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COAL CREEK FISHERIES
MONITORING STUDY NO. III

Final Report
September, 1985

By
Thomas M. Weaver
and
Robert G. White

Cooperative Fishery Research Unit
Montana State University
Bozeman, Montana 59717

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to
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EXECUTIVE SUMMARY

This report summarizes data collected on the fishery in Coal Creek between spring, 1982 and spring, 1985. Water levels and temperatures followed similar patterns annually; however, variations in annual peak flow timing and intensity were documented which may influence bull trout fry emergence and survival. Intergravel flow revealed that permeability was significantly greater ($\alpha = .10$) in bull trout spawning areas when compared to similar appearing nonspawning areas. Interstitial dissolved oxygen content in the spawning area averaged 8.1 mg/l during the bull trout incubation period. Intergravel water temperatures in natural redds were cooler during October and warmer during March, than in surrounding areas of undisturbed gravel. Instream debris photography showed larger materials were relatively stable while smaller debris (logged and natural) was less stable and often moved during spring runoff. Streambed sampling in known bull trout spawning areas showed annual fluctuations in material < 6.35 mm of up to 5.0%. Coal Creek's spawning area contained a significantly higher percentage ($\alpha = .05$) of fine material than other creeks sampled. Size distribution of the spawning gravel < 25.4 mm was approximately log-normal ($R^2 = .94$). Bull trout spawning site inventories during 1984 revealed fewer redds in Coal Creek and other spawning tributaries than during the past 2 years. Fish abundance estimates in Coal Creek showed relatively large annual fluctuations, but appeared to decline from 1982 to 1983, then increase in 1984. Juvenile bull trout abundance increased

markedly in the South Fork Bridge section. Embryo survival and fry emergence monitoring in Coal Creek showed adjusted survival to emergence in Coal Creek was 53%. Entombment of alevins was documented and may have resulted in up to 15% of the observed mortality. Average survival to emergence in the 1984-85 lab study ranged from <1.0% to 90% and was inversely related to the percentage of fine material. Emergence success was most highly correlated to the percentage of material < 9.52 mm. The best equation relating bull trout embryo survival to emergence and gravel composition was determined. Fry quality appeared to be inversely related to the percentage of fine material.

The following recommendations were presented: 1) Continue the monitoring of fish abundance, substrate composition and bull trout spawning runs in the Coal Creek Drainage; 2) Establish semipermanent transects for future habitat assessment; 3) use the simple linear equation developed during the lab testing to predict survival to emergence and confirm this equation in the natural incubation environment; 4) Determine the effects of peak flow timing and intensity on bull trout fry emergence and survival; and 5) Determine if juvenile bull trout carrying capacities may be increased.

ACKNOWLEDGEMENTS

We wish to thank the following individuals and organizations who made this study possible. Personnel of the Montana Department of Fish, Wildlife and Parks and their Research and Special Projects Division were a principal force in thiis effort. Brad Shepard and Pat Graham proposed the original study and Nick Hetrick played a valuable role in data collection. John Fraley and Pat Clancey arranged for the 1984-85 emergence sampling. Discussions with the Special Projects Biologists often yielded insight into survey techinques or apparatus design. Fisheries Manager Jim Vashro, along with the Region One fisheries staff provided the electrofishing equipment and field help necessary and conducted the 1984 spawning site inventories. Gary Anderson, Mike Hensler, Dennis Schuster, Jeff Holland, Tim Swant, Rick Dey and Joe Helwig assisted in data collection. Bob McFarland aided in the statistical analyses.

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The United States Fish and Wildlife Service provided the space and water supply required for the laboratory incubation testing at the Bozeman Fish Technology Center. Robert Piper and Charlie Smith directed this facility during the study.

Personnel of the Montana Cooperative Fishery Research Unit assisted whenever their services were required. Bill Schrader initially set up the artificial incubation environment and helped monitor laboratory fry emergence. Ron Spoon, Dave Belford and Bill Schrader assisted in planting the artificial incubation chambers. Gee King prepared the graphics and Gisela Knupp typed the manuscript.

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INTRODUCTION

In 1979, a study was initiated by the Montana Department of Fish, Wildlife and Parks (MDFWP) to collect baseline fish population and aquatic habitat information from major tributaries to the North and Middle Forks of the Flathead River. The Flathead River Basin Study was funded by the Environmental Protection Agency and annual reports identified "critical" spawning and rearing areas for native populations of westlope cutthroat trout and bull trout (Graham et al. 1980, Fraley et al. 1981, Shepard et al. 1982, Shepard and Graham 1983a). As part of the River Basin Study, a monitoring plan was designed and implemented to evaluate the effects of various land management activities on the fishery of the upper Flathead Basin, (Shepard and Graham 1983a, 1983b). During this monitoring effort it was determined that Coal Creek, a tributary to the North Fork in Flathead National Forest (FNF), Glacier View Ranger District (GVRD) contained a significantly higher percentage of fine material in the streambed than other streams sampled (Shepard and Graham 1983a). Coal Creek has been identified as a major bull trout spawning stream and contained areas critical for juvenile bull trout rearing. Migratory cutthroat trout were also documented in the Coal Creek drainage, along with resident cutthroat populations (Shepard et al. 1982). Adverse effects of high levels of fine sediment on salmonid populations are well documented and have been summarized by Cordone and Kelly (1961), Gibbons and Salo (1973) and Iwamoto et al. (1978).

Glacier View Ranger District had scheduled a timber harvesting program in the Coal Creek Drainage to begin after 1981; however, a spruce bark beetle infestation was identified in the upper drainage and the program was changed in an attempt to control the problem. During the new plan's first phase, beetle infested and high risk spruce was salvaged from 600 acres in the riparian zone. Phase two involved harvesting 14 million board-feet of primarily spruce along both ridges of the upper drainage. Extensive road construction and reconstruction was required, creating the potential for further degradation of important spawning and rearing areas through increased sedimentation.

In the summer of 1981 MDFWP and FNF met to discuss a study to evaluate the present condition of the fish resource in Coal Creek. Through efforts of Forest Service Regional Office, Supervisors Office and District personnel, funding became available and a contract was begun by MDFWP for FNF in 1982. Initial findings were reported by Shepard and Graham (1983c). In 1983, funding was available from Forest Insect and Disease Controll allowing continuation of the study. The 1983 work was contracted to the Montana Cooperative Fisheries Research Unit (MCFRU) at Montana State University. The Coal Creek Fisheries Monitoring Study Number II was designed to collect comparable fish population and habitat data; document the number of bull trout redds in known spawning areas on the district; and obtain information on bull trout embryo survival and fry emergence. Results and recommendations from the second year of study were reported by Weaver and White (1984).

The Coal Creek Fisheries Monitoring Study was continued in 1984 by MCFRU in cooperation with MDFWP and FNF. Major activities included under the continuation of Forest Service Contract Number 53-0385-3-2685 were:

1. Habitat assessment;
2. Instream debris monitoring;
3. Sediment coring and analysis;
4. Redd counts;
5. Fish abundance estimates; and
6. Embryo survival and fry emergence monitoring.

The following report contains data collected during the third year of study and discusses results from 1982 through the present time. This Final Report is intended to fulfill all contractual obligations by MCFRU. A portion of the data collected during these studies will be presented by Thomas Weaver as a thesis in partial fulfillment of the requirements for an M.S. degree in Fish and Wildlife Management from Montana State University.

DESCRIPTION OF STUDY AREA

Coal Creek is a major tributary entering the North Fork of the Flathead River 38.9 km above the junction of the North and Middle Forks (Figure 1). Coal Creek drains an area of 211.5 km^2 and is 31.2 km in length. Average channel gradient was 1.9% (MDFWP 1983). Major tributaries to Coal Creek include Cyclone, Dead Horse, Mathias and the South Fork of Coal Creek.

The parent material underlying the Coal Creek drainage was predominated by argillites and limestone. Quartzites and sandstone were also present. The material was classified by Martinson et al. (1982) as having a silty texture and moderately fast sediment transport capability. Valley walls adjacent to Coal Creek and its tributaries frequently had steep slopes, increasing erosion and sediment transport potential. Mean annual precipitation for the Coal Creek basin above Dead Horse Bridge was estimated at 135 cm by Enk et al. (1985) using precipitation maps given in Farnes (1975).

Land ownership in the Coal Creek Drainage was mixed. Private holdings comprised approximately 11%, principally in the lower portion of the drainage. The Montana Department of State Lands controlled approximately 19% located in the middle portion of the drainage. FNF managed the remaining 70% including the upper basin and the Wild and Scenic River corridor along the North Fork.

Between 1955 and 1982, an estimated 10.3 km^2 were clearcut on Forest Service land and 3.3 km^2 were harvested using other

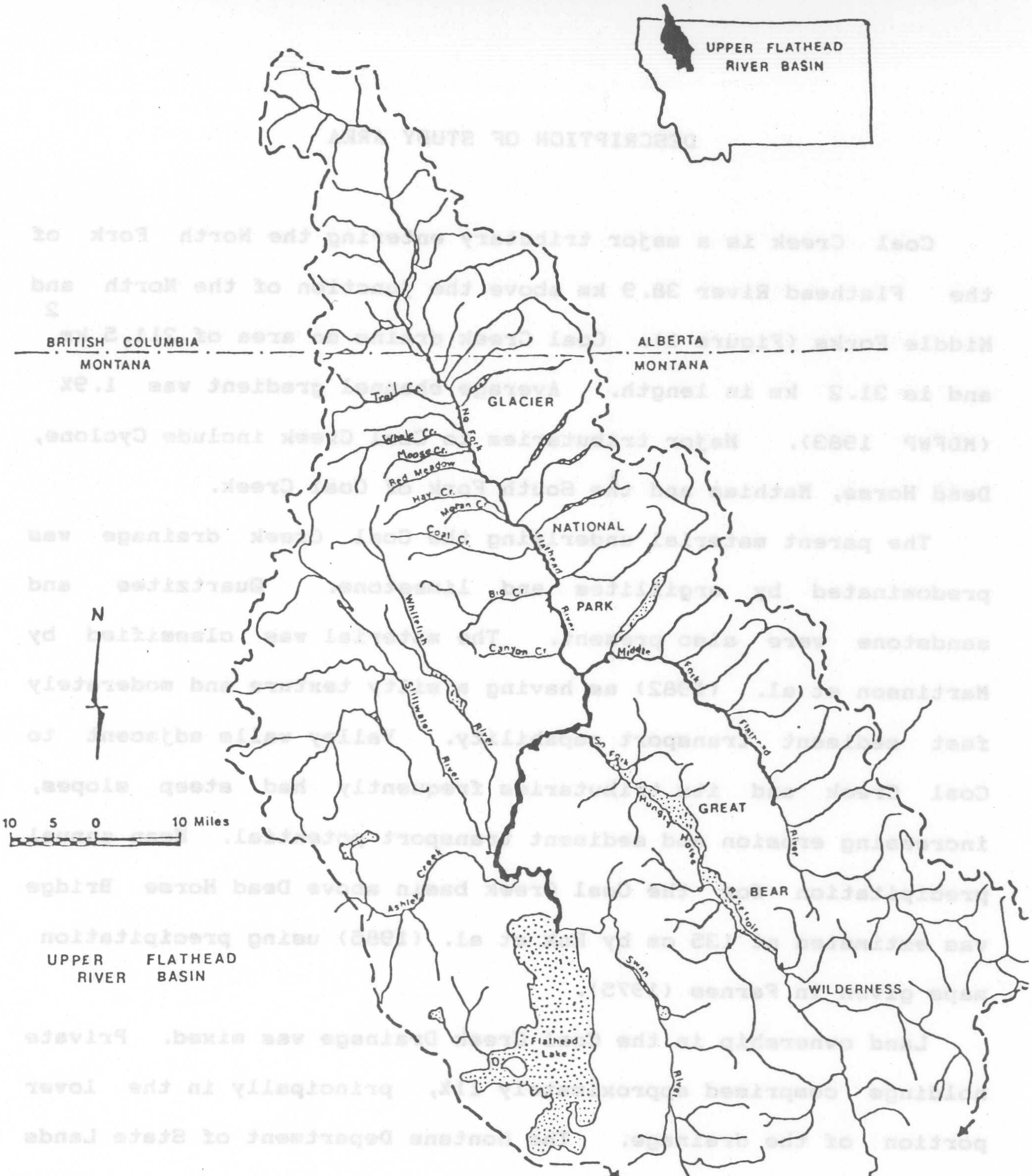

Figure 1. Drainage map of the Upper Flathead Basin. Adapted from Montana Department of Natural Resources and Conservation (1977).

methods. Salvage sales were not included in these estimates. An estimated 3.6 km^2 of state land have been clearcut and 1.2 km^2 have been partially cut. During the Coal Ridge Sale, 5 million board-feet of timber was removed in 1983 and a similar harvest occurred during 1984.

As of 1982, approximately 153.0 km of road existed on Forest Service land and 43.4 km existed on state land. All 36.7 km of road reconstruction planned during the Coal Ridge Sale was completed by fall of 1982 and the 18.5 km of new road required for the sale was completed by fall of 1984.

METHODS

HABITAT ASSESSMENT

Streamflows

Coal Creek's water level was monitored throughout the study period at the following bridge crossings:

1. Coal Creek Road - 317 (SE 1/4, NW 1/4, SE 1/4, Section 36, (Cyclone) Township 34 North, Range 21, West);

2. Dead Horse Road - 1693 (NW 1/4, SE 1/4, SW 1/4, Section 28, Township 34 North, Range 21 West); and

3. South Fork Coal Creek Road - 317 (SE 1/4, NE 1/4, SW 1/4. Section 24, Township 34 North, Range 22 West) (Figure 2).

Standard stage gages were installed on bridge abutments at each site and referenced to permanent benchmarks by MDFWP (Shepard and Graham 1983a). The stage gages were rechecked against benchmarks during summer, 1984. Water levels reported were standardized as gage height in feet. Point measurements of discharge were made throughout the study and combined with stage readings forming stage-discharge relationships. Flow measurements were made in conjunction with major activities to document discharge during surveys. Discharge measurements were made with a Marsh McBirney current meter and topsetting rod, following procedures described in Hewlett and Nutter (1969).

Water levels in eight other westside tributaries to the North Fork were monitored throughout the study at or near the North Fork Road (210) crossing. (Figure 1). Fluctuations within and between drainages were examined.

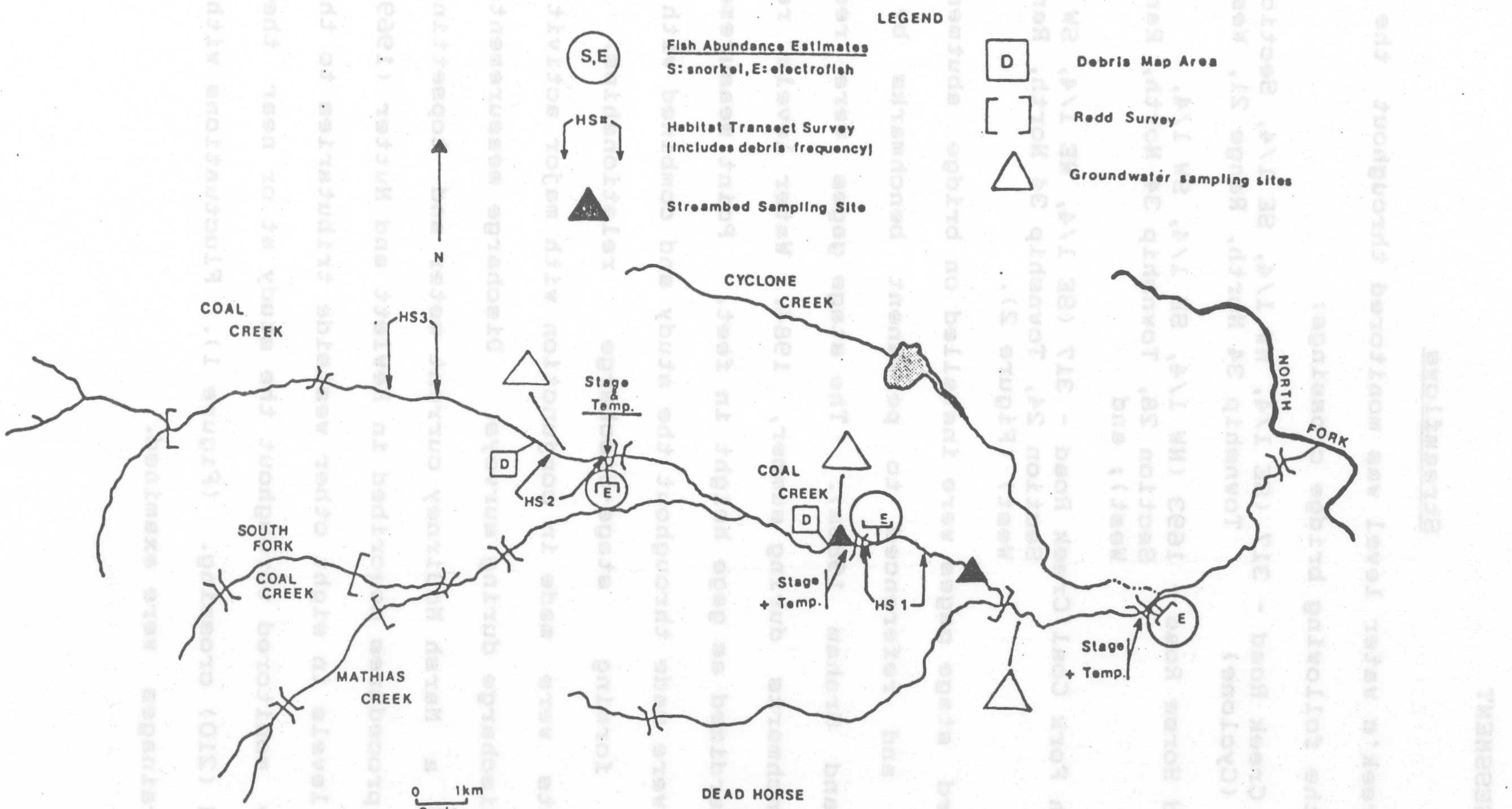

Figure 2. Map of the Coal Creek Drainage showing physical and biological sampling sites.

Water Temperatures

Foxboro recording thermographs were placed near each of the three bridges listed. Daily minimum and maximum temperatures were interpreted from charts and recorded. The unit at Cyclone Bridge was operated from 11 June to 8 November in 1982, 10 June to 15 December in 1983 and from 1 July to 31 October in 1984. The thermograph near the South Fork Bridge was maintained from 11 June to 8 November in 1982, 9 July to 15 December in 1983 and from 1 July to 31 October in 1984. The Dead Horse thermograph was monitored from 11 June to 8 November in 1982. This unit was reinstalled on 9 July, 1983 and maintained continuously until 31 October, 1984. Records obtained during the 1983-84 bull trout embryo incubation period were digitized providing information on temperature units accumulated.

Groundwater Sampling

Groundwater samples were collected from Coal Creek quarterly between fall, 1984 and summer, 1985. During each sampling period, three transects were sampled in the high density bull trout spawning area above Dead Horse Bridge. Transects above and below the spawning area were sampled for comparison (Figure 2). Transects were established by driving rebar stakes into each bank. A tape was stretched between the stakes and four sample locations on each transect were recorded as the distance from the left rebar while facing downstream (Table 1). All transects in the spawning area were located to allow sampling in the tailspill area of at least one natural redd.

Table 1. Groundwater sample site locations and distances between rebar stakes on each transect. Distances are meters from the left rebar when facing downstream.

Transect Number	Site Number 1	2	3	4	Right rebar
1	5.1	9.3	11.4 1/	13.0	18.9
2	4.1 1/	7.8	10.7	12.7	17.4
3	2.9 1/	6.5	8.9	11.7	17.1
4	4.0	6.3	9.1	12.6	18.5
5	2.2	4.7	7.8	10.3	14.8

1/ These sites were in natural bull trout redds.

At each site, three perforated standpipes similar to those described by Terhune (1958) were pounded into the streambed in a triangular arrangement (Figure 3). The standpipes were premarked so sampling depth was approximately 15 cm below the gravel surface. Bull trout eggs have been documented at this depth during core sampling of natural redds (Shepard and Graham 1983c, Weaver and White 1984). All water inside the standpipe was pumped out and permeability was documented by collecting and measuring inflow during a 1.0 minute period. The dissolved oxygen content of each sample was measured by the Winkler titration method (Wetzel 1974). Temperature of each groundwater sample was also recorded. These three parameters were compared in two ways:

1. Spawning vs non spawning areas; and
2. Selected vs available areas within high density spawning area.

Line Transects

During 1982 and 1983, aquatic habitat was evaluated using a line transect methodology similar to that described by Herrington and Dunham (1967) and used in previous surveys of Coal Creek (Shepard and Graham 1983c, Weaver and White 1984). Transects were located at 25 randomly selected sites per kilometer in the three established sections, located:

1. approximately 0.5 km below Dead Horse Bridge (HS1);
2. approximately 0.3 km above South Fork Bridge (HS2); and

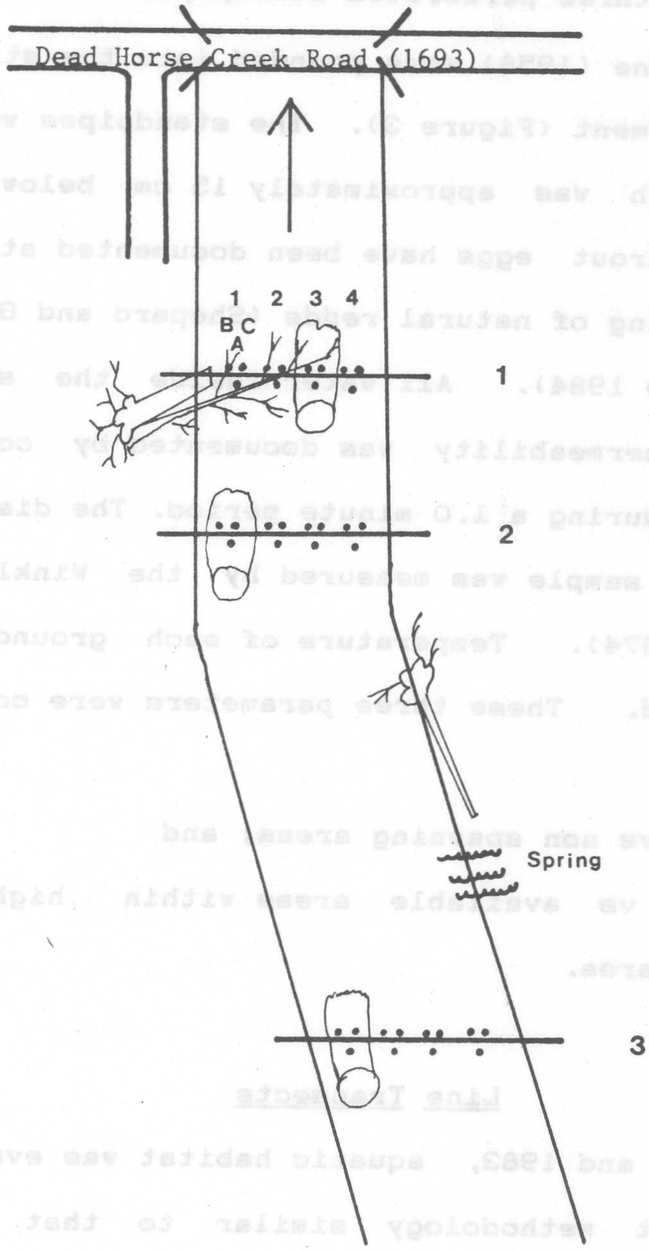

Figure 3. Diagram of groundwater transects and sample sites in the bull trout spawning area above Dead Horse Bridge.

3. above the Coal Ridge Lookout trailhead (HS3) (Figure 2).

Point estimates of the following parameters were made at 1.0 m intervals across each transect:

1. instream cover;
2. overhead cover; and
3. two predominant substrate size classes (Table 2).

For comparison with transect data, visual estimates of overall substrate composition, compaction, imbeddedness and D-90 were made, along with visual estimates of total instream and overhead cover on each transect. Depth was recorded at each point and the maximum depth on the transect was noted. Wetted width and channel width were also measured across each transect. Terminology used in the habitat assessment process was defined by MDFWP (1983) and is included in Appendix A.

Line transect data were entered into files on the ICIS 850 computer located at the MDFWP Regional Headquarters in Kalispell, Montana. Computer programs developed by MDFWP were used for data entry and summarization.

Debris Frequency

All channel debris encountered in each 1.0 km habitat survey section was identified and recorded by type, size class and age class (Table 3). Approximate debris locations were also recorded. Annual frequency of occurrence for debris classes were compared in each section.

Table 2. Substrate size class, instream cover and bank cover criteria.

Substrate size class

1. Particulate organic matter, silt or detritus
2. Less than 2.0 mm in diameter - sand
3. 2.0 to 6.4 mm in diameter - small gravel
4. 6.4 to 64.0 mm in diameter - large gravel
5. 64.0 to 254.0 mm in diameter - cobble
6. Larger than 254.0 mm in diameter - boulder, bedrock

Instream cover codes

0.	None	
1.	Aquatic vegetation	Below water surface
2.	Logs	Below water surface
3.	Debris	Below water surface
4.	Boulders	Below water surface
5.	Logs	Above water surface
6.	Debris	Above water surface
7.	Boulders	Above water surface
8.	Man made structure	

Bank cover codes

0. None
1. Undercut bank, log or root mass
2. Overhang <2 m above water surface
3. Overhang from 2 m up to canopy overstory
4. Overstory canopy

Table 3. Criteria used to classify organic debris by size and age in Coal Creek.

Size	Diameter
Large	> 305 mm (>12 inches)
Medium	152-305 mm (6 to 12 inches)
Small	52-151 mm (2 to 6 inches)
Branches	<52 mm (<2 inches)
Jams	Accumulation of debris
<u>Age</u>	
Old	Past years
New	This years (natural)
Logged	This year (cut)

INSTREAM DEBRIS MONITORING

MDFWP mapped the presence and location of woody debris in two sections of Coal Creek during summer, 1982 (Shepard and Graham 1983c). One section was located within the riparian cut area, approximately 2.0 km above the South Fork Road Bridge. The other section was located downstream, 0.5 km above Dead Horse Road Bridge.

During late July, 1983, semipermanent photopoints were established and the channel area in each section was photodocumented. Landmarks (i.e., mature trees, boulders) identifying transects were marked with red paint. A tape was stretched from these numbered landmarks at approximately a 90° angle to the channel. The photographer's location on this transect was selected for maximum effectiveness and the distance from the landmark and compass heading of the lense were recorded (Table 4). An Olympus OM-1 with a Zuiko 50 mm lense and Kodak 100 ASA color print film were used. This procedure was repeated during late July, 1984 and early July, 1985.

To further monitor debris recruitment and movement, the sections were divided into five equal segments during 1983 and debris in each segment was marked with a different colored paint. All debris in the 100.0 m immediately above each section was marked with a sixth color. Marked debris locations and channel configuration were monitored through July, 1985.

SUBSTRATE COMPOSITION

Twenty substrate samples were collected annually from Coal Creek's major bull trout spawning area. A standard hollow

Table 4. Location of debris monitoring photopoints in the two sections of Coal Creek during late July 1983.

Section	Date	Discharge (cfs)	Station Number	Distance Above Lower Rebar 1/ (m)	Photo Number	Landmark type	Distance From Landmark 2/ (m)	Compass Heading
			1	19.4 3/	1	Stump	3.5	275°
			2	43.2	2	Tree	0.0	110°
			3	65.9	3	Tree	1.0	315°
			--	--	4	--	11.0	110°
			--	--	5	--	11.0	80°
Dead Horse	7-28-83	82.6	4	65.9	6	Tree	1.0	220°
			5	85.2	7	Tree	11.0	35°
			--	--	8	--	11.0	190°
			6	106.3	9	Rebar	5.0	335°
			--	--	10	--		
			1	12.0 3	1	Tree	2.0	310°
			2	34.1	2	Tree	4.0	110°
			--	--	3	--	4.0	280°
Riparian Cut	7-30-83	35.8	3	96.6	4	Tree	3.0	245°
			--	--	5	--	6.0	90°
			4	113.8	6	Rock	0.0	100°
			--	--	7	--	0.0	85°
			5	133.8	8	Rock	2.5	85°

1/ All measurements above the lower rebar were made along the shortest route.

2/ These measurements were made from the landmark at a 90° angle to the channel.

3/ These measurements are distances below the lower rebar.

core sampler (McNeil and Ahnell 1964) was used, following methods developed for Glacier View Ranger District by MDFWP (Shepard and Graham 1982). Coring sites were located across the five transects sampled during previous studies (Shepard and Graham 1982, Shepard and Graham 1983c, Weaver and White 1984). Samples were placed in labeled bags and transported to the Flathead National Forest Soils Lab in Kalispell, or Montana State University in Bozeman, for analysis. After drying, each core sample was analyzed using the following sieve series:

76.10 mm (3.00 inch)

50.80 mm (2.00 inch)

16.00 mm (0.62 inch)

6.35 mm (0.25 inch)

2.00 mm (0.08 inch)

0.063 mm (0.002 inch)

pan

Sieve analysis of the 1984 samples included addition of the following sieve sizes:

25.40 mm (1.00 inch)

12.73 mm (0.50 inch)

9.52 mm (0.38 inch)

4.26 mm (0.19 inch)

0.85 mm (0.03 inch)

0.42 mm (0.016 inch)

All material retained on each sieve was weighed and the percent dry weight in each size class was calculated and compared.

To compare substrate composition of Coal Creek with other westside tributaries, core samples were collected annually from bull trout spawning areas in Big, Whale and Trail Creeks. Twelve samples were taken from established transects in Whale and Trail Creeks (Shepard and Graham 1982). A single coring site in Whale Creek required relocation in 1983 due to excessive depth and velocity. One site in Trail Creek was also relocated in 1983, allowing a natural redd to be sampled. Channel changes in the Big Creek sampling area forced the relocation of two transects and adjustment of the coring sites on the third transect in 1983. The 1984 coring locations in Big, Whale and Trail Creeks were identical to those sampled in 1983 (Weaver and White 1984). Maps showing the location of substrate sampling areas are included in Appendix B.

A Kruskal-Wallis test was run to determine if substrate composition differed between the creeks sampled (Lund 1979). Percentages of material less than 6.35 mm in cores from undisturbed streambed in the four creeks were compared using a Mann-Whitney test (Lund 1979).

BULL TROUT SPAWNING SITE SURVEYS

Bull trout spawning activity was monitored annually in the Coal Creek drainage. Preliminary surveys were conducted frequently from mid-August through early October. Final redd counts began in early October. Redds were identified and pace located while walking along the stream channel. Areas surveyed in 1984 were identical to those inventoried during the 1983 study (Weaver and White 1984).

To compare Coal Creek's spawning run with runs in other tributaries, preliminary surveys and final redd counts were conducted in the Big, Whale and Trail Creek drainages. Areas surveyed were those recommended for monitoring by MDFWP (Shepard and Graham 1983b). The lower 6.3 km of Hallowatt Creek and 4.0 km of Shorty Creek were also surveyed in 1981, 1982 and 1983. The 1984 redd counts in Big, Whale and Trail Creeks were conducted by MDFWP personnel.

FISH ABUNDANCE

During late summer, fish abundance estimates were completed annually in the three 150.0 m sections of Coal Creek established by MDFWP (Shepard and Graham 1983c). The sections were blocked off at each end with 12.7 mm wire mesh, anchored to the streambed by metal fence posts. Fish were captured using a bank electrofishing unit. Total length and weight of all trout and whitefish captured was recorded and sculpins were counted. Trout between 75 and 100 mm were marked with a fin clip and those larger than 100 mm were given a numbered tag.

Two-catch population estimates (Seber and LeCren 1967) were computed for the Cyclone Bridge and South Fork Bridge sections. Both two-catch and mark-recapture estimates (Vincent 1971) were made in the section below Dead Horse Bridge. Estimates, including 95% confidence intervals, were computed for cutthroat and bull trout 75 mm and longer. Smaller fish were able to escape through the block fences making estimation of their numbers impossible. Annual estimates and densities were compared.

EMBRYO SURVIVAL AND FRY EMERGENCE

Field Study

The 1983 embryo survival work in Coal Creek began in early September with the construction of eight artificial redds. A run, located 0.3 km above Dead Horse Bridge, having approximately the mean depth and velocity reported for bull trout redds in the Flathead Drainage was selected (Fraley et al.1981). Construction involved digging depressions in the streambed with a Pulaski and shovel and mounding the disturbed material immediately downstream. The mounds, or tailspill areas of completed redds were approximately 2.0 m in length.

After construction, a core sample was removed from the tailspill area of each artificial redd using a hollow core sampler (McNeil and Ahnell 1964). After core sampling was completed, four egg planting sites were prepared in each of the four upstream artificial redds. A closed bottomed, wire screen cylinder approximately 15.2 cm in height and 15.2 cm in diameter was burried in the tailspill at each site. The gravel displaced was carefully filled in around the cylinder so when positioned, the top of the wire screen was even with the tailspill surface (Figure 4).

Adult bull trout were captured above Dead Horse Bridge on 12 September, 1983 at approximately 0100 h. A lantern was used to locate the spawners which were easily captured with a dip net.

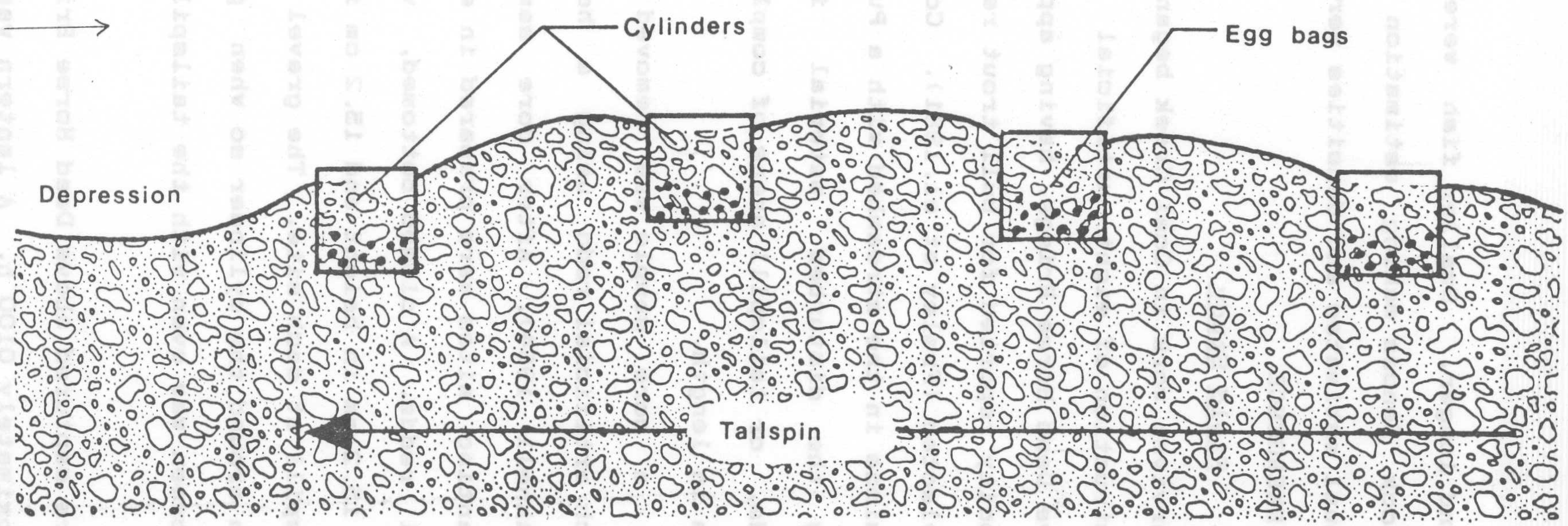

Figure 4. Cross-section of an artificial redd showing wire mesh cylinders and egg bags in place prior to burial.

approximately 1000 h, one male and one female were anesthetized. Eggs were taken dry, then fertilized in a stainless steel bowl. Spawners were released after a short recovery period. The gametes were mixed thoroughly and allowed to sit for several minutes. The eggs were then washed several times with creek water and transferred to a water cooler containing creek water. The cooler was covered and left immobile for 1.0 h, allowing eggs to water harden.

One hundred eggs were placed in each of 32 fiberglass screen bags, along with enough stream gravel to fill the bags. Egg bags measured 15.2 x 7.2 cm. A strip of blue flagging was attached to each bag to facilitate relocation. Half of the bags were stapled closed, to prevent escape of fry after hatching. Four sealed bags were planted approximately 15.0 cm deep in each of the downstream redds. The remaining egg bags were left open and planted in the previously prepared sites in the upstream redds. Care was taken to make sure the top of each open bag remained upright as the screen cylinders were filled with gravel. After egg planting was complete, additional gravel was added on each tailspill and they were covered with 12.7 mm wire mesh, to prevent spawning fish from disturbing the area. The wire mesh was removed when natural spawning subsided.

One egg bag was excavated from each of the downstream redds on four separate dates, to document embryo survival and development. During these samplings, each egg bag was carefully opened and emptied into a white lab tray containing water. Live and dead embryos were enumerated and preserved in a 10% formalin solution. A subsample of 10 sac-fry was randomly selected from each bag and measured to the nearest millimeter total length. Embryo survival was expressed as percent survival for each sampling time throughout the experiment.

The upstream redds were left undisturbed until late February, when emergence traps were placed over all egg bags. Trap design was similar to that described by Phillips and Koski (1969) and had been used in the Flathead Drainage by MDFWP (Fraley and McMullin 1983) (Figure 5). Trap frames measured 30.5 cm square and were covered with 1.6 mm mesh nylon netting forming a funnel approximately 0.5 m in length and were closed with an overhand knot near the end.

During trap placement, enough gravel was removed from the tailspills to expose the tops of the wire screen cylinder. This allowed traps to be located effectively. Once in position, the flaps of netting extending past the iron frame were tucked down into the gravel, sealing the traps. Traps were generally checked and cleaned twice weekly throughout March and three times weekly in April, until emergence began.

When emergence was first observed, the knots in the samplers were untied and replaced with locking nylon tie straps. Sampling involved cutting the nylon tie with a small pair of snips and placing the opened sampler entirely inside a slightly larger elongated capture net. The capture net was also 1.6 mm mesh and had a long, square wooden handle. This allowed the net to be held in position with a knee, freeing both hands. A subsample of 100 fry removed from the traps during the first 2 days of emergence was measured to the nearest millimeter total length

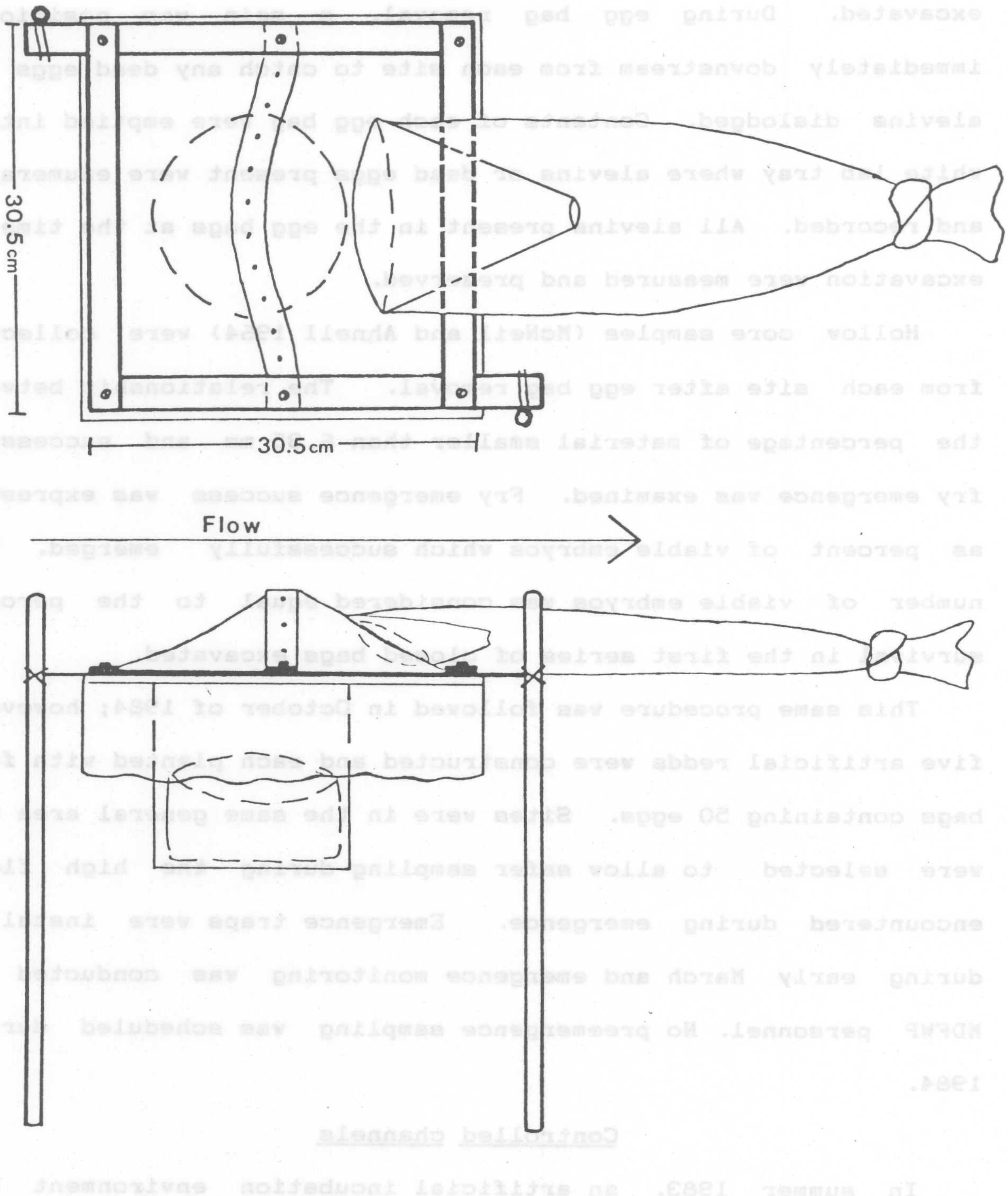

Figure 5. Diagram of fry trap showing a top view and a cross sectional view of a positioned trap.

and preserved in a 10% formalin solution. All other emergent fry were counted and released.

When emergence ended, the traps were removed and egg bags excavated. During egg bag removal, a sein was positioned immediately downstream from each site to catch any dead eggs or alevins dislodged. Contents of each egg bag were emptied into a white lab tray where alevins or dead eggs present were enumerated and recorded. All alevins present in the egg bags at the time of excavation were measured and preserved.

Hollow core samples (McNeil and Ahnell 1964) were collected from each site after egg bag removal. The relationship between the percentage of material smaller than 6.35 mm and successful fry emergence was examined. Fry emergence success was expressed as percent of viable embryos which successfully emerged. The number of viable embryos was considered equal to the percent survival in the first series of closed bags excavated.

This same procedure was followed in October of 1984; however, five artificial redds were constructed and each planted with four bags containing 50 eggs. Sites were in the same general area but were selected to allow safer sampling during the high flows encountered during emergence. Emergence traps were installed during early March and emergence monitoring was conducted by MDFWP personnel. No preemergence sampling was scheduled during 1984.

<u>Controlled channels</u>

In summer 1983, an artificial incubation environment was constructed at the Bozeman Fish Technology Center. Laboratory tests were designed to correlate bull trout embryo survival with gravel mixtures similar to those found in natural spawning areas. Approximately 3,000 kg of granitic streambed material was dried and sorted into size groups by sieving. Gravels were then recombined by weight to provide experimental mixtures which were similar in overall size distribution to natural spawning gravels (Tappel 1981, Shepard and Graham 1982) (Table 5).

Each experimental gravel mixture was designated by the percentage of material smaller than 6.35 mm and the percentage smaller than 2.00 mm. As an example, in the mixture 10:4, 10% of the material was smaller than 6.35 mm and 4% was less than 2.00 mm.

Three 1.2 m wide by 2.4 m long channels were each subdivided into eight 1.2 m long by 0.3 m wide by 0.3 m deep chambers, providing space for four replicates of six gravel mixtures (Figure 6). Gravel mixtures were randomly assigned to the incubation chambers. Water flow and gradient through each chamber was regulated by a valve at the inlet and height of standpipe. Four aluminum cylinders were placed in each chamber and gravel was carefully filled in around them to a depth of approximately 15.2 cm. The cylinders were left in place forming sites for egg planting (Figure 6).

In spring of 1984, all gravel in the incubation chambers was removed and the system was changed to recirculate the water. Four minnow-cool refrigeration units were installed to reduce water temperature as required. Portions of the system were insulated with 50.8 mm styrofoam sheeting. Approximately 3500 kg of alluvial deposit was obtained from the Flathead River near

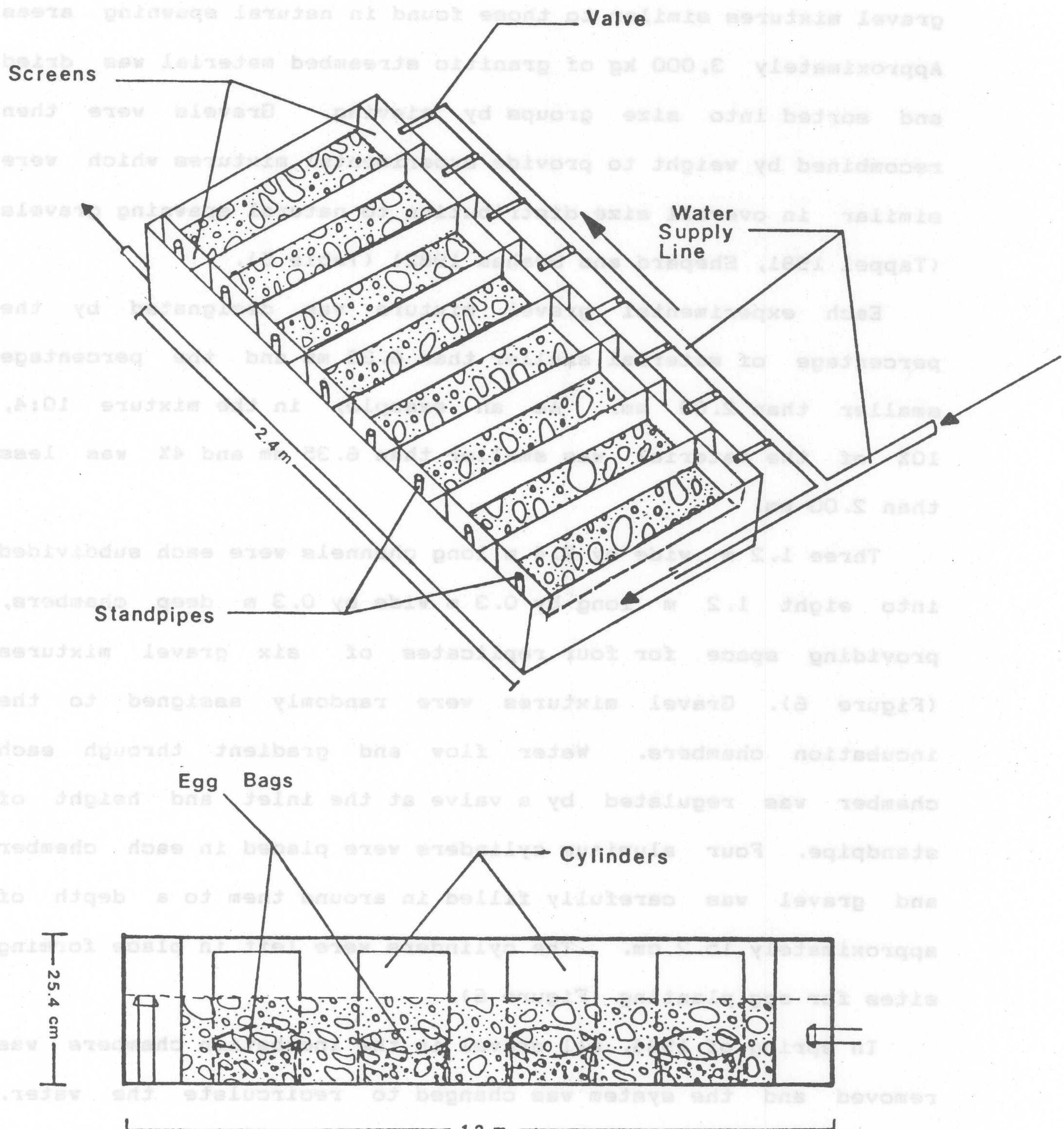

Figure 6. Diagram of incubation chambers showing egg planting sites.

Table 5. Size composition of gravel mixture used in bull trout embryo survival test during 1983-84.

Gravel mixture	Percentage of mixture smaller than given particle size (size in mm)								
	50.8	25.4	12.7	9.50	6.35	4.76	1.70	0.85	0.42
0:0	99.4	73.7	4.2	0	0	0	0	0	0
10:4	99.5	76.3	13.8	10.0	9.9	9.4	5.9	3.9	2.2
20:8	99.5	79.0	23.4	20.0	19.8	18.7	11.7	7.8	4.4
30:12	99.6	81.6	32.9	30.0	29.6	28.1	17.6	11.7	6.6
40:16	99.6	84.2	42.5	40.0	39.5	37.5	23.4	15.6	8.8
50:20	99.7	86.8	52.1	50.0	49.4	46.8	29.3	19.5	11.0

Columbia Falls. Gravels were sieve separated into the following size classes:

> 50.8 mm (2.0 inch)

25.4 - 50.8 mm (1.0-2.0 inches)

12.7 - 25.4 mm (0.5 - 1.0 inch)

6.35 -12.7 mm (0.25 - 0.50 inch)

< 6.35 mm (< 0.25 inch)

A random 1/10th sample was taken from the material smaller than 6.35 mm and further sieve analyzed using these additional size classes:

6.35 - 4.76 mm (0.25 - 0.19 inch)

4.76 - 2.00 mm (0.19 - 0.08 inch)

2.00 - 0.85 mm (0.08 - 0.03 inch)

0.85 - 0.42 mm (0.03 - 0.016 inch)

< 0.42 mm (< 0.016 inch)

Gravels were recombined by dry weight as in 1983. Table 6 shows the size composition of the six gravel mixtures used during 1984. Each experimental mixture contained more material from 25.4 to 50.8 mm than it's natural counterpart. This difference would only be a problem if this size material was detrimental to embryo survival. We are aware of no evidence indicating harmful effects of this size class. Experimental gravel mixtures were similar to the range of natural spawning gravel observed during core sampling in bull trout spawning areas of Big, Coal, Whale and Trail Creeks (Figure 7). Log-probability plots of both natural and artificial gravel mixtures showed approximately linear distributions for material smaller than 25.4 mm (Figure 7).

Table 6. Size composition of gravel mixtures used in bull trout embryo survival tests during 1984-85.

Gravel mixture	Percentage of mixture smaller than given particle size (mm)								
	25.4	15.9	12.7	9.52	6.35	4.76	2.00	0.85	0.42
0:0	13	7	4	3	0	0	0	0	0
10:4	24	18	16	13	10	8	4	2	1
20:8	46	37	32	26	20	16	8	4	1
30:12	62	52	46	39	30	25	12	4	2
40:16	72	62	59	50	40	34	16	6	2
50:70	83	72	69	60	50	41	20	8	3

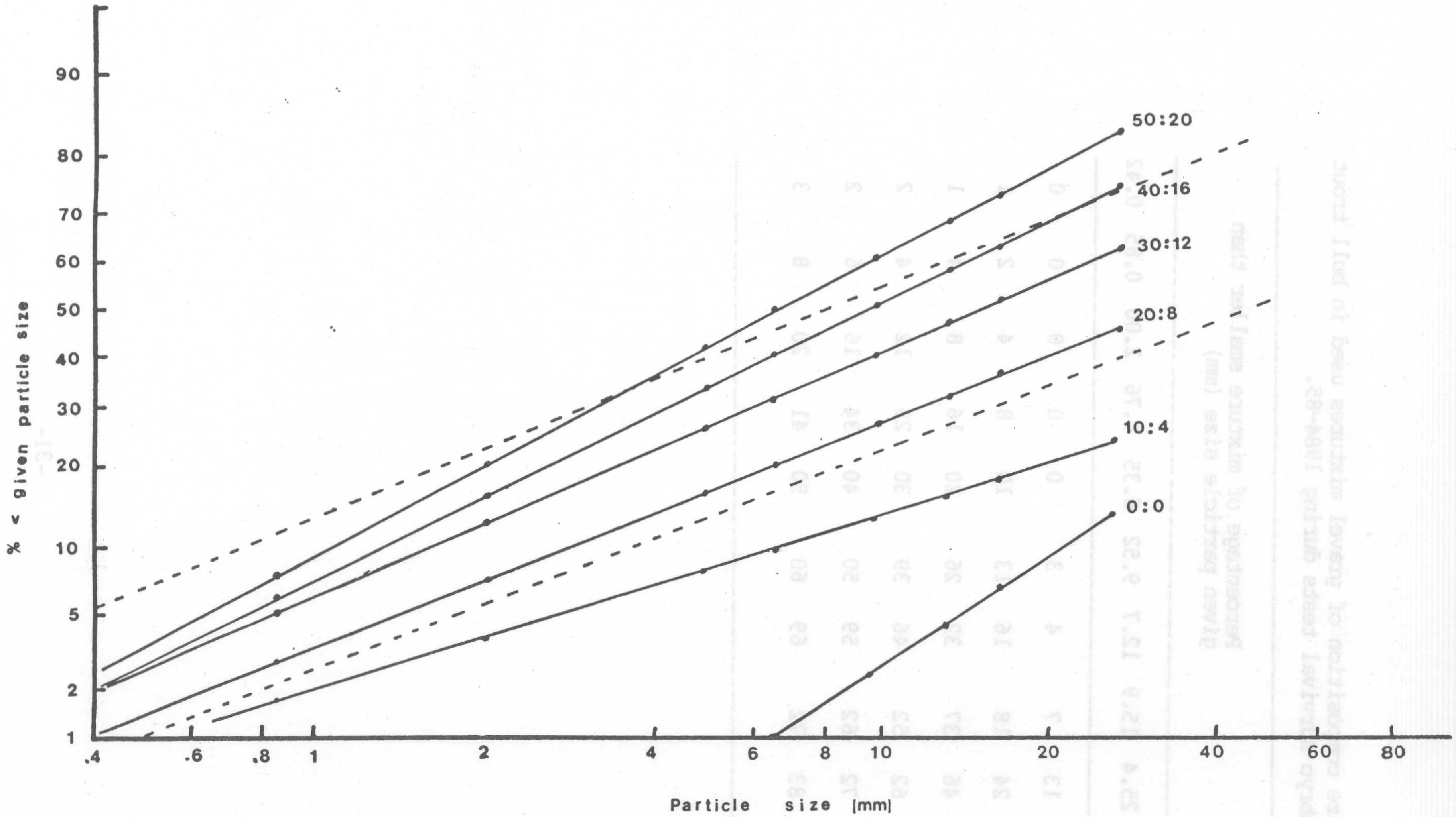

Figure 7. Log-probability plot of experimental gravel mixtures used in the labratory study. The area inside the dashed lines depicts the range of natural spawning substrate observed during core sampling in known bull trout spawning areas.

Adult bull trout were captured above Whale Buttes Bridge on 12 October 1984. Capture and spawning procedures were identical to those described previously. Fish spawned were retained along with a sample of both male and female gametes for disease testing. After water hardening, these eggs were placed on four trays in a shipping container packed with creek water ice, trucked to Kalispell, and flown to Gallatin Field, Bozeman, MT.

Upon arrival at the Technology Center, 50 eggs were placed in each of 92 fiberglass screen bags containing the gravel mixtures being tested. One open topped bag was placed upright inside each cylinder and covered with the gravel mixture. When all four cylinders in each chamber were full, the cylinders were pulled out and the inlet valve was opened.

Eggs from the upper tray of the shipping container were designated as lot 1 and used to plant one replicate of each gravel mixture. Trays 2, 3 and 4 were similarly labeled and stocked. The excess eggs from each lot were maintained separately in a Heath incubator as a check on fertilization success and non-sediment related mortality. Development was monitored by weekly egg sampling. Water level was kept just below the gravel surface to maintain a constant gradient of 2%. Water temperature was monitored continuously by a recording thermograph. Two egg bags were excavated from two randomly selected replicates of each gravel mixture just prior to hatching. Live and dead embryos or alevins were counted and recorded to aid in developing survival coefficients.

When the first emergent fry were observed, flows were increased to levels above the gravel surface. Fry in each chamber were captured, enumerated and preserved in 10% neutral buffered formalin. A subsample of the emergent fry was weighed and measured.

When emergence was complete, all egg bags were removed and the number of dead eggs in each was determined. Emergence success was expressed as percent of viable embryos which successfully emerged in each chamber during the test. Multiple regression was used to develop the best second-order equation relating bull trout survival to emergence and gravel composition.

RESULTS AND DISCUSSION

HABITAT ASSESSMENT

Streamflows

In 1984, Coal Creek's water level fluctuation patterns were similar to those recorded during the past 2 years, but stages were generally lower throughout much of the year (Figures 8, 9, and 10). Flows began rising in early April, peaked on about April 20 and then declined during the latter portion of the month. By early May, water levels were again rising, reaching the annual peak on 20 May, 1984. Peak flows at all three sites occurred 1-2 weeks earlier in 1984 than in the past 2 years. Annual peak flow in Big Creek at the Big Creek Work Center occurred approximately 1 week earlier than during 1982 and 1983 (files, USGS, Kalispell, Montana).

In early September, 1984, water levels at all three sites in Coal Creek increased, reaching an autumn peak on 8 September. Low autumn flows were recorded from late September through early November, coinciding with bull trout spawning and the early incubation period. By late February, 1985, flows had dropped to the lowest levels recorded during any of the Coal Creek Fisheries Studies. The gage reading at Dead Horse Bridge was approximately -0.33 (4 inches below the bottom of the gage). This new low reading was 0.53 ft (6.36 inches) below the previous low reading of 0.20, recorded during early March 1984. At this new low flow, an estimated 20 % of the spawning habitat available during late September, 1984 was dewatered. The effects of dewatering and air temperatures below freezing will be further discussed in the

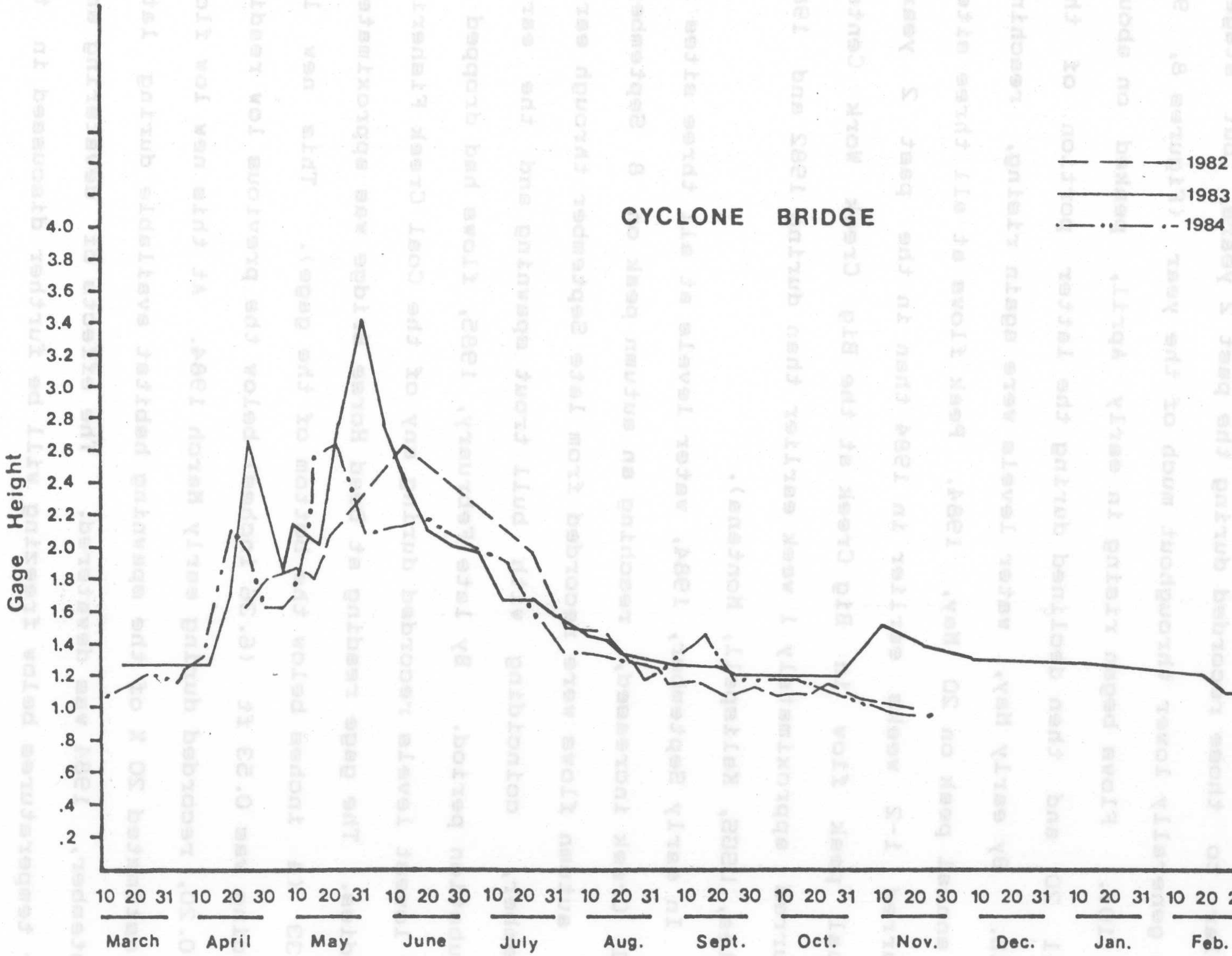

Figure 8. Gage height (in feet) of Coal Creek at the downstream bridge on Coal Creek Road (317) during the 1982, 1983 and 1984 study periods.

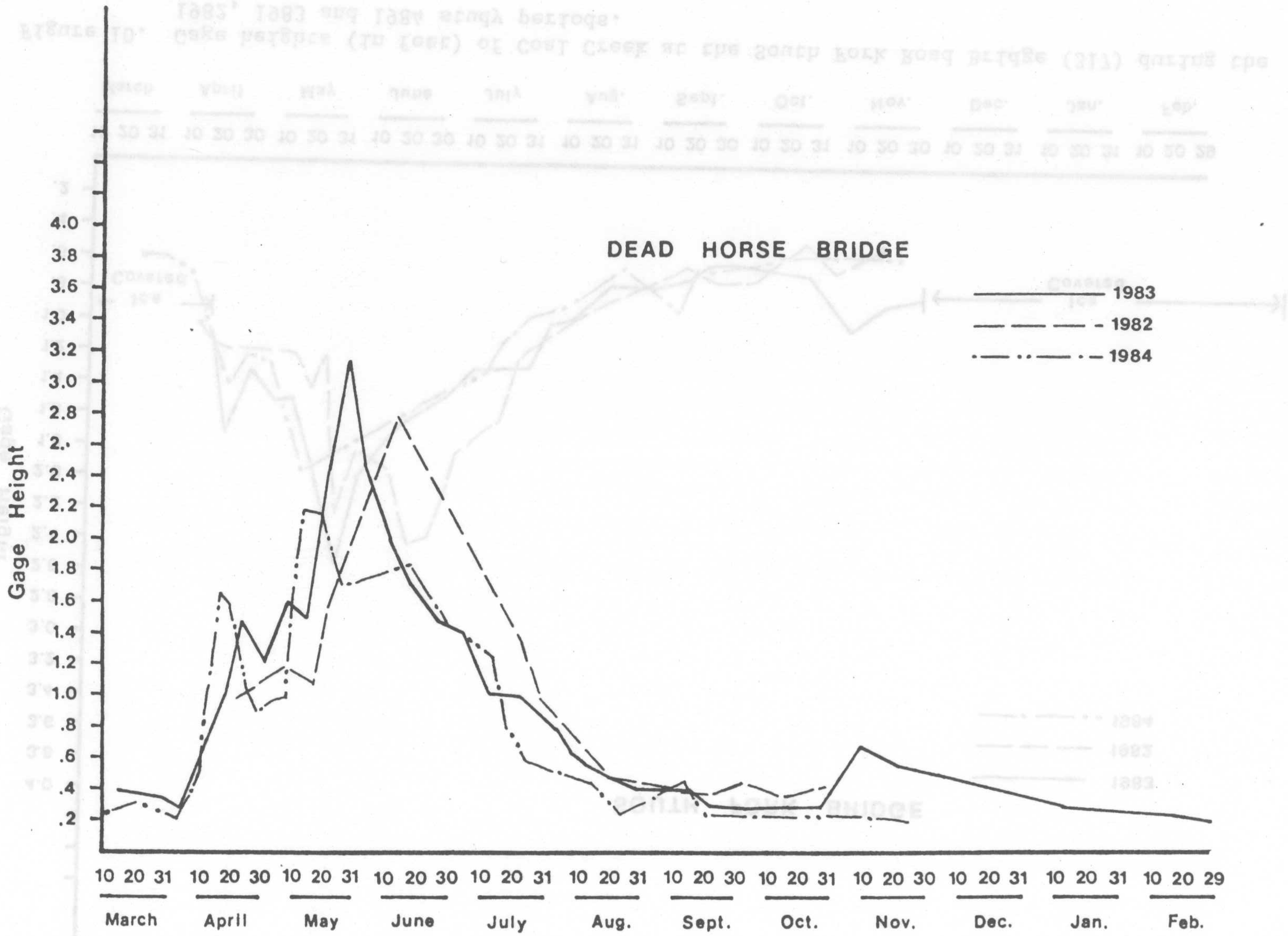

Figure 9. Gage height (in feet) of Coal Creek at the Dead Horse Road Bridge (1693) during 1982, 1983 and 1984 study periods.

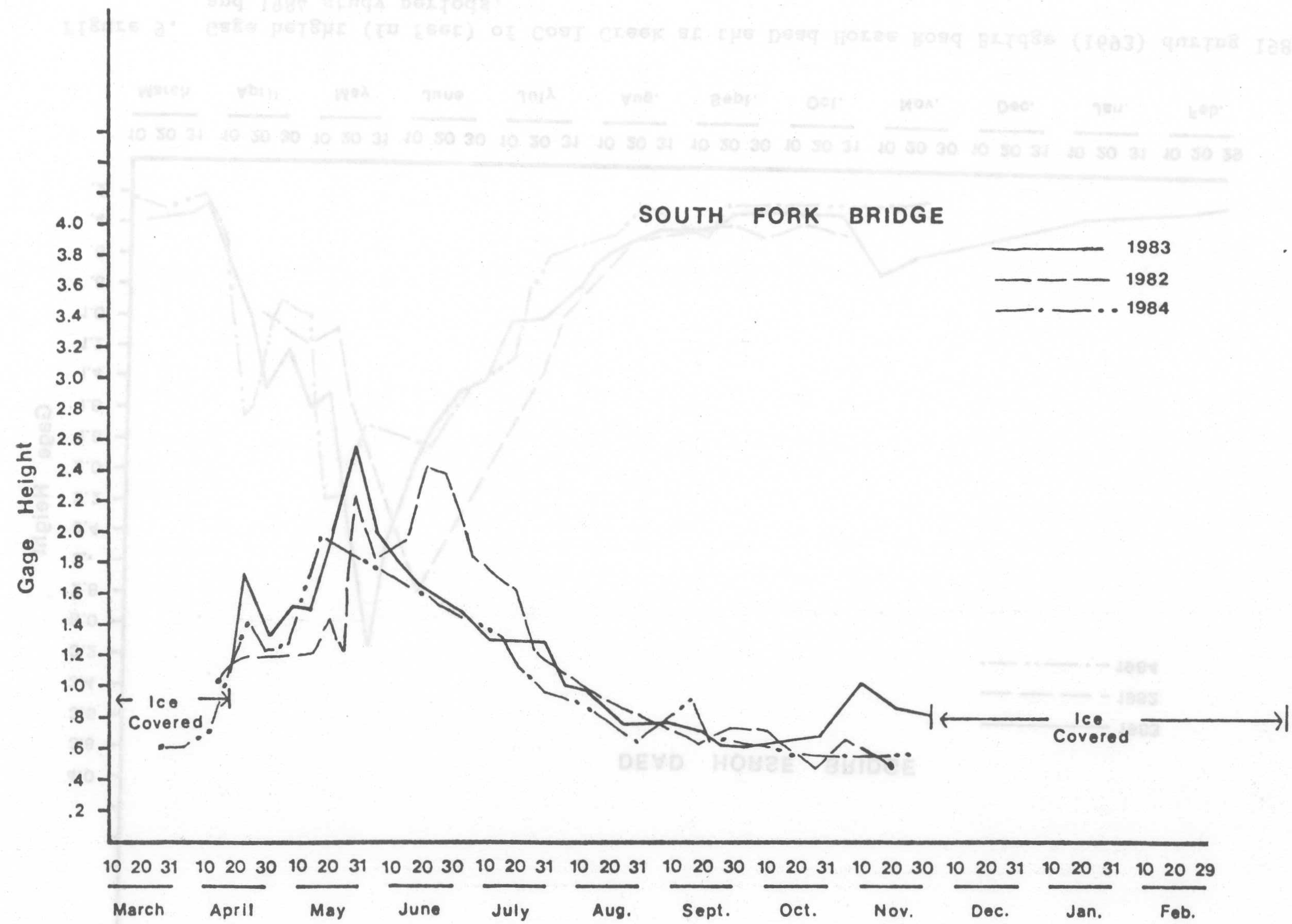

Figure 10. Gage heights (in feet) of Coal Creek at the South Fork Road Bridge (317) during the 1982, 1983 and 1984 study periods.

Embryo Survival and Fry Emergence section. Total ice and snow cover prevented a gage reading at both Cyclone and the South Fork Bridges during winter sampling.

A small peak flow period just prior to the annual peak has been documented in spawning areas annually since 1982 (Figure 9). Prior to this, no records are available for the study area. Periodic gage readings made during April and May, 1985, again showed a preliminary spring peak occcurred in early May. Weaver and White (1984) described the 1984 preliminary peak which occurred in late April and briefly discussed possible influences on bull trout fry emergence. As in 1984, this year's fry emergence from our artificial redds began during the declining flow period following the preliminary peak flow (15 May). Evidence suggests that this event may environmentally or physically stimulate fry activity within the gravel. During the 1984 study, 83% of the fry emerging from our artificial redds did so in the 4 day period immediately following the preliminary spring peak flow (Weaver and White 1984). We were unable to completely document emergence in 1985 due to the higher intensity of this event. The 1984 preliminary peak was approximately 250 cfs while this year's peak exceeded 400 cfs. Extreme bedload movement was observed and emergence traps were dislodged, preventing further monitoring of fry emergence.

On 22 May, 1985, water levels at Cyclone and Dead Horse Bridges exceeded the top of our stage gage and a point etimate of discharge made by USFS personnel at Dead Horse Bridge was approximately 1150 cfs (Wally Page-personal communication). Further work is required to assess the effects of peak flows and associated bedload movement on bull trout fry emergence and survival.

Point measurements of discharge made during the 1984-1985 study were added to the existing stage discharge relationships for each site (Figure 11). Seasonal water level fluctuations in other westside tributaries to the North Fork from 1979 through 1984 are presented in Appendix C.

Water Temperatures

Mean Weekly maximum and minimum water temperatures during 1984 followed trends similar to those recorded during past years (Figure 12). Summer maximum temperatures at all three sites occurred during early August , 1984 and were higher than summer maximums recorded during 1982 and 1983. Water temperature at Cyclone Bridge reached 16.1 ^{o}C, exceeding the previous high of 14.5 ^{o}C recorded on 6 August, 1983. The maximum temperature recorded in 1984 at Dead Horse Bridge was 12.8 ^{o}C, only 0.2 ^{o}C higher than in 1983. This year's maximum at the South Fork Bridge was 14.4 ^{o}C, exceeding the previous high of 12.9 ^{o}C on 6 August, 1983. The higher summer maximum temperatures observed during 1984 probably resulted from lower flows throughout July and August. The small increase in summer maximum temperature observed at Dead Horse Bridge (0.2 ^{o}C vs 1.6 ^{o}C at Cyclone Bridge and 1.5 ^{o}C at South Fork Bridge) illustrated the strong influence of groundwater in this area.

Daily fluctuations and the difference between mean weekly maximum and minimum temperatures were also most pronounced at Cyclone Bridge and least noticable at Dead Horse Bridge. This

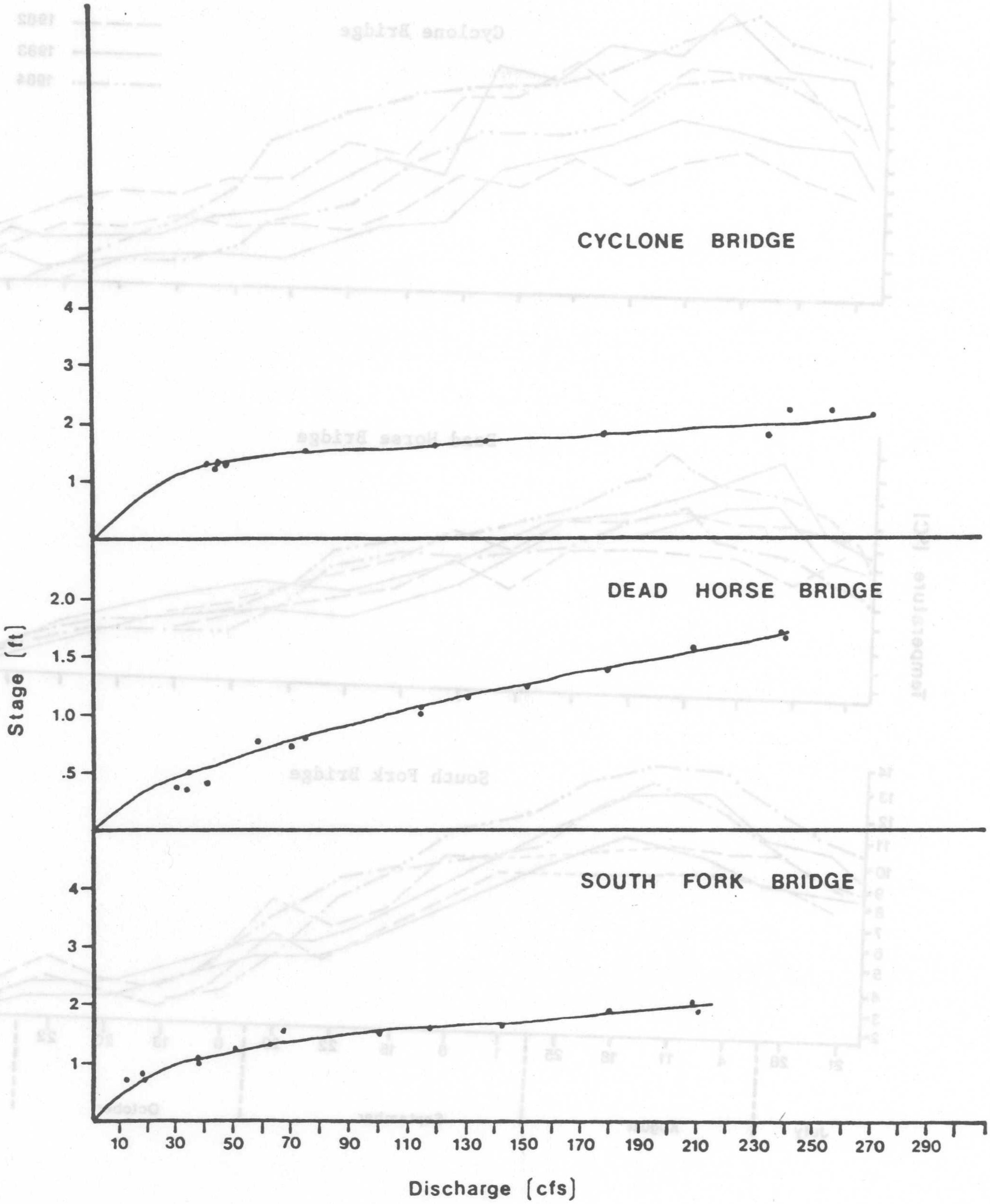

Figure 11. Stage discharge relationships for the three bridge crossings on Coal Creek. Points are discharge measurements made from 1982 through 1984.

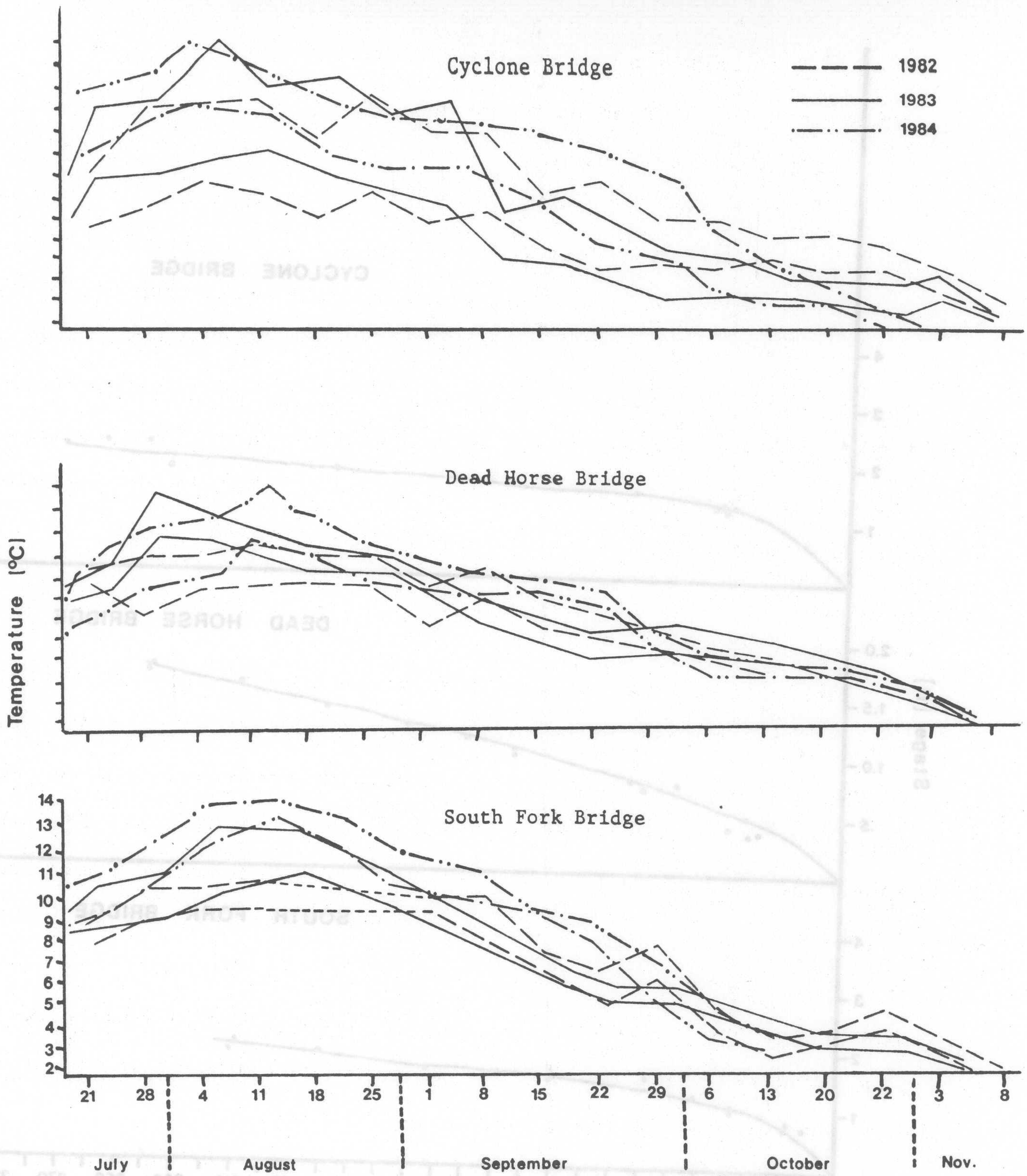

Figure 12. Mean weekly minimum and maximum water temperatures recorded by thermographs at the three bridge crossings on Coal Creek during 1982, 1983 and 1984.

further demonstrates the stabilizing effects of upwelling groundwater in the Dead Horse Bridge area.

Daily maximum temperature fluctuated around 9.0 °C throughout much of September in the Dead Horse Bridge spawning area and little spawning activity was observed. Most spawning in this area occurred during the last week of September, approximately 10 days later than in past years. We believe this was due to higher water temperatures associated with 1984 low flows. Although spawning began somewhat later, activity had subsided by the end of the first week in October, similar to timing observed during previous years.

Groundwater Sampling

Permeability

Mean permeability at sample sites in the spawning areas ranged from 120 to >530 cm/h during the October sampling (Table 7). The range of permeabilities observed outside the spawning area was lower and more restricted (<100 to 410 cm/h) (Table 7). Sampling apparatus only allowed extraction of 4 l/min from the standpipes which converted to a permeability of 530 cm/h (Terhune 1958). The permeabilities listed in Table 6 as >530 are a result of this limitation and no estimate of maximum permeability could be made. All three redds sampled and two undisturbed sites in the spawning areas hadpermeabilities greater than 530 cm/h.

A Mann-Whitney test was used to determine if a difference in median permeability values existed between samples from undisturbed sites in the spawning area and nonspawning area samples. Observed differences were not significant at the $\alpha=0.05$ level, but significance existed at the $\alpha=0.10$ level ($p=0.05997$).

Table 7. Mean values (n=3) for permeability, temperature and dissolved oxygen measurements from groundwater sampling in early October, 1984. Transects 1, 2 and 3 were in the bull trout spawning area; number 4 was below and number 5 was above it.

	Permeability ((cm/h)	Temperature (°C)	Dissolved oxygen
Transect 1			
site 1	500	4.6	8.68
site 2	120	3.7	8.03
site 3[1]	> 530	3.9	7.98
site 4	490	4.8	6.53
Transect 2[1]			
site 1	> 530	3.9	7.95
site 2	150	3.3	6.92
site 3	> 530	4.8	7.10
site 4	250	3.5	6.65
Transect 3			
site 1[1]	> 530	3.5	7.88
site 2	> 530	4.6	8.00
site 3	485	4.1	7.70
site 4	490	5.4	7.87
	range 120->530	range 3.7-5.4	range 6.53-8.68
Transect 4			
site 1	< 100	4.1	6.97
site 2	< 100	3.9	7.25
site 3	250	4.3	7.15
site 4	260	3.2	7.28
Transect 5			
site 1	310	4.1	6.28
site 2	275	4.1	6.98
site 3	340	3.8	7.35
site 4	410	4.4	7.40
	range <100-410	range 3.2-4.4	range 6.28--7.35

[1] These sites were located in the tailspill areas of natural bull trout redds.

Permeability in the spawning area was significantly greater than in nonspawning areas, even during the lowest flows observed (3 March, 1985). No significant differences were present between samples from natural redds (selected) and undisturbed (available) sites within the spawning areas.

Other researchers have examined embryo survival related to permeability. Wickett (1958) found that survival of pink and chum salmon eggs was related to permeability. McNeill and Ahnell (1964) concluded that highly productive spawning streams had high permeabilities (up to 24,000 cm/h). They considered permeability to be low at less than 300 cm/h. Reiser and Wesche (1979) found permeabilties greater than 5,100 cm/h in suitable brown trout spawning areas in the Laramie River, Wyoming. Studies conducted in the Flathead Drainage by MDFWP have related kokanee salmon embryo survival to gravel permeability (Decker-Hess and Clancey 1984).

Using 300 cm/h as an index, approximately 17% of the sites sampled in the spawning area had low permeability, while approximately 63% of those outside the spawning area would be considered low permeability. This tends to support the view that intragravel flow is an important factor in spawning area selection by bull trout.

Intragravel Water Temperature

No significant differences were observed in the comparison of intragravel water temperature in spawning versus nonspawning areas during the October sampling (Table 7). During the March sampling, interstitial water temperature of samples collected from the natural redds (($\bar{x}$=3.6 ^{o}C) was approximately 1.1 ^{o}C higher than samples from neighboring undisturbed sites ($\bar{x}$=2.5 ^{o}C) or sites outside the spawning areas ($\bar{x}$=2.5 ^{o}C).

McPhail and Murry (1979) compared Dolly Varden embryo survival to hatch in a range of water temperatures. The best success was observed at 2 and 4 ^{o}C. Optimum incubation temperature for bull trout embryos reared at the Kootenay River Trout Hatchery in British Columbia was 4-5 ^{o}C (Peter Brown-personal communication). Intragravel temperatures observed in Coal Creek during the incubation period were generally within this range (2.1-5.4 ^{o}C during October and March samplings). It appears that bull trout require cooler incubation temperatures than other salmonids.

Dissolved Oxygen

The range of interstitial dissolved oxygen observed in the spawning area during the incubation period (October and March samplings) also appeared to be suitable for successful incubation ($\bar{x}$=8.10 mg/l) (Table 7). Interstitial dissolved oxygen measurements were slightly higher at most sites during the March sampling.

Based on field experiments, Phillips and Campbell (1961) concluded intragravel oxygen concentration must average 8.0 mg/l for high survival of coho salmon and steelhead embryos. Reiser and Bjornn (1979) recommended concentrations near saturation with temporary reductions no lower than 5 mg/l for anadromous salmonids.

The July, 1985 sampling yielded the highest intragravel permeability and water temperatures observed while interstitial dissolved oxygen was generally lower than during fall and winter samplings.

Line Transects

Averages of physical habitat measurements differed slightly between 1982 and 1983 (Tables 8, 9 and 10). Mean channel width during 1983 was approximately 2.0 m greater in HS1 and HS2 and 1.0 m narrower in HS3 than measurements recorded during summer 1982. These small differences were probably due to the change in field personnel and the subjective nature of determining channel boundaries. Random site selection may have also resulted in variations in some parameters. Wetted width was approximately 1.0 m wider in each section during 1983. The difference in wetted width and average depth can be attributed to the higher discharges during the 1983 surveys; however the maximum depth and D-90 measurements reported for HS3 during the summer of 1982 were substantially greater than those recorded during 1983 (Table 10). This was most likely due to random sample site selection. A survey in spring, 1982, showed maximum depth and D-90 measurements quite similar to the 1983 survey (Shepard and Graham 1983c). The increased number of run and multiple channel habitat units observed during 1983 may also be explained by the higher discharges during surveys.

Point estimates of substrate composition showed all study sections remained relatively stable (Table 11). The difference between mean particle size percentages observed during summer of

Table 8. Comparison of mean physical habitat measurements in the Dead Horse Bridge section (HS1) of Coal Creek collected during the summer 1982 and 1983.

Habitat Unit	No.	Date	Flow (cfs)	Channel Width (m)	Wetted Width (m)	Average Depth	Maximum Depth	D-90 (cm)
Pool	5	7-30-82	76	19.7	16.4	65.8	195	21.6
Riffle	10	7-30-82	76	23.3	19.8	33.5	78	18.6
Run	9	7-30-82	76	23.6	16.9	46.0	115	23.3
Pocket water	0	7-30-82	76	--	--	--	--	--
Multiple channels	1	7-30-82	76	23.7	21.7	23.0	141	24.0
AVERAGE				22.7	18.2	44.0	195	21.1
Pool	2	7-25-83	115	22.1	22.1	80.0	160	20.0
Riffle	4	7-25-83	115	28.3	20.6	35.2	150	18.8
Run	14	7-25-83	115	22.9	16.8	42.4	100	20.1
Pocket water	0	7-25-83	115	--	--	--	--	--
Multiple channels	5	7-25-83	115	25.8	15.3	39.8	130	18.2
AVERAGE				24.3	19.5	40.2	160	19.3

Table 9. Comparison of mean physical habitat measurements in the South Fork Bridge section (HS2) of Coal Creek collected during the summer of 1982 and 1983.

Habitat Unit	No.	Date	Flow	Channel width (m)	Wetted width (m)	Average depth (cm)	Maximum depth	D-90 (cm)
Pool	2	7-29-82	39	17.7	15.6	47.0	88	23.1
Riffle	5	7-29-82	39	13.9	10.8	27.8	88	39.2
Run	9	7-29-82	39	14.9	10.8	39.3	100	39.2
Pocket water	9	7-29-82	39	11.6	10.1	31.7	85	68.2
Multiple channels	0	7-29-82	39	--	--	--	--	-
AVERAGE				13.7	10.9	34.9	100	48.6
Pool	1	7-27-83	63	12.9	12.9	58.0	90	48.0
Riffle	3	7-23-83	63	16.3	12.8	30.7	65	42.3
Run	11	7-27-83	63	14.5	9.8	35.5	100	41.4
Pocket water	7	7-27-83	63	11.4	9.5	31.8	65	43.0
Multiple channels	3	7-27-83	63	25.7	15.8	29.6	80	37.0
AVERAGE				16.2	12.2	37.1	100	42.3

Table 10. Comparison of mean physical habitat measurements in the Riparian Cut section (HS3) of Coal Creek collecteed during the summers of 1982 and 1983.

Habitat Unit	No.	Date	Flow	Channel width (m)	Wetted width (m)	Average depth (m)	Maximum depth (cm)	D-90 (cm)
Pool	4	7-29-82	39	15.1	9.7	42.5	109	50.5
Riffle	5	7-29-82	39	15.4	10.3	21.2	45	36.4
Run	8	7-29-82	39	15.2	9.0	25.6	57	43.5
Pocket water	6	7-29-82	39	12.5	9.8	25.0	51	56.3
Multiple channlels	2	7-29-82	39	15.1	10.5	18.5	54	40.0
AVERAGE				14.6	9.7	26.7	109	46.0
Pool	0	7-28-83	43	--	--	--	--	--
Riffle	11	7-28-83	43	12.9	10.9	18.3	51	31.9
Run	6	7-28-83	43	12.4	7.9	27.7	50	27.7
Pocket water	4	7-28-83	43	16.3	11.3	23.8	46	24.5
Multiple channels	4	7-28-83	43	15.0	11.2	26.5	70	23.0
AVERAGE				13.7	10.8	22.7	70	29.3

Table 11. Estimates of substrate composition, D-90 and percent imbeddedness by habitat unit in three study sections of Coal Creek during 1982 (left column) and 1983 (right column).

Habitat Unit	Number		SUBSTRATE Point Estimate (%) Organic Sand & Silt		Small Gravel		Large		Cobble		Boulder		D-90 (cm)		Imbeddedness (%)	
	1983	'82	1983	'82	1983	'82	1983	'82	1983	'82	1983	'82	1983	'82	1983	'82
Below Dead Horse Bridge (HS1)																
Pool	4	2	37	69	24	19	25	9	11	3	3	0	24	20	31	38
Riffle	2	4	7	11	19	32	38	38	36	15	0	2	26	19	12	31
Run	14	14	27	19	21	22	29	38	21	18	2	3	22	20	36	27
Pocket water	0	0	--	--	--	--	--	--	--	--	-	-	--	--	--	--
Other	5	5	15	17	24	22	35	41	25	20	1	0	24	18	32	32
Average			23	22	22	23	31	36	23	17	1	2	24	20	32	30
Above South Fork Bridge (HS2)																
Pool	3	1	26	0	23	0	16	17	22	30	13	54	--	48	29	38
Riffle	3	3	2	6	5	3	17	24	41	41	34	26	--	42	12	21
Run	12	11	5	12	6	10	15	27	44	35	30	16	--	41	19	31
Pocket water	5	7	4	4	8	6	19	26	42	34	27	30	--	43	17	42
Other	2	3	17	14	24	22	34	36	20	27	5	1	--	37	37	58
Average			9	9	11	9	19	27	37	34	24	21	--	42	19	36
Riparian Cut Area (HS3)																
Pool	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Riffle	5	11	8	10	11	14	41	40	35	34	5	2	26	32	27	33
Run	14	6	4	6	17	10	36	39	33	33	10	12	32	28	21	43
Pocket water	0	4	--	14	--	21	--	28	--	26	--	10	--	34	--	45
Other	5	4	24	15	20	19	22	33	19	24	15	8	38	23	37	60
Average			9	10	16	15	34	37	30	31	10	6	32	29	26	42

1982 and 1983 averaged 5% or less. The visual estimates of overall substrate composition during 1983 were quite similar to the mean percentages from the point estimates (Table 12). In HS1, the average difference between the two methods was less than 2% and in HS2 and HS3, average difference was approximately 5%. Shepard and Graham (1983c) reported similar results from a comparison of these methods. A 13% increase in imbeddedness was reported for HS3 between spring and summer of 1982 (Shepard and Graham 1983c). In 1983, a 15% increase over the summer 1982 figure was observed in HS2, while imbeddedness in the other two sections changed little.

Overhead cover was moderate in HS1 and HS3 and abundant in HS2. Average percentages from point estimates in 1983 generally agreed with the 1982 averages. A 14% increase in overhang less than 2m above the water's surface was recorded in 1983 in HS1. This was probably due to the higher discharge and wider wetted widths during 1983. Instream cover was moderate in HS1 and HS3 and abundant in HS2. Most instream cover was provided by submerged logs, debris and boulders. In HS3, submerged log cover increased 6% while submerged debris cover decreased by 10% from the summer 1982 survey. The decrease in submerged boulder cover in all three study sections may also be discharge related. Higher flows in 1983 made identification of deeply submerged cover more difficult. Visual estimates of total overhead cover underestimated results of the point samplings by 24%. Instream cover was underestimated by 21% when using the visual method. Shepard and Graham (1983c) reported a significant (α=0.05) difference between the two methods.

Table 12. Comparison of point and visual estimates describing substrate composition in three study sections of Coal Creek during 1983.

Habitat Survey Section	HS1 Point	HS1 Visual	HS2 Point	HS2 Visual	HS3 Point	HS3 Visual
<u>Substrate Class</u>						
Organic, Silt Sand	22	24	9	15	10	20
Small Gravel	23	24	9	16	15	19
Large Gravel	36	32	27	21	37	25
Cobble	17	17	34	29	31	30
Boulder	2	3	21	19	6	6

Debris Frequency

The number and percentage of debris by size and age class in HS1 during summer 1983 was extremely close to that observed in 1982, (Table 13). In HS2 and HS3 the number and percentage of debris in the old large and old medium classifications also remained similar to the summer 1982 surveys; however, numbers and percentages in the old small, old branches and logged branches classifications were much smaller during the 1983 surveys. We believe this was due to the consolidation of logged branches and smaller natural debris on existing jams. A single new debris jam was recorded in HS3, probably resulting from this type of accumulation on existing large and medium materials.

INSTREAM DEBRIS MONITORING

All classes of woody debris have been common in both sections since 1982. The larger debris has remained relatively stable since the initial surveys. Some movement of the medium size class was documented and substantial movement of the small branches and logged classifications has occurred. In summer 1982, the section located in the riparian sale area contained more newly recruited debris than the Dead Horse Bridge section. A large portion of this resulted from logging activity. A similar situation existed in summer 1983, although much of the small and logged debris had moved out of the section in the sale area during runoff. No major changes were observed in either section between the summers of 1983 and 1984. The 1984 spring peak flows in Coal Creek were the lowest recorded during the study. Final debris photographs were taken on July 4, 1985. By this time the majority of the small and logged debris had been moved out of

Table 13. Number and percent (in parentheses) of organic debris by type and age in the three habitat sections of Coal Creek during summer, 1982 (top) and summer, 1983 (bottom).

Area	Size	Old	New	Logged	Total
Below Dead Horse Bridge (HS1)					
	Large	90 (39)	1 (13)	0 (0)	91 (38)
		93 (42)	2 (20)	0 (0)	94 (41)
	Medium	59 (26)	2 (24)	0 (0)	61 (25)
		60 (27)	3 (30)	0 (0)	63 (27)
	Small	25 (11)	3 (37)	0 (0)	28 (12)
		19 (9)	4 (40)	0 (0)	23 (10)
	Branches	41 (18)	1 (13)	4 (100)	46 (19)
		36 (16)	1 (10)	0 (0)	37 (16)
	Jams	13 (6)	1 (13)	0 (0)	14 (6)
		12 (5)	0 (0)	0 (0)	12 (5)
	TOTAL: 1982	228 (95)	8 (3)	4 (2)	240 (100)
	1983	220 (96)	10 (4)	0 (0)	230 (100)
Above South Fork Coal Creek Bridge (HS2)					
	Large	179 (44)	0 (0)	0 (0)	179 (41)
		170 (51)	5 (29)	0 (0)	175 (49)
	Medium	103 (25)	1 (50)	0 (0)	104 (24)
		96 (29)	7 (41)	1 (12)	104 (29)
	Small	66 (16)	1 (50)	1 (4)	68 (15)
		39 (12)	1 (6)	1 (12)	41 (11)
	Branches	55(13)	0 (0)	27 (96)	82 (19)
		20 (6)	4 (24)	6 (75)	30 (8)
	Jams	7 (2)	0 (0)	0 (0)	7 (1)
		10 (3)	0 (0)	0 (0)	10 (3)
	TOTAL: 1982	410 (93)	2 (1)	28 (6)	440 (100)
	1983	335 (93)	17 (5)	8 (2)	360 (100)
Above Coal Ridge Lookout Trailhead-Riparian Cut (HS3)					
	Large	153 (34)	3 (33)	0 (0)	156 (33)
		150 (39)	0 (0)	0 (0)	150 (38)
	Medium	128 (28)	2 (22)	0 (0)	130 (27)
		118 (31)	4 (31)	0 (0)	122 (31)
	Small	100 (22)	3 (33)	0 (0)	103 (22)
		76 (20)	8 (61)	0 (0)	84 (21)
	Branches	66 (14)	0 (0)	11 (100)	77 (16)
		30 (8)	0 (0)	2 (100)	32 (8)

the riparian sale area and newly recruited debris was present in the Dead Horse section. The 1985 spring peak flows were the highest recorded during the study.

Debris photographs taken at similar discharges in late July, 1983 and early July, 1985 are presented in Appendix D, Figures 1-18. In the Dead Horse section, (Figures D1-D10) little change was evident at sites 1 and 2. The 1985 photograph of site 3 showed a newly recruited medium log on the jam. Site 4 also shows a newly recruited medium log along the right bank in 1985. Little change was evident at sites 5 and 6. Number 7 is the downstream view of the log jam shown in number 3. The new log mentioned and more smaller debris can be seen in the 1985 photograph. No major changes were observed at site 8. A new medium log was present at site 9 in 1985. This log had moved downstream approximately 15.0 m from its position in 1983, which is shown in photograph 10. During the 3 years of monitoring, most new debris in this section was supplied by natural recruitment and most movement occurred during high peak flows in spring, 1985.

The riparian sale area debris monitoring section is compared in Figures 11-18 of Appendix D. No major changes were evident between the 1983 and 1985 photographs, except for the reduced amount of smaller debris present in 1985. Photographs 4 and 6 are not available for this section from 1985.

Small debris and branches marked in the riparian sale area during summer 1983 were identified downstream in July, 1985. Distances moved ranged from several meters to 1.7km. Small debris marked in the Dead Horse section during 1983 was observed in a large log jam approximately 500m downstream in July 1985. Marking also indicated movement of medium sized debris within the Dead Horse Bridge section. Larger debris in both sections has been relatively stable since initial monitoring in 1982. It must be noted that this study's time span was probably not sufficient to adequately assess debris recruitment and movement.

The influence of woody debris on westslope cutthroat trout and juvenile bull trout densities and interactions has recently been assessed. Pratt (1984) observed that during daylight, juvenile bull trout distributed themselves along the stream bottom and sought slower velocities in association with submerged cover. Interstitial spaces in clean cobble substrate and unconsolidated debris along stream margins were the principle areas utilized. It may be possible that by increasing the percentage of submerged cover close to the substrate in pockets of slow water, bull trout rearing capacities might be increased.

Pools and deep runs formed by relatively stable, large debris and jams were principally utilized by westslope cutthroat (Pratt 1984). Artificially increasing the amount of pool area would probably have a greater influence on westslope cutthroat stocks than on juvenile bull trout populations. More work is required to determine bull trout carrying capacities in Flathead tributary rearing areas and to determine what factor(s) limit these populations.

SUBSTRATE COMPOSITION

Annual fluctuations in material smaller than 6.35 mm of up to 5.0% occurred in Big, Coal, Whale and Trail Creeks (Table 14). Two patterns of annual fluctuations were observed. Samples from Coal, Whale and Big Creeks showed increases in material smaller than 6.35mm between 1981 and 1982 (Shepard and Graham 1983c). Substrate composition remained relatively stable in these three creeks in 1983 and all showed some decline in this size material in 1984. Material smaller than 6.35 mm remained relatively stable in Trail Creek between 1981 and 1982, then increased in 1983 and again slightly in 1984. Only the increase observed in Whale Creek between 1981 and 1982 appeared to be more extreme than the annual variations observed during this short study. Small sample size in 1981 may have been responsible for a portion of that variation.

Results of the Kruskal-Wallis test showed there were significant differences in substrate composition in samples from the four creeks (α=0.05). Mann-Whitney tests have shown that since 1983, Coal Creek contained a significantly greater percentage of material smaller than 6.35mm, than the other three creeks (α=0.05).

Tappel (1981) and Shirazi and Seim (1979) found that particle size composition of spawning gravel, when plotted on log-probability paper, had size distributions close to log-normal. For the 48 samples collected in 1984 an average coefficient of determination (R^2) of 0.94 was obtained for the regression lines through the data, when material greater than

Table 14. Comparison of the annual mean percentages of material smaller than 6.35 mm and 2.00 mm from undisturbed sites in Coal, Whale, Trail and Big Creeks during 1981, 1982, 1983, and 1984.

Creek Year	n	Percent smaller than 6.35 mm	Percent smaller than 2.00 mm
Coal Creek			
1981	10	33	16
1982	19	38	17
1983	20	37	18
1984	18	33	16
Whale Creek			
1981	6	22	7
1982	8	35	15
1983	11	34	12
1984	11	28	11
Trail Creek			
1981	12	23	10
1982	16	22	10
1983	10	27	13
1984	9	28	12
Big Creek			
1981	6	22	8
1982	9	28	9
1983	11	28	11
1984	10	27	12

25.4mm was excluded from the plots. For samples close to log-normal (R^2 close to 1.0), any two points along the line can accurately describe the entire range of particle size distribution. Tappel (1981) developed a technique by which embryo survival could be related to the entire range of material less than 25.4 mm. The Controlled Channel portion of the Embryo Survival and Fry Emergence section discusses our application of this technique to bull trout.

BULL TROUT SPAWNING SITE SURVEYS

Bull trout spawning site inventories on sections of Big, Coal, Whale and Trail Creeks have been conducted annually from 1979 to 1984 (Table 15). Redd numbers observed in 1979 were the lowest recorded. This was the first year for which comparable counts were available. Annual counts increased steadily reaching a peak in 1982. The 1982 run was the strongest recorded to date and an increase in juvenile density should be observed in 1985 if seeding of available habitat was llimited by spawning prior to this run. The number of redds observed during the 1983 counts dropped from the 1982 levels but remained above the 5 year average (1979-1983). In 1984, the number of redds enumerated was slightly lower than in 1983.

Coal Creek's annual spawning run has shown similar fluctuations. The only major change was observed in 1982, when the number of redds observed in the South Fork of Coal Creek dropped from an average of 20 annually to 9 (Table 16). Since 1982, the maximum number of redds enumerated in the South Fork has been 5. Total redd counts were conducted in the Coal Creek Drainage from 1980 to 1984 (Table 16). Coal Creek ranks second

Table 15. Numbers of bull trout redds observed in the monitoring sections of four North Fork tributaries from 1979 through 1984.

Creek	1979	1980	1981	1982	1983	1984
Big	10	20	18	41	22	9
Coal	38	34	23	60	73	58
Whale	35	45	98	211	141	133
Trail	34	31	78	94	56	45
Total	117	130	217	406	292	245

Table 16. Total Number of bull trout redds observed in the Coal Creek Drainage annually from 1980 to 1984.

	1980	1981	1982	1983	1984
Coal Creek					
Above the S. Fork	4	7	20	13	3
Below the S. Fork	34	31	67	66	58
South Fork of Coal Creek	19	24	9	3	5
Mathias Creel	10	10	17	12	8
	67	72	113	94	73

to Whale Creek in the average number of bull trout redds among North Fork tributaries.

Spawning activity typically began during late August and peaked in mid to late September. The onset of spawning appeared to be linked to water temperature as spawning began when daily maximum water temperature dropped below 9.0 ^{o}C. Throughout the 1983 and 1984 spawning periods, most spawning activity occurred after dark. Several cases of redd superimposition were observed during the study. Comparison of bull trout redd frequency distributions illustrated that the same stream sections were selected annually (Shepard et al. 1982, Shepard and Graham 1983c, Weaver and White 1984).

Angling mortality on each spawning cohort was estimated to be as high as 40% under the previous two fish/day regulations (MDFWP-unpublished data). This figure was believed to be close to the maximum harvest which would still allow adequate seeding of the tributary rearing areas. In 1982 the creel limit was reduced to one fish/day but no current estimate of angling mortality is available.

FISH ABUNDANCE

Relatively large annual fluctuations in estimated westslope cutthroat and juvenile bull trout abundance were observed between 1982 and 1984 (Table 17). One prominent pattern was recorded. Estimated numbers and densities declined between 1982 and 1983, then showed an increase in 1984. This trend was observed in the Cyclone Bridge and South Fork Bridge sections.

Table 17. Comparison of fish population estimates and associated 95% confidence intervals for cutthroat and bull trout ≥75mm in total length, from the three electrofishing sections in Coal Creek during August of 1982, 1983 and 1984.

Section	Date	Flow (cfs)	Estimation Technique	$\hat{N}$	95% C.I.	$\hat{P}$	Density (#/100m2)
Cutthroat trout							
Cyclone Br.	8-10-82	75.9	Two-Pass	41	±18	.55	2.3
	8-24-83	45.9	Two-Pass	17	± 7	.64	1.1
	8-30-84	41.3	Two-Pass	25	±11	.60	1.8
Dead Horse Br.	8-5-82	58.8	M&R	12	± 9	2*	0.6
	8-23-83	41.6	M&R	56	±15	3*	2.8
	8-31-84	38.7	M&R	10	± 8	1*	0.5
South Fork Br.	8-4-82	31.2	Two-Pass	32	± 6	.74	2.5
	8-28-83	18.8	Two-Pass	23	± 2	.84	2.0
	8-29-84	16.0	Two-Pass	31	± 9	.65	2.8
Bull trout							
Cyclone Br.	8-10-82	75.9	Two-Pass	50	±43	.40	2.8
	8-24-83	45.9	Two-Pass	34	± 7	.71	2.1
	8-30-84	41.3	Two-Pass	52	±13	.63	3.4
Dead Horse Br.	8-5-82	58.8	M&R	130	±36	2*	5.9
	8-23-83	41.6	M&R	99	±33	1*	4.1
	8-31-84	38.7	M&R	89	±27	1*	4.2
South Fork Br.	8-4-82	31.2	Two-Pass	17	± 9	.60	1.3
	8-25-83	18.8	Two-Pass	18	± 3	.78	1.5
	8-29-84	16.0	Two-Pass	48	±12	.63	3.4

* These numbers are mortalities recorded between marking and recapture efforts.

A different trend was observed in the Dead Horse section, where estimated cutthroat abundance increased by 467% between the summers of 1982 and 1983. This increase was due to an experimental westslope cutthroat plant by MDFWP in September of 1982. In this experiment, over 90,000 westslope cutthroat averaging approximately 51mm total length , were planted just upstream from Dead Horse Bridge. Bull trout densities were lower in this section the summer following the plant, but as previously stated, a declining trend occurred in both other sections between 1982 and 1983. By the 1984 late summer estimates, cutthroat numbers and densities had returned to levels similar to those recorded prior to the plant. Estimated bull trout numbers in the Dead Horse section remained relatively constant between 1983 and 1984.

Pratt (1984) reported that a considerable degree of segregation was observed between westslope cutthroat and bull trout in sympatry, suggesting that bull trout densities should not be highly influenced by an increase in cutthroat. The decrease in bull trout density observed following the cutthroat plant may have been partially due to the plant; however, given the declining trend noted in the other sections and the number of cutthroat planted, increased cutthroat densities appeared to have little influence on juvenile bull trout density.

The largest natural fluctuation recorded was the increase in estimated bull trout numbers and densities in the South Fork Bridge section between 1983 and 1984 (Table 17). The progeny of the strong 1982 spawning cohort ranged from 46 to 75 mm during the 1984 late summer electrofishing, so they were not included in the population estimates. At Age II+, they will excede minimum size limitations of our gear and should show up in the 1985 late summer estimates. The small amount of data collected during this study is inadequate to assess the range of annual population variation occurring in Coal Creek and other rearing tributaries. More work is required to determine what critical factor(s) limit juvenile bull trout populations.

EMBRYO SURVIVAL AND FRY EMERGENCE

Field Study

The artificial redds were not visited until 3 March, 1985. Upon returning to the area, the lowest water level recorded at Dead Horse Bridge during the entire study (1982-present) was observed. Three of the five artificial redds were dewatered. Mortality in all 12 bags was 100%. Dead eggs were milky orange and somewhat wrinkled. Most were quite soft and easily mashed or broken. Apparently, mortality in dewatered redds resulted from freezing. A single egg bag was removed from one of the remaining wetted redds and a 74% survival rate was recorded.

Fry emergence traps were installed on the seven remaining egg bags. Emergence monitoring began on 25 April, 1985. During the sampling on 8 May, several traps had been dislodged, but were reset over the egg bags. First emergence was observed on 15 May, following a preliminary peak flow of approximately 300 cfs. Shortly after emergence began, streamflows increased to over 400 cfs and sampling was not possible. Discharge continued to increase, reaching a peak of approximately 1150 cfs on 21 May (Wally Page-personal communication). All but two emergence traps were washed out and both of the remaining traps had been torn.

The effects of high spring discharge and associated bed movement on bull trout embryo survival have not been determined. At moderately high flows bed movement could result in liberation of fry from the gravel which could be highly beneficial in the case of entombment. Extremely high flows during emergence would probably reduce survival regardless of the gravel composition.

The effects of dewatering have been better documented. Reiser and White (1981) reported incubating salmonid eggs appeared to be tolerant of long periods of dewatering, but alevins were not. Estimated alevin dewatering tolerance was less than 10 hrs. These results were from laboratory testing at air temperatures ranging from 10.0 to 17.7 ^{o}C. In a field experiment with brown trout embryos, Reiser and Wesche (1979) observed low egg survival (<1%) which they attributed to in-situ-freezing and extremely low water temperatures. Fraley and Graham (1982) documented total mortality of kokanee salmon embryos dewatered for 40 hrs at air temperatures around -12 ^{o}C. Air temperatures approaching -30 ^{o}C occurred in the Coal Creek area during December and January.

Survival and Development

The following deals with the survival and emergence work conducted in the Coal Creek during 1983-84. It should be noted that due to water temperature variations observed during groundwater sampling, the temperature units reported are approximations at best.

Adult fish were captured and spawned on 13 September, 1983. The first series of sealed egg bags was removed from the artificial redds on 24 October, 1983. Embryos had developed for

42 days and received approximately 236 temperature units to this point. Live embryos were in the eyed stage and we estimate eye-up occurred after about 35 days of incubation and 200 temperature units. Seventy-one percent survival was observed to the eyed stage (Table 18). Mortality prior to eye-up was assumed to be nonsediment related and this figure was used to determine the number of viable embryos in the emergence portion of the field study.

On 13 January, 1984, the second set of sealed bags were removed. Approximately 371 temperature units had accumulated during 123 days of incubation. Live embryos were in the alevin stage, averaging 19.3 mm in length (n=40). Hatching probably occurred around 3 January, after 113 days and 350 temperature units. Survival to hatch was 62% (Table 18).

The third series of sealed bags was excavated on 20 February. Approximately 454 temperature units had accumulated during the 161 days since planting. Alevins averaged 23.6 mm in length (n=40) and survival to this point was 64% (Table 18).

On 6 March, the remaining sealed bags were removed from artificial redd numbers six and eight. Mean survival was 60% (Table 18). Alevins averaged 26.6 mm in length (n=20) after approximately 497 temperature units and 177 days of incubation.

Since the timing and duration of the bull trout fry emergence period was not known at this time, the two remaining sealed bags were used as indicators for the proper timing of emergence trap removal. The final sealed bag in artificial redd number five was excavated on 2 April, after 215 days and approximately 570 temperature units (Table 18). Alevins averaged 26.8 mm in length (n=30) with 79% survival and yolk-sacs were nearly absorbed. On 13 May, the last sealed egg bag was removed from artificial redd number seven; survival to hatch was 68%, but five alevins examined had died prior to egg bag removal. Approximately 710 temperature units had accumulated during the 256 days since planting (Table 18).

Fry Emergence

Fry emergence was first observed on 23 April, 1984. During the 3 preceeding days, high discharge prevented emergence trap sampling and bed movement was observed. Most emergence (83%) was recorded in a 4 day period during the declining limb of the preliminary spring peak flow (23-27 April). Approximately 634 temperature units had accumulated during the 223 day incubation period. Three hundred-fifteen fry, with an average length of 27.2 mm (n=50), were captured during the first day of sampling. Over half of these emergent fry were dead, indicating that emergence probably began while flows were too high for sampling.

On 23 April, 1984, emergence traps which had been dislodged by high flow were removed along with the associated egg bags. Live alevins were still present in two of three bags (Table 19) and averaged 27.1 mm in length (n=16). Core samples from the exact location of each bag were collected immediately following bag removal. All remaining emergence traps were anchored to the substrate with rebar. By 18 May, emergence had slowed to less than 10 fry per week and since annual peak flows during past years had occurred in late May, we removed seven of the remaining emergence traps, excavated egg bags and collected substrate

Table 18. Bull trout embryo survival and development from sealed egg bags in the artificial redds in Coal Creek during the 1983-1984 period.

Sampling Date	Redd Number	Egg Bag Results # and % Live	# and % Dead	Total Recovered	Stream T.U.	Days
	5	80	20	100		
10-24-83	6	90	10	100	236	42
	7	56	44	100		
	8	57	43	100		
MEAN		71	29			
	5	91	5	96		
	6	80	14	94	371	123
1-13-84	7	35	56	91		
	8	42	52	94		
MEAN		62	32			
	5	80	5	85		
2-20-84	6	64	31	95	454	161
	7	54	36	90		
	8	58	35	93		
MEAN		64	27			
4-2-84	5	79	18	97	570	215
3-6-84	6	72	20	92	497	177
5-13-84	7	68	15	83	710	256
3-6-84	8	48	47	95	497	177

samples. During this sampling, 88 live and 46 dead alevins were observed in the egg bags (Table 19). The remaining six traps were monitored until 28 May when four were removed. Flows had remained fairly stable during this 10 day period and only two fry had emerged. Egg bags contained 13 live and 24 dead alevins (Table 19). The remaining two traps were monitored until 18, June but no emergence was observed. Upon excavation, 27 partially decomposed alevins were enumerated, showing that entombment, crushing or both may have occurred.

Adjusted emergence success during spring of 1984 was 53% (Table 19). It appeared that approximately 25% of the mortality occurred prior to "eye-up". The cause of this mortality could have been due to artificial spawning and handling, low fertilization success or incubation conditions in the gravel. A combination of these factors is the most likely explanation. Another substantial portion of the pre-emergence mortality in the artificial redds appeared to be from entombment, which may have been responsible for 10-15% of the mortality observed.

In gravels containing high levels of fine sediment, most researchers cited by Cordone and Kelly (1961), Gibbons and Salo (1973), and Iwamoto et al. (1978) attributed low emergence success to decreased gravel permeability or entombment of alevins. Groundwater sampling indicated permeability in the Dead Horse Bridge area may partially mitigate the effects of the high percentage of fine material.

When comparing emergence success with percentages of material less than 6.35 mm, an inverse relationship was evident

Table 19. Numbers of emergent fry and live and dead embryos observed in excavated egg bags from the artificial redds in Coal Creek during Spring of 1984.

Artificial Redd Number	Egg Bag Number	Number Emerged	Egg Bag Results: Live Alevins	Dead Alevins	Dead Eggs	Total
1	1[d]	73	0	5	9	87
	2[d]	16	0	22	31	69
	3[c]	27	4	11	19	61
	4[c]	10	4	6	39	59
2	1[c]	64	1	3	21	89
	2[c]	35	4	4	25	68
	3[a]	42	19	0	11	72
	4[a]	31	2	0	29	62
3	1[b]	20	20	6	26	72
	2[b]	57	1	7	13	78
	3[a]	53	0	0	24	77
	4[b]	54	2	1	22	79
4	1[b]	77	0	0	7	74
	2[b]	5	24	10	19	58
	3[b]	12	36	14	26	88
	4[b]	22	0	1	68	91
		598	117	90	389	1194
Adjusted Survival (%)		53				

a Removed on 23 April, 1984
b Removed on 18 May, 1984
c Removed on 28 May, 1984
d Removed on 18 June, 1984

(Figure 13). Linear regression analysis revealed that over 87% of the variability in embryo survival to emergence was correlated with this sized material. Salmonid embryo survival has been negatively correlated with fine sediment by other researchers. McNeill and Ahnell (1964) found pink salmon fry emergence was inversely related to the percentage of substrate smaller than 0.83 mm. Tagart (1976) reported survival to emergence of coho salmon in natural redds decreased when more than 20% of the substrate was smaller than 0.85 mm. Koski (1966) found that coho salmon embryo survival was best in low percentages of material smaller than 3.3 mm. In laboratory tests, Hall and Lantz (1969) reported an inverse relationship between material smaller than 3.5 mm and coho and steelhead fry emergence. Bjornn (1969) showed that emergence of chinook salmon and steelhead trout was impeded when more than 20% of the spawning gravel was smaller than 6.35 mm. Tappel (1981) conducted laboratory tests which revealed that over 90% of the variability in chinook salmon and steelhead trout embryo survival to emergence was correlated with changes in substrate size composition.

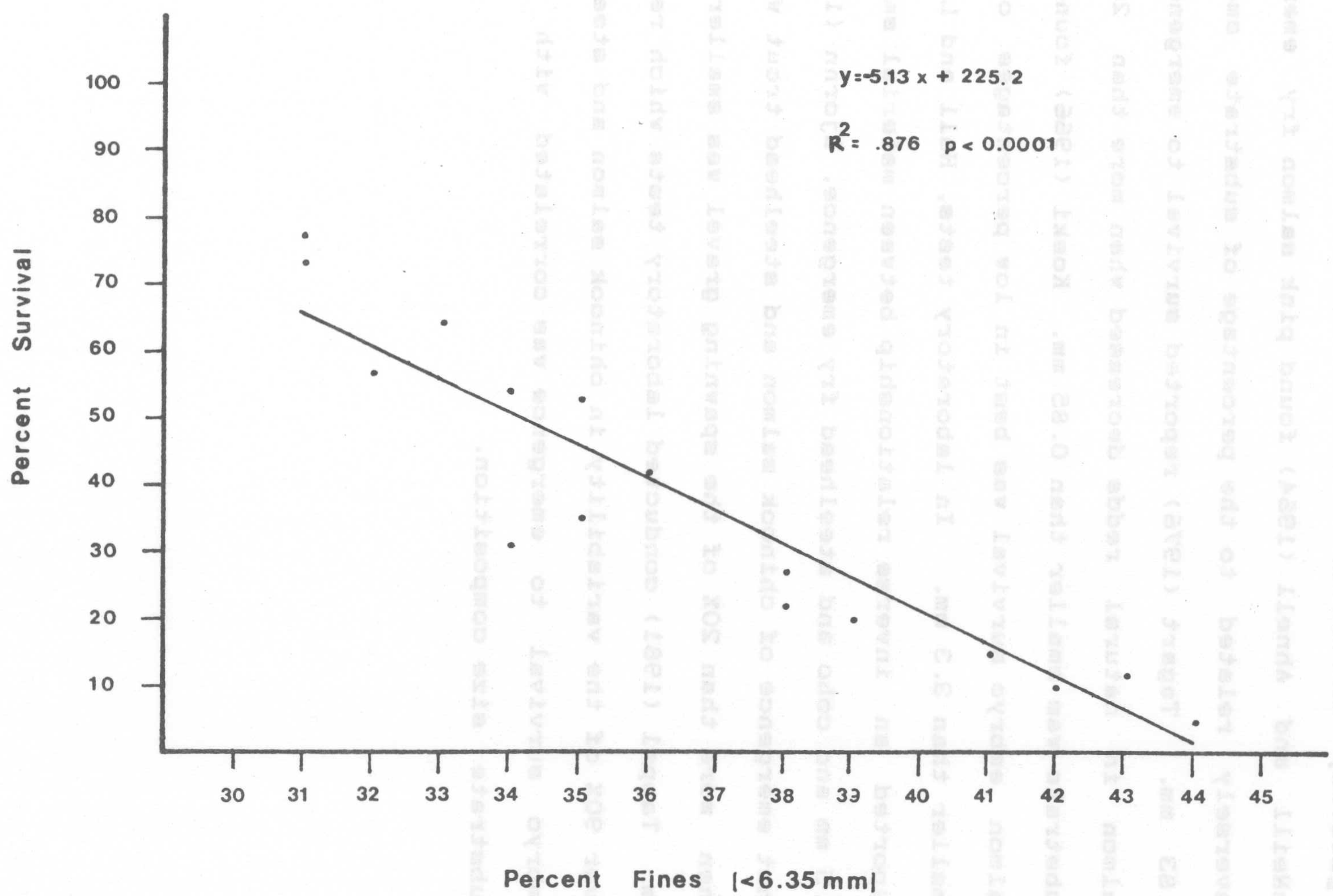

Figure 13. Relationship between bull trout survival to emergence and the percentage of substrate smaller than 6.35mm in diameter from artificial redds in Coal Creek during the 1983-84 field study.

CONTROLLED CHANNELS

Development Monitoring

During the 1983-84 test, eyed eggs were first observed in the Heath incubator on 1 November. Eye up had occurred sometime earlier but was not documented. The embryos had received approximately 335 temperature units during 42 days of incubation at this point. Fifty percent hatch occurred on 21 November, 62 days and 500 temperture units after fertilization (Table 20). The first emergent fry were observed on 1 January, 1984. Approximately 825 temperature units had accumulated during 103 days of incubation (Table 20). Most emergence occurred during the first 15 days of January, but was not complete until 1 March, 1984. No apparent difference in emergence timing was observed between gravel mixtures.

During the 1984-85 test, eyeup was first observed on 18 November, 230 temperture units and 37 days after fertilization (Table 20). Hatching began on 18 December and 50% hatch occurred on 24 December, after 73 days and 440 temperature units of incubation. Hatching was complete by 3 January, 1985. Fry emergence from the gravel filled incubation chambers was first observed on 22 January, after 107 days and 660 temperature units (Table 20). The majority of emergence occurred between 5 and 15 February and was complete by 1 April, 1985.

During the 1983-84 lab test, water temperature remained at approximately 8.0 ^{o}C throughout the developmental period. Temperature fluctuated between 4.0 and 8.0 ^{o}C during the 1984-85 lab test and a daily mean of 6.2 ^{o}C was recorded during the

Table 20. Number of days and Celsius temperature units required for bull trout embryos to reach prominent developmental stages in laboratory and field studies during 1983-84 and 1984-85.

Year Test site	Developmental stage eye up	50% hatch	emergence
1983-84 Laboratory	-- --	62 days 500 T.U.	103 days 825 T.U.
1984-85 Laboratory	37 days 235 T.U.	73 days 440 T.U.	107 days 660 T.U.
1983-84 Coal Creek [1]	35 days 200 T.U.	113 days 340 T.U.	223 days 635 T.U.
1984-85 Coal Creek	-- --	-- --	219 days --

[1] Temperature units in Coal Creek were calculated from surface flow in the stream channel and may not be indicative of intragravel water temperature.

incubation period prior to 50% hatch. In Coal Creek, water temperature between fertilizaton and 50% hatch ranged from 0 to 7.2 °C with a daily mean of 3.1 °C. Temperature units for Coal Creek were obtained from surface flow in the stream channel (Table 20). Considering the variation in intragravel water temperature observed during groundwater sampling, temperarture units from this test should be considered approximate.

Increasingly cooler water temperatures resulted in longer incubation periods; however, the number of temperature units required to attain each developmental stage was increasingly fewer as water temperature dropped. Developmental samples collected during the 1984-85 lab test are being photographed and described in detail by MCFRU personnel (Dr. William Gould - personal communication).

<u>Nonsediment Related Mortality</u>

Eggs maintained in the Heath incubator during both years of lab testing were used to quantify nonsediment related mortality in each egg lot. In the 1983-84 test, 70% survival to eye up was observed in lot number 1 and 86% survival to eyeup was recorded for lot 2.

On the initial day of the 1984-85 test (12 October), approximately 12h after fertilization, all recognizable dead eggs were removed from the Heath tray and recorded by lot (Table 21). The eggs were checked but not disturbed through the fragile period preceding eyeup. Once eyeup had occurred (18 November) dead eggs were periodically removed and enumerated. After the initial removal, mortality remained low until the

Table 21. Quantification and timing of bull trout embryo mortality in the Heath incubator during the 1984-85 incubation study.

Date	Number of dead eggs removed			
	Lot 1	Lot 2	Lot 3	Lot 4
10-12	28	36	48	69
11-12	13	7	12	2
11-25	9	11	16	12
11-26	3	2	1	1
11-27	0	0	2	2
11-30	8	5	4	7
12-3	9	5	6	6
12-4	1	1	2	6
12-5	7	4	1	3
12-6	1	3	3	5
12-10	15	24	14	17
12-11	8	14	11	10
12-15	34	66	36	58
12-18	19	44	53	39
12-19	11	8	5	10
12-27	24	43	40	56
1-20	19	13	31	38
1-27	52	42	20	35
	261	328	305	376
Number hatched	523	574	579	575
Total	784	902	884	951
%Survival	66.7	63.6	65.5	60.5

embryos approached hatching. An increase in mortality was observed between 10 December and completion of hatching (3 January). Survival to hatch was 67, 64, 66 and 60% in lots 1 through 4, respectively (Table 21). These percentages were used as survival coefficients and applied to the incubation chambers to estimate the number of viable embryos in each. Of the 200 eggs planted in each incubation chamber, 133, 127, 131 and 121 emergent fry were predicted from chambers stocked from lots 1 through 4, respectively.

On 18 December, a pair of egg bags were excavated from two randomly selected replicates of each gravel mixture. Results of this sampling confirmed that development and survival rates of embryos in the gravel were similar to those observed in the Heath incubator (Table 22).

Survival To Emergence

During the 1983-84 test, average emergence success ranged from 0% in the 50:20 mixture to 48% in the 10:4 mixture but variability between replicates of each mixture was large. (Table 23). A shortage of the 0:0 gravel mixture allowed only three replicates of this mixture. Although survival in the 0:0 mixture was expected to be highest among the mixtures tested, one chamber apparently malfunctioned resulting in only 37% emergence success. When this low value was omitted, average survival to emergence from the remaining two replicates of the 0:0 mixture was approximately 50%. Due to inconsistent results between replicates of several gravel mixtures, the 1983-84 data were not included in development of the survival equation.

Table 22. Survival coefficient of each egg lot developed from the Heath incubator compared to the adjusted survival in egg bags planted in the incubation chambers. Twe Egg bags were excavated from two replicates of each gravel mixture on 18 December 1984.

	Egg bag results			
Lot number	Observed survival (%)	Fungus mortality (%) [1/]	Adjusted survival (%) [2/]	Survival coefficient
1	56	7	63	.67
2	41	25	66	.64
3	40	20	60	.66
4	48	16	64	.60

1/ This mortality resulted from excessive contact of groups of eggs. Fungal growth on dead eggs spread to live embryos nearby forming clumps linked by fungal hyphae.

2/ Observed survival plus fungus mortality.

Table 23. Bull trout fry emergence success from six gravel mixtures during the 1983-84 incubation test.

Gravel mixture	Channel number	Egg lot number		Number Emerged	Emergence Success (%)
0:0	1	2		68	40
	21	2		91	53
	22	2		37	22
			Total	196	$\bar{X}$% (38)
0:4	8	2		100	58
	13	2		99	58
	15	2		73	42
	24	2		58	34
			Total	330	$\bar{X}$% (48)
20:8	4	1		68	49
	11	1		42	30
	14	1		83	59
	19	1		21	15
			Total	214	$\bar{X}$% (38)
30:12	7	1		29	21
	10	1		50	36
	12	1		17	12
	23	1		21	15
			Total	117	$\bar{X}$% (21)
40:16	2	1		2	1
	5	1		1	1
	16	1		3	2
	18	1		0	0
			Total	6	$\bar{X}$% (1)
50:20	3	1		0	0
	6	1		0	0
	19	1		0	0
	17	1		0	0
			Total	0	$\bar{X}$% (0)

Average survival to emergence during the 1984-85 test ranged from <1.0% in the 50:20 mixture to 90% in the 0:0 mixture (Table 24). As the amount of fine material increased, embryo survival decreased. Emergence success was correlated with the percentage of material smaller than 9.52 mm ($S_{9.52}$) and the percentage less than 0.85 mm ($S_{.85}$). Second-order terms [$(S_{9.52})^2$, $(S_{.85})^2$] and a cross-product term [$(S_{9.52})(S_{.85})$] were included as variables in the multiple regression analysis. The best equation relating bull trout embryo survival to emergence and gravel size composition was:

$$Y = 91.80 - 2.713(S_{9.52}) + 0.1170[(S_{9.52})(S_{.85})$$

This equation had an R^2 value of 0.93. The pattern of survival values produced by this equation showed that embryo survival was most strongly affected by materal smaller than 9.52 mm. The linear relationship between this size class and survival to emergence explained over 83% of the variation observed during the 1984-85 lab test. Linear relationships between material smaller than 9.52 mm and bull trout survival to emergence in both lab and field tests are compared in Figure 14.

Survival predictions generated by equations developed in the laboratory may be inaccurate when applied to field conditions for the following reasons. The ability of salmonids to change the size composition of the incubation site during redd construction was impossible to duplicate. The effects of groundwater upwelling and bedload movement prior to or during the emergence period could not be simulated in laboratory tests. The natural

Table 24. Bull trout fry emergence success from six gravel mixtures during the 1984-85 incubation test.

Gravel mixture	Channel number	Egg lot number	Number Emerged	Emergence success (%)
0:0	3	1	98	74
	8	2	59	92
	10	3	120	92
	20	4	64	100
		Total	341	$\bar{X}$% 90
10:4	6	1	33	49
	13	2	82	65
	15	3	57	44
	19	4	27	44
		Total	199	$\bar{X}$% 50
20:8	1	1	28	42
	12	2	32	25
	14	3	13	20
	22	4	31	26
		Total	104	$\bar{X}$% 28
30:12	5	1	13	19
	9	2	3	5
	18	3	5	4
	21	4	5	4
		Total	26	$\bar{X}$% 8
40:16	4	1	0	0
	11	2	2	3
	17	3	0	0
	24	4	1	1
		Total	3	$\bar{X}$% 1
50:20	2	1	0	0
	7	2	1	1
	16	3	1	2
	23	4	0	0
		Total	2	$\bar{X}$% .75

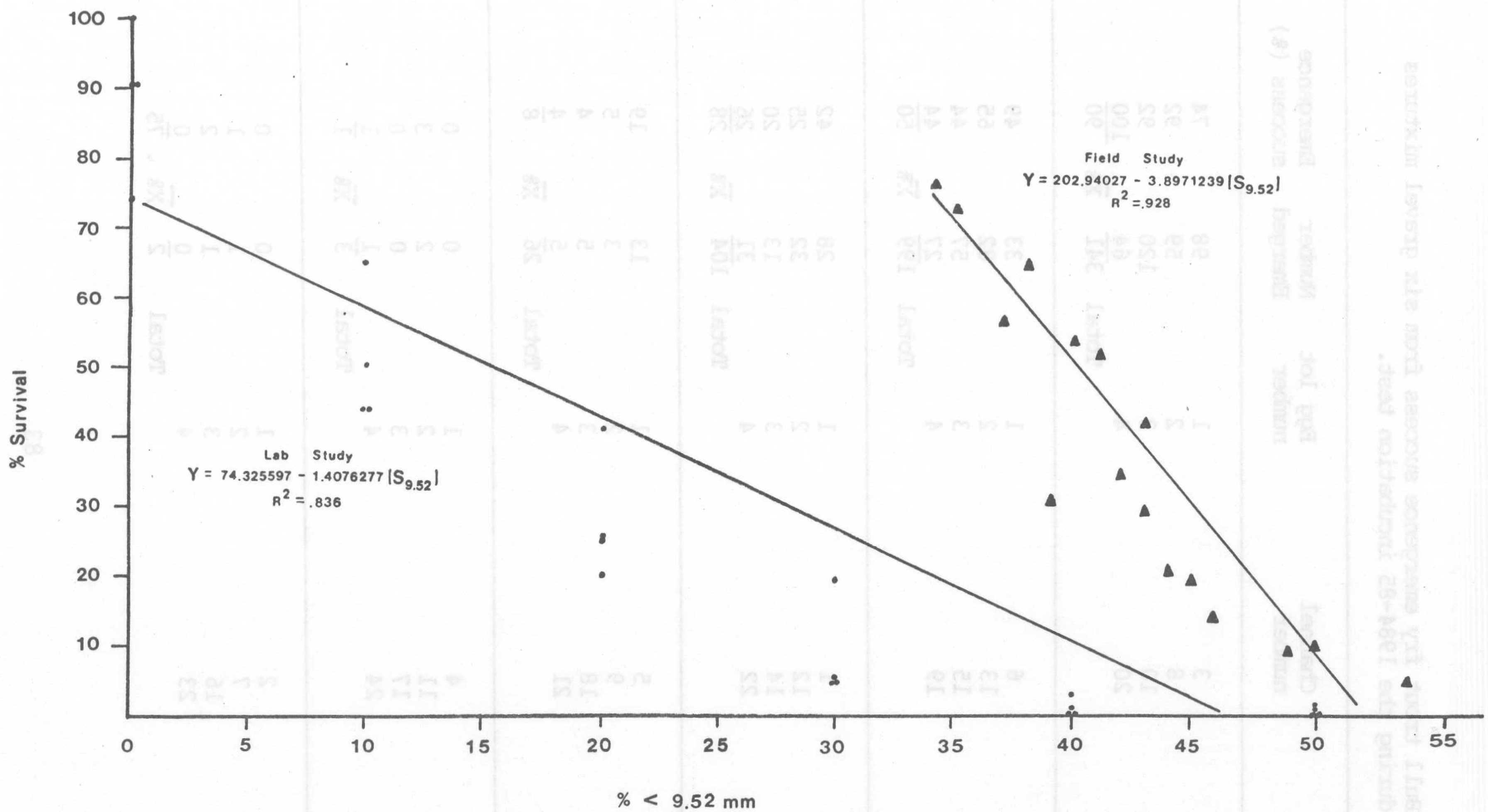

Figure 14. Relationships between bull trout survival to emergence and the percentage of substrate smaller than 9.52mm in diameter from the 1983-84 field study in Coal Creek(▲) and lab testing at the Bozeman Fish Technology Center (•) during 1984-85.

thermal regime resulted in an incubation period over 110 days longer than observed during lab tests.

Although bull trout embryo survival in streams may not exactly parallel predictions, these equations should provide an index of relative changes in survival. The relationship developed between bull trout embryo survival and gravel size composition could be used in combination with sediment models to predict the effects of future activities on embryo survival.

Fry Quality

The range of emergent fry lengths and weights varied little between the six gravel mixtures (Table 25). The smallest fry averaged 3.0 mm and 40 mg smaller than the largest. No statistically significant differences in fry length were observed ($\alpha = 0.05$), but fry emerging from the 30:12 chambers weighed significantly less than all other emergent fry ($\alpha = 0.05$). Fry emerging from the 40:16 and 50:20 mixtures were not included in this analysis due to the insufficient number available.

Phillips et al. (1975) found that coho salmon fry emerging from gravels with high percentages of sand were smaller than those from gravels with low percentages of sand. Steelhead fry size was similar in all gravel mixtures during the same test (Phillips et al. 1975). Koski (1975) reported that chum salmon fry from gravels with high percentages of sand were up to 3.0 mm shorter than those from gravels with lower sand content; however, the relationship was inconsistent. Tappel (1981) reported steelhead fry lengths were not statistically different between gravel mixtures, but a general trend of smaller fry in gravels with higher percentages of fine material was observed. Steelhead

Table 25. Average lengths and weights of bull trout fry after emergence from experimental gravel mixtures.

Gravel mixture	n	Length (mm) (Range)	Weight (mm) (Range)
0:0	50	26.5 (26-27)	126 109-139
10:4	50	26.6 (25-28)	119 (104-134)
20:8	50	26.4 (25-28)	118 (99-137)
30:12	23	25.9 (25-27)	112 (99-124)
40:16	2	25.5 (25-26)	102 (97-108)
50:20	---	---	---

fry from the gravel mixture with the highest percentage of fine material weighed significantly less than all others. No significant relationships were observed between chinook salmon fry and gravel size composition (Tappel 1981).

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Timing and intensity of annual peak flows may influence bull trout fry emergence and survival.
2. Favorable incubation conditions (permeability, dissolved oxygen and water temperature) appeared to be present in the Dead Horse Bridge spawning area.
3. Habitat assessments could detect any major change in the aquatic environment of Coal Creek.
4. Large debris was relatively stable while spring flows may move or consolidate smaller debris.
5. Coal Creek contained a significantly higher percentage of fine material than Big, White, or Trail Creek.
6. The 1984 bull trout spawning run was approximately equal to the 5 year average (1979-1983), but was smaller than the previous 2 years.
7. The relationship between embryo survival to emergence and gravel composition was best described by the percentage of material smaller than 9.52 mm.
8. The incubation environment in Coal Creek may not be adequately simulated by laboratory conditions.

RECOMMENDATIONS

1. Continue monitoring the fishery in Coal Creek on an annual basis using established methodologies and sample sites.
    a. conduct fish abundance estimates.
    b. collect and sieve analyze spawning area substrate samples.
    c. conduct spawning site inventories.
2. Any future habitat assessment or substrate scoring should be conducted across semi-permanent transects to allow better comparison of annual changes. Each transect should also be photodocumented.
3. Use the simple linear equation developed during the laboratory testing to predict survival to emergence based on core samples collected in known bull trout spawning areas:

    $$\% \text{ survival} = 74.325597 - 1.4076277\ (S_{9.52}).$$

    Confirm survival equation in the natural incubation environment using the field study procedures.
4. Determine the effects of variations in annual peak flow timing and intensity on bull trout fry emergence and survival.
5. Evaluate the various mechanisms which may potentially regulate juvenile bull trout populations in order to determine if carrying capacities may be increased.

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