PHYSICAL AND CHEMICAL CONDITIONS IN COHO SALMON *(ONCORHYNCHUS KISUTCH)* SPAWNING HABITAT IN FRESHWATER CREEK, NORTHERN CALIFORNIA

by

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ABSTRACT

The quality of coho salmon (Oncorhynchus kisutch) spawning habitat was determined for Freshwater Creek, Humboldt County, California during the 1987-1988 spawning season. A new standpipe was developed, calibrated and used to sample intragravel permeability and dissolved oxygen and take freeze cores in and adjacent to coho salmon spawning redds. Sample cores were taken inside and outside of redds just after spawning and just after fry emergence to determine gravel changes over time and space and to provide a database for future monitoring of spawning habitat quality. The sampling demonstrated that during spawning, coho increased the gravel permeability and the dissolved oxygen and decreased the percentage of fine sediments. Comparison of the data with previous coho studies indicated that the quality of spawning gravels in Freshwater Creek was excellent. A strong inverse relationship was demonstrated between permeability and the percentage of fines in the substrate. This could prove to be useful for inexpensive gravel quality monitoring. The standpipe promises to be a useful tool in Salmonid fisheries management and research.

ACKNOWLEDGEMENTS

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A heartfelt thanks goes to my major professor, Dr. Terry Roelofs, who inspired me to return to school against my better judgement and who was and continues to be a source of advice and encouragement (and patience). Dr. Thomas Lisle helped me maintain my focus and encouraged the development of the new method. Dr. Carlton Yee ably rounded out my committee with his Macintosh computer advice. Sincere thanks must go to Don Allan for his tireless help in the field, his timely brainstorms and his continued support and friendship. Scott McBain pushed me to make the extra effort in this study and continues to help improve the sampling method. Harry Comino, Don Miller, Bill Alexander and Steve Salzman helped make my wild ideas come to life with their advice and machines. James Wroble helped get me started back to school and with the analysis. My partners and colleagues at Trinity Restoration Associates have pushed, prodded and always supported me in this effort. Numerous landowners and particularly the Pacific Lumber Company graciously granted access to their Freshwater Creek property for this as well as other fisheries studies.

My sincerest thanks, of course, goes to Margo for putting up with my dreams and taking care of my life in the meantime and to Calder, who makes me wish I were seven again.

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INTRODUCTION

Each fall in the Pacific Northwest, coho salmon (Oncorhynchus kisutch) leave the ocean and return to their natal streams with a single, final purpose: to reproduce and then die. Eggs are buried in redds under about 25 cm of gravel. Deposition in the substrate protects the eggs from predators and provides the eggs with a good flow of oxygen-rich water throughout the two to three month incubation period. In most cases, the redd areas selected by female coho are located at the tails of pools where the hydraulic conditions are such that the substrate is small enough to be moved by the adult fish and large enough to allow good intragravel water flow. If substrate conditions are right, a large percentage of the eggs will hatch and the resultant fry will emerge to continue their intricate lifecycle, ultimately to return to the same stream to spawn and die.

Coho salmon populations have been dramatically reduced from historic levels (California Advisory Committee on Salmon and Steelhead 1988). Because of the important commercial and aesthetic value of these fishes, considerable effort has been focused on the maintenance and restoration of good spawning habitat for wild salmonids. Maintenance of Salmonid stream habitat is complicated by the fact that a stream constitutes the bottom of a watershed and that few Pacific northwest watersheds have been spared from intense upslope resource management, such as roadbuilding, logging, grazing, etc. Soil disturbances from these resource activities can eventually result in unnaturally high fine sediment levels in streams and consequent negative impacts to the habitat that anadromous salmonids use during the freshwater portion of their life history.

The growing awareness of potential sediment impacts on salmon spawning (and rearing) habitat has prompted a significant amount of research into the actual effects of fine sediment on salmon populations. A growing body of evidence indicates that abnormally high sediment levels in streams can cause a reduction in the survival rates of salmonids while they are in freshwater (Everest et al. 1987). These findings have led to research into methods that can be used to monitor fine sediment levels, as well as land management techniques that reduce sediment input into streams.

This study explores a new technique that can be used to both monitor the quality of Salmonid spawning gravels and provide a useful research tool. A modified standpipe, which combines a freeze coring method using liquid nitrogen as the cryogenic medium (Skaugset 1980) and a well-established method of measuring intragravel permeability (Terhune 1958), provides an investigator with a tool that can measure several critical gravel variables at a single location. The standpipe was used to measure sediment particle size distribution and intragravel permeability and dissolved oxygen (DO) inside and just outside of coho salmon redds in Freshwater Creek, Humboldt County, California and to determine any changes in these parameters from the time of egg deposition to fry emergence. These measurements provide an indication of spawning gravel quality and an important database for future monitoring of the Freshwater Creek basin.

LITERATURE REVIEW

Introduction

Coho salmon and other Salmonid embryos incubate under several centimeters of gravel substrate in a redd (or nest) for several months. During this period, the intragravel environment must permit a constant flow of water to deliver dissolved oxygen and to remove metabolic wastes. In order to insure high survival rates for their eggs, adult female salmonids attempt to select gravel conditions for redd construction that will meet the incubation requirements.

Numerous studies have examined the gravel conditions of Salmonid spawning habitat and the effects these conditions have on the survival of incubating Salmonid embryos. A thorough assessment of these studies was conducted by Chapman (1988). Much of the following review is summarized from this source.

Redd construction

While salmon have a wide variety of particle sizes to select from to deposit their eggs, they generally tend to select the areas of streams where the hydraulic conditions are such that fine sediments, for the most part, are sorted out (Platts et al. 1979). Suitable spawning substrate ranges from 1.3 cm to 15 cm with 20% less than 6.4 mm (Hassler 1987). Riffle crests, pool tails and riffles generally exhibit these conditions. Coho spawn in water depths of 0.1 to 0.54 m. with water velocities ranging from 0.18 m/s to 0.90 m/s (Hassler 1987; Regnart 1991).

Once the suitable location is found, the female salmon constructs the redd. She digs a pit by turning on her side and flexing her tail violently, thereby lifting gravel into the water column. Water current moves the finer sediments far downstream leaving a pile of “clean”, sorted gravel, called the tailspill, immediately downstream of the pit (Burner 1951). The bottom of the pit, that Chapman (1988) refers to as the egg pocket centrum, is composed of several particles too large for the female to move. Eggs are deposited in the egg pocket centrum by the female and then are fertilized by one or more attending male salmon.

The female then moves slightly upstream and digs another pit. The particles removed from the second pit are washed downstream and cover the first egg pocket with clean, sorted gravel. Egg deposition and fertilization are repeated in the second centrum and the procedure continues upstream for several days. For coho salmon, the result is a redd that averages 2.8 m2 in area (Reiser and Bjorn 1979) and may have several clusters of eggs buried under from 18 to 38 cm of gravel (Briggs 1953) (Figure 1).

The incubation period for coho salmon eggs is from 35 to 50 days until hatching (Shapovalov and Taft 1954) and another 2 to 7 weeks until the fry emerge from the gravel depending on water temperature (Shapovalov and Taft 1954). Throughout this period, the embryos depend on intragravel conditions for their development and survival. Beginning with Harrison in 1923 (Chapman 1988), considerable research effort has focused on these intragravel conditions and the effects they have on Salmonid survival to fry emergence. Intragravel parameters such as the substrate composition, dissolved oxygen, gravel permeability, apparent water velocity, organic material in the substrate, and water temperature have all been investigated in this regard (Everest et al. 1987; Chapman 1988).

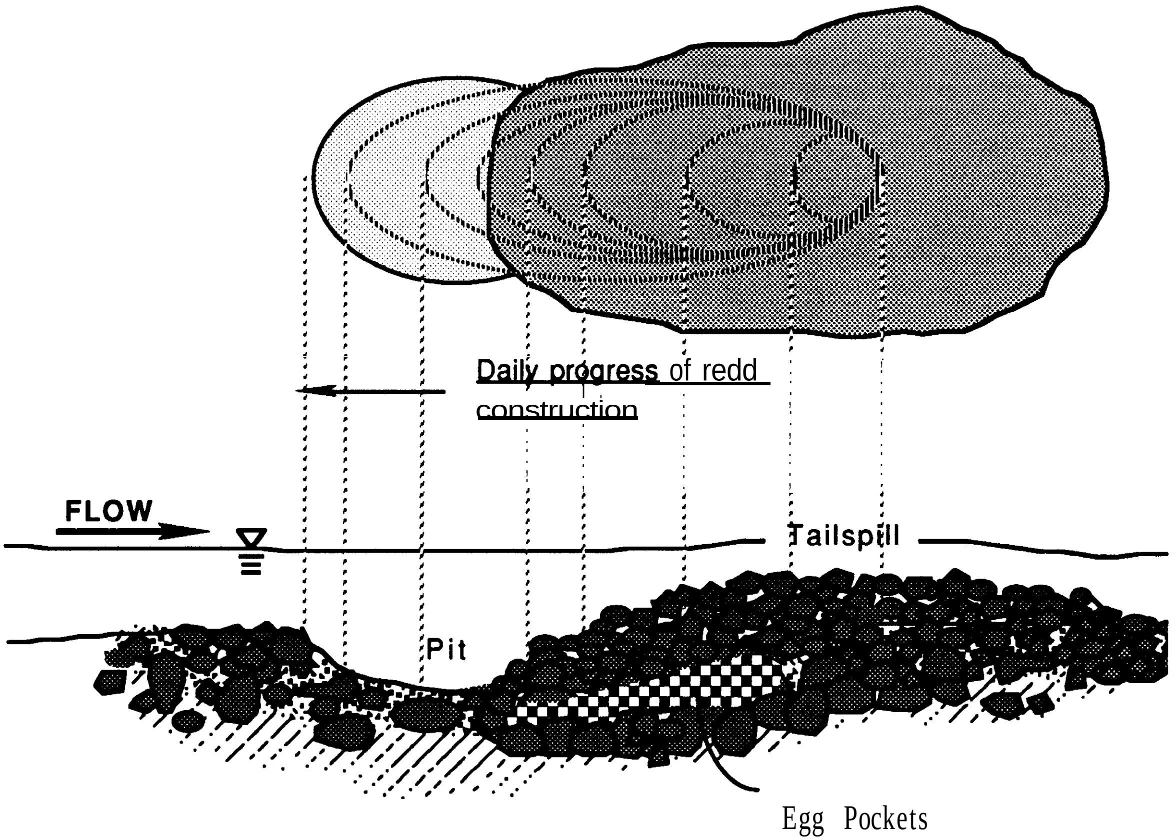

Figure 1. Salmon redd construction (adapted from Burner **1951).**

Dissolved oxygen

Referring to Salmonid egg incubation, Chapman (1988) states that "any decremental reduction in dissolved oxygen levels from saturation probably reduces survival to emergence or post-emergent survival". Chapman (1988) cites evidence that exposure to levels of dissolved oxygen below saturation may cause premature hatching and reduced size at hatching. This may not show up in survival to emergence studies but may reduce the likelihood of post-emergent survival.

Permeability

Permeability is a measure of the ability of a porous medium to pass water and as such is a quality that remains the same for a gravel sample regardless of water discharge (Chapman 1988; Greenkom 1983). This independence of discharge combined with the development of an inexpensive method of measuring intragravel permeability (Terhune 1958) made permeability an attractive index for monitoring gravel quality. Since then, numerous studies have explored the relationships between permeability and other gravel parameters. Tagart (1976) found that in coho redds, low dissolved oxygen was associated with low permeability. McNeil and Ahnell (1964) demonstrated that permeability decreased with an increase in fine sediment < 0.833 mm. The Karmen-Cozeny equation (Johnson 1980) shows that permeability is a function of particle size, shape, and gravel porosity. Chapman (1988) used data from Koski (1966) and found that survival of coho salmon was directly related to permeability.

Particle Size Distribution

In 1923, C. W. Harrison first demonstrated a relationship between substrate composition and survival of salmonid eggs to emergence (Chapman 1988). This relationship has since been examined and verified for coho salmon in several studies of natural redds. Koski (1966) found that survival to emergence was inversely related to the percentage of fines <3.3 mm. Cederholm et al. (1981) showed decreased survival in natural coho redds with increased percentages of fines <0.85 mm. In another study of natural coho salmon redds, Tagart (1976) showed an inverse relationship between survival and fine sediment <0.85 mm and a positive relationship between survival and sediment <26.9 mm but >3.35 mm.

The interest in fine sediment effects on fisheries stems from evidence that upslope resource management practices, such as road building and maintenance, timber harvest, grazing, etc. can increase the amount of sediment input into stream channels (Adams 1979; Adams and Beschta 1980; Everest et al. 1987; Burns 1972). Since fisheries and upslope land uses must coexist in watersheds, much study has focused on the best management practices to minimize negative effects to fishery habitat (Everest et al. 1987; Chapman 1988). The impacts of fine sediment on developing salmonid embryos are not limited to heavily managed stream systems. Variability is the key when describing sediment in streams and high levels of fine sediment may be present in some streams draining pristine, unmanaged watersheds (Adams and Beschta 1980; Everest et al. 1987).

Some characteristics of salmonid redd construction appear to have evolved to mitigate for naturally high levels of fine sediment. The act of digging the redd removes some of the fines during the spawning process. Salmon redds contain less silt and sand than the surrounding substrate (Chapman 1988; Everest et al. 1987; Regnart 1991). Everest et al. (1987) reviewed the literature and mention unpublished data of Allen et al. that shows an average reduction in fines < 3.2 mm due to coho salmon spawning from 21.6% to 9.1% in the Toutle River.

The shape of a redd has an effect on the hydraulics associated with it (Burner 1951; Everest et al. 1987). Everest et al. (1987) feel that the pit of a redd acts as a settling basin in which fines tend to deposit before they impact the tailspill where the eggs are. They also believe that fines tend to remain suspended in the accelerated water velocities and turbulence over the tailspill and do not readily deposit on the tailspill. The end result would be that the area where the eggs are deposited remains cleaner than the surrounding substrate as long as the topography of the redd remains intact. This hydraulic effect is probably negligible during large flow events.

Gravel Quality Indexes

Biological studies of spawning gravel, such as those mentioned above, have related survival to the percentage of that particle size class that has the most significant effect on salmonid embryo survival. Consequently various size classes have been used, making it difficult to compare studies. Several alternative gravel quality indexes have been developed to permit comparisons between studies (Platts et al. 1983). These indexes define spawning gravels using all of the particle sizes of a sample rather than limiting the description to a portion of the particle sizes as in the case of percentage of fines below a certain size. Geometric mean diameter (dg) is a statistical measure, used by several disciplines, which relates to the permeability and porosity of gravel samples, rather than just particle sizes (Platts et al. 1979). The fredle index is derived from the geometric mean diameter and a sorting coefficient and is purported to indicate sediment permeability as well as particle size distribution (Lotspeich and Everest 1981). Tappel and Bjornn (1983) developed a method of characterizing a gravel sample from two particle size classes and related them to survival to emergence of chinook salmon ***(Oncorhynchus tshawytscha)*** and steelhead trout ***(Oncorhynchus mykiss).***

OBJECTIVES

This research project was designed to determine the quality of coho salmon spawning habitat on Freshwater Creek and to provide a database for future monitoring of fine sediment in the basin. Specific objectives were to:

1) Compare the permeability, dissolved oxygen and percentage of fines of spawning gravels just after spawning with those parameters just after fry emergence.
2) Compare gravel parameters within coho salmon redds with those in adjacent undisturbed areas.
3) Determine the infiltration rates of fines into redds during the coho salmon incubation period for the different sections of Freshwater Creek.
4) Determine the relationships between intragravel permeability, dissolved oxygen, and percent fines.
5) Determine which gravel index, percent fines <2 mm, geometric mean diameter, or fredle index is the best independent variable to describe gravel permeability.
6) Develop and test a new standpipe which can measure permeability, dissolved oxygen and substrate composition by freeze coring.

STUDY AREA

Location

The Freshwater Creek basin drains approximately 9227 hectares of prime redwood and Douglas-fir forest land, located in Humboldt County between Eureka to the south and Arcata to the north (Figure 2). Elevations of the watershed range from 823 meters at the headwaters in the coastal mountains to sea level at the mouth in Humboldt Bay. The climate, typical of northcoastal California, is characterized by heavy rain between November and March and coastal fog much of the rest of the year. Annual rainfall amounts to about 100 cm near the mouth and 150 cm in the headwaters. The moisture thus provided maintains a healthy forest of redwood ***(Sequoia sempervirens),*** Douglas-fir ***(Psuedotsuga menziesii),*** white fir ***(Abies concolor)*** and Sitka spruce ***(Picea sitchensis).*** A thick riparian woodland borders the upper creek and consists of willow ***(Salix spp.),*** alder ***(Alnus rubra),*** black cottonwood ***(Populus trichocarpa),*** blackberry ***(Rubus ursinus),*** salmonberry ***(Rubus spectasbilis)*** and other herbaceous plants.

Mainstem Freshwater Creek is approximately 23 km long. A six meter waterfall prevents anadromous access beyond 14.5 km from the mouth (Km 14.5). Four main tributaries, Little Freshwater, Graham Gulch, Cloney Gulch and South Fork Freshwater each provide from 2 to 4 km of anadromous fish habitat.

Ownership land uses

The lower 6 km of Freshwater Creek is primarily cattle grazing land and is characterized by a low gradient, silty stream bed with very little

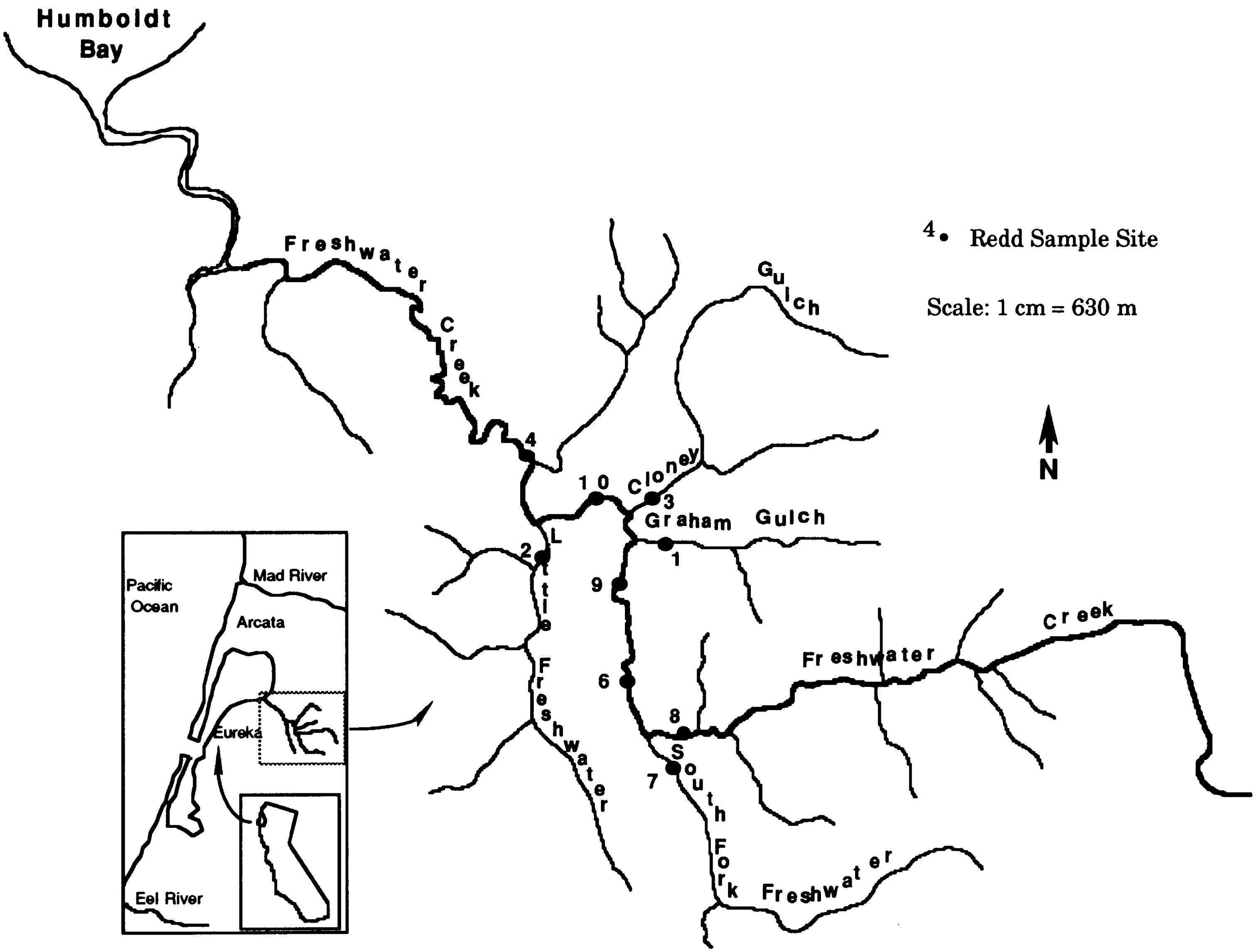

Figure 2. Freshwater Creek basin map with coho study redd sites, Humboldt County, California, 1988.

salmon spawning habitat. From Km 6 (Howard Heights Road) to Km 10, the mainstem Freshwater Creek is mainly small parcel residential and provides some coho spawning habitat.

Pacific Lumber Co. owns the rest of the watershed, from Km 10 to the headwaters and virtually all of the four main tributaries, and is actively managing it for timber production. The watershed was first harvested in the early 1900's and is now under production for second-growth redwood. Logging in the anadromous section of the mainstem Freshwater Creek began during the summer of 1988, after the sampling period for this contract. Prior to that, second growth logging had been limited to the Little Freshwater Creek and Cloney Gulch sub-basins.

Restoration history

According to various local sources, Freshwater Creek had, by the early 1970's, lost what had been sizeable runs of chinook and coho salmon. Since then, the effort to restore the salmon to the creek has targeted two objectives: 1) to reestablish the salmon stock using hatchery techniques; and 2) restore salmonid spawning and rearing habitat. Much of the early restoration work involved planting chinook and coho fry from nearby stream systems into Freshwater Creek by the Humboldt Fish Action Council (HFAC), a private non-profit organization, and the clearing of large woody debris (LWD) from the stream by the California Conservation Corps (CCC).

In 1985, HFAC was awarded a grant from the California Department of Fish and Game (CDFG) to set up a semi-permanent trap on Freshwater Creek and trap chinook and coho salmon for spawning and eventual release into the system.

Salmonid habitat restoration work has been performed in the watershed throughout the 1980's. Prior to 1985, CCC crews performed removal and modification of jams composed of large woody debris (LWD). From 1985 to the present, habitat restoration crews from Redwood Community Action Agency (RCAA) and HFAC have been funded by CDFG grants to stabilize streambanks, exclude cattle from the stream corridor, improve fish access through road culverts, modify LWD jams and improve spawning and rearing habitat (Barnard 1987).

In late 1986, the HFAC joined in a cooperative effort with CDFG and Humboldt State University (HSU), under the direction of Dr. Terry Roelofs, Professor of Fisheries, to intensively evaluate the fisheries of the Freshwater Creek basin. Dr. Roelofs, assisted by his fisheries students and HFAC volunteers, began a long-term study of the basin. Students for this project have collected and analyzed physical, chemical, and biological data as part of their course work. Additional research conducted on Freshwater Creek includes the present coho spawning habitat study, spawning surveys, habitat typing using methods of Bisson et al. (1981), instream flow study using the Instream Flow Incremental Methodology (IFIM), coho salmon and steelhead habitat preference criteria study, downstream smolt migration trapping, and a study of the basin geology.

MATERIALS AND METHODS

Modified Standpipe and Equipment

A modified standpipe was constructed from a 1.2 m length of 3.8 cm inner diameter black iron pipe. A steel driving point was fabricated and welded onto one end (bottom) of the pipe. Another section of steel was designed to fit loosely into the top end of the pipe and serve as a driving head to absorb the impact of a sledge hammer used to drive the pipe into the gravel to be sampled. A 2.54 cm diameter hole was drilled through the pipe near the top end to accomodate a **1.6** cm to 1.9 cm steel rod used to extract the pipe with the attached gravel core. The result was an inexpensive, durable freeze core standpipe to be used with liquid nitrogen (Figure 3).

In order to measure intragravel permeability, the freeze core pipe was next modified according to a design from Terhune (1958). The lower end, just above the steel driving point, is perforated with forty eight 3.2 mm diameter holes in sixteen evenly spaced rows of three. Each vertical group of three holes was connected by grooves **1.6 mm** wide and **1.6 mm** deep to help prevent blockage of the holes by small particles. When the modified standpipe is driven into a gravel streambed, intragravel water enters the pipe through the holes and permits the determination of intragravel permeability as well as the measurement of various intragravel water quality parameters, such as dissolved oxygen (using an electronic DO probe), temperature, etc.

The determination of gravel permeability with this (or a Terhune) standpipe requires that water from the gravel sample be allowed free access into the pipe. On the other hand, liquid nitrogen freeze coring demands that water be excluded from the standpipe. In order to make the

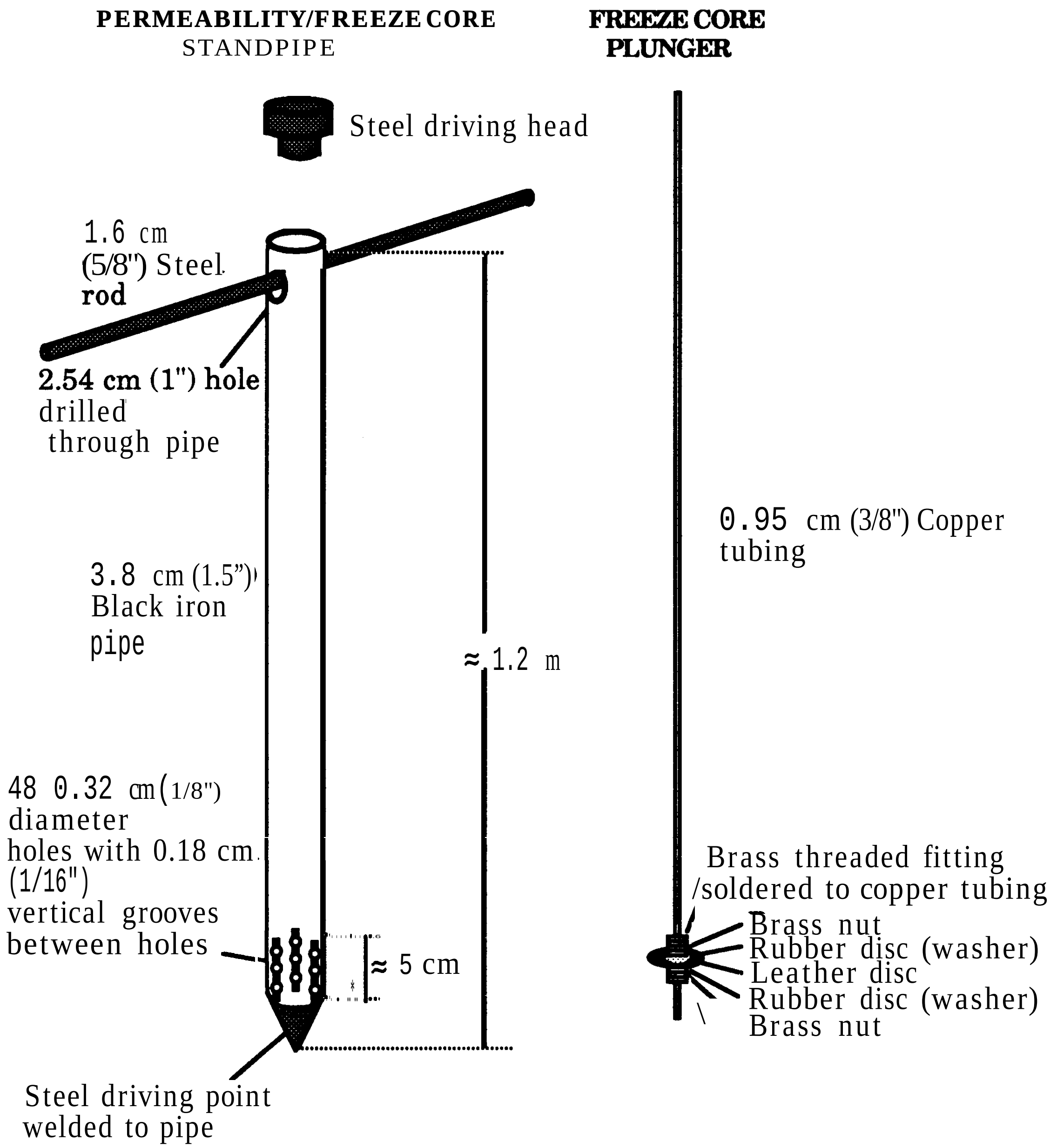

Figure 3. Modified permeability/freeze core standpipe and plunger used to study coho redds in the Freshwater Creek basin, Humboldt County, 1988.

permeability standpipe function as a freeze core device, a plunger apparatus was designed that effectively limits water from filling any higher than the top of the perforations.

The plunger consists of a length of 9.6 mm copper tubing somewhat longer than the standpipe (Figure 3). A threaded brass pipe fitting is slid over and attached to the copper tubing either by soldering or with compression fittings. The following are threaded onto the pipe fitting in the specified order: a large nut, a metal washer, a rubber washer, a leather disc cut slightly larger than the inner diameter of the standpipe, another rubber washer, a metal washer and another nut. The leather disc is the main seal and should be cut to fit tightly, both into the standpipe and also around the threaded pipe fitting. These pieces are threaded to a location on the copper tubing where they are just above the topmost perforation of the standpipe when the copper tubing is inserted all the way into the standpipe. When the finished plunger is fully inserted into the standpipe, the leather disc should be located just above the topmost perforation. If the nuts are tight and the leather disc has been cut to fit well, water should be effectively limited to the region of the perforations.

In addition to the standpipe, permeability sampling requires a means to pump water out of the standpipe under a constant head of pressure and to measure the amount of water drawn in a given amount of time. The pumping apparatus consists of a 500 ml graduated cylinder fitted with a two holed rubber stopper. Sections of 9.6 mm copper tubing with lengths of flexible tubing are inserted into each hole and connected to the vacuum pump and to the copper plunger (Figure 4).

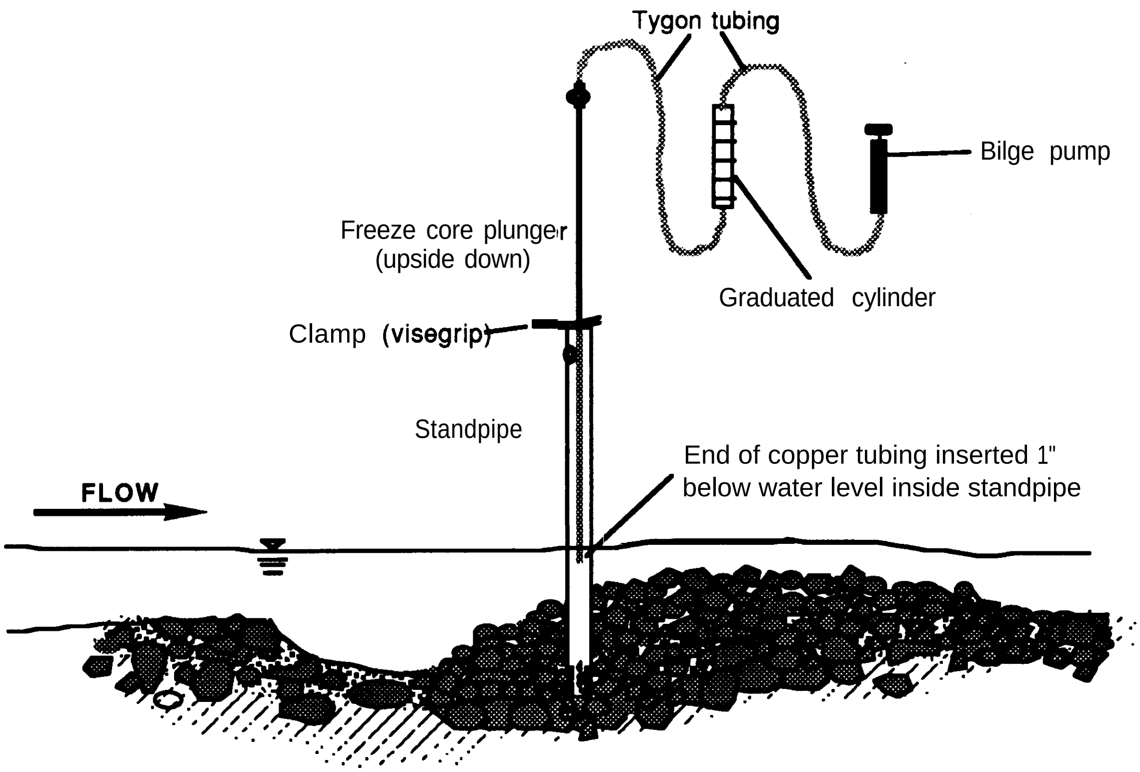

Figure 4. Gravel permeability testing with the modified permeability/freeze core standpipe, 1988.

Data Collection

Redd Site Selection

The Freshwater Creek basin was divided into nine 2-4 km. sections for the purpose of spawning surveys. The mainstem comprised 5 sections, based on access, and the four main tributaries made up the other four. Each week during the winter, when water turbidity permitted visibility, several two-person crews were dispatched to various sections to survey for spawning redds, live adult fish, and spawned out carcasses. Redd locations were marked in the field with flagging depicting the date of the survey. During many of these surveys, live fish were identified actively spawning on redds. Redds used for this thesis were selected only from those redds on which coho salmon were seen spawning or digging.

The selection of redds for sampling was based on the spawning surveys and for that reason the nine survey sections were used as sampling strata for freeze core sampling sites. All positive coho redds in the lower 500 meters of each section were inspected for sampling suitability. In order to be suitable, a redd had to be fresh and demonstrate a relatively discernible tailspill and pot. These were then numbered from downstream up and one redd was randomly selected from them for freeze core sampling.

Site Mapping

Once the redd had been selected, the immediate channel area was well flagged and mapped in detail to accomodate positive location for the second, post-emergence sampling phase. Channel mapping was conducted by stretching a tape parallel to the streamflow down the middle of the channel between two pieces of rebar. The distance was measured from, and perpendicular to, the mid-channel tape to all in-channel features, such as woody debris, active channel margins, margins of the redd, etc. Each measurement was translated to graph paper and the result was a detailed portrayal of the redd features relative to stream and bank features.

The mid-channel tape was left standing during both sampling phases in order to precisely locate each core site on the map. Rebar stakes were left in the stream channel between sampling periods and were located on the map relative to permanent markers above the active channel margins on the streambanks.

Core Samnle Site Selection

Four permeability/freeze core samples were taken for each redd during the egg incubation period (pre-emergence) and four more taken after fry emergence (post-emergence), usually about two months later. Two of each group of four were taken within the redd, and the remaining two just upstream of the redd in undisturbed gravel (Figure 5).

Samples within redds were located on the upstream “slope” of the mound, near the pot, in areas where it was likely an egg pocket would be located. The sampling strategy within redds was designed to account for variations in particle size distribution within a small (approximately 0.8 m x 0.8 m) region of the mound and, in the case of the post-emergence cores, to avoid resampling spots that were previously disturbed. The sampling region was divided into quadrants. Pre-emergence cores were taken

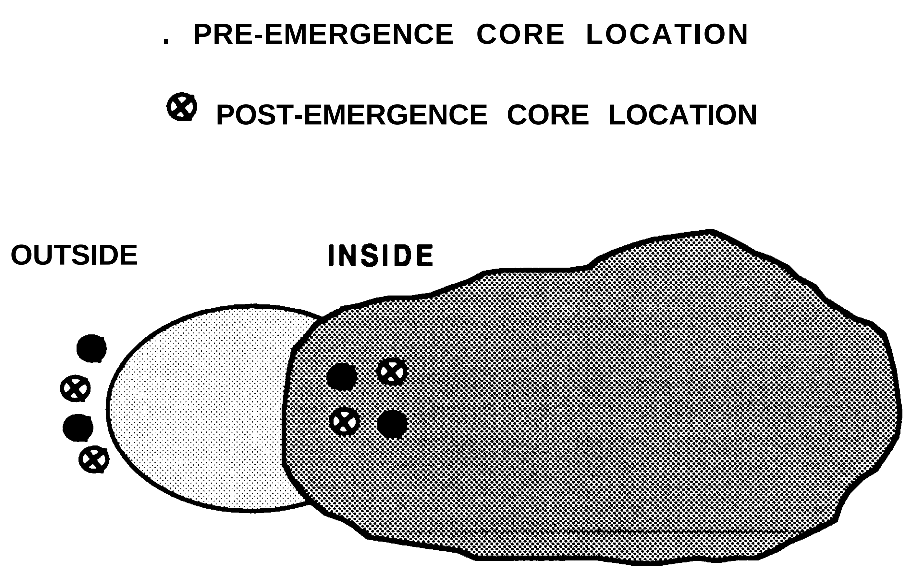

Figure 5. Permeability/freeze core sampling design used inside and outside of coho salmon redds in the Freshwater Creek basin, Humboldt County, 1988. (See Figure 1 for a schematic of redd morphology).

diagonally to each other, post-emergence cores were later located in the remaining two undisturbed quadrants (Figure 5).

Sample cores taken outside of redds were located to represent undisturbed gravel conditions that the salmon selected for spawning. Where appropriate, core sites were selected on undisturbed gravels immediately upstream of the pit of the sample redd, and sampled using a quadrant layout similar to the inside redd cores. Occasionally, the area upstream of the sample redds contained larger substrate than coho salmon typically move and in those cases, outside cores were located adjacent to the redd. In all cases, the specific core locations were carefully mapped to positively avoid post-emergence sampling in areas that may have been disturbed by the pre-emergence sampling.

Pre-emergence sampling occurred between February 1, 1988 and March 9, 1988. Post-emergence sampling began on April 27, 1988 and continued until June 11, 1988.

Depth of Core Sample

The study objectives demanded that gravel parameters of permeability, dissolved oxygen and particle size distribution be measured at the depth of egg deposition. Studies suggest that coho salmon typically bury their eggs under approximately 25 cm of cleaned gravel (Terhune 1958; Chapman 1988). Although only a small percentage of freeze core samples contained eggs, those few indicated that the sampling depth of 25 cm was appropriate.

Dissolved Oxygen Sampling

A perforated standpipe provides access to intragravel water so that the dissolved oxygen content of this water can be measured. Two commonly used methods are available: 1) a modified Winkler titration method in which water is drawn up through a syringe and analyzed (Terhune 1958); or 2) a potentiometric method using an electronic dissolved oxygen meter with a probe which can be inserted down the standpipe. For this investigation, a Hach Portable Dissolved Oxygen Meter (Model #16046) was used to measure dissolved oxygen in mg/L, of both intragravel water and surface water adjacent to the standpipe. After driving the standpipe into the gravel, at least 400 ml of water were drawn out of the standpipe before DO sampling, to remove any water that may have seeped in from the surface water or gravel depths higher than that being sampled.

Subsurface DO was compared to stream surface DO for each standpipe location, except for Core# 3-l and 3-2, where the DO meter failed to function due to water contact with internal wiring. Dissolved oxygen measurements were taken inside and outside the standpipe and were used to calculate the "relative DO saturation" of intragravel water to surface water:

$$\text{Relative DO Saturation} = \frac{\text{Subsurface (Intragravel) DO (mg/l)}}{\text{Surface DO (mg/l)}} \times 100$$

Permeabilitv Test

Gravel permeability was measured with the modified standpipe according to Terhune (1958). In his method, a graduated pumping apparatus is used to measure the rate at which water flows through the perforations and into the standpipe under a 2.54 cm head of pressure. The measured inflow rate (ml/sec) is then used to interpolate the gravel sample permeabilitv (cm/hr) using a "Permeability versus Standpipe Inflow" calibration curve. The calibration curve that Terhune (1958) formulated is appropriate for his 3.2 cm, aluminum standpipe design but my modifications to his standpipe design demanded that my design be recalibrated in a flume permeameter.

One person (pumper) held the graduated cylinder and operated the vacuum pump while a second person (timer) lowered the copper plunger into the standpipe and listened for a characteristic "slurp" which indicated the end of the plunger had just made contact with the water surface inside the standpipe. A one inch wooden spacer was rested on top of the standpipe and a 'Visegrip" clamp attached to the copper tubing just at the top of the spacer. When the spacer was removed, the 'Visegrip" was allowed to rest on top of the standpipe, effectively holding the copper plunger with the end exactly 2.54 cm below the water surface within the standpipe (Figure 4).

The timer pinched the flexible tubing and readied a stopwatch. The pumper then began to operate the vacuum pump thereby creating a vacuum throughout the graduated cylinder apparatus. Once a vacuum was generated, the timer released the pinched tubing and at the same instant started the stopwatch as the pumper continued to operate the pump. Water from inside the standpipe was drawn into the graduated cylinder until the cylinder was almost full or an appropriate amount of time had elapsed (15 - 60 seconds). The timer then simultaneously removed the copper plunger from below the water surface and stopped the stopwatch. To arrive at the inflow rate under a 2.54 cm hydraulic head, the measured volume and time were corrected by subtracting from them respectively the volume of the first inch of water, 29.0 ml for the 3.8 cm diameter pipe, and the time it takes to remove it from the standpipe, estimated at 0.25 sec. The inflow rate, in ml/sec, was calculated from the corrected volume and time and then used to interpolate the sample permeability, in cm/hr, from the calibration curve (Figure 6).

Three or more inflow measurements (pump tests) were conducted at each standpipe location. The mean inflow rate for each sample site was calculated and was then used to interpolate the sample permeability from the “Permeability vs. Standpipe Inflow” curve (Figure 6). This same sampling procedure was used for the permeability calibration.

Permeability Calibration

Since the modified standpipe design uses a different type of pipe material than Terhune (1958), calibration of the new standpipe was conducted to determine whether the “Permeability versus Standpipe Inflow” plot of Terhune (1958) was appropriate. A plywood hydraulic flume permeameter was constructed to measure the permeability of a homogeneous gravel mixture (Figure 7). When water flows through the gravel-filled permeameter, the following four properties can be measured: 1) the flow rate through the gravel (Q); 2) the length of the gravel sample (L); 3) the average cross-sectional area of the gravel sample (A); and 4) the change in height of the water level over the distance L (Ah), using the simple piezometers. Permeability (K) of the gravel can then be calculated according to the following equation adapted by Terhune (1958) from Darcy’s Law (1856):

$$K = \frac{Q\,L}{A\,\Delta h}$$

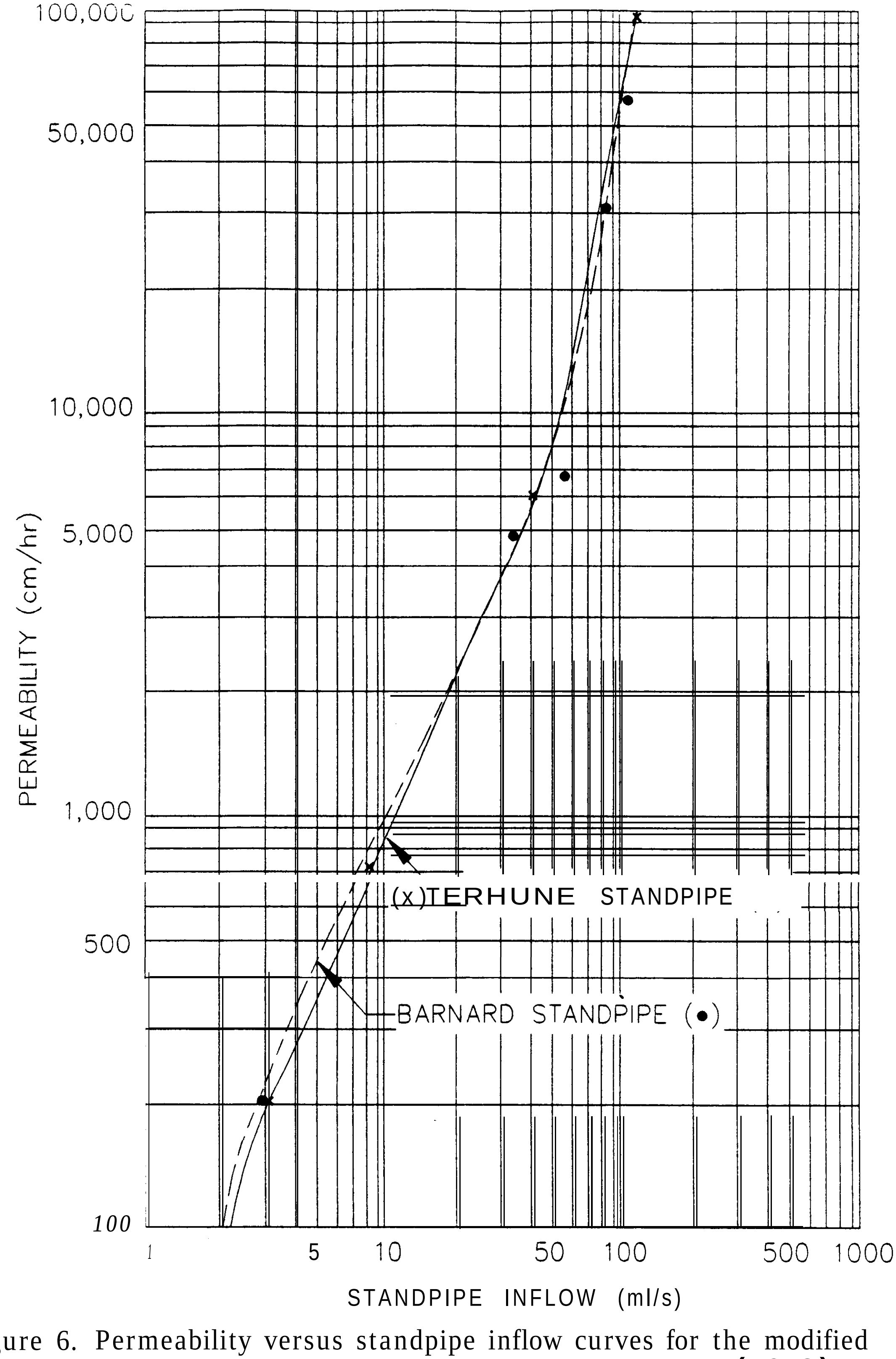

Figure 6. Permeability versus standpipe inflow curves for the modified permeability/freeze core standpipe and the Terhune **(1958)** standpipe.

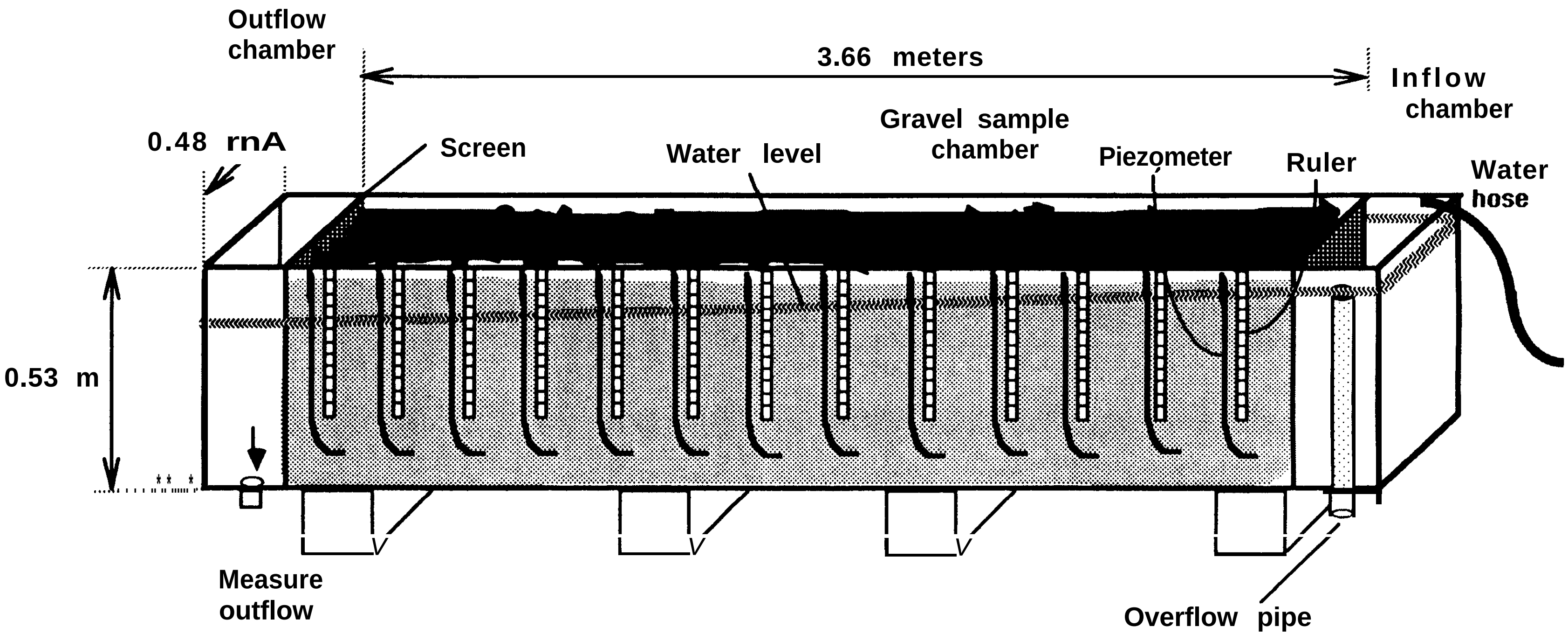

Figure 7. Open trough flume permeameter used to calibrate the modified permeability/freeze core standpipe, 1988.

Once the permeability of the gravel sample was determined, five standpipes were inserted along the hydraulic flume and the inflow rate for each standpipe was measured and then all were averaged. Five homogeneous gravel mixtures were tested and the resulting permeabilities (K) and average inflow rates (Q) were plotted on a log-log graph and an appropriate calibration curve generated (Figure 6).

Freeze Core

Liquid nitrogen is an effective cryogenic medium for substrate freeze coring since it volatizes at a temperature of -195.8^{0}C (Chemical Rubber Company 1966) and can rapidly remove heat from surrounding material. Nitrogen is also relatively inexpensive at about $1.50 per liter or $12.00 for a single freeze core sample requiring eight liters. In addition, it is relatively portable for remote sampling using 16 - 20 liter stainless steel or fiberglass Dewar flasks, both of which proved to be durable.

After the dissolved oxygen and permeability measurements were made, the standpipe and sample site were prepared for freeze coring. The standpipe was driven down about 5 cm with the driving head until the top perforations were at the depth desired for the bottom of the frozen sample, since gravel will tend not to freeze to the pipe in the perforated region. In gravel sites with high permeability, a successful freeze core required slowing the surface and intragravel water flow past the pipe by placing a sheet metal collar down into the gravel surrounding the standpipe, and placing a sandbag against the upstream side of the collar (Figure 8).

The plunger apparatus was inserted into the standpipe, making sure the leather disk thoroughly sealed the inside of the pipe. A funnel was placed over the plunger and into the standpipe. The vacuum apparatus was

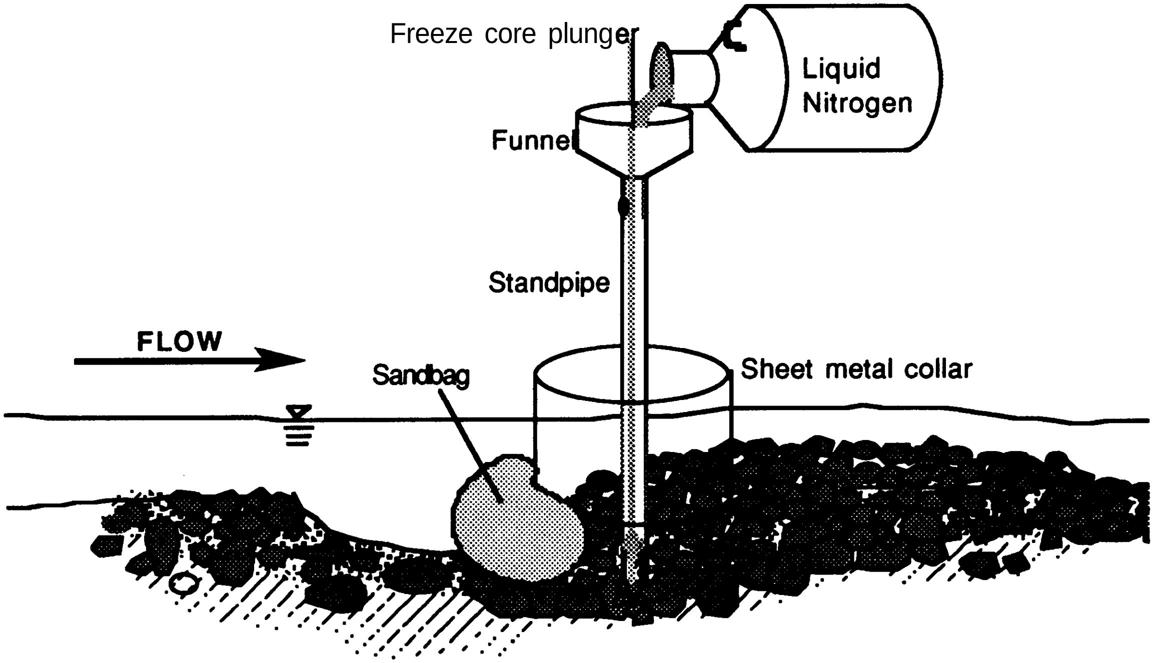

Figure 8. Freeze core sampling with the permeability/freeze core standpipe on coho redds in the Freshwater Creek basin, Humboldt County, 1988.

attached to the top end of the plunger and one person operated the pump while the other pushed the plunger slowly into the standpipe until the leather disk was located just above the top perforation. While one person continued to pump water up through the plunger, the second person poured liquid nitrogen slowly from a Dewar flask into the funnel. The vacuum apparatus was removed from the plunger and the pouring of liquid nitrogen continued.

For best results, the liquid nitrogen was poured into the standpipe until it boiled up through the funnel. Then the nitrogen was allowed to boil down before pouring again. In this manner, the liquid nitrogen level was maintained above the gravel surface. Eight to ten liters of liquid nitrogen were usually sufficient to achieve a good core unless gravel permeability was high, in which case more nitrogen was used. After allowing the final liquid nitrogen to boil down, the funnel was removed, the steel rod inserted through the holes near the top of the standpipe and two people pulled the standpipe with frozen gravel sample out of the substrate. Visual observation of the frozen sample was then made to determine any stratification of particles, or the presence and depth of eggs or other organisms within the sample.

Wet Sieving

Any analysis of the particle size distribution in a gravel sample requires that the sample be removed from the standpipe, run through a series of sieves, and the volume or weight of each sieve subsample determined and expressed as a percentage of the total sample (Platts et al. 1983). The wet sieving method (Platts et al. 1983) used in this study can be done entirely in the field without having to transport gravel samples back to a laboratory. The standpipe sample was thawed in a bucket of water with a propane torch used to heat up the standpipe. The wet sample was run through a geometrically decreasing series of sieves, 32, 16, 8, 4, 2, 1, 0.5, 0.25, and 0.125 mm screens with a pan on the bottom. Water was flushed through to aid the sieving process. Excess water was decanted out of each sieve subsample and then each subsample was poured into a bucketful1 of water from which the volume of water displaced was measured. The resultant volume was then modified by using a correction factor which accounts for the water retained by the particular particle size (Platts et al. 1983), and finally expressed as a percentage of the total sample volume.

Data Analysis

Field measurements of permeability, dissolved oxygen and particle size distribution were recorded for each of the 72 core samples and entered into the Microsoft Excel spreadsheet program. Analysis sheets for each freeze core sample included all the measurements made in the field as well as calculations of relative DO saturation (subsurface versus surface DO), average inflow (ml/sec) and permeability (cm/hr), corrected volume of material collected on each sieve (ml), percentage of the total sediment volume that passed through each sieve, percentage of fines < 2 mm, geometric mean diameter (dg) (Platts et al. 1983), sorting coefficient (So) and fredle index (Platts et al. 1983). The spreadsheet was programmed to generate particle size distribution curves for each sample. A statistical software program, Statview 512+ by Abacus Concepts, Inc., was used to perform simple regressions and ANOVA statistics. Multiple comparisons were made with the Fisher Protected Least Significant Difference test

(PLSD) (Winer 1971). A significance level of 5% was used to determine statistical significance.

RESULTS

Permeability Calibration

Permeability calibration for the modified standpipe was conducted with seven gravel mixes according to the method of Terhune (1958). The particle size distributions for the seven test samples of gravel are listed in Appendix A.

The limits of the permeability test were established using pure sand for the lowest permeability and pure pea gravel for the highest. The permeability of the pea gravel approached the upper limit measureable by the permeameter or the standpipe. Higher permeability than that of the pea gravel resulted in such rapid flow through the permeameter, that the difference in height of water from one end of the permeameter to the other was not discernible on the piezometers. Permeability higher than that for pea gravel also resulted in higher inflow rates into the standpipe than the vacuum apparatus could remove.

Five gravel/sand mixes were prepared to generate permeabilities intermediate between the upper and lower limits. Attempts to thoroughly homogenize the gravel/sand mixes were successful in three of the five intermediate samples. The three successful samples (numbers 2, 3, and 4 in Appendix A) demonstrated relatively low variability between inflow rates measured at five locations in each gravel sample. The other two intermediate samples showed much higher variablility than was deemed acceptable, indicating the samples were not mixed thoroughly. These latter two samples were discarded.

The permeabilities and inflow rates for the five acceptable gravel samples were plotted on a log-log graph and a curve generated between the five points by eye (Figure 6). The four points determined by Terhune (1958) using his Mark VI standpipe were plotted on the same graph and correspond closely to the calibration curve I developed. Because of the close fit, it was deemed unnecessary to experiment with more gravel samples.

Field Data

Ten coho salmon redds throughout the Freshwater Creek basin were sampled (Table 1). The field data and calculations are compiled on analysis sheets, arranged in Appendix B so that the four cores (two inside, two outside) taken at each site during one sampling period (pre-emergence or post-emergence) are displayed together on one page. Immediately following each site analysis sheet is a graph displaying the particle size distribution curve for each of the four samples per site (Appendix B).

Permeability

All field inflow measurements are reported in Appendix B for each standpipe sample on respective data sheets. Permeability values, interpolated from mean inflow rates for each sample, are tabulated in the PERMEABILITY column of Table 1.

The modified standpipe and the “Permeability vs Standpipe Inflow” curve (Figure 6) each have an upper and lower limit to the range of possible measurements. The range limitations of the “Permeability vs Standpipe Inflow” curve are between 3 ml/sec which represents 200 cm/hr, and approximately 130 ml/sec which represents a permeability of 100,000 cm/hr. Inflow rates measured for this investigation covered the full range of the standpipe: from 0.0 ml/sec measured in clay, where it required several minutes for the standpipe to fill up; to over 119 ml/sec, where the pumping

Table 1. Summary of permeability/freeze core data for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

REDD NO.	CORE NO.	SAMPLING PERIOD	CORE LOCATION	STREAM LOCATION	D.O. SATURATION	PERMEABILITY	% FINES < 2 mm	% FINES < 1 mm	GEOM. MEAN DIAMETER	FREDLE INDEX
1	3	PRE-EMERG	INSIDE	MID TRIB	82.20	5000	15.32	8.50	12.47	4.23
1	4	PRE-EMERG	INSIDE	MID TRIB	88.98	3000	9.82	5.83	20.72	10.36
1	5	PRE-EMERG	OUTSIDE	MID TRIB	82.54	960	11.94	9.36	15.84	5.97
1	6	PRE-EMERG	OUTSIDE	MID TRIB	80.51	780	14.75	9.21	16.66	7.45
1	11	POST-EMERG	INSIDE	MID TRIB	87.38	6700	3.48	2.15	33.78	26.9 1
1	12	POST-BMERG	INSIDE	MID TRIB	83.51	4500	8.52	5.04	20.36	10.40
1	13	POST-EMERG	OUTSIDE	MID TRIB	53.61	370	9.52	7.56	15.11	6.24
1	14	POST-EMERG	OUTSIDE	MID TRIB	66.67	2500	6.55	4.36	27.87	20.85
2	3	PRE-EMERG	INSIDE	LOW TRIB	60.15	500	17.44	12.91	9.73	3.16
2	4	PRE-EMERG	INSIDE	LOW TRIB	66.94	400	15.21	11.29	11.82	4.46
2	5	PRE-EMERG	OUTSIDE	LOW TRIB	31.82	•	23.34	17.18	7.30	2.02
2	6	PRE-EMERG	OUTSIDE	LOWTRIB	79.25	•	16.54	10.56	9.40	3.30
2	13	POST-EMERG	INSIDE	LOW TRIB	51.79	•	11.04	7.05	13.74	6.06
2	14	POST-EMERG	INSIDE	LOW TRIB	75.00	1300	8.24	5.40	19.15	9.83
2	11	POST-EMERG	OUTSIDE	LOW TRIB	72.55	· •	35.53	32.19	3.39	0.20
2	12	POST-EMERG	OUTSIDE	LOW TRIB	94.12	•	29.89	25.65	4.29	0.73
3	1	PRE-EMERG	INSIDE	MID TRIB	·	1000	11.63	6.47	16.99	7.60
3	2	PRE-EMERG	INSIDE	MID TRIB	·	340	16.34	11.05	10.79	3.55
3	3	PRE-EMERG	OUTSIDE	MID TRIB	69.40	300	12.85	9.75	18.40	8.27
3	4	PRE-EMERG	OUTSIDE	MID TRIB	45.61	•	11.30	7.46	21.54	9.97
3	11	POST-EMERG	INSIDE	MID TRIB	84.55	900	15.38	8.94	15.58	6.01
3	12	POST-EMERG	INSIDE	MID TRIB	85.45	6800	3.14	2.01	34.42	27.84
3	13	POST-EMERG	OUTSIDE	MID TRIB	56.36	•	10.69	5.61	20.50	10.76
3	14	POST-EMERG	OUTSIDE	MID TRIB	52.73	•	19.22	12.26	12.25	3.68
4	1	PRE-EMERG	INSIDE	LOW MAIN	89.39	•	7.51	3.41	15.85	8.25
4	2	PRE-EMERG	INSIDE	LOW MAIN	83.10	50000	1.90	1.10	27.62	17.70
4	3	PRE-EMERG	OUTSIDE	LOW MAIN	62.50	14000	7.40	4.90	18.54	10.51
4	4	PRE-EMERG	OUTSIDE	LOW MAIN	73.61	1600	16.69	13.04	11.02	3.90
4	11	POST-EMERG	INSIDE	LOW MAIN	73.83	5600	9.41	5.44	14.45	7.01
4	12	POST-EMERG	INSIDE	LOW MAIN	82.24	8500	4.87	2.38	22.70	12.82
4	15	POST-EMERG	OUTSIDE	LOW MAIN	75.23	1600	13.45	8.69	10.01	4.00
4	16	POST-EMERG	OUTSIDE	LOW MAIN	71.56	4000	9.85	4.79	13.84	6.28
6	1	PRE-EMERG	INSIDE	MID MAIN	75.76	11000	3.11	1.77	30.21	21.36
6	2	PRE-EMERG	INSIDE	MID MAIN	84.80	1800	9.35	6.98	22.21	12.57
6	3	PRE-EMERG	OUTSIDE	MID MAIN	66.67	•	9.94	8.79	19.84	10.32
6	4	PRE-EMERG	OUTSIDE	MID MAIN	82.79	470	2.37	1.66	33.39	25.39
6	12	POST-EMERG	INSIDE	MID MAIN	81.58	40000	0.35	0.17	39.54	32.13
6	13	POST-BMERG	INSIDE	MID MAIN	75.89	5100	2.79	1.65	27.36	16.87
6	16	POST-EMERG	OUTSIDE	MID MAIN	81.37	3600	6.01	4.97	23.22	13.27
6	17	POST-EMERG	OUTSIDE	MID MAIN	80.39	300	10.50	8.31	17.02	7.86
7	1	PRE-EMERG	INSIDE	UPPER TRIB	86.96	11500	5.09	2.56	26.35	16.84
7	2	PRE-EMERG	INSIDE	UPPER TRIB	94.56	6000	5.05	2.58	26.11	16.68
7	3	PRE-EMERG	OUTSIDE	UPPER TRIB	74.71	2200	12.11	7.27	17.56	7.68
7	4	PRE-EMERG	OUTSIDE	UPPER TRIB	75.86	300	25.01	15.31	10.34	2.21
7	11	POST-EMERG	INSIDE	UPPER TRIB	88.00	10000	5.97	3.09	23.41	13.51
7	12	POST-EMERG	INSIDE	UPPER TRIB	89.00	6000	1.44	0.86	36.38	29.42
7	13	POST-EMERG	OUTSIDE	UPPER TRIB	79.79	200	12.68	7.94	16.57	6.82
7	14	POST-EMERG	OUTSIDE	UPPER TRIB	56.38	•	37.70	34.79	4.15	0.63
8	1	PREEMERG	INSIDE	UPPER MAIN	68.18	20000	5.52	2.64	17.38	8.76
8	2	PRE-EMERG	INSIDE	UPPER MAIN	65.15	11500	6.15	3.34	21.12	11.44
8	3	PRE-EMERG	OUTSIDE	UPPER MAIN	80.99	3950	9.80	7.22	15.83	7.12
8	4	PRE-EMERG	OUTSIDE	UPPER MAIN	74.38	4200	5.61	3.98	18.28	9.59
8	12	POST-BMERG	INSIDE	UPPER MAIN	84.76	4700	4.51	2.22	19.41	9.70
8	13	POST-EMERG	INSIDE	UPPER MAIN	77.36	8000	6.85	2.97	21.49	11.52
8	14	POST-EMERG	OUTSIDE	UPPER MAIN	81.31	26000	2.90	1.89	24.73	15.20
8	15	POST-EMERG	OUTSIDE	UPPER MAIN	79.21	9500	8.50	4.29	13.50	6.70

Table 1. Summary of permeability/freeze core data for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988. (continued)

REDD NO.	CORE NO.	SAMPLING PERIOD	CORE LOCATION	STREAM LOCATION	D.O. SATURATION	PERME-ABILITY	% FINES < 2 mm	% FINES < 1 mm	GEOM. MEAN DIAMETER	FREDLE INDEX
9	1	PRE-EMERG	INSIDE	MID MAIN	82.46	1500	11.83	6.83	19.56	10.18
9	2	PRE-EMERG	INSIDE	MID MAIN	84.00	50000	3.03	2.01	31.57	23.62
9	3	PRE-EMERG	OUTSIDE	MID MAIN	68.33	360	14.50	7.29	14.21	5.05
9	4	PRE-EMERG	OUTSIDE	MID MAIN	76.67	1400	13.01	5.47	16.11	6.71
9	11	POST-EMERG	INSIDE	MID MAIN	77.12	600	18.11	11.34	12.60	3.99
9	12	POST-EMERG	INSIDE	MID MAIN	78.81	5800	3.00	1.71	32.95	24.66
9	13	POST-EMERG	OUTSIDE	MID MAIN	60.71	1600	8.86	5.13	21.73	12.42
9	14	POST-EMERG	OUTSIDE	MID MAIN	67.86	2000	7.97	5.92	20.86	12.05
10	1	PRE-EMERG	INSIDE	LOW MAIN	82.40	6300	1.27	0.73	33.00	23.80
10	2	PRE-EMERG	INSIDE	LOW MAIN	77.60	70000	2.81	2.25	31.72	23.73
10	3	PRE-EMERG	OUTSIDE	LOW MAIN	78.42	12000	7.11	4.58	22.17	12.73
10	4	PRE-EMERG	OUTSIDE	LOW MAIN	76.98	3100	9.41	7.05	16.62	8.31
10	11	POST-EMERG	INSIDE	LOW MAIN	76.19	5500	6.74	4.10	21.44	12.24
10	12	POST-EMERG	INSIDE	LOW MAIN	76.19	900	8.87	5.60	17.32	7.84
10	13	POST-EMERG	OUTSIDE	LOW MAIN	76.70	1250	8.85	6.85	18.98	9.18
10	14	POST-EMERG	OUTSIDE	LOW MAIN.	78.64	4400	9.63	7.04	17.78	8.89

Definitions:

REDD NO. - Corresponds to the location of the redd within the basin (Figure 2):

1) Graham Gulch
2) Little Freshwater Creek
3) Cloney Gulch
4) Lower mainstem Freshwater Creek, downstream of Little Freshwater Creek
5) Middle mainstem Freshwater Creek. Discarded as possible chinook salmon redd.
6) Middle mainstem Freshwater Creek, Index section.
7) South Fork Freshwater Creek
8) Upper mainstem Freshwater Creek, upstream of South Fork Freshwater Creek
9) Middle mainstem Freshwater Creek, upstream of Graham Gulch
10) Lower mainstem Freshwater Creek, upstream of Little Freshwater Creek.

CORE NO. = Corresponds to location and time of core sampling: Numbers below 10 sampled just after spawning (pre-emergent); Numbers above 10 sampled just after emergence (post emergent).

SAMPLING **PERIOD =** Time period when core was taken:
PRE-EMERG -just after spawning (2/1/88 - 3/9/88)
POST-EMERG - just after fry emergence (4/27/88 - 6/11/88)

CORE **LOCATION =** Location relative to redd:
INSIDE - core sampled within the mound of the redd
OUTSIDE - core sampled just upstream of the redd pit

STREAM LOCATION = Location of the redd within the Freshwater basin:
LOW MAIN - Lower mainstem (Redds #4 and #10)
MID MAIN - Middle mainstem (Redds #6 and #9)
UPPER MAIN - Upper mainstem (Redd #8)
LOW TRIB - Little Freshwater Creek (Redd #2)
MID TRIB - Cloney Gulch and Graham Gulch (Redds #l and #3)
UPPER TRIB - South Fork Freshwater Creek (Redd #7)

D.O. SATURATION = Relative DO saturation (%) of intragravel water to surface water

PERMEABILITY = Sample permeability (cm/hr)

% FINES <2 mm= Percentage by volume of a core sample which passes through a 2 mm sieve (%)

% FINES **<1 mm =** Percentage by volume of a core sample which passes through a **1 mm sieve (%)**

GEOM. MEAN DIAMETER = Geometric mean diameter of particles in a core sample (mm)

FREDLE INDEX = Fredle index of particle size distribution of a core sample apparatus could not remove water faster than water entered the standpipe.

Of the 72 permeability samples taken for this study, 11 were outside of the range limitations of the standpipe or the curve. One sample (#4-1, Table 1) had a permeability above the range and ten samples exhibited an inflow rate < 3 ml/sec for which permeability could not be determined. These 11 samples were discarded from further analysis.

The mean permeability for all 61 samples for which permeability could be determined was 7765 cm/hr with a standard deviation of 13,216 cm/hr. The mean permeability for samples within redds was 10,904 cm/hr with a standard deviation of 16,413 cm/hr while the mean permeability for outside redd samples was 3812 cm/hr with a standard deviation of 5662 cm/hr. The difference between the means was 7091 cm/hr, significant at a 5% level (Table 2). Permeability was thus 65% higher within redds than outside of redds.

A frequency distribution of the permeability measurements demonstrated a distribution skewed towards the low end of the permeability scale. A natural log (l(n)) transformation of permeability measurements resulted in a more normal distribution. The transformed permeability values were used for further analyses, presented later.

Dissolved Oxygen

In every case, the DO of intragravel water measured inside the pipe was lower than that of the DO of the surface water outside the pipe. The mean relative DO saturation for all seventy samples for which a valid DO measurement was made was 75.25% with a standard deviation of 11.48. The mean relative DO saturation for the 34 samples within redds was

Table 2. One factor ANOVA comparing permeability inside and outside of nine coho redds in the Freshwater Creek basin, Humboldt county, 1988.

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	756819179.264	756819179.264	4.592
Within groups	59	9.724E9	164810799.018	p = .0363
Total	60	1.048E10		

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
INSIDE	34	10904.118	16413.467	2814.886
OUTSIDE	27	3812.593	5662.203	1089.691

Comparison:	Mean Diff.:	Fisher PLSD:
INSIDE vs. OUTSIDE	7091.525	6622.565 •

• Significant at 5% level

79.45% with a standard deviation of 8.95 while the mean for outside redd samples was 71.28% with a standard deviation of 12.28. The difference of 8.16% between the inside mean and the outside mean is significant at a 5% level (Table 3).

Freeze Cores

A wide variety of shapes and sizes of freeze cores were taken during this study. In general, cores taken in areas of high permeability were smaller in diameter and volume than those from low permeability sites. Areas with high percentages of sand and other fines tended to freeze easier than "cleaner" gravels and resulted in larger cores. Volumes of cores ranged from a high of 9510 ml for Core# 3-4, which had a permeability below the standpipe range, to a low of 1245 ml for Core# 4-l which had a permeability higher than the standpipe range.

A number of samples contained large rocks or large pieces of woody debris. Wood and other organics were removed from all samples before measuring. All rocks, regardless of size, were kept and measured with their respective samples. In Adams (1979) study, large rocks which were more than 50% outside the freezing front of the core were removed from the sample. In this present study, it was determined that large rocks were necessary to best represent the substrate when determining percentage of fines. All of the rocks remaining in the top 32 mm screen after sieving were visually measured and any that were estimated greater than 64 mm on their secondary axis were measured and recorded as >64 mm on the data sheets (Appendix B).

Table 3. One factor ANOVA comparing percentage of relative DO saturation inside and outside of coho redds in the Freshwater Creek basin, Humboldt County, 1988.

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	1164.786	1164.786	9.998
Within groups	68	7922.489	116.507	p = .0023
Total	69	9087.276		

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
INSIDE	34	79.446	8.952	1.535
OUTSIDE	36	71.284	12.28	2.047

Comparison:	Mean Diff.:	Fisher PLSD:
INSIDE vs. OUTSIDE	**8.162**	**5.151 ***

* Significant at 5% level

Several freeze core attempts missed the bottom or top few centimeters of the substrate. In cases where the missing portion was minimal, and the core appeared representative of the substrate, the samples were kept. Most cases where the core was incomplete were the result of high permeability and/or high surface flow, or due to problems pouring the liquid nitrogen (see Discussion).

On eight occasions, water leaked past the leather seal and resulted in a sample that had to be entirely discarded. Usually when leakage occurred, there was no gravel frozen to the standpipe. Occasionally, some gravel near the top of the sample froze but the bottom of the core was unrepresented.

Substrate Composition

For the 72 freeze cores, the percentages of fines <2 mm ranged from a low of 0.35% for Core #6-12 (inside redd) to a high of 37.7% for Core #7-14 (outside redd) (Table 1). The mean for percentage of fines for all 72 cores was 10.32% with a standard deviation of 7.26. The mean of all cores taken inside redds was 7.53% with a standard deviation of 4.99, while the mean for all cores outside of redds was 13.11% with a S.D. of 8.13. A one factor ANOVA compared the mean percent fines of the cores taken inside of redds with that from outside redds and demonstrated a significant difference of 5.58% at the 5% significance level (Table 4).

In order to account for the natural variability that occurs even amongst closely spaced gravel samples, further analysis used the means for each pair of samples. Table 5 lists the means of relative DO saturation, In permeability, percentage of fines, dg, and fredle index for each pair of core samples.

Table 4. One factor ANOVA comparing percentage of fines <2 mm inside and outside of nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	1	560.511	560.511	12.328
Within groups	70	3182.533	45.465	p = 8.0000E-4
Total	71	3743.044		

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
INSIDE	36	7.53	4.986	.831
OUTSIDE	36	13.111	8.128	1.355

Comparison;	Mean Diff.:	Fisher PLSD:
INSIDE vs. OUTSIDE	-5.58	3.17 *

* Significant at 5% level

Table 5. Summary of average permeability/freeze core data for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

REDD NO.[1]	SAMPLING PERIOD	CORE LOCATION	AVG. DO SATURATION	AVG. PERM.	AVG. % FINES<2 mm	AVG. % FINES<1 mm	AVG. GEOM MEAN DIAM	AVG. FREDLE
1	PRE-EMERG	INSIDE	85.90	4000	12.57	7.17	16.60	7.30
1	PRE-EMERG	OUTSIDE	81.53	870	13.35	9.29	16.25	6.71
1	POST-EMERG	INSIDE	85.45	5600	6.00	3.60	27.07	18.66
1	POST-EMERG	OUTSIDE	60.14	1435	8.04	5.96	21.49	13.55
2	PRE-EMERG	INSIDE	63.55	450	16.33	12.10	10.78	3.81
2	PRE-EMERG	OUTSIDE	55.54	·	19.94	13.87	8.35	2.66
2	POST-EMERG	INSIDE	63.40	1300	9.64	6.23	16.45	7.95
2	POST-EMERG	OUTSIDE	83.34	·	32.71	28.92	3.84	0.47
3	PRE-EMERG	INSIDE		670	13.99	8.76	13.89	5.50
3	PRE-EMERG	OUTSIDE	57.51	300	12.08	8.61	19.97	9.12
3	POST-EMERG	INSIDE	85.0	3850	9.26	5.48	25.00	16.93
3	POST-EMERG	OUTSIDE	54.55	·	14.96	8.94	16.38	7.22
4	PRE-EMERG	INSIDE	86.25	50000	4.71	2.26	21.74	12.98
4	PRE-EMERG	OUTSIDE	68.06	7800	12.05	8.97	14.78	7.21
4	POST-EMERG	INSIDE	78.04	7050	7.14	3.91	10.50	9.92
4	POST-EMERG	OUTSIDE	73.40	2800	11.65	6.74	11.93	5.14
6	PRE-EMERG	INSIDE	80.28	6400	6.23	4.38	26.21	16.97
6	PRE-EMERG	OUTSIDE	74.73	470	6.16	5.23	26.62	17.06
6	POST-EMERG	INSIDE	78.74	22550	1.57	3.91	33.45	24.50
6	POST-EMERG	OUTSIDE	80.88	1950	8.26	6.64	20.12	10.57
7	PRE-EMERG	INSIDE	90.73	8750	5.07	2.57	26.23	16.76
7	PRE-EMERG	OUTSIDE	75.29	1250	18.56	11.29	13.95	4.95
7	POST-EMERG	INSIDE	88.50	8000	3.71	1.98	29.90	21.47
7	POST-EMERG	OUTSIDE	68.09	200	25.19	21.37	10.36	3.73
8	PRE-EMERG	INSIDE	66.67	15750	5.84	2.99	19.25	10.10
8	PRE-EMERG	OUTSIDE	77.69	4075	7.71	5.60	17.06	0.36
8	POST-EMERG	INSIDE	81.06	6350	5.68	2.60	20.45	10.61
8	POST-EMERG	OUTSIDE	80.26	17750	5.70	3.09	19.12	10.95
9	PRE-EMERG	INSIDE	83.20	25750	7.43	4.42	25.57	16.90
9	PRE-EMERG	OUTSIDE	72.50	880	13.76	6.38	14.66	5.30
9	POST-EMERG	INSIDE	77.97	3200	10.56	6.53	22.70	14.33
9	POST-EMERG	OUTSIDE	64.29	1800	8.42	5.53	21.30	12.24
10	PRE-EMERG	INSIDE	80.00	38150	2.04	1.49	32.36	23.77
10	PRE-EMERG	OUTSIDE	77.70	7550	8.26	5.82	19.40	10.52
10	POST-EMERG	INSIDE	76.19	3200	7.81	4.85	19.30	10.04
10	POST-EMERG	OUTSIDE	77.67	2025	9.24	6.95	10.30	9.04

[1]See Table 1 for redd locations within the basin

Linear Regression Analysis

Determining the particle size distribution requires lengthy procedures to collect and process the gravel sample. It would be useful for fishery biologists to be able to predict gravel quality and particle size distribution of a gravel sample by just knowing the permeability and/or the dissolved oxygen of that sample. In order to test the predictability of particle size distribution and gravel quality, knowing the permeability and/or dissolved oxygen in the gravel, several simple regressions were used to compare the dependant variables of percentage of fines <2 mm, geometric mean diameter, and fredle index with the independant variables of relative DO saturation (Figure 9) and ln(x) of permeability (Figure 10).

None of the three gravel indexes used showed a strong linear relationship to intragravel dissolved oxygen (Figure 9). The dg and fredle indexes show a slightly higher correlation with DO than with percentage of fines.

On the other hand, regressions of ln(x) of permeability as a function of particle size distribution show a strong relationship (Figure 10). While the dg and fredle index show considerably more correlation to permeability than they do to DO, they are not nearly as good an indicator of permeability as percentage of fines <2 mm. Simple observation of the regression plot suggests a strong relationship between percentage of fines and permeability and the R^2 value of 0.531 demonstrates that much of the variation in permeability is explained by percentage of fines.

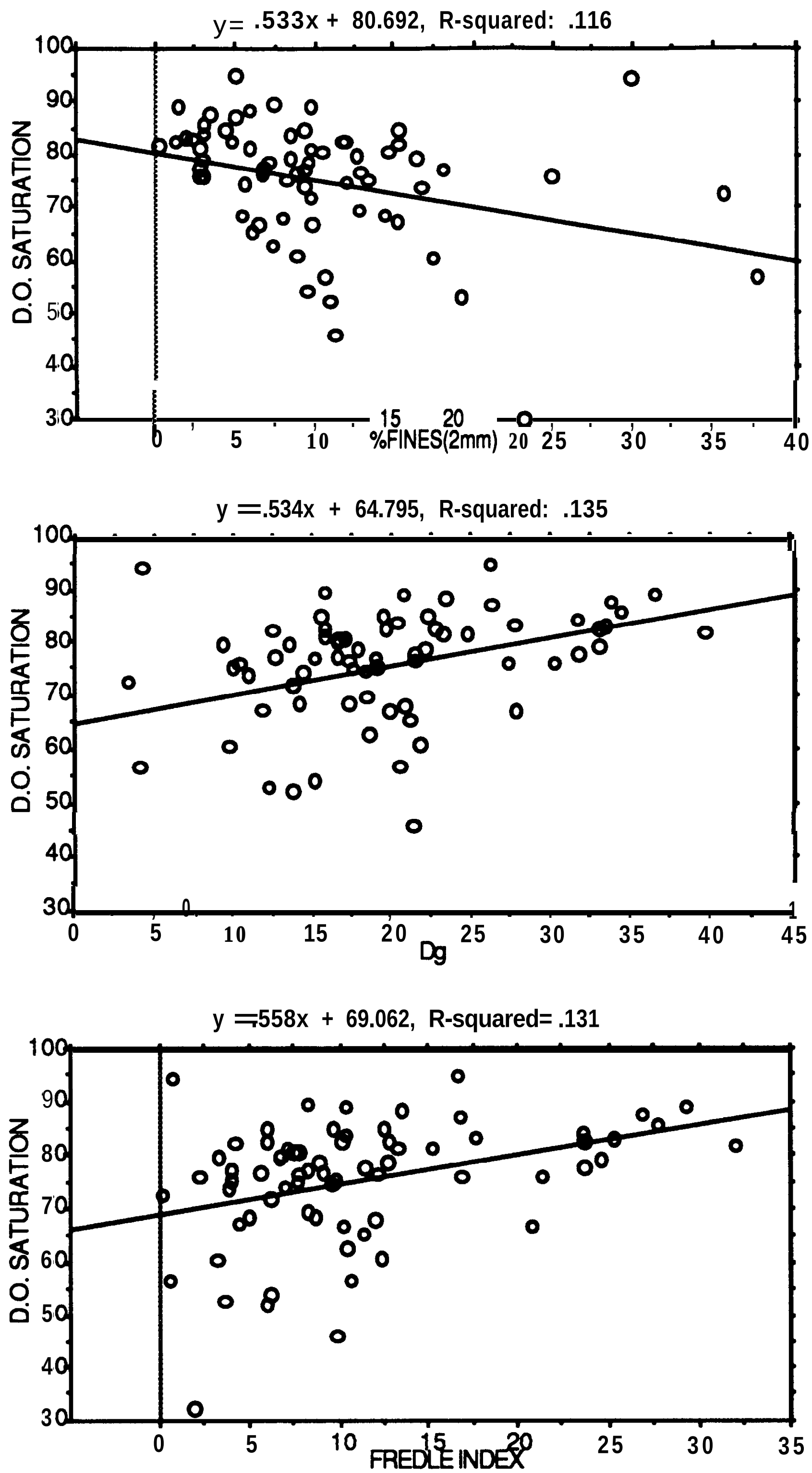

Figure 9. Simple linear regressions between the dependent variable relative DO saturation and the independent variables percentage of fines <2 mm, geometric mean diameter, and fredle index for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

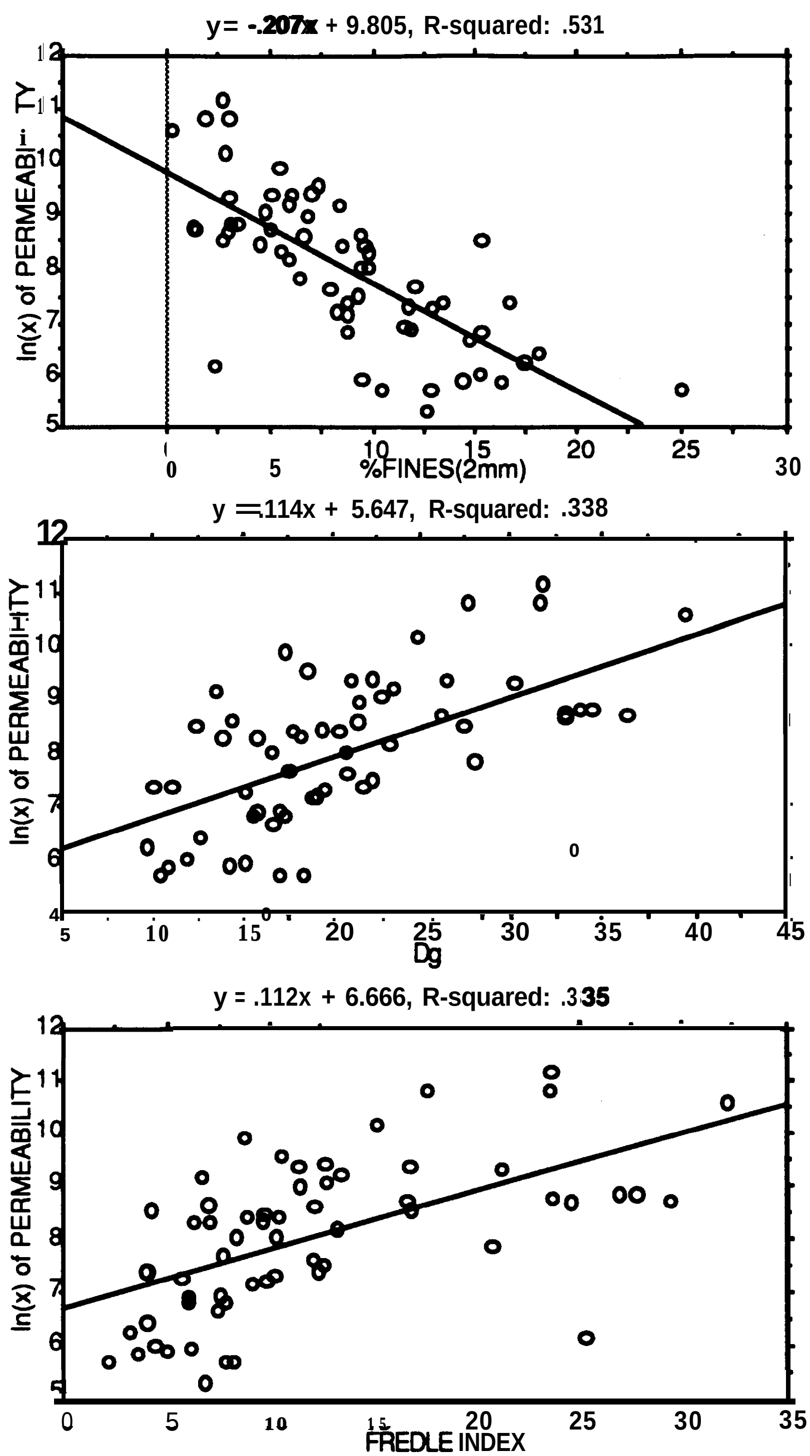

Figure 10. Simple linear regressions between the dependent variable Ln(x) of permeability and the independent variables of percentage of fines <2 mm, geometric mean diameter (Dg) and fredle index for nine coho redds in the Freshwater Creek basin, Humboldt county, 1988.

Three Factor ANOVA

Each pair of the 72 core samples is uniquely categorized by a combination of two factors of location and one of time. The location of any core is either inside or outside a redd (CORE LOCATION) and is in one of six stream reaches (STRM. LOCATION): upper mainstem (site #8); middle mainstem (sites #6 and 9); lower mainstem (sites #4 and 10); upper tributary (site #7); middle tributary (sites #l and 3); and lower tributary (site #2). The time that each core was taken is either just after spawning (PRE-EMERGENT) or just after fry emergence (POST-EMERGENT).

These three factors of CORE LOCATION, STREAM LOCATION and TIME were used in a three way analysis of variance (ANOVA) to assess the effect of each factor individually and their interactive effects on each of the three measured variables of percentage of fines <2 mm (Table 6), relative DO saturation, and permeability. A separate three way ANOVA was run for each variable.

The factors of CORE LOCATION and STRM. LOCATION each had an effect on the percentage of fines that is significant at the 5% level (Table 6). This is to say that cores taken inside redds had significantly less fines than those taken outside of redds and that cores taken in different sections of the stream exhibited significantly different percentages of fines. In addition, the interaction of CORE LOCATION and STRM. LOCATION had a significant effect. This is interpreted to mean that the differences in the percentage of fines inside redds compared to outside redds will change depending on the location of the sampling site within the watershed. In all of the sampled stream reaches, the percentage of fines were lower inside redds than outside redds (Table 6).

Table 6. Three factor ANOVA comparing percentage of fines <2 mm by stream location, location relative to redd and over time for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
STRM LOCATION (A)	5	554.134	110.827	11.708	3.0E-4
TIME (B)	1	1.969	1.969	.208	.6565
AB	5	50.948	10.19	1.076	.4206
CORE LOCATION (C)	1	344.605	344.605	36.406	1 .OE-4
AC	5	270.838	54.168	5.723	.0063
Bc	1	44.253	44.253	4.675	.0515
ABC	5	115.685	23.137	2.444	.095
Error	12	113.587	9.466		

*Significant at 5% level

(Sample size)
(Mean % fines)

	TIME:	PRE	POST	Totals:
STRM LOCAON	UP MAIN	2 6.775	2 5.69	4 6.233
	MID MAIN	9.917 / 6	7.142 / 6	8.529 / 12
	LOW MAIN	4 6.765	4 8.96	8 7.863
	UP TRIB	2 11.815	2 14.45	4 13.132
	MID TRIB	2 13.035	2 12.11	4 12.573
	LOW **TRIB**	**2** **18.135**	**2** **21.175**	**4** **19.655**
Totals:		**18** **10.338**	**18** **10.308**	**36** **10.323**

	CORE LOCATION	INSIDE	OUTSIDE	Totals:
STRM LOCATION	**UP MAIN**	2 5.76	2 6.705	4 6.233
	MID MAIN	**6** **7.393**	**6** **9.665**	**12** **8.529**
	LOW MAIN	4 5.425	4 10.3	8 7.863
	UP TRIB	2 4.39	2 21.875	4 13.132
	MID TRIB	2 11.625	2 13.52	4 12.573
	LOW TRIB	2 12.985	2 26.325	4 19.655
Totals:		**18** **7.532**	**18** **13.113**	**36** **10.323**

Table 6. Three factor ANOVA comparing percentage of fines <2 mm by stream location, location relative to redd and over time for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988. (continued)

	CORE LOCATION	INSIDE	OUTSIDE	Totals:
TIME	PRE	9 8.246	9 12.43	18 10.338
	POST	9 6.819	9 13.797	18 10.308
Totals:		18 7.532	18 13.113	36 10.323

	TIME:	PRE		POST		Totals:
	CORE LOCATION	INSIDE	OUTSIDE	INSIDE	OUTSIDE	
STRL 8 ATDN	UP MAIN	1 5.84	1 7.71	1 5.68	1 5.7	4 6.233
	MID MAIN	3 8.743	3 11.09	3 6.043	3 8.24	12 8.529
	LOW MAIN	2 3.375	2 10.155	2 7.475	2 10.445	8 7.863
	UP TRIB	1 5.07	1 18.56	1 3.71	1 25.19	4 13.132
	MID TRIB	1 13.99	1 12.08	1 9.26	1 14.96	4 12.573
	LOW TRIB	1 16.33	1 19.94	1 9.64	1 32.71	4 19.655
Totals:		9 8.246	9 12.43	9 6.819	9 13.797	36 10.323

On the other hand, the time of sampling appeared to make no significant difference in the percentage of fines (Table 6). Thus, over the egg incubation period, there tended to be no net intrusion or removal of fine sediments inside or outside of redds. This is likely due to the lack of high flows between sampling sessions.

In light of the fact that this study will provide a monitoring database, it is useful to focus on the cores that were taken outside of redds as representative of unworked gravels in potential coho spawning areas. Particularly useful for this purpose is Table 6 that demonstrates the effect of the interaction of CORE LOCATION and STREAM LOCATION on the percentage of fines. By focusing on the percentage of fines found outside of redds, it can be seen that the tributaries, in general, exhibit a higher percentage of fine sediment than the mainstem sections, with that of the lowermost tributary, Little Freshwater Creek, highest of all. Based on the results in Table 6, it appears that during the post-emergence sampling the percentage of fines in spawning areas in the three mainstem sections increased in a downstream direction. A simple ANOVA was conducted on the percentage of fines outside of redds at the mainstem sample sites (sites #4,6,8,9 andlO) and failed to show any significant difference in the means of the three sections (Table 7).

The three factor ANOVA on the variable "relative DO saturation" shows that the CORE LOCATION factor and the interaction of it with the STREAM LOCATION factor have a significant effect on intragravel DO at the 5% level (Table 8). These results are similar to those of the percent fines ANOVA (Table 6) except that STREAM LOCATION has just less than a significant effect on DO. Cores taken outside of redds in tributaries

Table 7. One factor ANOVA comparing average percentage of fines <2 mm for cores taken outside coho redds in mainstem Freshwater Creek, Humboldt County, 1988.

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	18.184	9.092	1.342
Within groups	9	60.988	6.776	p = .309
Total	11	79.172		

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
UP MAIN	2	6.705	1.421	1.005
MID MAIN	6	9.665	3.124	1.275
LOW MAIN	4	10.3	1.841	.921

Table 8. Three factor ANOVA comparing relative DO saturation by stream location, location relative to redd and over time for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

Source:	df:	Sum of Sauares:	Mean Sauare:	F-test:	P value:
STRM LOCATION (A)	5	13045.951	1609.19	17.832	1 .OE-4
TIME (B)	1	556.708	556.708	16.296	.0016
AB	5	1871.906	374.381	10.959	4.0E-4
CORE LOCATION (C)	1	15.874	15.874	.465	.5084
AC	5	781.872	156.374	4.577	.0144
Bc	1	280.556	280.556	8.213	.0142
ABC	5	2070.496	414.099	12.122	2.0E-4
Error	12	1409.942	134.162		

	TIME:	PRE	POST	Totals:
STRM LOC ATION	UP MAIN	2 72.18	2 80.66	4 76.42
	MID MAIN	6 79.638	6 74.578	12 77.108
	LOW MAIN	4 78.003	4 76.325	8 77.164
	UP TRIB	2 83.01	2 78.295	4 80.652
	MID TRIB	2 28.755	2 69.775	4 49.265
	LOW TRIB	59.545 2	73.37 2	66.458 4
	Totals:	18 70.934	18 75.387	36 73.161

	CORELOCATI...	INSIDE	OUTSIDE	Totals:
STRM LOC ATION	UP MAIN	2 73.865	2 78.975	4 76.42
	MID MAIN	6 81.872	6 72.345	12 77.108
	LOW MAIN	4 80.12	4 74.208	8 77.164
	UP TRIB	2 89.615	2 71.69	4 80.652
	MID TRIB	2 42.5	2 56.03	4 49.265
	LOW TRIB	2 63.475	2 69.44	4 66.458
	Totals:	18 75.034	18 71.287	36 73.161

Table 8. Three factor ANOVA comparing relative DO saturation by stream location, location relative to redd and over time for nine coho redds in the Freshwater Creek basin, Humboldt County, 1988. (continued)

TIME	CORE LOCATION	INSIDE	OUTSIDE	Totals:
TIME	PRE	9 70.697	9 71.172	18 70.934
	POST	9 79.372	9 71.402	18 75.387
Totals:		18 75.034	18 71.287	36 73.161

	TIME:	PRE		POST		Totals:
	CORE LOCATION	INSIDE	OUTSIDE	INSIDE	OUTSIDE	
STRM LOCATION	UP MAIN	1 66.67	1 77.69	1 81.06	1 80.26	4 76.42
	MID MAIN	3 83.023	3 76.253	3 80.72	3 68.437	12 77.108
	LOW MAIN	2 83.125	2 72.88	2 77.115	2 75.535	8 77.164
	UP TRIB	1 90.73	1 75.29	1 88.5	1 68.09	4 80.652
	MID TRIB	1 0	1 57.51	1 85	1 54.55	4 49.265
	LOW TRIB	1 63.55	1 55.54	1 63.4	1 83.34	4 66.458
Totals:		9 70.697	9 71.172	9 79.372	9 71.402	36 73.161

appear to have lower relative DO saturation levels than the mainstem counterparts, although the differences are not significant (Table 8).

A similar three way ANOVA on ln(x) of permeability was attempted but could not run because of the eleven missing values (permeability was beyond the range of measurement of the standpipe, one too high. and ten too low). In order to use the ANOVA as an observational analysis tool, the missing values were replaced with the appropriate minimum (200 cm/hr) or maximum (100,000 cm/hr) values which can be measured with the modified standpipe. The resultant table is not included here, but the three factor ANOVA suggests that the CORE LOCATION and STREAM LOCATION factors individually have the only significant effects on permeability. The results were similar to the DO and percent fines ANOVAs in that the mean permeabilities of the outside cores were lower in all of the tributaries than in the mainstem.

In order to determine if there was a significant difference in the means of gravel measurements taken outside redds between the three mainstem sections, simple ANOVAs were performed. One might expect that the uppermost “transport” section of stream would have the lowest percentage of fines and the highest permeability and DO while the lower “storage” section would experience high percentage of fines and low permeability and DO. The respective three way ANOVA tables (Tables 7, 9) support this expectation for percentage of fines and DO, although the simple ANOVAs showed no significant differences in the respective means. On the other hand, the simple ANOVA for permeability (Table 10) showed a significant difference in means, and follow-up multiple comparison tests were conducted to determine where the differences were. Fisher’s Protected Least Significant Difference test (PLSD) (Winer, 1971)

Table 9. One factor ANOVA comparing average relative DO saturation for cores taken outside coho redds in mainstem Freshwater Creek, Humboldt County, 1988.

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	66.047	33.024	.671
Within groups	9	442.7	49.189	p = .5349
Total	11	508.748		

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
UP MAIN	2	78.975	1.817	1.285
MID MAIN	6	72.345	8.681	3.544
LOW MAIN	4	74.208	4.569	2.285

Table 10. One factor ANOVA and multiple comparison of average Ln(x) of permeability for cores taken outside coho redds in mainstem Freshwater Creek, Humboldt County, 1988.

Source:	DF:	Sum Squares:	Mean Square:	F-test:
Between groups	2	8.541	4.27	10.797
Within groups	9	3.56	.396	p = .0041
Total	11	12.1		

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
UP MAIN	2	9.948	1.041	.736
MID MAIN	6	7.007	.542	.221
LOW MAIN	4	8.444	.58	.29

Comparison:	Mean Diff.:	Fisher PLSD:
UP MAIN vs. MID MAIN	2.042	1.162 •
UP MAIN vs. LOW MAIN	.605	1.232
MID MAIN vs. LOW MAIN	-1.437	.918 *

* Significant at 5% level

showed that the mean permeability of the middle section was significantly lower than that of either the upper or the lower section (Table 10).

The means for percentage of fines <2 mm, ln(x) of permeability and relative DO saturation for all of the outside cores taken in the Freshwater Creek basin are listed in Tables 11, 12 and 13 with their respective statistics. These should provide a good database for any future monitoring of physical attributes of spawning gravels in Freshwater Creek.

Table 11. Average percentage of fines <2 mm for cores taken outside of nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
UP MAIN	2	6.705	1.421	1.005
MID MAIN	6	9.665	3.124	1.275
LOW MAIN	4	10.3	1.841	.921
UP TRIB	2	21.875	4.688	3.315
MID TRIB	2	13.52	2.036	1.44
LOW TRIB	2	26.325	9.03	6.385

Table 12. Average relative DO saturation for cores taken outside of nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
UP MAIN	2	70.975	1.817	1.285
MID MAIN	6	72.345	8.681	3.544
LOW MAIN	4	74.208	4.569	2.285
UP TRIB	2	71.69	5.091	3.6
MID TRIB	2	56.03	2.093	1.48
LOW TRIB	2	69.44	19.658	13.9

Table 13. Average permeability (cm/hr) for cores taken outside nine coho redds in the Freshwater Creek basin, Humboldt County, 1988.

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
UP MAIN	2	10912.5	9669.685	6837.5
MID MAIN	6	1234.167	585.649	239.09
LOW MAIN	4	5243.75	2809.239	1404.619
UP TRIB	2	725	742.462	525
MID TRIB	2	150	212.132	150
LOW TRIB	2	0	0	0

DISCUSSION

Technique

The primary focus of this study was to develop a database of spawning gravel conditions, including dissolved oxygen, substrate composition and permeability, in Freshwater Creek. However, in the course of preparing for the field work, shortcomings associated with comparing parameters measured using two separate standpipes became clear. High variability of permeability, DO and gravel composition even within riffles have been reported (Koski 1966; Adams and Beschta 1980; McBain unpublished; Everest et al. 1987) and tend to confound comparisons between more than one measuring device. It was apparent that a device was needed that could measure various intragravel parameters including substrate composition from a single location.

Development of the modified standpipe is a significant advancement for management and research of salmonid spawning habitat. The standpipe offers the researcher the capability of measuring the particle sizes, arrangement, permeability and dissolved oxygen concentration in natural egg pockets as recommended by Chapman (1988).

Permeability measurement is much less time consuming than substrate coring. The modified standpipe can be used to further investigate the relationship between permeability and substrate composition. Where the relationship proves significant, permeability measurement may be used to predict the percentage of fines without the need for substrate cores.

The modified standpipe combines two standard techniques, liquid nitrogen freeze coring and permeability measurement, which have each been well documented and accepted. Nonetheless, as with any instrument, the researcher must not assume more precision than the method can promise. Each method has sources of variability along with those variables unique to the modified standpipe which all need to be recognized.

The Terhune (1958) method of permeability measurement is a practical, well tested technique that, when used properly, provides an index of permeability rather than a precise estimator (Young et al. 1989; McBain unpub.). Variability can occur during both the inflow measurement and interpretation of permeability from the Permeability/Inflow curve. Variation during inflow measurement was minimized by taking three replications at each site and having one person consistently taking the measurements. Variation due to graphic interpretation of permeability from the Permeability/Inflow curve (Figure 6) occurs because the log-log curve is more precise for lower inflow rates than for higher rates. Permeability interpolation was conducted by one person for the entire study using the curve generated for the modified standpipe. The calibration results indicate that the Terhune (1958) standpipe and the modified standpipe measure essentially the same inflow and that either the "Permeability vs. Standpipe Inflow" curve of Terhune (1958) or Barnard can be used for any standpipe which ranges from 3.2 cm to 4.1 cm inner diameter as long as the perforations follow the Terhune (1958) design.

Variations in size and shape of freeze cores taken with the modified standpipe were caused by differences in the following: substrate composition; permeability; surface water flow; technique of pouring nitrogen into the standpipe; and leakage of water past the leather plunger. Those samples with high percentage of fines and low permeabilities tended to freeze easier and resulted in large cores. Although the composition of the substrate or the permeability could not be altered, the sheet metal collar and sandbag (Figure 8) effectively reduced surface and perhaps subsurface flow and kept the freezing effect of the liquid nitrogen from dissipating too rapidly.

The method of pouring the liquid nitrogen had a surprisingly significant effect on the size and success of the freeze cores. The top of the nitrogen inside the standpipe appears to be the critical freezing location. If the level of nitrogen is maintained high in the pipe by pouring slowly but continuously, the top layer of gravel effectively freezes to the pipe, but the bottom tends to be thin. On the other hand, when the nitrogen is poured until it boils near the funnel and then allowed to boil down before it is refilled, the bottom of the core freezes well but the top tends to be thin. A combination of these pouring techniques usually resulted in a uniform freeze core, although under certain circumstances, one or the other worked best. In most cases, eight liters of nitrogen applied correctly resulted in a good 20-30 cm diameter core. Ten to fifteen liters were used where permeability was higher than normal.

In all cases, the primary concern when using the modified standpipe technique is to make sure the plunger disk completely seals the standpipe. If there is any doubt about the integrity of the seal, then a new seal should be prepared. Throughout this study, leather disks were used and lasted long enough for about five freeze cores before needing replacement. In another study using the same standpipe, McBain (unpub.) effectively modified the plunger seal by using two leather disks and placing rubber gaskets above and below the leather. A recent improvement of the modified standpipe uses a plunger disk made out of a synthetic rubber material called "Viton" which appears to be extremely durable (Barnard and McBain in prep.).

Dissolved Oxygen

Dissolved oxygen is the intragravel parameter most critical to egg survival and to size of fish at emergence, and as such is important to investigate and monitor (Chapman 1988). Intragravel DO values were lower inside or outside of redds than in surface waters in all cases. I assume that the difference is due to respiration by decomposing organics in the gravel. Intragravel biological oxygen demand (BOD) is a difficult variable to measure and although it is likely that sediment composition and permeability have an effect on DO, the effect may be masked by the BOD (Ringler and Hall 1988). Koski (1966) also found the relationship between percentage of fines and DO to be weakly correlated. Linear regression analysis comparing DO with substrate composition for this study confirmed that there is a significant relationship but that it is a weak one and not likely useful for estimating particle size from DO measurement.

Coho salmon in Freshwater Creek effectively increased intragravel DO levels by an overall average of 8.16% over undisturbed gravels in the act of building redds. Although the difference is significant, the variability due to BOD mentioned above renders dissolved oxygen too insensitive to serve as a suitable parameter for future monitoring in the basin.

Permeability

Coho salmon spawning in Freshwater Creek increased the overall average permeability of the gravels over the background level by more than a factor of two, from 3813 cm/hr to 10,904 cm/hr (Table 2). Chapman (1988) using data from Koski (1966) showed that a permeability increase of the magnitude found in my study could significantly increase the percentage of survival to emergence for coho salmon.

Although more of an index of gravel quality than a precise estimator of egg survival (Young et al. 1989), permeability measurement seems to hold promise as a cost-effective method of monitoring substrate composition. Regression analysis demonstrated that over 50% of the variation in permeability is explained by percentage of fines <2 mm (Figure 9). McNeil1 and Ahnell (1964) and McBain (unpub.) demonstrated a similar inverse relationship between permeability and percentage of fines <0.833 mm and <l mm respectively. It is interesting to note that the use of dg and the fredle index as gravel quality indicators has been suggested to improve upon the percentage of fines method because they provide better indicators of permeability and pore size (Platts et al. 1983). The results of this study indicate that percentage of fines <2 mm is a much better indicator of permeability than either dg or the fredle index.

Particle Size Distribution

Prior studies of salmonid spawning gravels have shown a high variability of percent fines and other gravel parameters even amongst closely spaced samples. The same variability was demonstrated during this study (Table 1). In some cases, a partial cause for this variability is the small quantity of sediment in each sample.

Coho salmon spawning in Freshwater Creek removed nearly 43% of the fine sediment <2 mm from gravel (Table 4). This finding is consistent with a number of studies for coho and other salmonids (Burner 1951; McNeil and Ahnell 1964; Everest et al. 1987; Regnart 1991). The significance of this cleaning process is that higher survival rates to emergence are associated with less fines (McNeil and Ahnell 1964; Koski 1966; Tagart 1976; Phillips et al. 1975; Platts et al, 1983; Chapman 1988; Everest et al. 1987).

A number of studies have investigated the percentage of egg survival associated with substrate composition, but there is little consistency in the definition of fines between studies. It is therefore difficult to compare or apply the findings to this study. In an effort towards consistency with other disciplines such as hydrology, soils and geology, particles less than 2 mm were considered fines for this study. Platts et al. (1979) found that 2 mm provided the best fit to geometric mean diameter for chinook salmon spawning substrate in the Salmon River. Of more significance is that gravel permeability in Freshwater Creek was more closely related to percentage of fines <2 mm than to the geometric mean diameter and fredle index (Figure 9). This is in contrast to the claim of Platts et al. (1979) that geometric mean diameter relates to permeability better than percentage of fines.

Chapman (1988) used data from Koski (1966) to develop regressions between egg survival to emergence as a function of both the geometric mean diameter and the fredle index. The mean fredle index inside Freshwater Creek coho redds was 13.8 with a standard deviation of 6.1 which represents 100% survival (Chapman 1988). The mean dg of 22.54 (standard deviation of 6.23) also relates to 100% survival to emergence. Using the regression lines of Chapman (1988), I conclude that the quality of the gravel in redds in the Freshwater Creek basin remained excellent for coho salmon spawning during the 1987/88 season.

There was no significant infiltration of percentage of fines into Freshwater Creek gravels over the sampling period (Table 6). The gravel composition did not change much, probably because there was only one large storm late in the sampling period on June 1, 1988. Large flow events during the sampling would likely have caused larger fluctuations in substrate composition. Since changes in the gravel conditions of redds is so dependent on flows, the best thing to monitor from year to year is the gravel conditions right after spawning.

Perhaps the best baseline data this study has to offer are those taken in the unworked gravel sites outside of redds (Tables 11, 12, and 13). In addition, the one factor ANOVAs for the mainstem outside cores (Tables 7, 9, 10) provide the statistics specific to each of the three stream sections which may be useful to detect local changes in substrate parameters, although the differences were for the most part not significant.

CONCLUSIONS

The overall quality of the coho salmon spawning gravel in the Freshwater Creek basin remained high during winter and spring 1987/88 and should have supported a high rate of survival to emergence of coho fry. There was no significant change in permeability, dissolved oxygen or percentage of fines in coho salmon spawning gravels throughout the incubation period, probably due to the lack of high flows.

In the course of digging redds, female coho salmon significantly reduced the percentage of fines in the gravel, and thereby increased the intragravel permeability and dissolved oxygen.

The physical gravel parameters used in this study are related to each other at a 5% significance level as follows:

1) Relative dissolved oxygen saturation is positively related to the ln(x) of permeability.
2) Ln(x) of permeability is inversely related to the percentage of fines <2 mm.

Relative dissolved oxygen saturation appears to be inversely related to the percentage of fines <2 mm but not significantly.

The three gravel quality indexes of percentage of fines <2 mm, fredle index and geometric mean diameter as independent variables were compared to the dependent variable ln(x) of permeability. Percentage of fines <2 mm best accounts for the variation in In(x) of permeability.

The modified standpipe developed for this study can be a useful tool both for continued research into salmonid spawning habitats and helping quantify effects of gravel quality on salmon spawning. The standpipe may also be important in studying cumulative effects of land management activities. It must be stressed that this sampling technique provides an index of gravel quality rather than a precise estimator of survival to fry emergence.

REFERENCES CITED

Adams, J.N. 1979. Variations in gravel bed composition of small streams in the Oregon Coast Range. M.S. Thesis, Oregon State University, Corvallis, OR.

Adams, J.N. and R.L. Beschta. 1980. Gravel bed composition in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Science 37: 15141521.

Barnard, K.N. 1987. Freshwater Creek salmonid habitat restoration project final report. CDFG Contract #85-0811. Redwood Community Action Agency, Eureka, CA.

Barnard, K.N. and S. McBain. In prep. A modified standpipe to determine permeability and particle size distribution of salmonid spawning gravels.

Bisson, P., J.L. Nielsen, R.A. Palmason, and L.E. Grove. 1981. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. p. 62-73. **In:** N.B Armantrout (ed.) Proceedings of a Symposium: Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division American Fisheries Society, Portland, OR.

Briggs, J.C. 1953. The behavior and reproduction of salmonid fishes in a coastal stream. Calif. Dept. Fish Game Fish Bull. 94. 62 pp.

Burner, C.J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildlife Service Fishery Bulletin 61:93-110.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Am. Fish. Soc. 101:1-17.

California Advisory Committee on Salmon and Steelhead Trout. 1988. Restoring the Balance 1988 Annual Report to the Legislature and Department of Fish and Game, Sacramento, California.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Trans. Am. Fish. Soc. 117: 1-21.

Chemical Rubber Company. 1966. Handbook of Chemistry and Physics. Cleveland, Ohio.

Cederholm, C.J., L.M. Reid,and E.O. Salo. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, Washington. p.3874. In: Proceedings from the conference Salmon-Spawning Gravel: A Renewable Resource in the Pacific Northwest? Rep. 39. State of Washington Water Research Center, Pullman, WA.

Darcy, H. 1856. Les fountaines publiques de la Villa de Dijon, Dalmont, Paris.

Everest, F.H., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cederholm. 1987. Fine sediment and salmonid production: a paradox. p. 98-142 In: E. Salo and T. Cundy (ed). Streamside management and forestry and fishery interactions. University of Washington, College of Forest Resources, Contribution 57, Seattle, WA.

Greenkorn, R.A. 1983. Single-fluid flow through porous media. Handbook of Fluids in Motion. Ann Arbor Science. Ann Arbor, Michigan.

Hassler, T.J. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) -- coho salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.70). U.S. Army Corps of Engineers, TR EL-82-4. 19 pp.

Johnson, R.A. 1980. Oxygen transport in salmon spawning gravels. Canadian Journal of Fisheries and Aquatic Science 37: **155-162.**

Koski, K.V. 1966. The survival of coho salmon (Oncorhynchus kisutch from egg deposition to emergence in three Oregon coastal streams. M.S. Thesis, Oregon State University, Corvallis. **84** p.

Lotspeich, F.B. and F.H. Everest. 1981. A new method for reporting and interpreting textural composition of spawning gravel. USDA For. Serv. Res. Note PNW-369. 11 p. Pac. Northwest For. and Range Exp. Stn., Corvallis, Oregon.

McBain, S. unpublished. A spawning gravel database for the McCloud River, California. Senior thesis for B.S. in Engineering, Humboldt State University, Arcata, CA. 1989.

McNeil, W.J., and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report-Fisheries 469.

Phillips, R.W., R.L Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 104:461-466.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. USDA For. Ser. Gen. Tech. Report INT138. 70 p. Inter-mountain For. and Range Exp. Stn., Ogden, Utah.

Platts, **W.S.,** M.A. Shirazi, and D.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environmental Protection Agency, Corvallis, OR. EPA-600/3-79-043: 33 pp.

Regnart, J.R. 1991. Physical parameters associated with coho salmon (Oncorhynchus kisutch) redds in northwest California. M.S. Thesis, Humboldt State University, Arcata, CA.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. Pages 1-54 in W.R. Meehan, ed. Influence of forest and rangeland on anadromous fish habitat in western North America. U.S. For. Serv. Gen. Tech. Rep. PNW-96. Pac. Northwest For. and Range Exp. Stn., Portland, OR.

Ringler, N.H., and J.D. Hall. 1988. Vertical distribution of sediment and organic debris in coho salmon (Oncorhynchus kisutch) redds in three small Oregon streams. Canadian Journal of Fisheries and Aquatic Science 45:742-747.

Shapovalov, L., and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (Salmo *gairdneri gairdneri)* and silver salmon *(Oncorhynchus kisutch)* with special reference to Wade11 Creek, California and recommendations regarding their management. Calif. Dept. Fish Game Fish Bull. 98.375 pp.

Skaugset III, A.E. 1980. Fine organic debris and dissolved oxygen in streambed gravels in the Oregon Coast Range. MS. Thesis, Oregon State University, Corvallis, OR.

Tagart, J.V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. M.S. Thesis, University of Washington, Seattle, WA. 101 p.

Tappel, P.D. and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3:123-135.

Terhune, L. D. B. 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. J. Fish. Res. Board Can. 15(5): 1027-1063.

Winer, B.J. 1971. Statistical Principles in Experimental Design McGraw-Hill, New York, New York.

Young, Michael W., Wayne A. Hubert and Thomas A. Wesche. 1989. Evaluation of variation in permeability measurements when using the Mark VI standpipe. Canadian Journal of Fisheries and Aquatic Science. 46: 447449.