.20	1.15	0	1.40	1.0	0	0.25	0.70	0.70
	24	10.0	2.5	4.5	3.5	36.7	1.30	0.60	0.1	1.50	1.0	0.35	0.60	1.30	1.20
	25	4.5	1.5	3.0	3.0	12.4	0.75	1.45	0.80	0.80	1.45	0.50	0.45	2.30	1.70
	26	12.0	2.5	3.50	4.0	43.0	0.60	2.1	1.15	1.00	1.75	0.65	0.85	2.0	1.30
	27	10.0	2.5	5.0	4.5	43.3	1.00	0.85	0.10	1.30	0.65	0.35	0.45	1.85	1.40
	28	11.0	4.0	5.0	4.0	47.7	0.85	1.75	1.20	1.00	1.25	0	0.40	2.70	1.65
	29	9.0	4.0	5.0	4.0	39.0	1.10	1.60	0.75	1.40	1.55	0.25	0.45	2.40	2.0
	30	12.0	2.0	7.5	5.0	64.0	1.15	1.40	0.55	1.15	1.55	0.45	0.40	3.00	2.1
	31	8.0	1.5	2.5	2.5	18.7	0.60	0.65	0.30	0.90	0.95	0	0.20	1.50	1.50
	32	16.0	5.0	9.0	10.0	141.3	0.80	1.55	0.80	1.30	2.45	0.70	0.50	2.80	2.40
	33	16.0	3.0	5.0	6.5	86.7	1.25	0.50	0	1.30	0.85	0.15	0.40	2.25	1.65
	34	21.0	4.5	7.0	7.0	138.3	0.95	1.70	0.45	1.14	1.05	0	0.60	1.80	1.10
	35	16.0	4.0	4.5	5.5	78.7	0.75	0.55	0.15	1.0	0.85	0.25	0.20	1.35	1.35
	36	18.0	2.5	8.0	8.0	127.5	1.70	0.70	0.25	1.35	0.90	0	0.20	1.20	1.20
	37	4.5	1.0	1.5	2.0	7.5	0.70	1.40	0.95	0.85	0.85	0.15	0.40	2.20	1.70
Mean $\overline{X}$		11.85	2.58	4.65	4.55	55.58	1.01	1.24	0.55	1.19	1.17	0.21	0.46	1.87	1.31
Range		4.5–23.0	1.0–6.0	1.5–9.0	2.0–10.0	7.5–199.3	0.5–2.35	0.45–2.25	0–1.45	1.70	9.40–2.45	0–0.70	0.10–1.15	0.25–3.50	0.25–2.80
10/19/77															
Bear Valley Creek	1	8.0	3.0	5.0	2.0	25.3	1.55	1.15	0.70	1.35	1.40	0.45	0.95	1.80	1.25
9/26/78	2	16.0	6.0	8.0	9.0	130.7	1.05	1.45	—	—	—	—	—	—	—
	3	8.0	3.0	4.0	4.0	30.7	0.80	2.20	—	—	—	—	—	—	—
	4	12.0	2.5	5.0	5.0	55.0	1.80	1.85	—	—	—	—	—	—	—
	5	17.0	4.0	6.0	7.0	104.8	1.00	1.10	—	—	—	—	—	—	—
	6	11.0	2.0	5.0	6.0	55.0	1.75	1.70	—	—	—	—	—	—	—
	7	9.0	3.5	4.0	4.0	35.3	0.90	1.65	—	—	—	—	—	—	—
10/6/78	8	7.0	2.0	3.0	4.0	23.3	0.60	0.45	—	—	—	—	—	—	—
	9	7.0	2.0	3.5	3.5	22.8	0.90	1.35	—	—	—	—	—	—	—
Mean $\overline{X}$		10.56	3.11	4.83	4.94	53.66	1.15	1.43	—	—	—	—	—	—	—
Range		7.0–16.0	2.0–6.0	3.0–8.0	2.0–9.0	22.8–130.7	0.60–1.80	0.45–2.20	—	—	—	—	—	—	—

Appendix 5, Table 1. Continued.

Spring Chinook Redd Measurements (Continued)

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
8/27/78															
Lemhi River	1	11.0	4.0	5.0	5.0	53.2	1.50	3.0	1.35	2.10	2.05	0.25	1.0	3.2	2.4
	2	9.0	4.0	5.0	5.0	43.5	1.60	2.35	0.45	2.10	1.90	0	1.0	3.40	2.0
	3	13.0	4.5	7.0	7.0	85.6	1.0	3.10	1.05	1.50	2.60	0.85	0.50	4.00	3.2
	4	17.0	2.5	4.0	4.0	63.8	1.0	3.20	1.70	1.25	3.10	1.50	0.60	3.90	2.8
	5	17.5	2.0	6.0	5.0	84.6	0.8	2.50	0.35	1.25	2.35	0.15	0.70	4.0	2.2
	6	20.0	3.0	5.0	5.0	93.3	1.15	3.60	1.40	1.60	3.40	0.25	0.80	4.70	1.35
	7	11.0	3.0	4.5	4.0	44.0	0.90	1.75	0.95	1.20	1.80	0	0.50	3.0	2.40
	8	13.0	4.5	7.0	6.0	79.1	1.05	2.70	0.65	1.45	1.00	0	0.50	3.40	2.0
	9	14.5	3.5	6.0	7.0	88.2	1.30	2.40	0.90	1.50	1.95	0.10	0.50	3.30	2.40
Mean $\overline{X}$		14.0	3.44	5.50	5.33	70.59	1.14	2.73	0.98	1.55	2.24	0.34	0.68	3.66	2.31
Range		9.0-20.0	2.0-4.5	4.0-7.0	4.0-7.0	43.5-93.3	0.80-1.60	1.75-3.60	0.35-1.70	1.20-2.10	1.0-3.4	0-1.50	0.5-1.0	3.0-4.70	1.35-3.2

Summer Chinook Redds

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
9/13/78															
Salmon River	1	18	5.0	8.0	8.0	135.0	1.90	2.40	0.60	2.20	2.05	0	1.30	3.0	1.90
	2	20.0	3.0	6.0	8.0	130.0	2.0	2.60	1.10	2.35	2.60	0.85	1.60	2.60	1.20
	3	12.0	4.0	6.0	8.0	80.0	1.80	3.0	0.50	2.30	2.40	0.45	1.85	2.40	1.0
	4	10.0	5.0	6.0	6.0	58.3	1.95	3.20	1.20	2.30	2.60	0.70	—	—	—
Mean $\overline{X}$		15.0-	4.25	3.50	7.50	100.83	—	—	—	—	—	—	—	—	—
Range		10.0-20.0	3.0-5.0	6.0-8.0	6.0-8.0	58.3-135.0	—	—	—	—	—	—	—	—	—
	5	—	—	—	—	—	1.80	2.50	—	—	—	—	—	—	—
	6	—	—	—	—	—	1.60	2.80	—	—	—	—	—	—	—
	7	—	—	—	—	—	2.50	2.90	—	—	—	—	—	—	—
	8	—	—	—	—	—	2.10	1.90	—	—	—	—	—	—	—
	9	—	—	—	—	—	2.00	2.70	—	—	—	—	—	—	—
	10	—	—	—	—	—	2.60	2.25	—	—	—	—	—	—	—
	11	—	—	—	—	—	2.40	3.20	—	—	—	—	—	—	—
	12	—	—	—	—	—	2.20	1.25	—	—	—	—	—	—	—
	13	—	—	—	—	—	2.00	3.00	—	—	—	—	—	—	—
	14	—	—	—	—	—	1.50	2.70	—	—	—	—	—	—	—
	15	—	—	—	—	—	1.00	3.00	—	—	—	—	—	—	—
	16	—	—	—	—	—	1.30	2.80	—	—	—	—	—	—	—
	17	—	—	—	—	—	1.50	3.20	—	—	—	—	—	—	—
	18	—	—	—	—	—	1.80	3.30	—	—	—	—	—	—	—
	19	—	—	—	—	—	1.40	2.60	—	—	—	—	—	—	—
	20	—	—	—	—	—	1.25	2.80	—	—	—	—	—	—	—

Appendix 5. Table 1. Continued.

Summer Chinook Redds (Continued)

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
9/13/78															
Salmon River	21	--	--	--	--	--	1.20	2.40	--	--	--	--	--	--	--
	22	--	--	--	--	--	1.10	2.80	--	--	--	--	--	--	--
	23	--	--	--	--	--	2.0	3.60	--	--	--	--	--	--	--
	24	--	--	--	--	--	1.80	3.00	--	--	--	--	--	--	--
	25	--	--	--	--	--	2.10	3.40	--	--	--	--	--	--	--
	26	--	--	--	--	--	2.30	3.20	--	--	--	--	--	--	--
	27	--	--	--	--	--	1.80	2.90	--	--	--	--	--	--	--
	28	--	--	--	--	--	1.90	2.70	--	--	--	--	--	--	--
	29	--	--	--	--	--	2.30	2.80	--	--	--	--	--	--	--
	30	--	--	--	--	--	2.00	2.85	--	--	--	--	--	--	--
	31	--	--	--	--	--	1.20	2.30	--	--	--	--	--	--	--
	32	--	--	--	--	--	1.35	1.75	--	--	--	--	--	--	--
	33	--	--	--	--	--	1.15	2.40	--	--	--	--	--	--	--
	34	--	--	--	--	--	1.90	2.80	--	--	--	--	--	--	--
	35	--	--	--	--	--	1.60	2.70	--	--	--	--	--	--	--
	36	--	--	--	--	--	1.50	2.00	--	--	--	--	--	--	--
	37	--	--	--	--	--	2.00	2.60	--	--	--	--	--	--	--
	38	--	--	--	--	--	1.45	2.30	--	--	--	--	--	--	--
	39	--	--	--	--	--	1.85	1.85	--	--	--	--	--	--	--
	40	--	--	--	--	--	1.50	2.00	--	--	--	--	--	--	--
	41	--	--	--	--	--	1.80	1.35	--	--	--	--	--	--	--
	42	--	--	--	--	--	1.45	1.75	--	--	--	--	--	--	--
	43	--	--	--	--	--	1.10	3.00	--	--	--	--	--	--	--
	44	--	--	--	--	--	2.20	4.20	--	--	--	--	--	--	--
	45	--	--	--	--	--	1.00	3.00	--	--	--	--	--	--	--
	46	--	--	--	--	--	2.80	2.80	--	--	--	--	--	--	--
	47	--	--	--	--	--	1.60	1.50	--	--	--	--	--	--	--
	48	--	--	--	--	--	1.50	1.45	--	--	--	--	--	--	--
	49	--	--	--	--	--	1.80	2.80	--	--	--	--	--	--	--
	50	--	--	--	--	--	1.80	1.90	--	--	--	--	--	--	--
Mean $\overline{X}$		--	--	--	--	--	1.75	2.60	--	--	--	--	--	--	--
Range		--	--	--	--	--	1.00-2.80	1.25-4.20	--	--	--	--	--	--	--

Appendix 5, Table 1. Continued.

Steelhead Redds

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\bar{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\bar{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\bar{V}$ tail (fps)	Pt V tail (fps)
5/27/78															
Hayden Creek	1	10.0	5.0	4.0	3.50	39.2	1.60	2.26	---	0.90	2.84	---	0.80	2.62	---
Mean $\bar{X}$		10.0	5.0	4.0	3.50	39.2	1.60	2.26	---	0.90	2.84	---	0.80	2.62	---
Range															
6/1/78															
Lemhi River	1	10.0	5.0	5.0	4.50	47.5	1.20	3.27	---	1.80	2.60	---	0.80	3.12	---
	2	14.0	4.0	6.0	7.0	86.3	0.65	1.26	---	1.00	1.26	---	0.40	1.26	---
	3	8.0	5.5	5.5	7.0	50.0	0.65	1.99	---	1.00	1.57	---	0.40	2.09	---
	4	2.0	8.0	6.0	8.0	146.7	1.00	1.99	---	1.50	1.65	---	0.50	2.09	---
	5	---	---	---	---	---	1.35	2.19	---	1.30	2.72	---	0.50	2.48	---
	6	9.0	4.5	4.0	5.5	43.5	0.80	2.72	---	1.40	2.19	---	0.40	2.72	---
	7	7.0	2.5	4.0	5.0	29.8	1.10	2.60	---	1.45	2.38	---	0.85	2.84	---
	8	8.0	3.5	5.0	6.5	44.0	0.55	1.99	---	1.15	1.57	---	0.70	1.83	---
	9	9.0	4.0	6.0	7.0	55.5	1.20	2.72	---	1.75	2.38	---	1.15	2.98	---
	10	9.0	5.0	3.0	2.5	27.8	0.90	1.38	---	1.30	1.19	---	0.20	1.32	---
	11	7.0	3.0	3.50	5.0	29.2	0.50	1.23	---	0.80	0.86	---	0.30	1.38	---
	12	16.0	4.0	8.0	10.0	133.3	0.90	1.75	---	1.30	1.57	---	0.50	1.75	---
	13	7.0	3.0	3.5	5.0	29.2	0.70	2.19	---	0.90	1.50	---	0.30	1.99	---
	14	5.5	2.0	3.0	4.0	18.3	0.80	1.75	---	1.30	1.75	---	0.50	2.09	---
	15	11.0	5.0	7.0	8.0	78.8	0.80	1.91	---	1.15	1.63	---	0.50	2.19	---
6/5/78	16	8.0	4.0	4.0	5.0	36.0	1.05	2.19	---	1.30	1.91	---	0.60	2.38	---
	17	13.0	4.0	8.0	11.0	114.8	0.90	2.48	---	1.15	2.19	---	0.40	2.38	---
	18	7.5	3.0	4.0	4.0	28.8	0.80	2.38	---	1.05	2.19	---	0.40	2.19	---
	19	8.0	2.5	4.0	6.0	38.0	0.55	1.51	---	0.85	1.44	---	0.30	1.11	---
	20	8.0	4.0	5.0	6.0	42.7	0.55	2.72	---	1.05	2.48	---	0.30	2.60	---
6/7/78	21	15.0	3.0	2.5	3.0	42.5	0.60	2.19	---	0.80	1.91	---	0.35	2.19	---
	22	9.0	4.0	4.0	5.0	40.5	1.00	2.48	---	0.95	2.48	---	0.35	2.84	---
	23	8.0	3.5	4.5	5.0	36.7	1.00	1.68	---	1.15	1.57	---	0.40	1.99	---
	24	10.5	2.5	4.0	4.0	39.4	0.80	3.32	---	1.25	1.44	---	0.50	2.98	---
	25	8.0	2.0	4.0	5.5	35.3	1.00	1.57	---	1.25	1.57	---	0.40	2.09	---
	26	---	---	---	---	---	0.70	3.48	---	1.10	2.72	---	0.60	2.98	---
	27	8.0	2.5	3.0	3.5	25.3	0.50	1.19	---	1.10	0.62	---	0.30	0.89	---
	28	10.0	2.0	3.0	4.0	33.3	0.60	1.26	---	1.15	1.32	---	0.35	1.65	---
	29	11.0	4.0	4.5	4.0	45.8	1.00	2.84	---	1.15	2.28	---	0.40	2.72	---
	30	9.0	2.0	3.5	5.0	36.0	0.95	3.12	---	1.45	2.72	---	0.70	2.84	---
	31	9.5	2.0	3.0	5.0	36.4	1.00	1.44	---	1.40	1.69	---	0.40	1.65	---
	32	7.5	3.0	4.0	6.0	36.3	0.60	2.19	---	1.00	0.57	---	0.60	1.91	---
	33	7.0	3.0	4.0	4.5	28.6	0.75	2.19	---	1.10	1.69	---	0.40	1.75	---
	34	17.0	4.0	5.0	7.0	99.2	1.00	1.69	---	1.40	1.15	---	0.40	1.91	---
	35	12.0	5.0	5.0	6.0	66.0	0.75	2.19	---	1.05	1.83	---	0.40	2.48	---

Appendix 5, Table 1. Continued.

Steelhead Redds - Spring 1979 (Continued)

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
Lemhi River (Cont'd.)	22	12.0	1.5	3.5	5.0	47.0	0.8	2.50	—	1.00	0.75	—	0.50	2.80	--
	23	13.0	4.0	4.5	4.5	57.42	1.30	0.85	—	1.0	1.30	--	0.35	2.00	--
	24	8.0	3.0	3.5	4.0	29.33	0.50	1.20	—	0.55	0.75	—	0.10	0.70	—
	25	13.5	2.5	6.0	6.5	76.50	1.05	1.50	--	1.40	1.30	—	0.25	1.55	—
	26	14.0	2.0	4.0	6.5	68.83	0.90	2.6	--	1.25	1.80	--	0.30	2.60	—
	27	10.5	3.0	4.0	5.0	45.50	0.80	1.4	—	0.95	1.55	—	0.40	2.00	—
	28	10.5	2.5	5.0	6.0	53.38	0.90	2.85	—	1.40	2.60	—	0.45	3.20	—
	29	9.0	2.5	3.0	4.0	30.75	1.00	1.90	—	1.05	2.35	--	0.50	2.60	—
	30	13.5	3.0	2.5	5.0	51.75	0.75	1.75	—	0.90	1.30	—	0.30	2.05	--
	31	9.0	2.5	3.0	5.0	35.25	0.60	1.80	--	0.75	1.65	—	0.30	2.0	—
	32	9.0	3.5	4.0	4.0	35.25	0.70	2.35	—	0.80	2.50	—	0.40	2.4	--
	33	7.0	2.0	3.0	3.0	19.83	0.65	1.40	--	0.95	1.40	—	0.55	2.2	--
	34	6.0	3.0	4.0	5.0	26.00	0.85	1.70	—	0.90	1.70	—	0.60	2.65	—
	35	8.0	2.5	2.5	3.0	22.00	0.90	1.90	—	1.00	2.0	—	0.50	2.90	—
	36	11.0	2.0	3.0	5.0	42.17	0.90	2.20	—	0.95	1.75	—	0.35	2.15	—
	37	13.0	2.5	7.0	5.0	68.25	1.0	2.20	—	1.40	1.50	—	0.45	2.45	—
	38	10.0	3.5	4.0	5.0	44.17	0.65	2.20	--	0.95	2.0	—	0.50	2.70	—
	39	9.0	2.0	4.0	4.5	35.25	0.80	2.50	—	0.90	2.7	—	0.40	3.15	—
	40	10.0	3.0	4.0	4.5	40.83	0.80	2.55	—	1.30	2.3	—	0.60	3.50	--
	41	12.0	2.0	4.0	4.0	44.0	1.0	1.60	—	1.00	2.15	--	0.30	2.90	--
	42	12.0	3.5	5.0	6.5	66.0	0.9	1.60	—	1.10	1.75	—	0.30	2.00	--
	43	10.5	3.0	3.0	4.5	39.38	0.8	2.20	—	1.00	1.35	—	0.40	2.40	--
	44	10.5	2.5	4.0	5.0	44.63	1.20	1.35	—	1.30	1.05	--	0.40	2.00	—
Overall															
Mean $\overline{X}$		10.13	3.01	4.15	5.23	47.17	0.828	1.926	—	1.06	1.68	—	0.42	2.15	—
Range		5.5-22.0	1.5-8.0	2.0-8.0	2.5-11.0	17.0-146.7	0.50-1.60	0.50-3.48	—	.55-1.75	.50-3.10	—	0.10-1.15	.70-3.50	—

Bull Trout Redds

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
10/6/78															
Bear Valley	1	4.0	1.5	2.0	1.5	6.7	1.10	1.15	--	--	--	--	--	--	--
	2	3.0	1.5	2.0	1.0	4.3	0.85	1.35	--	--	--	--	--	--	--
	3	2.5	0.8	1.0	1.5	3.0	0.30	0.65	--	--	--	--	--	--	--
	4	8.0	3.0	3.0	3.5	26.0	1.30	1.15	--	--	--	--	--	--	--
Mean $\overline{X}$		4.38	1.70	2.0	1.88	10.0	0.89	1.08	--	--	--	--	--	--	--
Range		2.5-8.0	0.8-3.0	1.0-3.0	1.0-3.5	3.0-26.0	0.30-1.30	0.65-1.35	--	--	--	--	--	--	--
Overall															
Mean $\overline{X}$		9.49	3.48	4.41	5.48	49.65	0.80	2.04	--	1.13	1.73	--	0.45	2.04	--
Range		5.5-22.0	2.0-8.0	2.5-8.0	2.5-11.0	17.0-146.7	0.50-1.35	1.01-3.48	--	0.65-1.75	0.57-2.72	--	0.20-1.15	0.89-3.12	--

Appendix 5, Table 1. Continued.

Steelhead Redds (Continued)

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
6/7/78															
Lemhi River (Cont'd.)	36	8.0	2.0	2.5	4.0	25.3	0.80	1.11	--	1.05	1.44	--	0.40	1.57	--
	37	9.0	2.0	3.5	5.5	38.3	0.50	1.01	--	0.75	1.05	--	0.30	0.93	--
	38	10.0	4.0	6.5	7.0	63.3	0.70	1.65	--	0.90	2.19	--	0.30	1.65	--
	39	7.5	3.0	4.0	4.0	28.8	0.60	2.19	--	1.00	1.65	--	0.40	2.48	--
	40	22.0	4.0	4.0	4.0	88.0	0.90	1.83	--	0.70	1.38	--	0.30	1.57	--
	41	8.0	3.0	3.0	4.5	30.0	0.80	1.44	--	1.00	1.75	--	0.40	1.69	--
	42	8.0	4.0	6.0	6.0	45.3	0.40	1.65	--	0.65	1.26	--	0.30	1.15	--
	43	5.5	2.0	3.0	3.5	17.0	0.50	1.65	--	0.65	1.38	--	0.30	1.10	--
	44	12.0	3.0	5.0	7.0	68.0	1.0	1.99	--	1.35	1.38	--	0.65	2.19	--

Steelhead Redds - Spring 1979

Date Location	Redd #	Length	Width upper (ft)	Width pit (ft)	Width tail (ft)	Redd area (ft^2)	Depth upper (fps)	$\overline{V}$ upper (fps)	Pt V upper (fps)	Depth pit (ft)	$\overline{V}$ pit (fps)	Pt V pit (fps)	Depth tail (ft)	$\overline{V}$ tail (fps)	Pt V tail (fps)
5/24/79															
Lemhi River	1	15.0	2.0	4.0	5.5	66.25	1.00	2.50	--	1.55	2.20	--	0.50	3.20	--
	2	9.0	2.0	3.5	5.0	36.0	1.00	1.70	--	0.95	2.50	--	0.55	2.70	--
	3	9.0	1.5	2.5	3.5	25.5	0.95	1.75	--	0.75	2.00	--	0.40	2.30	--
	4	16.0	4.0	8.0	8.0	117.33	0.80	1.30	--	0.55	1.10	--	0.20	1.00	--
	5	10.0	2.0	4.5	6.0	48.33	1.30	2.00	--	1.00	2.15	--	0.30	2.60	--
	6	10.5	3.0	5.5	4.0	45.5	0.80	0.90	--	0.80	0.80	--	0.30	1.40	--
	7	9.0	4.0	3.0	5.5	39.75	0.55	0.50	--	0.60	0.90	--	0.20	1.25	--
	8	11.0	3.5	5.0	6.5	60.50	1.20	1.45	--	1.10	1.80	--	0.40	2.00	--
	9	11.0	2.5	3.0	4.5	40.33	0.85	2.50	--	1.10	2.00	--	0.40	2.65	--
	10	8.0	2.0	2.0	4.0	24.0	0.70	1.00	--	0.70	0.50	--	0.20	0.70	--
	11	11.0	3.0	4.0	5.0	47.67	0.85	1.75	--	1.00	1.60	--	0.40	2.10	--
	12	9.5	2.0	3.5	7.0	47.5	0.65	1.90	--	0.65	2.10	--	0.25	1.80	--
	13	8.0	3.0	3.0	4.0	28.0	0.70	1.80	--	1.00	1.90	--	0.55	2.25	--
	14	10.0	3.0	3.0	7.0	50.0	0.70	1.85	--	1.00	1.40	--	0.50	2.80	--
	15	10.0	2.5	3.5	5.0	40.83	0.70	1.85	--	1.00	1.20	--	0.40	1.85	--
	16	9.0	2.0	4.0	8.0	51.0	0.60	1.65	--	1.0	1.25	--	0.40	2.10	--
	17	10.0	3.5	3.5	5.0	42.5	0.85	3.40	--	1.0	3.10	--	0.40	3.10	--
	18	7.0	2.5	3.5	3.0	21.58	0.70	1.45	--	0.95	1.55	--	0.50	3.2	--
	19	14.0	3.0	4.0	5.0	60.67	0.90	1.20	--	1.25	1.00	--	0.30	1.75	--
	20	9.0	3.0	4.0	5.0	39.0	0.5	1.25	--	1.00	0.35	--	0.20	1.50	--
	21	8.0	1.5	3.5	3.0	23.33	0.6	1.80	--	0.70	1.60	--	0.30	1.90	--

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4. *Title* Influence of Streamflow Reductions on Salmonid Embryo Development and Fry Quality	5. *Report Date* March 1981 6. 8. *Performing Organization Report No.*
7. *Author(s)* Dudley W. Reiser and Robert G. White	10. *Project No.* A-058-IDA
9. *Organization* Idaho Water and Energy Resources Research Institute	11. *Contract/Grant No.* 14-34-0001-8014
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15. *Supplementary Notes*

16. *Abstract*

From 1977-1979 field and laboratory tests were conducted to determine the impacts of streamflow reduction over redds on salmonid embryo incubation and fry quality. Laboratory tests were conducted in artificial stream channels located at the Hayden Creek research station and in incubation chambers installed in the University of Idaho fisheries wet lab. Field tests utilized sections of Big Springs Creek and Bear Valley Creek. Tests were designed to evaluate the effects of reducing depths and velocities over redds on spring chinook salmon and steelhead trout embryo incubation success and resulting alevins.

During field tests, empirically measured intragravel velocities were in all cases greater than computed values using the U.S. Fish and Wildlife Services Instream Flow Group technique, although a good correlation existed between the two. Incubation flow recommendations based on the IFG technique should provide for suitable incubation velocities.

17a. *Descriptors*

Incubation flows, salmonid embryo, Hayden Creek

17c. *COWRR Field & Group*

08 I

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