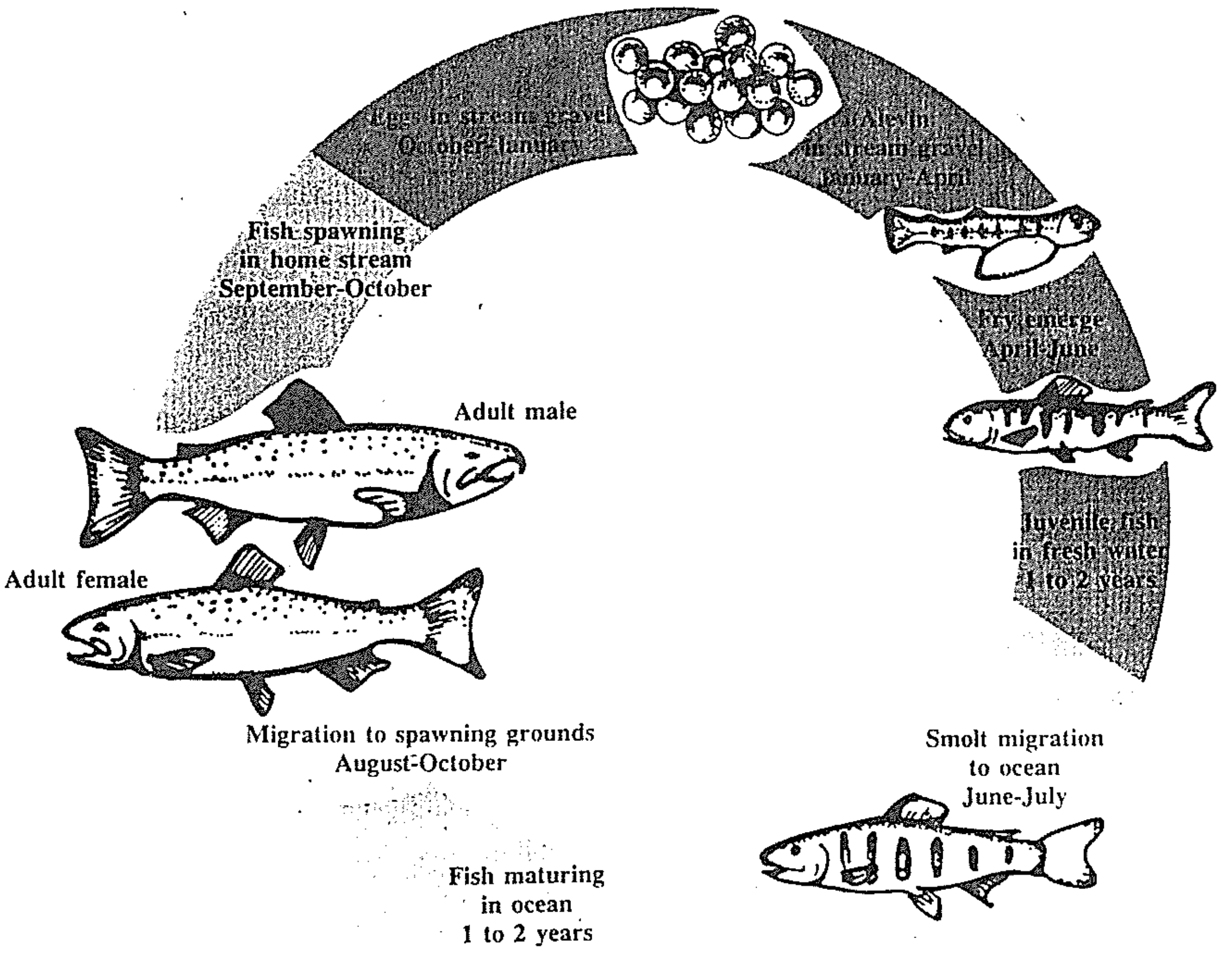
PROTOCOLS FOR ASSESSMENT OF DISSOLVED OXYGEN FINE SEDIMENT AND SALMONID EMBRYO SURVIVAL IN AN ARTIFICIAL REDD



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PROTOCOLS FOR ASSESSMENT OF DISSOLVED OXYGEN, FINE SEDIMENT AND SALMONID EMBRYO SURVIVAL IN AN ARTIFICIAL REDD

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EXECUTIVE SUMMARY

Salmonid spawning is a protected beneficial use of water quality in Idaho. Several nonpoint source activities cause accelerated sedimentation, which adversely effect salmonid spawning. An interim water quality criterion for intergravel dissolved oxygen has been developed to protect salmonid spawning. Validation of the interim criterion and the need for further data require methodologies for monitoring sediment effects, which develop data leading to more refined criteria.

A methodology for monitoring sediment impact has been developed. The techniques use intergravel dissolved oxygen, fine sediment and salmonid embryo survival in artificial egg pockets. The techniques permits measurement of the fine sediment infiltrating artificial egg pockets and the dissolved oxygen concentration in the gravels. These values are compared with egg survival and alevin escapement from the artificial egg pockets. Field testing of the methods on seven streams in Idaho have verified that the techniques are workable during different seasons and in different stream conditions.

Preliminary data analysis indicates that levels of fine sediment intrusion appear related to egg survival. Also quantities of fine sediment found in substrate are related to watershed development. Streams studied in the Idaho batholith contained relatively coarser-textured intergravel fines which resulted in little or no dissolved oxygen depression, and therefore, did not limit embryo development. Observed mortalities appeared to be the result of entrapment of alevins when fines were excessive. Streams in geologies which produce silt and clay-textured fines appeared to suppress intergravel oxygen concentrations and growth and survival of developing embryos.

ASSESSMENT OF SPAWNING HABITAT QUALITY

Introduction:

Under Idaho's Water Quality Standards (IDHW, 1985), nonpoint sources of pollution are regulated according to their impacts on specific protected beneficial uses. Salmonid spawning is a designated beneficial use common in the waters of Idaho. Watersheds dominated by forest, range and cultivated agriculture activities are frequently associated with salmonid spawning. These nonpoint source activities can cause accelerated sedimentation of streams and lakes, potentially impacting salmonid spawning at the site of embryo incubation and emergence. Since the public is intensely interested in the state's fishery, impacts to salmonid reproduction are a significant issue.

To address this concern, the State is developing water quality criteria for the protection of salmonid spawning from habitat degradation by fine sediments. Water quality criteria for the protection of salmonid spawning must address effects of sediment in the streambed environment. An extensive review of the literature concerning the effects of sediments indicated that, there currently are no specific numeric criteria for salmonid spawning (Chapman and McLeod, 1988). Chapman suggested interim criteria as a temporary measure.

One criterium suggested by Chapman (1988) was to use the intergravel dissolved oxygen concentration. Fine sediments interfere with the flow of water through spawning gravel and therefore the transport of oxygen to incubating fish eggs. The oxygen requirement of incubating salmonid eggs has been well established in the literature, (Hayes, et. al. 1951; Alderdice, et. al. 1958; Silver, et. al. 1963; Shumway, et. al. 1964; Mason, 1969). An interim criterium of 6 mg/L intergravel oxygen or 90% of saturation, whichever is greater has been proposed for Idaho (Harvey, 1989). A separate criterium to account for the impact of fine sediments on the emergence ability of fry would be valuable, however, no technique for salmonids has been accepted.

Techniques to assess the impact of fine sediments on salmonid spawning in the natural setting are required. Two methods have provided some promising results. The measurement of intergravel dissolved oxygen using the procedure developed by Hoffman (1986) is simple and effective. Measurement of salmonid egg incubation success in relation to fine sediment by the technique developed by McHenry and Platts (unpublished results) has also been effective and is an excellent bioassessment tool. These two techniques together provide a comprehensive approach to monitoring several inter-related parameters. These include intergravel dissolved oxygen, percent fine sediment, egg survival and alevin escapement.

The artificial redd approach has the added benefit of non-interference with a natural redd or egg pocket. Accumulation of additional information on the interrelation of fine sediments and incubation within spawning gravel should permit establishment of acceptable sediment based criteria to protect salmonid spawning.

In the following section, specific protocols are presented for the artificial redd monitoring approach. The final section documents the protocol's utility with results from seven streams inhabited by rainbow trout, steelhead and fall chinook salmon.

FIELD SURVEY METHODS

Equipment:

The technique requires construction of an artificial redd in-stream followed by burial of egg baskets and oxygen sampling tubes. Some items must be custom built while the remainder are commercially available.

Basket Construction:

Polyethylene net baskets are required to contain the eggs in an artificial (or simulated) egg pocket and to prevent alevins from migrating laterally after hatching. The baskets are supported in the stream bed gravel matrix by an iron frame. Frames are fashioned from 0.95 cm or 0.64 cm rebar steel. Two bars are bent and welded as shown in Figure 1. The baskets are constructed of extruded PVC net (Internet Incorporated, Minneapolis, MN). Cylinders either 30.5 cm (salmon & steelhead) or 20.8 cm (trout) in height were constructed from a rectangular piece of netting. Two layers (0.64 cm and 0.32 cm or 0.24 cm mesh) were used to form the cylinder, with the heavier 0.64 cm mesh netting as the outer layer. The 0.32 cm mesh is used for fall/winter spawning and incubation monitoring. The 0.24 cm mesh is used in wintertime when growth of alevins is comparatively smaller(this mesh is available in nylon netting which can be inserted in the basket). Circular bottoms and tops were fabricated from the same mesh sizes of netting. Seams of the baskets were sewn with 44 kg test monofilament fishing line (Figure 1).

Intergravel Monitoring Pipes:

Intergravel Monitoring Pipes were constructed using a design similar to Hoffman (1986). Well screen (30.5 cm of 3.2 cm diameter, 0.152 mm continuous coil slot) forms the outer shell of the device. An inner 0.95 cm plastic pipe which is perforated in three locations with 0.16 cm holes is positioned inside the screen and stabilized by 3.2 cm schedule 40 PVC caps on either end. The internal pipe is connected to approximately 91 cm of 0.95 cm tygon tubing through a hole in one PVC cap. The tubing is fitted at its end with a clamp and a 0.95 cm Universal Compression Fitting

Redd Caps:

Since fine sediments can limit emergence of alevins from the gravel, a device to cap the artificial egg pockets and permit escapement into a trap is necessary. Redd caps were constructed of nylon mosquito netting. Netting was sewn into a funnel shape with one end slightly larger than the egg basket diameter. The opposite end narrowed to a 5 cm diameter. A capture bottle was affixed to the short end with a 6.35 cm ring clamp. The bottle was constructed from a 250 ml polyethylene centrifuge bottle. The centrifuge bottle bottom was removed and covered with nylon mosquito netting. The bottom netting and the funnel net was affixed by 6.35 cm ring clamps. The screened bottle permits water to flow through, but retains fry. The redd cap nets are affixed to the egg baskets with large ring clamps built from a series of smaller clamps. (Figure 3).

Figure 3. Artificial egg pocket capping device to capture emerging alevins. Approximately 40% of actual size.

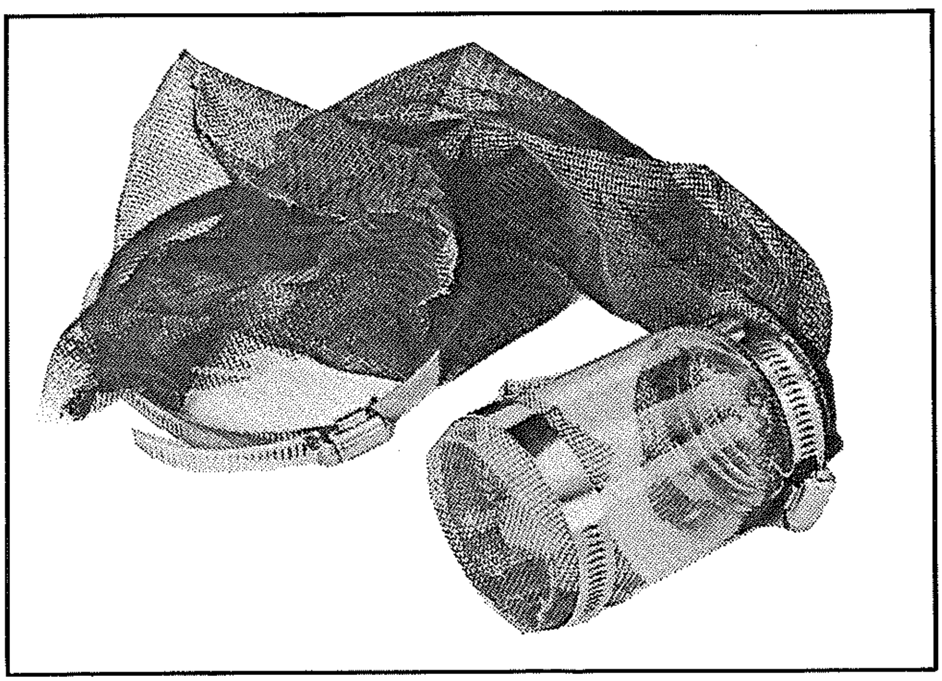


Figure 1. Egg Basket and frame. Basket is constructed of PVC netting material (5-10 mm mesh). Approximately 38% of actual size. Note Double Layers.

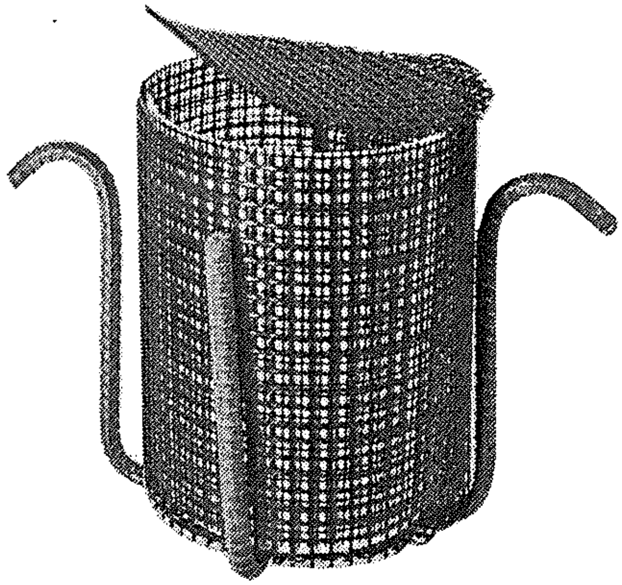
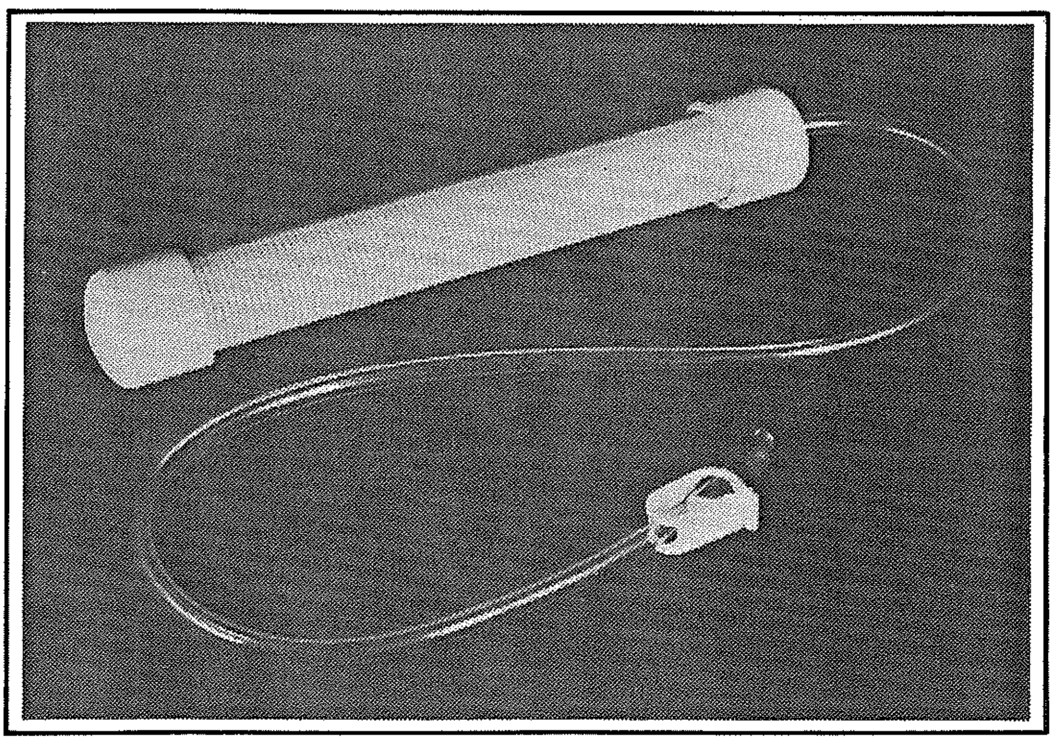


Figure 2. Intergravel dissolved oxygen monitoring probe. Approximately 29% of actual size.



Miscellaneous Equipment:

Several pieces of miscellaneous equipment are required to use the artificial redd method for assessing the condition of spawning gravel. A flow meter with wading rod to measure water velocity and depth is necessary for determining redd location. A shovel is required for redd construction. Flat plastic dishes, a funnel, and a 20.5 cm length of PVC pipe are required to load eggs into the artificial egg pockets. Monofilament fishing line is required to sew temporary lids on the baskets. A screwdriver is required to affix redd capps. A 30.5 cm diameter McNeil sediment corer is used to shield the egg baskets from the current to prevent loss of fine sediments while removing baskets. Plastic dish tubs (28.5 cm by 35 cm) are used to receive gravel emptied from the baskets to count alevins. A hand held utility pump (Fisher Scientific,Cat #13-875-109) is used to pump water from the intergravel monitoring tube. The pump is driven with a battery operated drill. Graduated cylinders and Erylenmyer flasks are required to measure and collect water. A dissolved oxygen meter (YSI Yellow Springs, OH.) is used to measure oxygen and temperature.

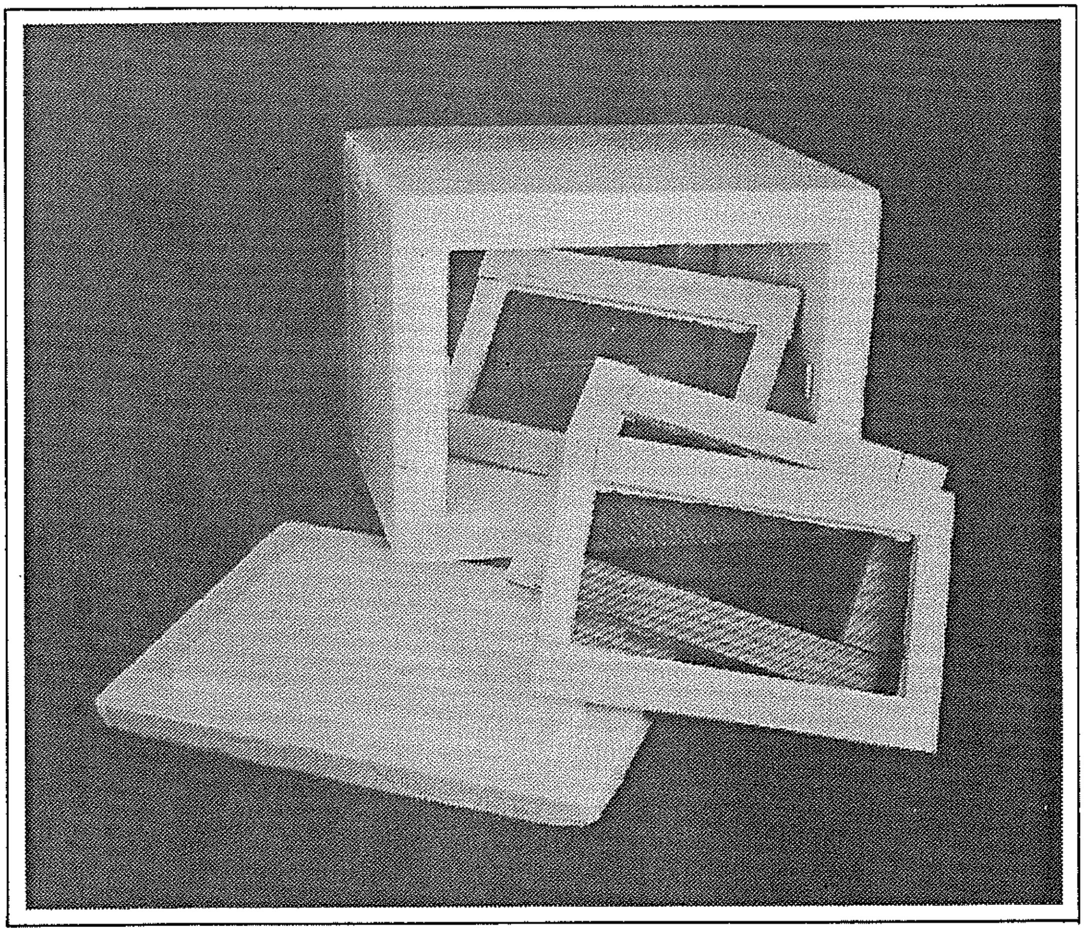
Egg Storage and Handling:

Eggs of the desired salmonid species are obtained through the Department of Fish and Game or private fish egg suppliers. Idaho Department of Fish & Game should be consulted to insure that the correct species of fish is being used to prevent the introduction of undesirable species to a particular watershed. The technique retains all fish in an enclosed system. Thus, the assessment can be made without allowing introduction of specimens into the drainage basin under normal conditions.

For the purposes of spawning gravel assessment, recently eyed eggs are required. These eggs are resistant to damage by handling and require a lengthy incubation period in the gravel before hatching. This characteristic maximizes the period during which eggs are exposed to any fine sediment load. Fish hatcheries are not normally able to supply recently eyed eggs, so care must be taken to make requests early and coordinate directly with hatchery personnel to obtain the most recently eyed eggs of the species required.

Eggs should be carried in a small insulated cooler (Figure 4). A device with fine mesh racks covered with damp cloth and a single layer of eggs allows the best transport conditions. A rack of ice above the layers of eggs allows cold water to drip over the eggs. A layer of sponges under the racks will absorb excess water. With care, and the proper egg handling equipment eggs can be kept two or three days in viable condition.

Figure 4. Salmonid egg transport equipment. Approximately 19% of actual size.



Egg Basket Location:

Artificial redds should be placed in the stream in locations which meet the spawning criteria of the salmonid species used. This approach allows an assessment of spawning gravel sedimentation in as close to natural conditions as currently possible. Since spawning sites are often in deposition zones, placement in these areas usually insures that the baskets will not be washed out. Standard preference criteria for spawning have been developed by the Idaho Dept. of Fish and Game (Cochnaner & Elms, 1986) and are provided in Table 1.

Table 1. Spawning site selection characteristics for various species of *trout-salmon*. (Cochnaner & Elms, 1986)

Spring Chinook:		
	Water Depth	0.3 to 0.4 meter (1.0 to 1.3 feet)
	Velocity	0.3 to 0.6 m/s (1.0 to 2.0 ft/sec)
	Substrate	60% + 0.3 to 7 cm (gravel) and less than 35% cobble.
Cutthroat Trout:		
	Water Depth	0.23 to 0.3 meter (0.75 to 1.1 ft.)
	Velocity	0.18 to 0.21 m/s (0.7 to 0.9 ft/sec)
	Substrate	0.3 to 7 cm predominates with minor amounts of cobble.
Rainbow Trout:		
	Water Depth	0.2 to 0.3 meter (0.75 to 1.1 ft)
	Velocity	0.18 to 0.21 m/s (0.7 to 0.9 ft/sec)
	Substrate	0.3 to 7 cm predominates with minor amounts of cobble.
Brown Trout:		
	Water Depth	0.15 to 0.3 meter (0.7 to 1.1 ft)
	Velocity	0.17 to 0.22 m/s (0.6 to 1.0 ft/sec)
	Substrate	0.3 to 7 cm predominates with minor amounts of cobble.
Brook Trout:		
	Water Depth	0.18 to 0.32 Meter (0.6 to 1.0 ft)
	Velocity	0.18 to 0.33 m/s (0.5 to 1.1 ft/sec)
	Substrate	0.3 to 4 cm predominates with minor amounts 4 to 7 cm.
Steelhead:		
	Water Depth	0.37 to 0.6 meter (1 to 2 ft)
	Velocity	0.5 to 0.65 m/s (1.5 to 2.1 ft/sec)
	Substrate	Mostly 0.3 to 7 cm with 10 to 25% cobble.

Appropriate sample size to provide a statistically significant sample is important. Studies on the South Fork of the Salmon River by Platts and McHenry (unpublished results), and our pilot studies indicate that a minimum sample size of seven baskets is required (p=.05). This is enough to simulate at least 3 redds on 3 separate suitable habitats each having multiple (2 or 3) egg pockets.

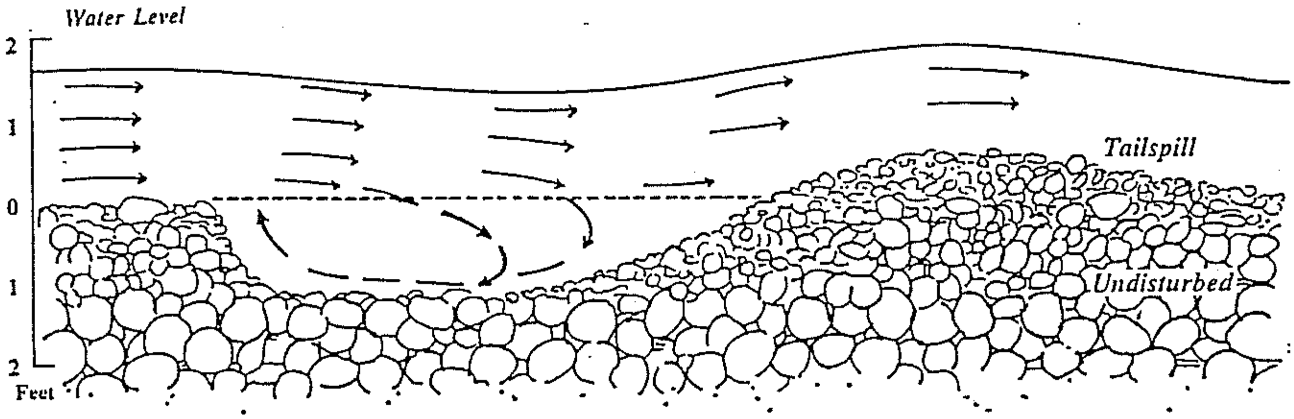
Placement of Egg Baskets:

Eyed salmonid eggs are placed in streambed gravel using the egg baskets as follows. A shovel is used to excavate the egg pockets at a suitable site. Gravel is lifted by the spade into the stream flow and released. This action mimics the actions of the spawning female (Burner, 1951). A depression and a downstream tailspill are soon formed. At the same time, gravel is naturally sorted by the stream with the heaviest particles falling first to the streambed and the finer particles carried further downstream, thus separating much of the fine material from the gravel. In nature, the largest particles in the substrate cannot be lifted by the female spawning fish. Those particles form in the pocket centrum into which the fish deposits her eggs (usually 2 or 3 particles form this centrum). The length of the depression is oriented with the current, and is approximately equal to 2 times the length of the average spawning female. The width of the egg pocket is no more than the width of the spade. The depth of the egg pocket is approximately one fourth of the length of the fish. Generally, the depth of excavation ranges from 18 to 43 cm for salmon, and 8-22 cm for trout.

A subsample of the disturbed gravel is taken from the upstream edge of the tailspill for particle size analysis. The basket is then filled two to four inches in depth with gravel from the same location. At this point, two or three larger rocks (on the upper end of the optimum particle size range, or the largest particles available at the site if none present are as large as the upper end of the optimum range), are placed in the basket to represent an egg pocket centrum. A plastic PVC pipe (1.9 cm diameter) is centered in the centrum and tailspill gravel is filled around the pipe to the basket top. One hundred eggs are counted from the carrying racks into a small plastic dish. If egg temperature is 2°C different from the water temperature, the eggs will require acclimation to the water temperature. Acclimation is achieved by incrementally adding water at the temperature of the stream to the eggs. Fifteen to twenty minutes should be permitted for acclimation. The eggs are carefully poured into a funnel placed at the top of the plastic pipe. As the eggs are poured, the pipe is gently raised, allowing gravel to gradually cover the eggs as they are dispersed vertically into the gravel. A small quantity of water is washed down the pipe to assure complete deposition of the eggs. The pipe is removed allowing the gravel to fall into place. Any space left above the basket is filled with additional tailspill gravel. A top of PVC netting is sewn onto the basket securely to restrict any escape of alevins from the basket.

The basket, placed in its rebar frame, is lowered into the depression immediately upstream of the tailspill at a level which will allow only the top of the frame to be visible after gravel deposition (or approximately even with the streambed elevation). As it is held in this position, the shovel is used once again to lift streambed gravel immediately upstream of the depression into the stream flow. The procedure is followed until the basket top is level with the top of the gravel and the metal rack top protrudes only slightly above the gravel. The basket installation produces another tailspill and adjacent upstream depression where the next gravel can be taken and the next basket placed. When basket placement is complete, a redd topography of depressions and gravel mounts similar to a natural redd is created (Figure 5). A map of the basket locations should be made for relocation. Flagging can be tied to the rebar to aid in relocation.

Figure 5. Longitudinal cross-section through a constructed redd.



Currents within a salmon redd. (From Burner 1951.)

Intergravel Sampling Pipe Placement:

The intergravel sampling pipe must be placed as close as possible to the fish eggs during incubation. For this purpose intergravel pipes are placed horizontally within the artificially constructed egg pockets, either adjacent to or if possible, inside the egg baskets, and at the same elevation as the eggs themselves. The tygon tube leading into the intergravel pipe is buried except for a length sufficient to clear the highest water surface expected by 3 or 4 inches in length.

Gravel Sampling

Gravel samples are taken prior to the egg incubation as described in the "Egg Placement" section. The initial gravel sample is taken to establish the gravel composition at the time of egg placement. After the incubation, gravel from the baskets is collected for analysis. Gravel samples are placed in thick polyethylene soil sample bags for transport to the laboratory.

To obtain representative samples of fines in and around the area of incubation, samples must be collected from the outfall of gravels excavated for the egg pocket. These simulate natural concentrations, since they are the same gravels the fish used to cover the eggs. An excellent way to collect these gravels, is to place a collection bag flat on the substrate immediately downstream of the excavation for the egg basket. As the egg pocket is being constructed, gravels fall downstream onto the collection bag, covering it completely to a depth of from 6-12 inches (depending on size of egg pocket being constructed). After completing the excavation, lift the handles on the collection bag and bring up a full sample of gravel. This avoids loosing any fine sediments to effects of the stream current, and assures obtaining samples from the proper location.

A gravel collection bag may also be placed underneath the egg basket at the time it is introduced into the substrate. After incubation the basket may then be extracted by pulling up on the bag handles (which allows the bag to surround and completely cover the egg basket), and lifting the entire basket from the stream using the collection bag. This reduces the possibility of losing fine sediment to the stream during basket extraction, and the need to bring along the bulky McNeil sampler.

Dissolved Oxygen and Temperature Monitoring:

Dissolved oxygen and temperature of the water column and intergravel water are measured periodically during the egg incubation period. Surface measurements were made by placing the oxygen electrode near the basket's location on the surface of the stream bed. Intergravel measurements are made by pumping water from the intergravel sampling pipe. Water is pumped with a utility pump, which operates on the peristaltic principle. This ensures the water is not oxygenated in the pumping process. The pump is driven by a battery operated drill. The void volume of the tubing used in the monitoring pipe is first pumped into a graduated cylinder. This water is discarded. The dissolved oxygen probe is placed into an Erlenmeyer flask and water from the intergravel pipe is pumped very slowly over the probe. When the oxygen reading stabilizes, the value is recorded. An intergravel temperature is also recorded at this time.

The frequency of measurement is dependent on the salmonid species used. Late summer and fall spawners have long overwinter incubation periods. During the early incubation, water temperatures are quite low and development is slow. As snowmelt occurs, temperatures increase and development increases. Monthly measurement (if possible) is recommended in the early phase. Every two weeks is sufficient once waters begin to warm. Spring spawned eggs develop under higher water temperatures. Development occurs rapidly. Weekly or even bi-weekly measurements are required.

Estimation of Egg Incubation Period:

The incubation period of the eggs must be estimated for the time of egg hatching and alevin emergence. The thermal incubation requirements of most salmonid species are known (Leitritz & Lewis, 1976). The accumulation of thermal units by the planted eggs is determined from the periodic intergravel temperature measurements. A thermal unit is defined as a degree fahrenheit-day at temperature over 32° F. It is most convenient to plot the temperature in degrees fahrenheit against days. The area under this curve in excess of 32° fahrenheit is the thermal units accumulated. Care must be taken to add the thermal units accrued by the eggs in hatchery incubation, since published time to emergence is based on the period from egg fertilization. Employing this technique permits an accurate estimation of the time to hatch. Estimation of alevin emergence from the gravel is less well defined. One can expect emergence one to two weeks after hatching (Blaxter, 1988).

Redd Capping:

The egg baskets are capped to help differentiate between the impact of sediment on oxygen transfer to the eggs and entombment of the alevins by sediment. The basket mesh prevents lateral migration of alevins. The basket also provides a superstructure onto which a capture net can be affixed. Capture nets are affixed when thermal unit accumulation is sufficient for egg hatching. The basket lid is removed. Nets are affixed with ring clamps. The bottle end of the capture net is laid downstream. Cobbles are placed around and on top the bottle to restrain the net from twisting in the current and to provide a shadowed area into which alevins can migrate.

Basket Removal:

After eggs have received sufficient thermal units to hatch and alevins have been given sufficient time to emerge (two weeks) egg baskets are removed from the artificial redds. Baskets must be shielded from the current when they are removed to retain fine sediment. A McNeil sediment core sampler is placed over the basket and redd cap as a current shield. Where water levels were too deep to reach the frame hooks, they are reached with two hooks constructed of rebar rod. The basket is lifted by the hooks at the frame top, together with the shielding cover. The basket is quickly placed into a plastic dish tub. The basket with its capture net attached, can then be carried to shore for opening.

As described above, it may be more desirable to use a gravel collection bag with handles to facilitate extraction of the egg basket rather than a McNeil sampler.

Alevin Count:

The redd cap is removed from the basket and fry are carefully counted. The gravel is then carefully emptied into the plastic pan and searched for living alevins, dead alevins and eggs. The number of each is recorded. The gravel and fine sediment is collected into a plastic soil sample bag for later analysis.

Gravel Analysis:

Gravel samples are analyzed for size distribution by percent weight. Samples are oven dried at 100° C for 24 hours. Samples are mechanically shaken for 10 minutes through brass sieves (76.2, 25.0, 12.5, 9.5, 6.3, 4.75, 0.85, 0.212 mm openings). The material retained on each sieve is weighed and the percentage of the total weight it represents calculated.

Table 2. Materials and Equipment for Intergravel Dissolved Oxygen Monitoring, Artificial Egg Pockets, and Redd Caps.

EQUIPMENT	SOURCE	APPROXIMATE PRICE
■ *Intergravel Dissolved Oxygen Monitoring Equipment*		
Well Screen (12" of 1" dia. 0.006" continuous slot)	Waterwell Boise 208-344-6690	$12.50/ft
PVC Caps (1 1/4" 40, 2 per pipe)	Hardware Store	$ .50/ea
Plastic Aquarium Pipe (3/8" OD)	Zamzows Boise	$ .75/3 ft
Tygon Tubing (3' minimum of 1/4" ID, 3/8" OD)	Hardware Store	$ .20/ft
Universal Nut & Unions (3/8" and 3/8"X 3/8" AB Port #'s BD961-P)	Hardware Store	$ 1.25/ft
Utility Pump (1988 catalog #13-875-104)	Fisher Scientific	$106.00/ea
Battery Powered Drill (Black & Decker or comparable)	Hardware Store	$150.00/ea
Dissolved Oxygen Temp. Meter (Yellow Springs Instruments or comparable)	Fisher Scientific	$800 - 1,100 ea
500 or 1,000 ml Erlenmeyer flask	Fisher Scientific	$4.50 ea
■ *Artificial Egg Pockets and Redd Capps*		
1/4" or 3/8" Rebar Steel for frame	Metal Dealer	$3.34/20 ft.
1/4" or 1/8" mesh size Extruded Polyethylene Net (Cat XX-1670+XV-1170)	Internet Corp. Minneapolis, MN	$ .25/ft
3/32" mesh size Bulk netting (Cat CC612)	Eagar Inc. (ph 1-800-423-6249)	$3.90/ft (110"wide)
Monofilament Fishing Line (20lb test)	Sporting Goods	$ 5.00/spool
Mosquito Netting	Sporting Goods	$ .35/sq. yd.
Hose Clamps (5-2 1/2" clamps)	Hardware Store	$ .60/ea
Nalgene Polypropylene Bottle (250 ml wide mouth 1988 cat #02-893B)	Fisher Scientific	$17.64/dozen

RESULTS OF FIELD TESTING

South Fork Salmon River:

The pilot study to assess egg to alevin survival in the field was first conducted by Platts and McHenry (unpublished results) in conjunction with the U.S. Forest Service Intermountain Research Station in Boise. The project began in 1986 with a test of the egg basket procedure using Chinook Salmon incubation on the South Fork Salmon River and Red River, a tributary of the South Fork Clearwater River.

More definitive tests were conducted in 1987-88, and 1988-89 when 3000 eyed chinook salmon eggs were planted each fall at Poverty Flat on the South Fork Salmon River. The protocol in these initial tests placed baskets within actual redds sited in the field. Sites were selected on the Poverty Flat gravel bar, an area used by Chinook for spawning. Thirty separate baskets with 100 eggs each were buried with intergravel dissolved oxygen tubes for the overwinter incubation period (about 130 days). Subsurface temperature and dissolved oxygen were monitored concurrently during this period. In the spring, baskets were excavated, surviving alevins, dead alevins, and undeveloped eggs were enumerated, and the substrate from each basket was analyzed in the laboratory for fine sediment composition.

Although differences between intergravel and surface oxygen concentrations varied from almost no difference to as much as 4 mg/l, dissolved oxygen levels within the substrate never approached the proposed criteria minimum, which is 6.0 mg/l. The lowest of the twenty measured concentrations was 8.9 mg/l.

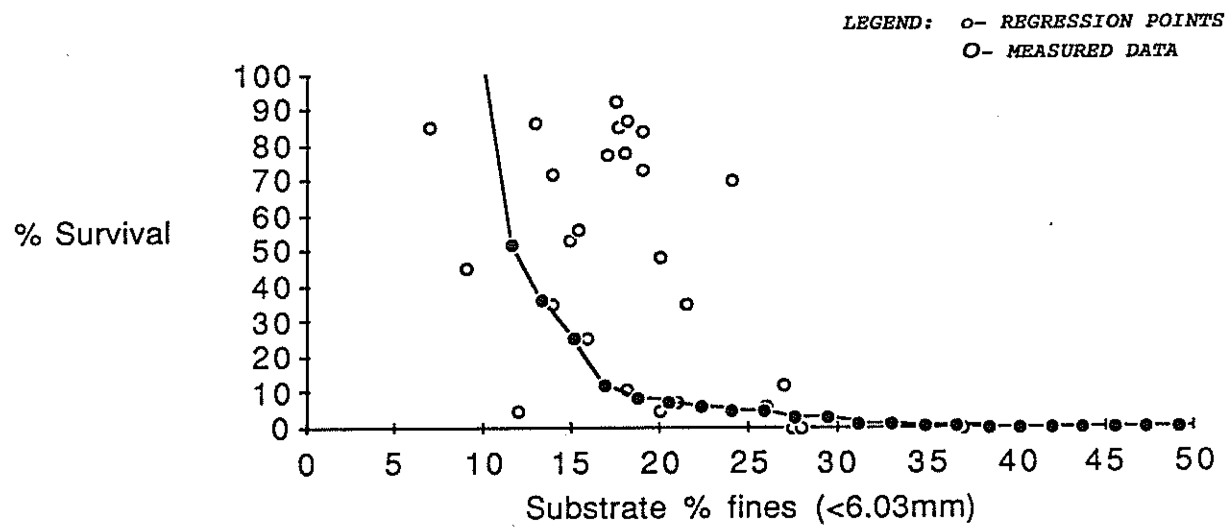
High intergravel dissolved oxygen observations in the South Fork Salmon River are thought to be due to a larger percentage of fines greater that 9.5 mm. Higher permeability fines - mostly sand in this case, is typical of streams in the Idaho Batholith. Also, during the winter months, water temperatures are low, (the maximum observed was 4 degrees C) thus high dissolved oxygen, and low biological oxygen demand would be expected.

During the 1987-88 test, survival within the egg baskets ranged from 0 to 95%. The 1988-89 data displayed a smaller range, perhaps because a number of the eggs were damaged by a fungus. It was determined that egg placement within the baskets *must be as evenly distributed as possible because if only one or two eggs in the batch are infected, all eggs touching those will also be affected by the fungus*. Therefore, the technique of gradually depositing eggs while lifting the access tube is critical to an even distribution of egg placement in the gravel and the prevention of egg mortality in masses.

Using the better distribution 1987/88 data, we have determined for the Poverty Flat site that, redds in clean substrate are associated with greater egg survival. Figure 6 shows the results of a regression analysis relating survival to percent fine sediment in the Poverty Flat substrate. The relationship is significantly (p=0.05) and inversely correlated, indicating that as the amount of fines increases, survival decreases exponentially. As shown, survival falls off rapidly at levels of 20 to 25 percent fines. There was no survival in substrates with more than 27 percent fines, and four of the egg baskets were representative of these high levels.

Figure 6. Survival versus % Fines
SF Salmon River - 1987/88

% Survival = 3000559 E ^ (% Fines * -.73)
r = -.76



A recent report by Platts, et al. (1989), indicates that the percent volume of fine sediment in spawning areas of the South Fork has declined from a high of around 46 percent in 1969 to 25 percent in 1985 as averaged over all 5 key spawning areas in the system. These data compared with Figure 6 would indicate that at present, alevin survivals may still be somewhat depressed, but likely improving.

The results on the South Fork Salmon River indicate that alevin mortality as caused by fine sediment is probably not related to depression of intergravel dissolved oxygen (IGDO) concentrations, but rather due to entrapment by the heavy concentrations of sand within the substrate. Such deposits filling the interstices within the substrate make migration through the gravels difficult. In fact, entrapment was observed on a sizable number of non-surviving, but somewhat well developed fry. In these cases, often a sand cap was present within or above the egg pocket.

Rock Creek (Twin Falls County):

Dissolved oxygen monitoring tubes were installed in artificially constructed redds on Rock Creek, Twin Falls County, during the fall, 1988, and again in 1989. This initial test of the intergravel oxygen technique did not include egg basket installations for assessment of survival to emergence. Intergravel dissolved oxygen and temperature were then monitored over the period of normal incubation for Brown trout in this stream, (October through early February). Monitoring stations were located at eight previously established water quality sites, located along the full length of the stream (Maret, 1990).

At one station, intergravel oxygen levels fell to below the minimum criterion by December, when IGDO measured 5.4 mg/l. In January, dissolved oxygen had recovered only slightly to 6.2 mg/l even though temperatures were lower.

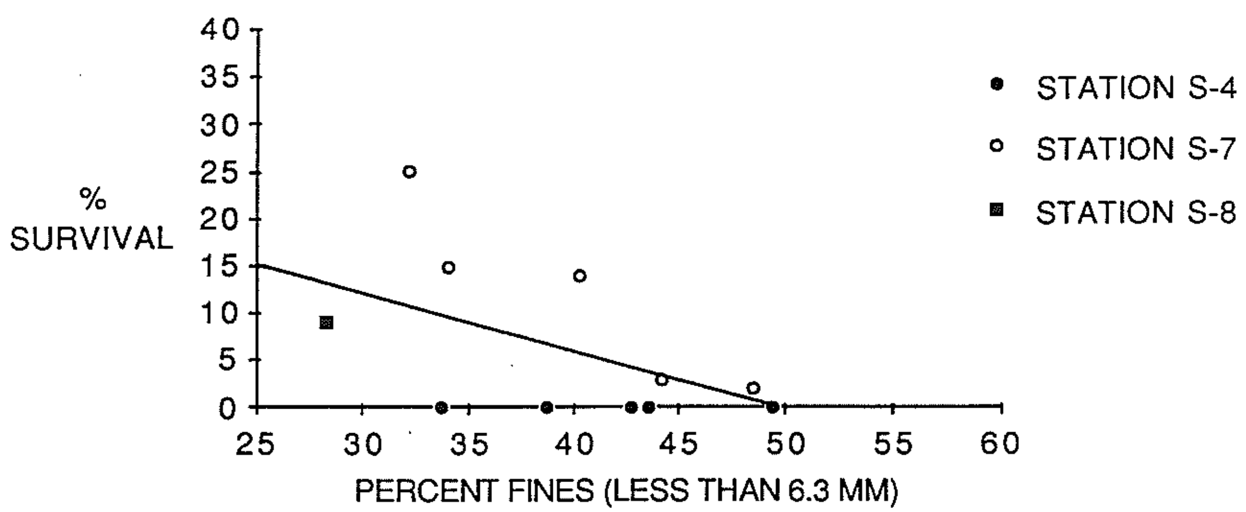
Two other stations on Rock Creek approached critical minimums during the winter period. The difference between surface and intergravel dissolved oxygen concentrations was significant at these impacted sites. Water volume dissolved oxygen in December and January ranged between 10.0 and 12.0 mg/l. IGDO averaged 2 mg/l lower overall, but several samples at the impacted sites had concentrations greater than 4 mg/l lower than surface dissolved oxygen. These differences were attributed to the effect of fines in the intergravel environment on the flow of water and oxygen to the measuring probe.

In the spring of 1989, egg baskets were installed along with IGDO monitoring tubes, following protocols described earlier, to assess the effects of survival on rainbow trout embryos. During this period, the annual spring flood displaced or buried several tubes and baskets. The substrate on Rock Creek is loose and mobile during high flows, reflecting the instability of the entire channel.

Little data are available for the springtime intergravel oxygen concentrations. The few samples that were available measured about 2 mg/L above the minimum criteria.

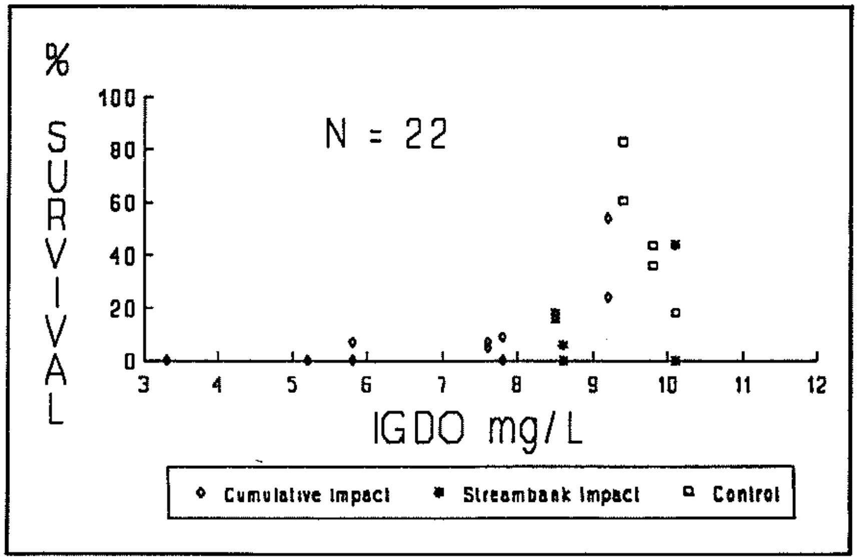
Eleven egg baskets from three separate stations survived the spring flooding. Survival rates show a definite relationship to the percentage of fines within the gravel substrates of the artificial redds. Figure 7 depicts this relationship showing survival declining with increased percent fines. A significant correlation was established for this relationship (r=-.70, p<= .05). Survival rates are very low, reflecting the high percentage of fine sediment in the substrates of Rock Creek. Based on the regression curve in Figure 7, it appears that as percent fine sediment (less than 6.3 mm) approaches 40%, survival rates approach zero, and do not increase to above 15% until intergravel fines decrease to 30%.

Figure 7. Rock Creek - % Fines versus % Survival
% Surv = 40.9 - .85 x % fines (r= -.70)



In the fall of 1989, egg baskets and intergravel pipes were installed on severely impacted, impacted, and control sites in Rock Creek to assess brown trout incubation survival to emergence as related to dissolved oxygen. Egg baskets were excavated in winter, 1990. Results show a definite relationship between intergravel DO and survival, with survival declining relative to lower mean dissolved oxygen concentration. These relationships are shown in figure 8. Note that lower oxygen concentrations were associated with impacted sites in the stream.

Figure 8. Intergravel dissolved oxygen concentration versus alevin survival on Rock Creek, 1990.



It is probable, based on the results observed at Rock Creek, that alevin mortality is due, at least in part, to the effect of fine sediment on permeability and delivery of dissolved oxygen to developing embryos. In addition, it is important to note that a number of artificial redds were destroyed by hydrologic modifications on the streambed during flooding. The current channel instability, and large loads of loose gravel moving on the substrate may be more adverse to rainbow trout incubation and survival, under present channel conditions, than the amount of in-site fine sediment.

Dog & Trinity Creeks - paired watersheds

A pair of third order streams tributary to the South Fork Boise River upstream of Anderson Ranch Reservoir were chosen for testing a paired watershed monitoring strategy. Dog and Trinity Creeks have similar watershed characteristics, stream types, and aquatic habitats. Trinity Creek has been extensively logged and roaded. Dog Creek watershed is minimally developed. A comparison of watershed features is displayed in Table 2.

Monitoring stations were located in B3 channel types (those with 1.5 to 4 percent gradient, and cobble/gravel substrates) near the mouths of both drainages (Rosgen, 1985). Both streams are moderately steep, and habitats are mostly riffles. The few habitats suitable for spawning are located at pool tailouts.

Egg baskets and intergravel pipes were installed on Dog and Trinity Creeks on April 12, 1989 to monitor rainbow trout incubation and survival to emergence as related to percent fine sediment and intergravel dissolved oxygen concentration. The following intergravel oxygen data were recorded during the incubation period.

Table 3. COMPARISON DATA:DOG CREEK (UNDISTURBED) AND TRINITY CREEK (DISTURBED)

DESCRIPTOR	*DOG CREEK*	*TRINITY CREEK*
Watershed:		
Soils	Inceptisols-on granodiorite	Inceptisols-on granodiorite
Vegetation	Ponderosa Pine to sub-alpine fir and grasslands	Ponderosa Pine to sub-alpine fir and grasslands
Stream class:		
Gradient	4%	4%
Substrate:		
Fines	11.3%	13.9%
Gravel	26.1%	32.6%
Cobble	57.7%	49.2%
Boulder	4.9%	4.3%
Habitat: (Stream reach equals 10 stream widths)		
Pools	3	3
Riffles	13	12
Runs/glides	3	4

TABLE 4. Dog and Trinity Creek dissolved oxygen data.

STATION	*DATE*	*IGDO(mg/l)*	*WATER COLUMN DO (mg/l)*
Dog Creek 1	4-12	11.4	12.0
Dog Creek 2	4-12	11.0	12.0
Trinity 1	4-12	11.0	11.8
Trinity 2	4-12	10.8	11.6
Dog Creek 1	5-4	11.2	12.5
Dog Creek 2	5-4	11.2	12.5
Trinity 1	5-4	9.6	11.8
Trinity 2	5-4	11.0	11.5
Dog Creek 1	5-17	8.6	11.6
Dog Creek 2	5-17	10.4	11.0
Trinity 1	5-17	9.8	10.6
Trinity 2	5-17	9.8	10.8
Dog Creek 1	5-23	10.3	12.3
Dog Creek 2	5-23	10.3	11.4
Trinity 1	5-23	11.4	13.1
Trinity 2	5-23	11.8	13.1

These data show that dissolved oxygen depressions were minimal during the incubation period, and that surface oxygen concentrations were consistently greater than 10 mg/l. The data also indicate that IGDO should have no adverse affects on incubation. The conclusions are similar to those on the South Fork Salmon River, in that the fines are mostly in the sand to fine gravel range (derived from Idaho Batholith), and permeabilities associated with these textures would not be restrictive to the transport of dissolved oxygen.

Figures 9 and 10 display comparisons of percent embryo survival to the amount of fine sediment and intergravel dissolved oxygen concentrations respectively. Fine sediment concentrations are higher in the samples taken from the disturbed watershed, as is the estimate of alevin survivals. The higher sediment observation in Trinity Creek correlates well with our embeddedness and pool filling measurements, and seems to reflect the increased amount of sediment production associated with development in this watershed.

These data suggest that Dog Creek with lower percent fines had lower IGDO concentrations. This is an indication that something other than fine sediment is controlling dissolved oxygen levels in the intergravel environment. It is suggested that fines predominatly of sand size do not significantly reduce permeability.

Survival rates are very low in the samples taken from these streams. A large amount of fungal mortality was observed. For these reasons, conclusions drawn from figures 8 and 9 may be misleading. Nevertheless, rates of survival are fairly comparable to the observations from other tests we have conducted.

Bear Valley area streams:

Egg baskets and intergravel dissolved oxygen pipes were installed in three low-gradient, meadow streams in the headwaters of the Middle Fork Salmon River on the first of June, 1989. Among the three streams, two are located within the River-Of-No-Return Wilderness. Of these two, Sulphur Creek is in pristine condition, and Elk Creek is impacted by cattle grazing. The third stream, Bear Valley Creek, is impacted by cattle, and roaded throughout the drainage.

Eyed Steelhead eggs were obtained from the nearby Sawtooth Hatchery and injected into the baskets on this same date. At this time, the spring snowmelt flood was in recession, but water levels were still close to bankful stage.

Figure 9. Dog/Trinity Creeks - % fines versus % survival

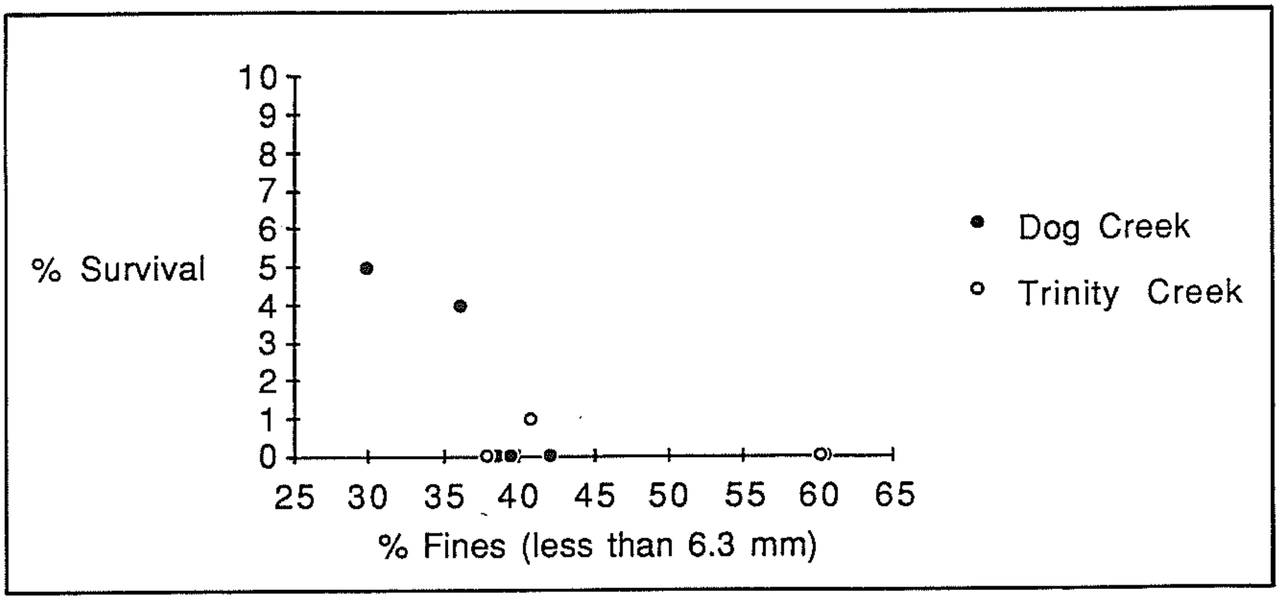
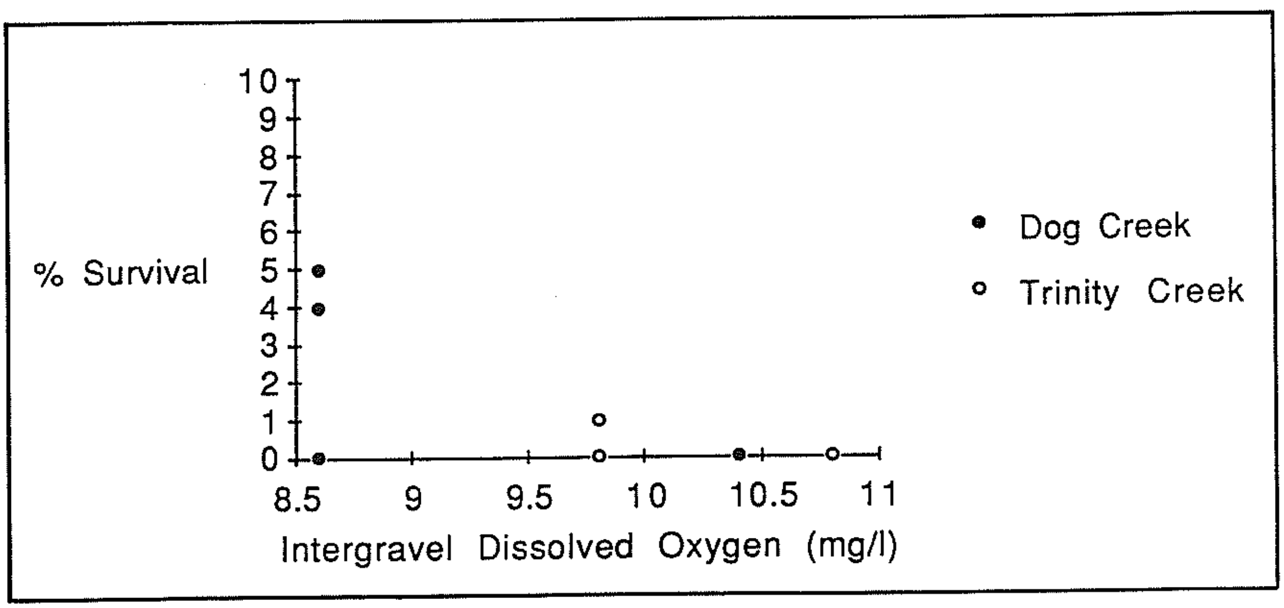


Figure 10. Dog/Trinity Creeks - IGDO versus % survival



Under these conditions, initial water temperatures and both surface and intergravel dissolved oxygen levels were of some concern. Dissolved oxygen measurements ranged between 6.1 and 6.9 mg/l at all sites - very close to the critical minimum concentrations for incubation. Water temperatures ranged between 7 and 12 degrees C. Interestingly the levels of oxygen increased, rather than decreased through the incubation period while stream temperatures gradually rose. By the first of July, the following conditions were observed:

TABLE 5. Intergravel and water column dissolved oxygen and temperature of the Middle Fork Salmon River headwater streams, July, 1989.

STREAM	*IGDO (mg/l)*	*WATER COLUMN DO (mg/l)*	*TEMPERATURE (°C)*
Sulphur Creek	9.0	9.8	9.5
Elk Creek	7.5	8.5	1.4
Bear Valley Cr	8.1	8.8	9.0

We have concluded that although there was some natural depression of dissolved oxygen during the runoff period, it did not exceed minimum criteria levels, and therefore intergravel dissolved oxygen will probably have little impact on embryo survivals. The major impact of sediment appears to be its effect on entrapment, as observed at other sites within the Idaho Batholith.

The egg baskets constructed for streams in the Bear Valley area did not trap emerging alevins. Openings in the basket mesh were too large for the size of steelhead alevins, several of which were observed to swim out while excavating the baskets from the channel. This problem and its solution are discussed in the protocols section. We have therefore estimated survival by counting dead alevins and undeveloped eggs in the egg baskets, subtracting from the original number injected into the basket, and assumed that all un-enumerated individuals escaped. Because mortality can be affected by other factors and because of the difficulty in accounting for all alevins in egg masses, the estimates of survival are artificially high. It is difficult to account for all undeveloped eggs due to decomposition.

Mean concentrations of intergravel fines and surviving alevins seems to correlate well with the levels of development within the three watersheds. The following illustrates this point:

TABLE 6. Percent fine sediment and embryo survival in Middle Fork Salmon River headwater streams.

WATERSHED	*% FINE SEDIMENT*	*EMBRYO SURVIVAL (%)*
Sulphur Creek (mostly pristine)	21.6	78
Elk Creek (grazed, roadless)	29.1	73
Bear Valley Cr (grazed, roaded)	35.5	63

On both Sulphur and Bear Valley Creeks, survival drops off rapidly at around 30% fines, which agrees well with observations already presented in this paper for other sites in the Idaho Batholith. The Elk Creek data are scattered, probably because so many alevins were lost from the egg baskets during excavation.

Sample Size Statistics and Spatial Variability-Percent Fines

Tests were made to determine the value on N, the number of samples required to accurately estimate the mean. As reported in a number of studies reviewed by Chapman and McLeod (1987), measurements of substrate percent fines demonstrated rather large spatial variance. There are indications from other studies, however, that such variance may be smaller in the egg pockets of spawning salmonid fishes due to the winnowing on fines. and species preference for specific substrate sixes. In a study by Young, Hubert and Wesche (1989), concentrations of fine sediment were significantly lower within the egg pockets of brook trout in Wyoming.

Percent fines data from the egg baskets were analyzed to assess variance on the mean. Predictions of mean fine sediment assume that the data are normally distributed. The W test developed by Shapiro and Wilk (1965) was used to assess whether the data fit a normal distribution. In all cases, the dissolved oxygen data followed a normal probability distribution at p = .95. The same was true for all percent fines data. In some cases, a lognormal distribution provided a better fit.

Statistics on the sample sizes for egg pocket percent fine sediment, and dissolved oxygen concentration are shown in tables 7 and 8 respectively.

Data collected in the South Fork Salmon, and Bear Valley studies adequately represented the mean. Spatial variability in these cases was small, and the statistic predicted that only two samples were needed to represent the mean.
Data from the Sulphur, Dog, Rock 4, and Elk Creek stations indicated slightly greater variability on egg pocket percent fines. Based on these studies, about 7 to 8 samples per station would be required to adequately represent the mean.

At two stations, Rock 7 and Trinity, variability was high. These are steep gradient streams (> 3%), and spatial variability may be related to diversity in bed morphology. The Trinity Creek sample was unique in that the sample was collected following spring snowmelt, and several egg baskets were inundated with deposited fines, while others were essentially scoured by the current.

As indicated by the statistics in Table 4, we observed extremely low variability in intergravel dissolved oxygen concentrations. This is due, in part, to the rather narrow range on concentrations observed naturally in most streams.

TABLE 7. Sample size needed to predict the true mean-% fines
Conditions = unknown variance, N < 30

Parameter: Egg pocket % fines (< 6.3mm)

Station ID	N	Mean	Std. Error of the Mean	Probab. Type II Error	Test Power on N	Prediction of N at 95% Conf.
SF Salmon	29	20.1	1.7	.03	.97	2
Bear V	5	27.5	1.1	.03	.97	2
Sulfur	5	15.4	2.2	.06	.94	7
Dog Creek	5	37.2	2.1	.05	.94	6
Rock 4	5	41.6	2.3	.06	.94	8
Rock 7	5	39.8	3.0	.08	.92	13
Elk	5	21.1	3.6	.10	.90	10
Trinity	5	49.7	6.1	.18	.82	29

Sample size recommended: Low gradient (<3%) streams = 7
High gradient (>3%) streams = 13

Table 8. Sample size needed to predict the true mean.
Parameter: Egg pocket-dissolved oxygen (mg/l)

Station ID	N	Mean	Std. Error of the Mean	Probab. Type II Error	Test Power on N	Prediction of N at 95% Conf.
SF Salmon	3	9.9	0 .80	.03	.97	1
SF Salmon2	4	13.3	0 .13	.01	.99	1
Rock 3	10	6.8	0 .60	.01	.99	1
Rock 4	12	6.6	1.00	.02	.98	2
Rock 5	11	9.2	0 .30	.01	.99	1
Rock 8	10	9.5	0 .30	.01	.99	1
Dog	3	11.1	0 .10	.01	.99	1
Trinity	3	9.8	0 .10	.01	.99	1

Sample size recommended = 2

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