

MONITORING THE IMPACTS
AND PERSISTENCE OF FINE
SEDIMENT IN THE
PRAIRIE CREEK WATERSHED

1990-1992

WY90-WY91
19 19

FINAL REPORT

for

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EXECUTIVE SUMMARY

The impacts and persistence of fine material deposited in Prairie Creek during an October, 1989, storm that came off a highway construction alignment were studied for three years. The first year's results are documented in Redwood National Park (1991). The second two years are documented in this report, and conclusions were drawn from all three years of data.

Precipitation, water and sediment discharge, and streambed mobility were monitored to determine persistence of fines. Salmon egg survival and factors affecting survival were studied to determine impacts to the fishery from the bypass-derived sediment. In Water Year 1991 (WY91=winter 1990-1991), results were compared between the impacted reach and a much less impacted reach (control) on Prairie Creek above Brown Creek. Lost Man Creek was used as a second control reach only when fry emergence from natural redds was compared. In WY92, both reaches were used as controls in the egg survival studies.

1. Hydrologic season: Rainfall was low both years. Total rainfall during the period October 1 through July 1 was 54.6 inches, or 81% of normal in WY91. It was 44 inches, 66% of normal in WY92. All rainfall intensities were below a 2-year recurrence interval.

Maximum flows of the WY91 and WY92 seasons occurred January 12-15, 1991 and April 17, 1992, respectively. Peak flows were small, well below the 2-year recurrence interval for all gaging stations on Prairie and Brown Creeks.

2. Suspended sediment: Total suspended sediment per square mile measured in Prairie Creek and one of its impacted tributaries, Brown Creek, showed that Prairie Creek below Brown Creek transported twice as much sediment (per unit drainage area) than above Brown. A site several miles farther downstream transported more than three times as much. Total suspended sediment loads in WY91 were higher than WY92; both years had lower loads in the impacted reaches than WY90. Sediment transport decreased in Brown Creek each year from WY90 to WY92, indicating the bulk of the bypass-derived sediment still resided in the impacted tributaries, even when the October 1989 storm was excluded.

3. Subsurface fine sediment: Similar to WY90, insignificant streambed scour occurred during WY91 and WY92. Fine sediment in subsurface storage in Prairie Creek and Brown Creek channels was not flushed out to any significant extent over the winter periods. The source for suspended sediment was probably from local mobilization of surface deposits and new erosion.

Infiltration of subsurface fines into cleaned gravels in Brown Creek was similar in WY90 and WY91, but slightly lower in WY92 because peak stream flows were lower. Brown Creek had infiltration rates almost twice that of Prairie Creek. Total suspended sediment loads were higher in WY90 than WY91 in the impacted, but not the control reach.

4. Salmon egg survival: Egg survival rate in Prairie Creek artificial redds was very low in WY91 (6.5% in the impacted reach, 15.9% in the control reach), but higher in WY92 (43.5% in the impacted reach, 32.2% in the control reach). Survival rates were probably lowest in WY91 because the eggs were exposed to larger storms, more fine sediment, and more worms. Eggs exposed to the largest storm of the year in the impacted reach in WY91 had less than 1% survival, compared to 9% in the control reach. The low survival rates in the control reach that year might have been from worm infestations.

Most mortality was in the egg stage. Fry that hatched in Prairie Creek were able to successfully emerge.

Lost Man Creek produced more salmonid fry from natural redds than the impacted reach of Prairie Creek. In WY91, only 3 of 10 redds trapped on Prairie Creek produced at least one fry, (including the 3 on the Prairie Creek control reach which produced none). All 3 redds trapped on Lost Man Creek produced fry. In WY92, all 3 redds in the control reach of Prairie Creek produced fry, 5 of 9 produced fry in Lost Man Creek, and only 2 of 7 produced fry in the impacted reach.

Both years, over 90% of all spawning on Prairie Creek took place in the impacted reach below Brown Creek, and most of that (about 70%) occurred below Boyes Creek. In WY91, only 1 of 11 artificial or natural redds in the reach below Boyes Creek had greater than 0% egg survival, indicating reproductive success for salmon was probably very low that year. In WY92, reproductive success appeared to improve, but was still moderately low, particularly below Boyes Creek (30% egg survival).

5. Fine sediment and permeability in redds: In both years, weight of fine sediment infiltrating into artificial redds over the incubation period did not significantly differ between the impacted and control reaches. In WY91, it averaged 2.4% for < 1 mm in the affected reach (12.5% by volume) and 1.2% in the control reach (12.1% by volume). In WY92, it averaged 0.9% (9.0% by volume) in the affected reach and 1.8% (12.2% by volume) in the controls. However, when local variations in gravel framework were accounted for, fine sediment levels averaged higher in the affected reach in WY91, but not in WY92. Geometric mean of the gravel framework (excluding fines) and sediment flux were good predictors of fines infiltration rates in WY91. The gravel framework was the best predictor of fines infiltration in WY92.

In most redds in the impacted reach, permeability in the gravel immediately surrounding the eggs (egg pocket) decreased over the incubation period. In WY91 average permeability did not change significantly in the control reach. In WY92 the permeability decreased in the control reach at a similar rate as the affected reach, but final inflow rates in both reaches were generally much higher in WY92 than WY91.

The higher final permeability rates and lower amount of fines in WY92 may partially account for the higher egg survival rates for that year. In WY91, particularly in the impacted reach,

egg survival was partially correlated to amount of fine sediment and gravel permeability in the redd. The correlations were minimal in WY92, which was probably because the values for these variables did not reach adverse levels. Both years, suspended sediment flux rates accounted for about 40% of the variance in egg survival. In addition large amounts of worms in the egg pocket of the redd appeared to reduce egg survival. In WY91, these worms were common (62% infestation rate) and increased their distribution in the redds greatly in Prairie Creek over the previous year. In WY92, the worms almost completely disappeared from the redds again (3% infestation rate), and survival was much higher. The higher fines levels in redds of WY91 may have contributed to the greater worm abundance found that year.

Strong spatial trends were observed in percent fines infiltration, which indicated that infiltration of fines was highest immediately downstream of impacted tributaries.

Conclusions:

Persistence of Fines: Following the October 1989 storm, a January 1990 storm flushed some surface fine sediment from the system. During the next year, less surface sediment was flushed from the system than the year before. During the third year, flows were lower and even less surface sediment was flushed from the system. Fine sediment deposited in the subsurface gravels remained in the system all three years. The fine sediment is expected to persist until the present drought ends.

Impacts of Bypass Sediment: Results suggest that salmonids that spawned the first winter in the affected Prairie Creek reach just after the January 1990 storm had good reproductive success because little bypass sediment infiltrated into the redds. Fish that spawned just before this storm may have had lower success. The following year, fine sediment, some of which was bypass-derived, infiltrated the redds mostly in January and March, and aquatic worms became abundant in these redds. The worms even infested redds in stream reaches having low levels of bypass sediment. As a result of the detrimental effects of the worms and sediment, salmonids that spawned in Prairie Creek in WY91 had very poor reproductive success. The third year, storms were smaller and moved less sediment into the redds, worms were practically non-existent in the redds and reproductive success improved, but was still moderate to low. Poorest success was below Boyes Creek confluence, where fine sediment levels were highest. Pre-October storm data indicated this reach once had similar levels of fines in riffles as other upstream reaches on Prairie Creek, which suggests the storm was responsible for the increase in fines and low egg survival. Without more pre-October 1989 storm data for comparison, the amount of infiltrating fine sediment derived from the bypass versus natural sources could not be determined. However, the severity of the low egg survival in WY91 is suggestive that the bypass was at least partially responsible.

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance statistical test
BO	Boyes Ck Gaging Station
BT	Big Tree Ck Gaging Station
cm	centimeters
CDFG	California Department of Fish & Game
cfs	cubic feet per second
DO	Dissolved Oxygen
FEIS	Final Environmental Impact Statement
ft	feet
g	grams
hr	hours
K-W	Kruskal-Wallis statistical test
L	liters
LB	Lower Brown Ck Gaging Station
mi	miles
min	minutes
mg/l	milligrams per liter
m	meters
mm	millimeters
NRWQCB	Northcoast Regional Water Quality Control Board
P	the probability that a difference or correlation is due to random chance
PABR	Prairie Creek above Brown Creek
PABY	Prairie Creek above Boyes Creek
PAMY	Prairie Creek above May Creek
PBBR	Prairie Creek below Brown Creek
PBBT	Prairie Creek below Big Tree Creek
PBBY	Prairie Creek below Boyes Creek
PCFFA	Pacific Coast Federation of Fisherman Association
PL	Gaging Station on Prairie Ck below Brown Ck
PU	Gaging Station on Prairie Ck above Brown Ck
PW	Gaging Station on Prairie Ck above the Wolf Ck Bridge
ppm	parts per million
PSW	U.S. Forest Service Pacific Southwest Forest and Range Experiment Station, Arcata, California
Q	discharge
r	correlation coefficient
r ²	coefficient of determination
RI	recurrence interval
RNP	Redwood National Park
SE	standard error
t	tons
UB	Upper Brown Ck Gaging Station

WY
yr

Water Year
year

I. INTRODUCTION

A. Background

Construction of the U.S. Highway 101 Bypass project through the eastern boundary of Prairie Creek Redwoods State Park and portions of Redwood National Park (RNP) has been in progress since 1984. The highway right-of-way traverses the headwaters of several small tributaries to Prairie Creek (Figure 1). In October, 1989, a relatively small rainfall event generated numerous mudflows on the long, steep fillslopes that drain into the tributaries. Several hundred tons of sediment eroded from the project and flowed into the Prairie Creek stream system. In anticipation of damage to fish and other aquatic resources, the California Department of Transportation (Caltrans) proposed monitoring to study the impacts and persistence of this fine sediment. This project, which was funded by Caltrans and implemented by RNP and the U.S. Forest Service Pacific Southwest Range and Experiment Station (PSW), was designed to monitor the following for the first year:

1. Rainfall, streamflow, and suspended sediment discharge;
2. Sediment transport and surface and subsurface deposition of fines;
3. Spawning activity and percent fines, permeability, dissolved oxygen and salmonid egg survival in redds; and
4. Benthic macroinvertebrate abundance and diversity.

Monitoring began during the 1989-90 winter. Results from the first year were reported in RNP (1991). Briefly, results indicated much of the fine sediment that eroded off the highway bypass project and settled on the surface and in the subsurface of the tributary and mainstem streambeds was not remobilized by the end of the first winter. The egg survival study indicated that steelhead trout (*Oncorhynchus mykiss*) probably successfully spawned and produced sac-fry during the study period in 1991. However, 1990 rainfall was only 67% of normal, and flows during the study period (February-April) were insufficient for mobilizing and depositing sediment into the cleaned artificial redds. Thus, redds remained clean, and most steelhead eggs survived to hatch. The study only covered the eyed egg-to-hatching portion of a steelhead's life cycle. Therefore, we suspected that if rainfall had been closer to normal, and if survival using fertilized eggs to emergence had been studied, survival might have been less successful. Furthermore, other species such as coho salmon (*O. kisutch*) and chinook salmon (*O. tshawytscha*) spawn earlier in the winter, so accumulations of fine sediment in their redds could have been much greater and could have more strongly impacted hatching and survival.

To predict the future of salmon runs on Prairie Creek and to determine the nature and duration of mitigation needed to compensate for impacts (such as artificially sustaining fish production), we needed more information. Rather than measuring physical variables and egg survival separately as we did in the first year, we designed this study to measure them together in the same redd. We also selected a different species--coho salmon--which we expected to be more sensitive to sedimentation due to the earlier timing of its spawning runs.

Survival of fertilized eggs to emergence as well as to hatching was evaluated. Additionally, in hopes of recording the effects of a more normal rainfall year, we continued to monitor sediment transport to help determine the persistence of the fine material.

B. Study Objectives

The overall objectives of this study were as follows:

1. To determine persistence of fine sediment derived from the U.S. Highway 101 Bypass Project in Brown and Prairie Creeks.
2. To determine how sediment inputs from the project affect coho salmon egg survival in Prairie Creek.

Specific objectives of the persistence of fine sediment study were as follows:

1. To determine precipitation, water discharge, and sediment discharge in order to formulate a sediment balance for Prairie and Brown Creeks.
2. To determine frequency and degree of streambed scour, and to quantify the rate at which fine sediment is flushed from a stream.

Specific objectives of the egg survival study were as follows:

1. To determine survival of coho salmon from fertilized egg to the hatching stage in artificial redds on impacted vs. unimpacted reaches of Prairie Creek.
2. To determine timing and survival of fertilized eggs to the emergence stage for coho salmon in artificial redds on impacted vs. unimpacted reaches of Prairie Creek.
3. To determine which physical variables measured in artificial redds (percent fine sediment, permeability, intragravel dissolved oxygen concentration) were correlated with survival of coho salmon embryos and sac-fry.
4. To determine timing of emergence and egg survival from natural redds on Prairie Creek and compare those results to artificial redds on impacted vs. unimpacted reaches of Prairie Creek.
5. To separate natural variability from bypass sediment impacts by quantifying the relationships between fine sediment content, permeability, suspended sediment flux, proximity to tributaries, and gravel framework size in redds.

C. Study Area

The Prairie Creek watershed lies within the coast redwood region near the town of Orick in northern California. Prairie Creek, tributary to Redwood Creek, is 14 mi long, drains an area of 30 mi², and flows along U.S. Highway 101 through portions of private agricultural land and old-growth forests in Prairie Creek Redwoods State Park and Redwood National Park. The stream reaches studied contained important spawning habitat and included five mi of Prairie Creek from just upstream of the mouth of May Creek north to 1.5 mi upstream of the mouth of Brown Creek, and two Prairie Creek tributaries, Brown Creek and Lost Man Creek (Figures 1 and 2). The reaches of Prairie Creek downstream of Brown Creek and within the major tributaries, Brown, Boyes, and May Creek, were impacted by the October 1989 storm. The reach above Brown Creek was slightly impacted by sediment inputs from a small tributary, Ten Tapo Creek. This reach was used as a control stream because, based on the previous year's studies, impacts appeared to be much less in this stream. Lost Man Creek was also used as a control in the studies. It also was less than an ideal control stream because it had been impacted by logging. However, it received no sediment from the bypass.

From the confluence of Boyes Creek upstream, unnatural sediment inputs into Prairie Creek have been minimal. Boyes Creek and May Creek tributaries were partially logged in the 1960's and had contributed some sediment from these activities into lower Prairie Creek before bypass construction.

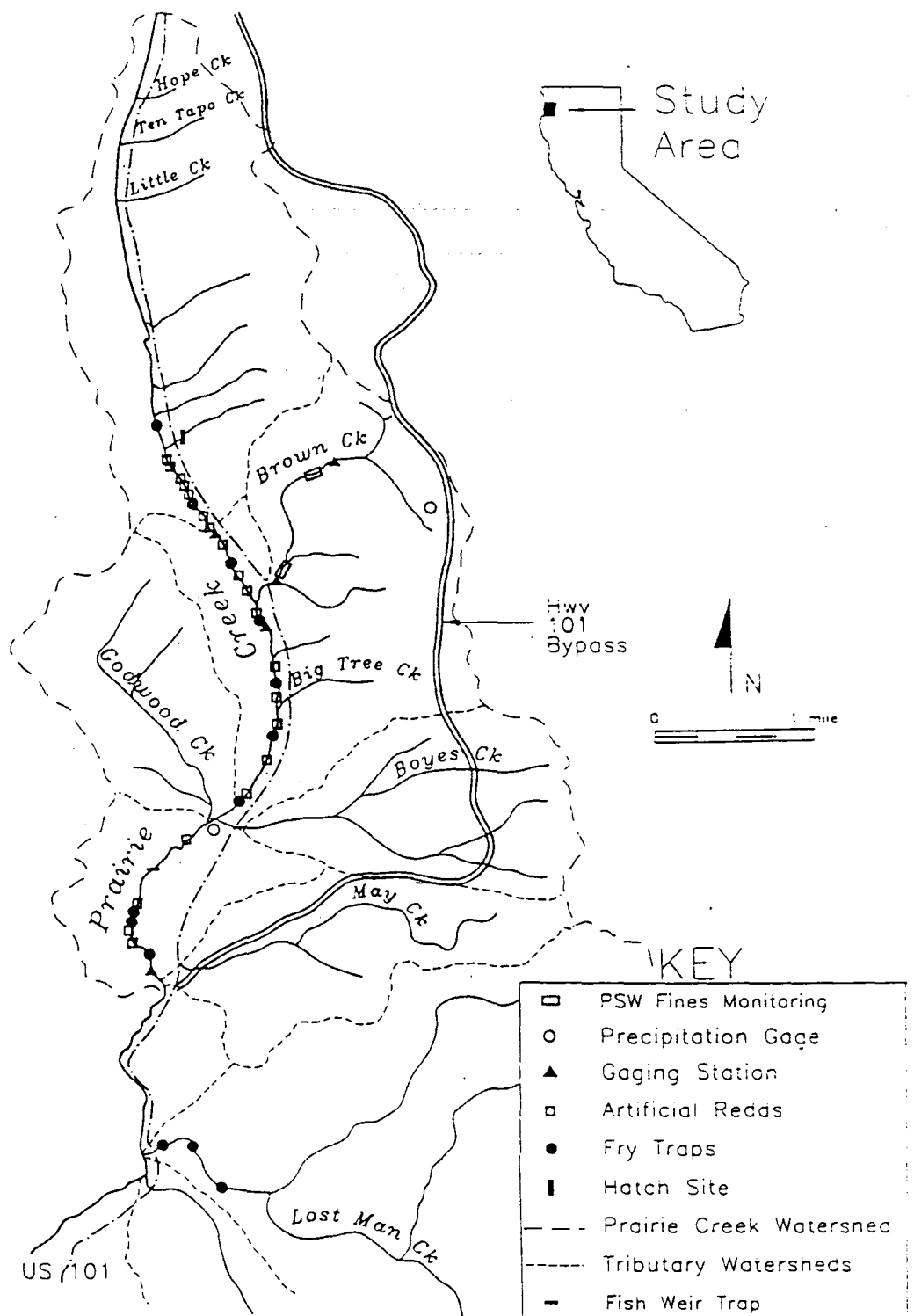


Figure 1. Location map of study area and sites for WY91.

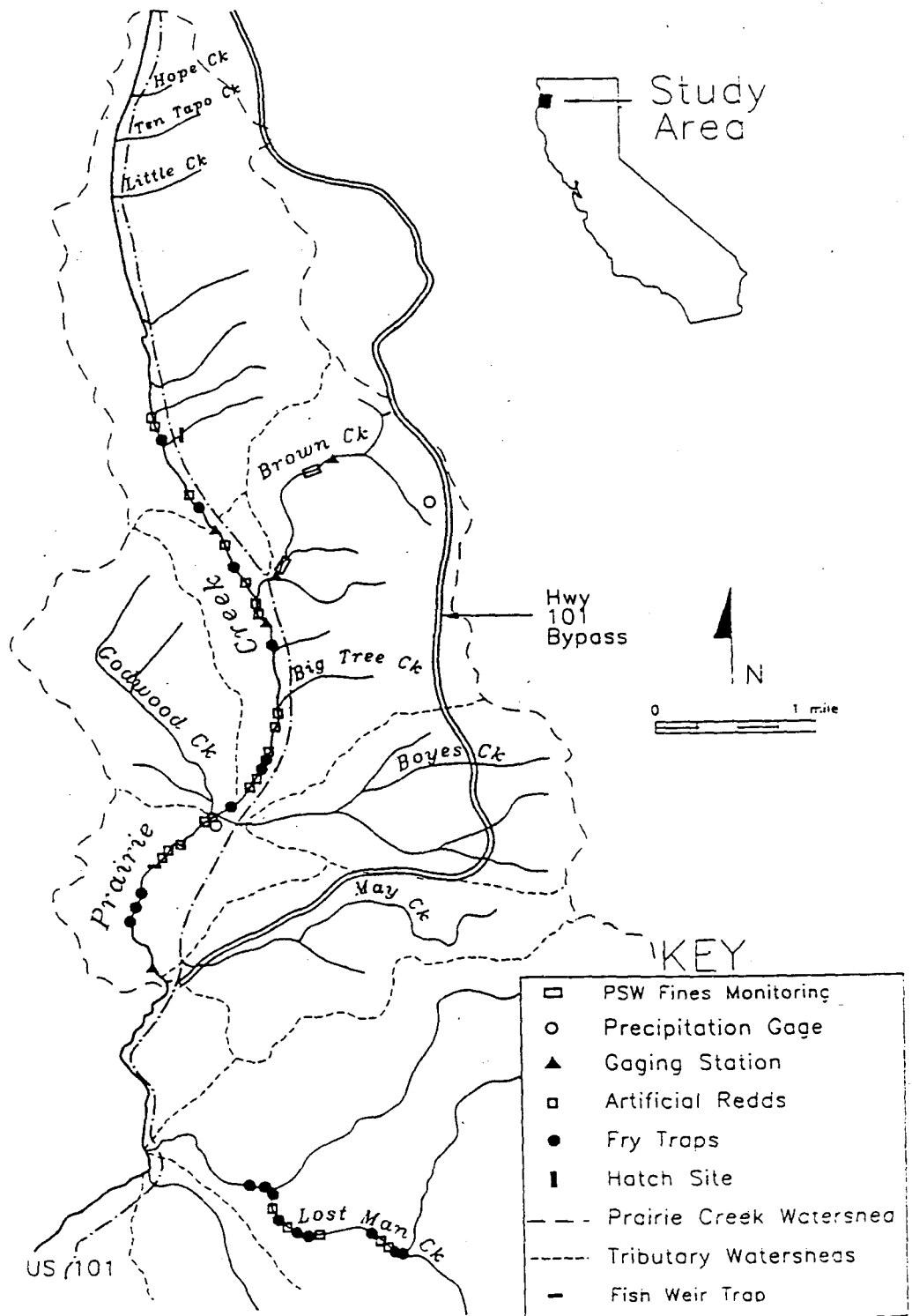


Figure 2. Location map of study area and sites for WY92.

II. SEDIMENT TRANSPORT

A. Study Objective

The purpose of this portion of the study was to determine the persistence of fine sediment in some of the affected streams over the winter periods. This section reports on results of monitoring precipitation, stream water and suspended sediment discharge (flux) and streambed mobility for WY91 and WY92 in Prairie Creek and one of the affected tributaries, Brown Creek. To calculate suspended sediment loads at various points on the streams over time, water and sediment discharge were quantified. Precipitation was monitored to document the hydrologic season.

The rate at which fine sediment is flushed from a stream system also depends on the frequency and degree of streambed scour. As the bed scours, all fine sediments within the streambed down to the depth of scour are released into the flow and carried away. We determined the depth and frequency of streambed scour to discover whether subsurface fines were being released.

Sediment transport through the fluvial system is also important to monitor because it provides both the material and mechanism for fines deposition into the gravel bed of the stream, including salmonid redds, which is discussed in Section III. Redwood National Park conducted most of the monitoring on Prairie Creek. The U.S. Forest Service's Pacific Southwest Research Station (PSW) performed all work on Brown Creek in WY91.

B. Methods

Precipitation. Rainfall estimates for the Prairie Creek basin are based on records from a continuously recording raingage on the bypass right-of-way in the headwaters of Brown Creek (Figure 1). This raingage uses a tipping-bucket assembly connected to a data logger and continuously records the amount of rain at 10-minute intervals.

Because of equipment malfunction, data were not recorded for one day on March 23, 1991. Precipitation for this period was estimated by plotting a relationship of WY91 precipitation measured on the bypass, with that measured at Redwood National Park South Operations Center offices in Orick. This comparison suggests rainfall during the period of missing record was about 1.2 inches.

Water Discharge Data Collection. Methods used to measure water and suspended sediment discharge are those accepted by the U.S. Geological Survey and are found in the National Handbook of Recommended Methods for Water Data Acquisition. Both metric and English units were used in these studies.

Water discharge and sediment transport were intensively monitored at five gaging sites in the Prairie Creek watershed (Figure 1). Three stations were located in Prairie Creek and two

gaging stations were located in Brown Creek (PSW study sites). The gaging stations are referred to as:

PAMY	Prairie Creek at the Wolf Creek Bridge (above May Creek)
PBBR	Prairie Creek below Brown Creek
PABR	Prairie Creek above Brown Creek
LB	Lower Brown Creek
UB	Upper Brown Creek

At these stations, water stage was recorded continuously with pressure transducers and data recorders. Shelters housed automatic recording and sampling equipment.

Measured water discharge can be directly correlated with known stage. Stage vs. discharge relationships were developed for the PAMY, PBBR, PABR, LB, and UB gaging sites. Stage observations were monitored both manually and electronically. Manual stage observations were made by reading staff plates and crest stage gages mounted on streambanks. Crest stage gages were made of 3/4-in PVC pipe, with a 1/2-in PVC quarter-round pipe used as a graduated dipstick. The lower end of the PVC pipe was perforated and covered with a single layer of filter cloth to prevent clogging by fine sediment. After each observation, ground cork was applied to the base of the dipstick. As stage rose, the cork floated and deposited a high-water mark on the dipstick, which was correlated to the gage datum at the site.

Stage data were continuously recorded on Campbell 21X or ENMOS data loggers. Submerged pressure transducers sensed stage fluctuations and were housed inside a 4- or 6-in diameter PVC perforated pipe in the stream channel. Pipe interiors were lined with filter fabric to deter fine sediment from clogging pipes. Data loggers were battery powered and housed in waterproof enclosures. Stage, time, and date were recorded at 10-min intervals. All stage readings had an approximate precision of ± 0.02 ft.

Flood Frequency Estimates. Runoff in WY91 and WY92 was exceptionally low with respect to peak stormflows. To help put the relative severity of the year's storms in perspective, flood peaks recorded from both winters can be compared with long-term flood frequency estimates for the gaging sites. Peak flow rates of various recurrence intervals were estimated using unit peak flow rates (cfs/mi^2) from USGS annual exceedence probability distributions for two gaged tributaries to Prairie Creek (RNP 1991). These tributaries were Little Lost Man Creek (USGS Station No. 11482468) and an unnamed tributary flowing into Prairie Creek between Ten Tapo and Brown Creeks (USGS Station No. 11482400), draining 3.56 and 0.40 mi^2 , respectively. Unit peak flows for these two basins were very similar; thus, they were averaged to estimate unit peak flows of various recurrence intervals. These data were then multiplied by the respective drainage areas of the sites gaged for this study, to estimate flood magnitudes.

Suspended Sediment Flux. Suspended sediment was collected by automatic pumping water samplers. Model 2700 ISCO water samplers and Campbell 21X microloggers were installed at UB, LB, PABR, PBBR, and PAMY gaging stations. A float and rod assembly, which was anchored to the streambed, automatically positioned the sampler intakes at 0.6 of the water depth at varying water stages (Eads and Thomas 1983).

A storm was defined as a period of time when the stage is continuously above a specified threshold. ISCO samplers were programmed to automatically start collecting samples when the river stage went above threshold. Suspended sediment samples were taken at random times within every 2-hr interval during a storm. Samplers automatically shut off when stage dropped below the threshold or all 24 bottles were filled.

During WY91, a total of 568 suspended sediment water samples were collected from Prairie Creek and 57% of the samples were analyzed. A total of 477 samples were collected and analyzed from Brown Creek. ISCO water samples were analyzed by North Coast Laboratories, Arcata, California and at the PSW U.S Forest Service laboratory facilities, Arcata, California. Depending on sediment concentrations, samples were analyzed by the filtration or evaporation method.

Suspended sediment flux (or load) is the amount of suspended sediment which is transported in a given time interval, and is calculated by multiplying suspended sediment concentration by water discharge by a given time interval. Sediment loads carried by Brown and Prairie Creeks were calculated for the five gaging stations from November through June. RNP analyzed sediment data for Prairie Creek with a different computer program than PSW used for the Brown Creek data. As a result, the technique used to calculate sediment flux for Brown Creek gaging stations was slightly different than that used for Prairie Creek stations. Details on sediment flux calculations are described in Appendix A.

In WY92, suspended sediment samples were collected on Prairie Creek during 12 storm discharge events during the season. Although the same equipment was used to obtain samples as in previous years, the sampling strategy was changed based on the previous year's results. This resulted in smaller gaps in the record of suspended sediment samples from each storm sampled and, consequently, more complete suspended sediment hydrographs. We believe this change in sampling strategy yielded more accurate estimates of suspended sediment flux.

Streambed mobility. Scour chains were used to measure bed mobility and were established at 23 sites on Prairie Creek in WY91: Eleven sites were located above Brown Creek and twelve below Brown Creek. Scour chains were installed at the three gaging stations and at the 20 artificial redd sites (See Section III). At each site, a scour chain was installed on either side of the artificial redd in an undisturbed portion of the creek.

Figure 3 illustrates how the scour chain method works. Aluminum chains 80-cm long were anchored into the streambed with a dowel attached to the lower end. The chain and anchor

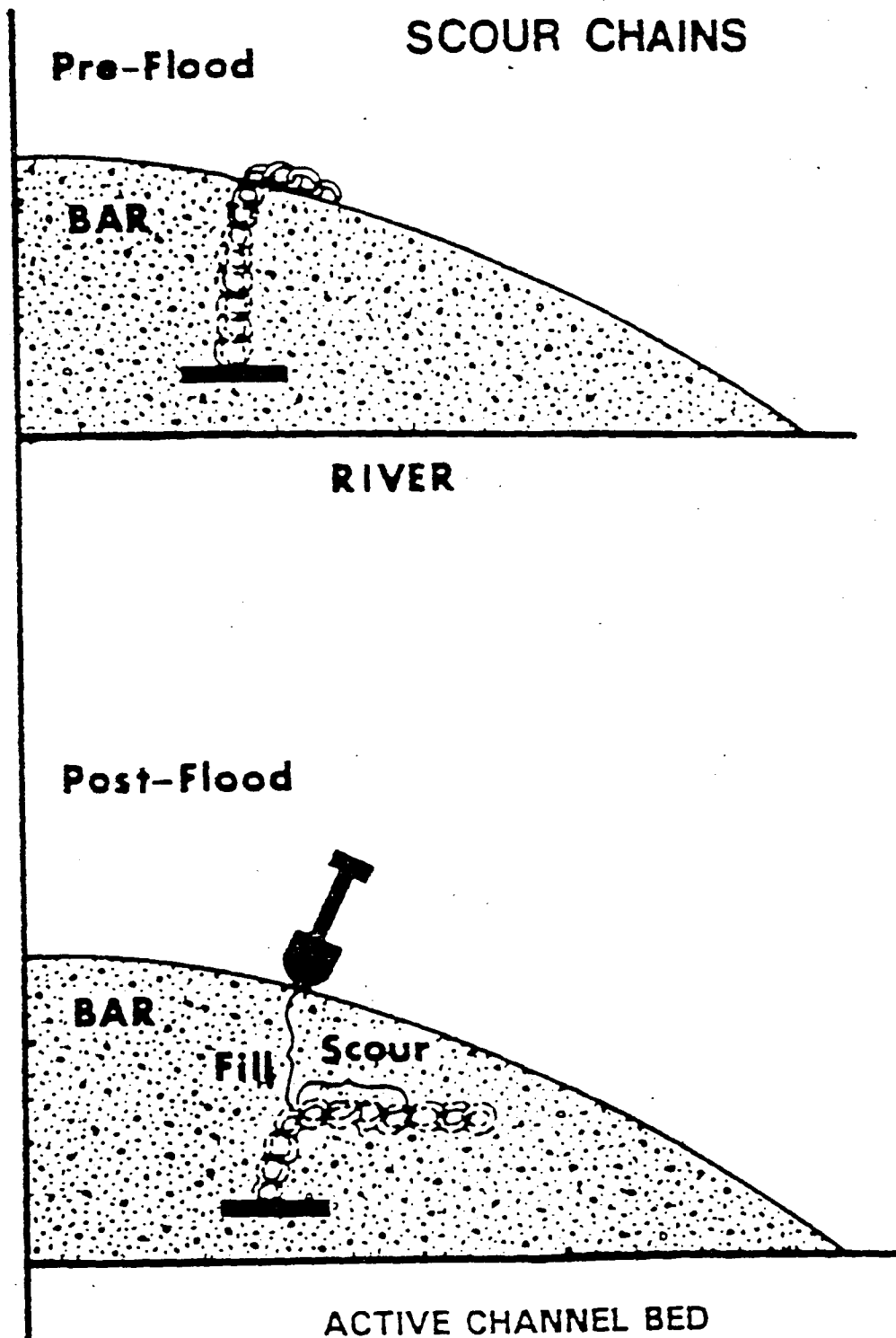


Figure 3. Scour chains in streambed, pre-flood and post-flood.

dowel were inserted into a pipe and the pipe was driven vertically into the streambed with a sledgehammer. The pipe was then removed and the scour chain left in place. The length of chain above the streambed was measured at the beginning of the season and at the end of the winter storm season.

To record the amounts of scour and/or fill resulting from high discharge events in WY92, the scour chains installed in the streambed in WY91 were left in Prairie Creek at several sites in the affected and control reach during WY92. Additional scour chains were installed in WY92 on each side of some of the WY92 artificial redds on the affected reach (the six most downstream sites).

C. Results

Precipitation. Average annual rainfall from 1971 to 1990 at the Humboldt County Prairie Creek Fish Hatchery was 67 in, and at least 80% fell during moderately intense winter storms between October and March. Rainfall during summer months was infrequent. During WY91, the Prairie Creek watershed experienced below normal rainfall. As of July 1, 1991, total winter rainfall was 54.6 in, or 81% of normal for that period. Figure 4 shows the cumulative precipitation curve from October 1, 1990 to July 1, 1991, generated from the bypass gage.

Besides the low seasonal rainfall, the Prairie Creek watershed experienced low rainfall intensities during the winter of 1990-1991. Every 2 years, 2 to 2.6 in of rain can be expected to fall within a 6-hr period in the Redwood Creek watershed (Janda et al. 1975). Table 1 lists depth-duration data for 2- and 6-hr durations recorded at the bypass raingage from October, 1990 to July, 1991. During the winter of 1991, the highest rainfall depth in a 6-hr period was only 1.57 in, and 1.00 inch in a 2-hr period, recorded on November 25, 1990. The maximum 6-hr rainfall depths in WY91 are comparable to those measured in WY 90 (both 1.57 in), whereas maximum 2-hr rainfall depths were 47% greater in WY91 than in WY90 (1.00 in vs. 0.68 inches in WY90).

In WY92 (Figure 2), the seasonal total (44 inches) was only two-thirds of normal. A plot of cumulative rainfall for that study period is shown in Figures 5, a through c. In general, WY92 was relatively dry, as were the two previous years of this study.

Water Discharge. Figure 6 shows the hydrographs for Prairie Creek and Brown Creek gaging sites from October 1, 1990 to July 1, 1991. The largest flow of the season occurred January 12 - 15, 1991. Maximum recorded discharge on Prairie Creek was 103 cfs at PABR, 170 cfs at PBBR, and 329 cfs at PAMY. Maximum discharge on Brown Creek was 21 cfs at UB, and 39 cfs at LB. Estimated flood peaks for the 2-, 5-, 10-, 25-, and 50-yr recurrence intervals, along with recorded flood peaks for the WY91 are presented in Table 2.

Figures 7, a through b, show the continuous record of discharge at the three Prairie Creek stations for the WY92 season. The largest discharge event of the season occurred on April

Table 1. Maximum rainfall depths at 2- and 6-hr durations at the bypass raingage in Brown Creek headwaters, 1990-1991.

Date	Rainfall Depth (in.)	
	2-hr Duration	6-hr Duration
11-13-90	0.47	1.24
11-25-90	1.00	1.57
12-10-90	0.47	1.10
01-12-90	0.59	1.28
02-02-90	0.59	1.06
03-02-90	0.98	1.45
03-04-90	0.80	1.24
04-05-90	0.53	1.12
05-07-90	0.61	1.06

Table 2. Recorded flood peaks for WY91 and peak flow estimates for various recurrence intervals at gaging sites on Prairie Creek and Brown Creek.

Gaging Station	Area (mi²)	Peak Flow WY 91	Peak flow rates (cfs) at various recurrence intervals				
			2-yr	5-yr	10-yr	25-yr	50-yr
<u>Prairie Creek:</u>							
PABR (above Brown Ck)	4.06	103	327	581	727	1031	1234
PBBR (below Brown Ck)	6.36	170	512	909	1138	1615	1933
PAMY (at Wolf Ck)	12.60	329	1014	1802	2255	3200	3830
<u>Brown Creek:</u>							
UB (Upper)	0.72	21	58	103	129	183	219
LB (Lower)	1.40	39	113	200	251	356	426

17. The instantaneous peak discharge rates at the three stations were 290, 150, and 80 cfs at PAMY, PBBR, and PABR, respectively. This event was far less (about 25%) than the estimated 2-year recurrence interval flood, further indicating the meagerness of the 1992 runoff season.

CUMULATIVE RAINFALL: Water Year 1991
October 1, 1990 – July 1, 1991
Hwy 101 Bypass of Prairie Creek State Park

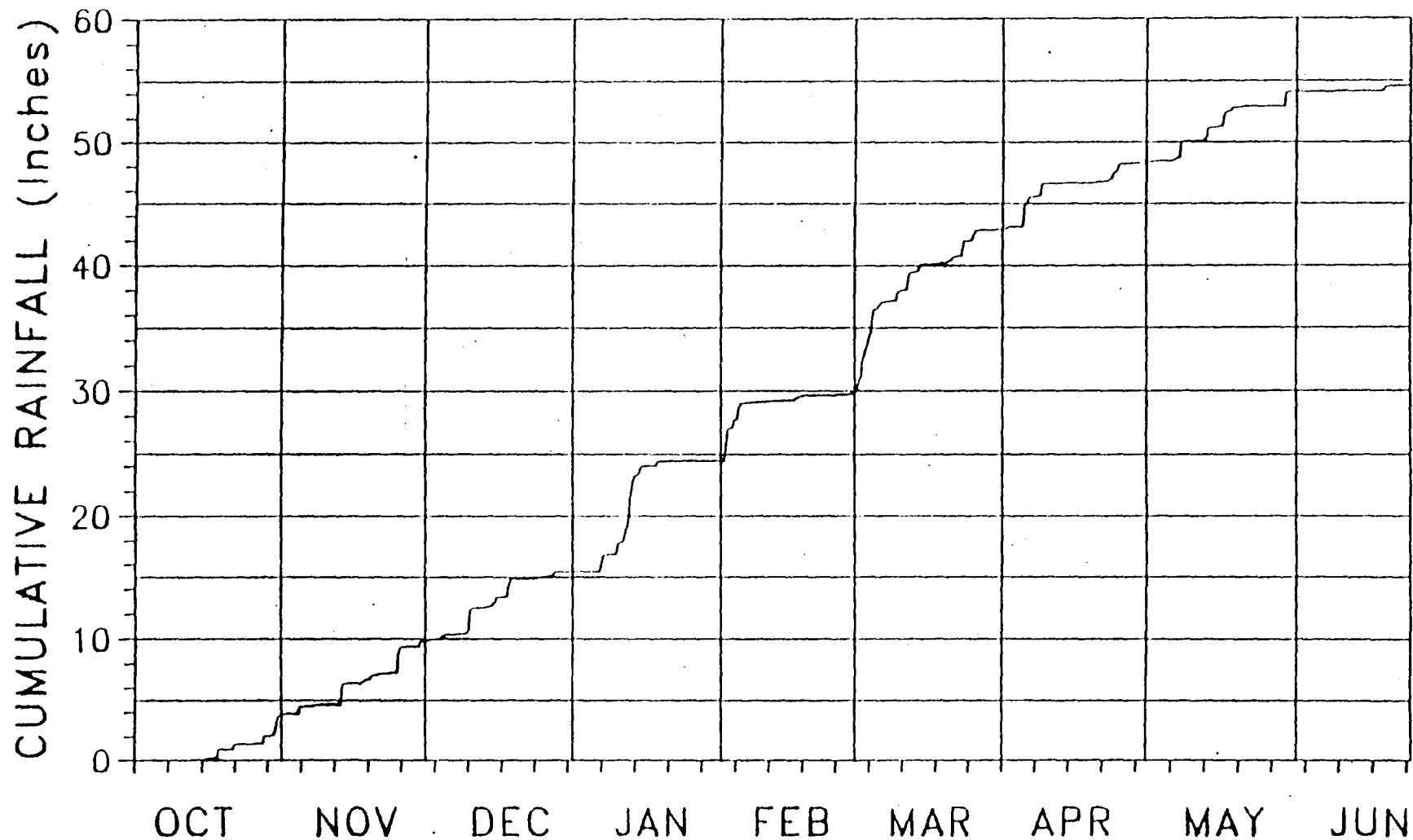


Figure 4. Cumulative rainfall, water year 1991.

Figure 5a. Cumulative rainfall in Prairie Creek for October 1 through December 31, 1992.

CUMULATIVE RAINFALL AT PRAIRIE CREEK HWY 101 BYPASS, 1991-92 WATER YEAR

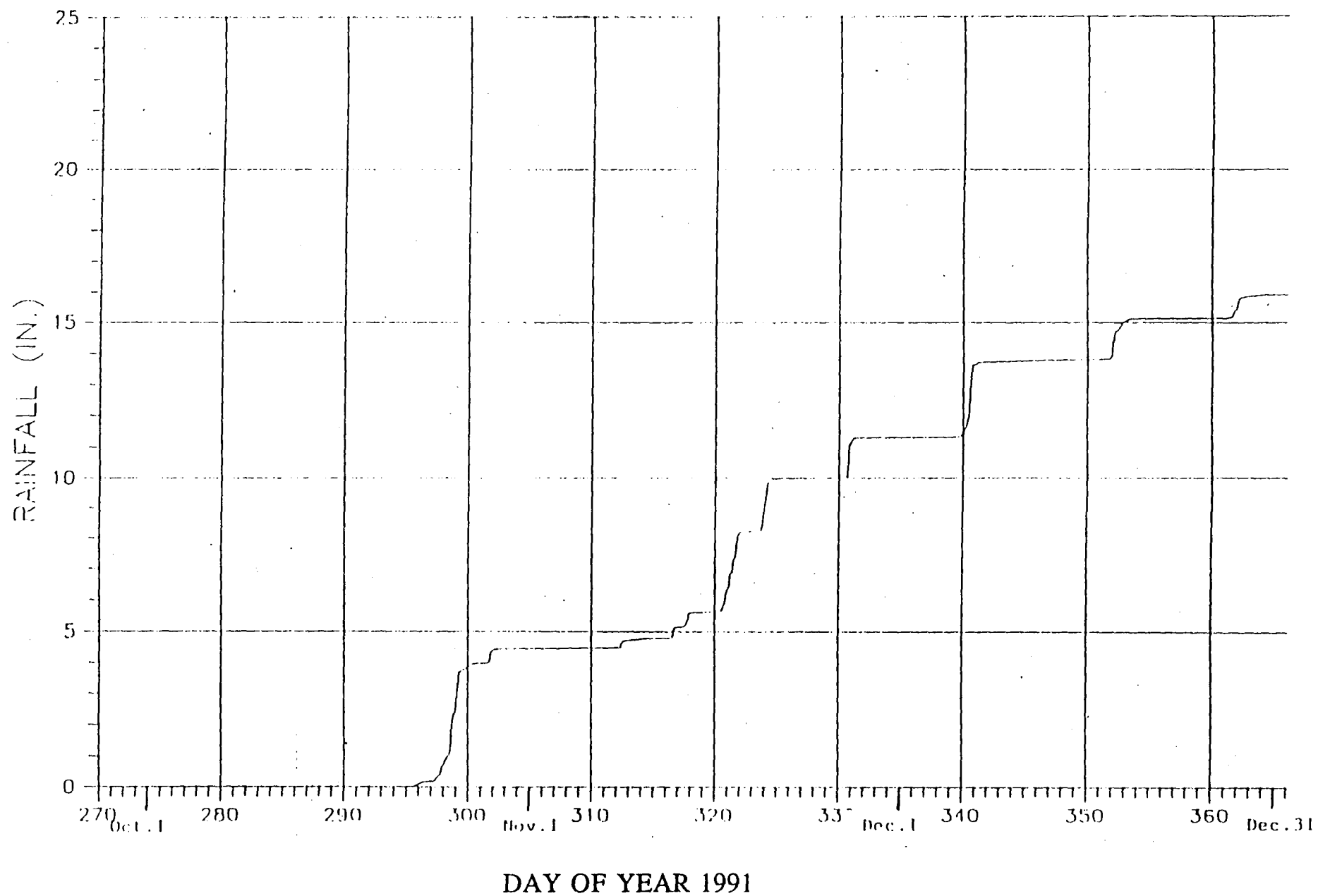


Figure 5b. Cumulative rainfall in Prairie Creek for January 1 through March 31, 1992.

CUMULATIVE RAINFALL AT PRAIRIE CREEK HWY 101 BYPASS, 1991-92 WATER YEAR

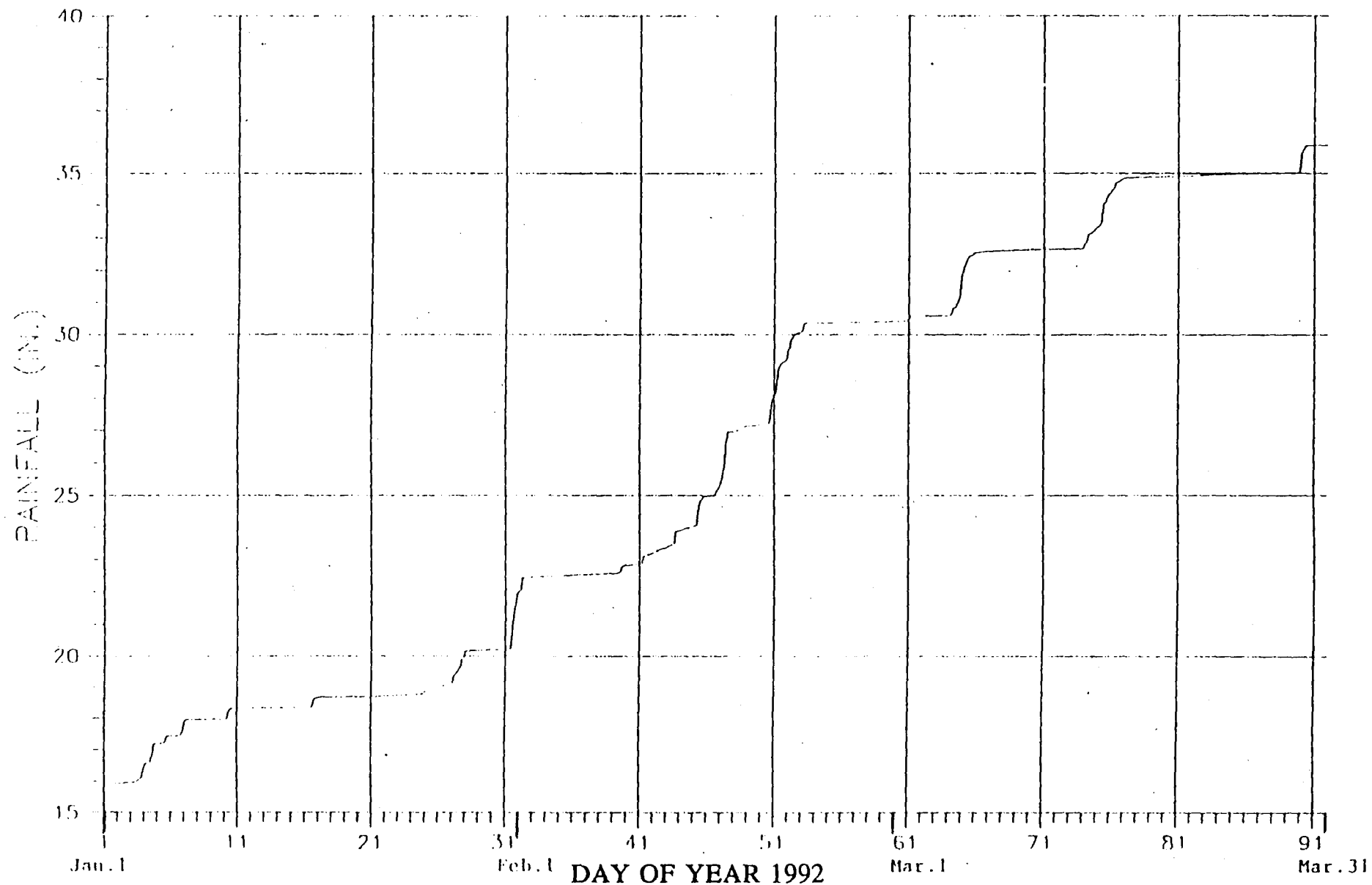
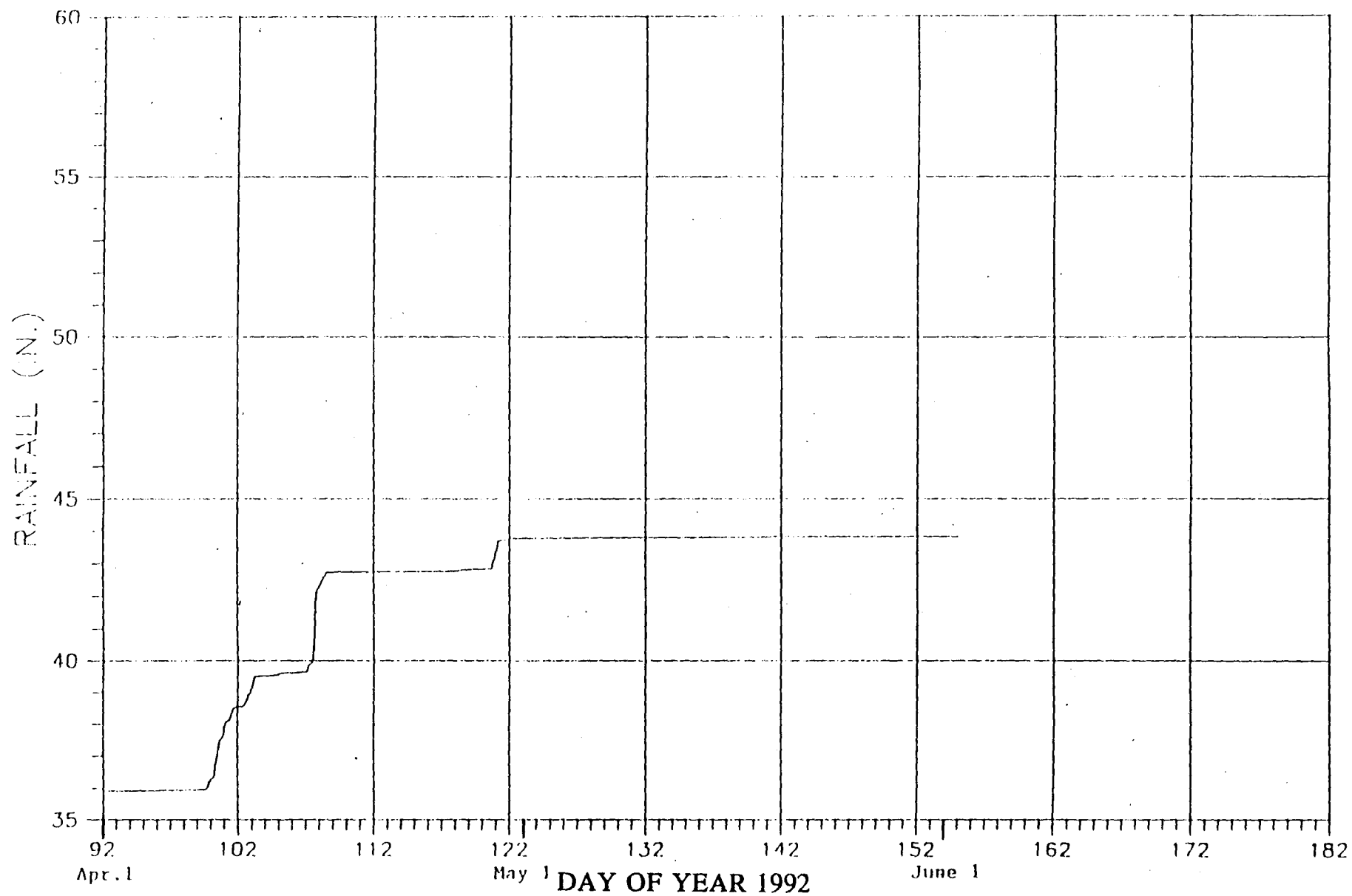


Figure 5c. Cumulative rainfall in Prairie Creek for April 1 through June, 1992.

CUMULATIVE RAINFALL AT PRAIRIE CREEK HWY 101 BYPASS, 1991-92 WATER YEAR



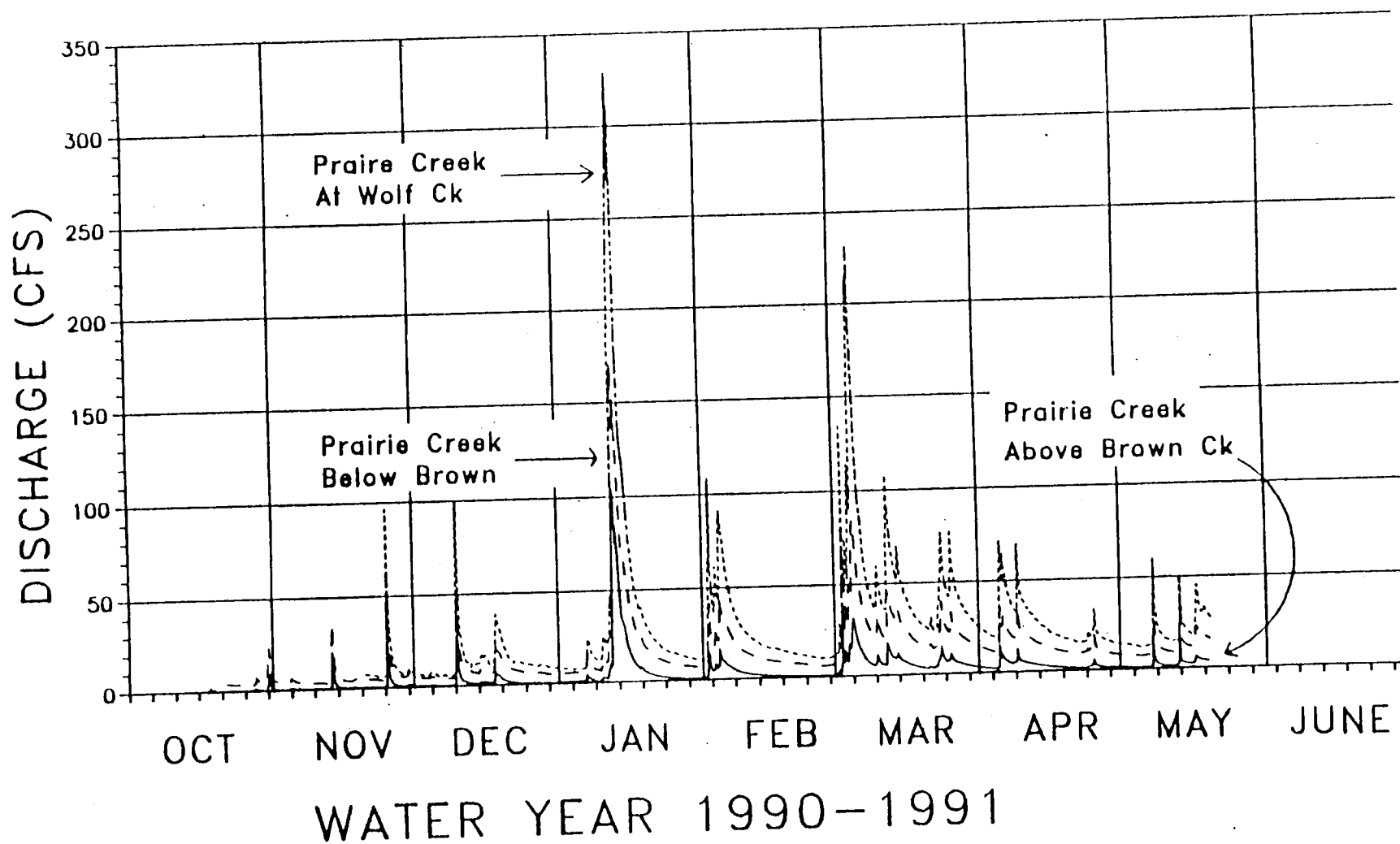


Figure 6. Water discharge at the Prairie Creek gaging stations
October 1, 1990 through December 31, 1991.

Figure 7a. Water discharge at the Prairie Creek gaging stations, October 1 through December 31, 1992.
 REDWOOD NATIONAL PARK Prairie Cr. Bypass Study Hydrograph 10/01/91 -- 12/31/91

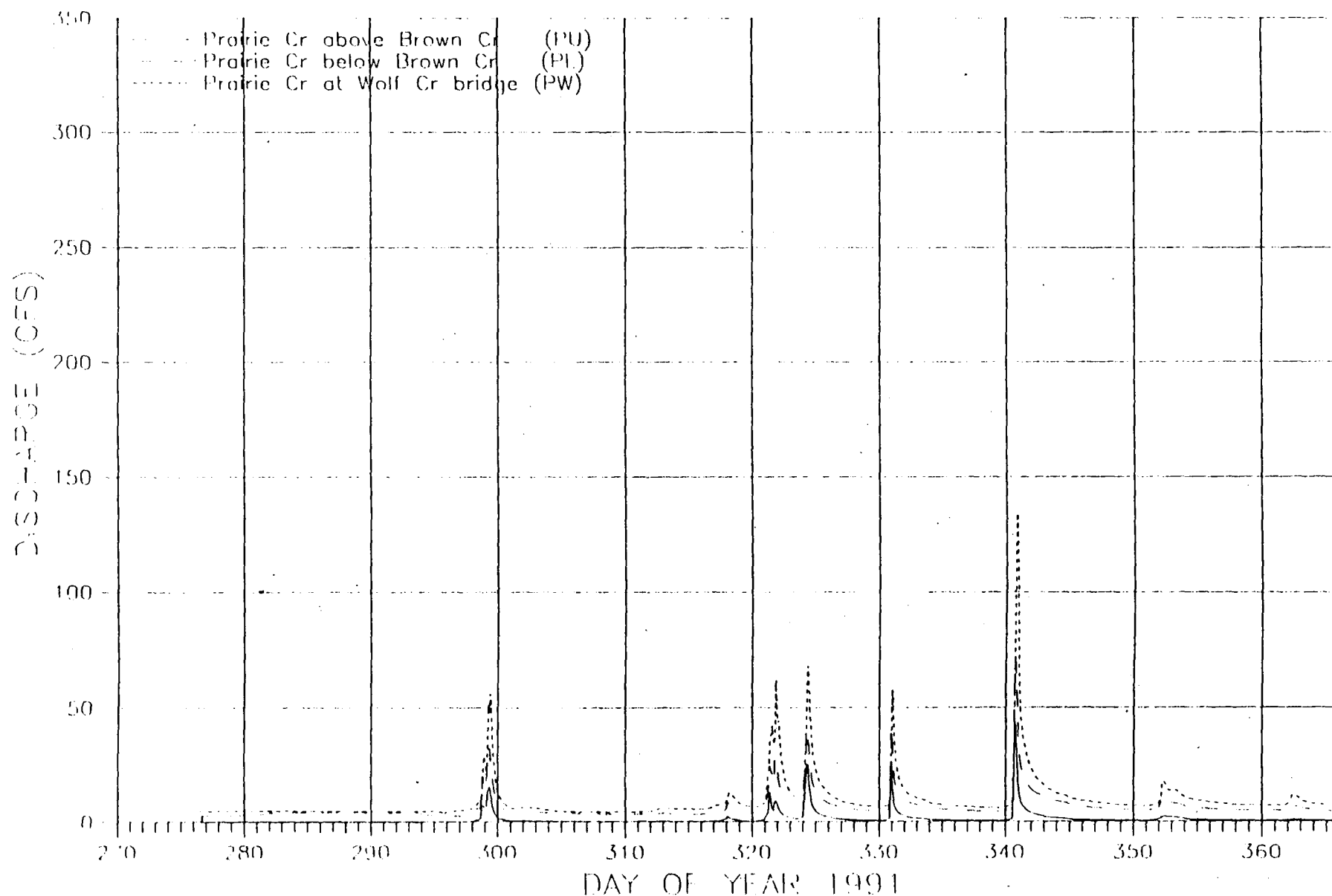


Figure 7b. Water discharge at the Prairie Creek gaging stations, January 1 through March 31, 1992.

REDWOOD NATIONAL PARK Prairie Cr. Bypass Study Hydrograph 01/01/92 - 03/31/92

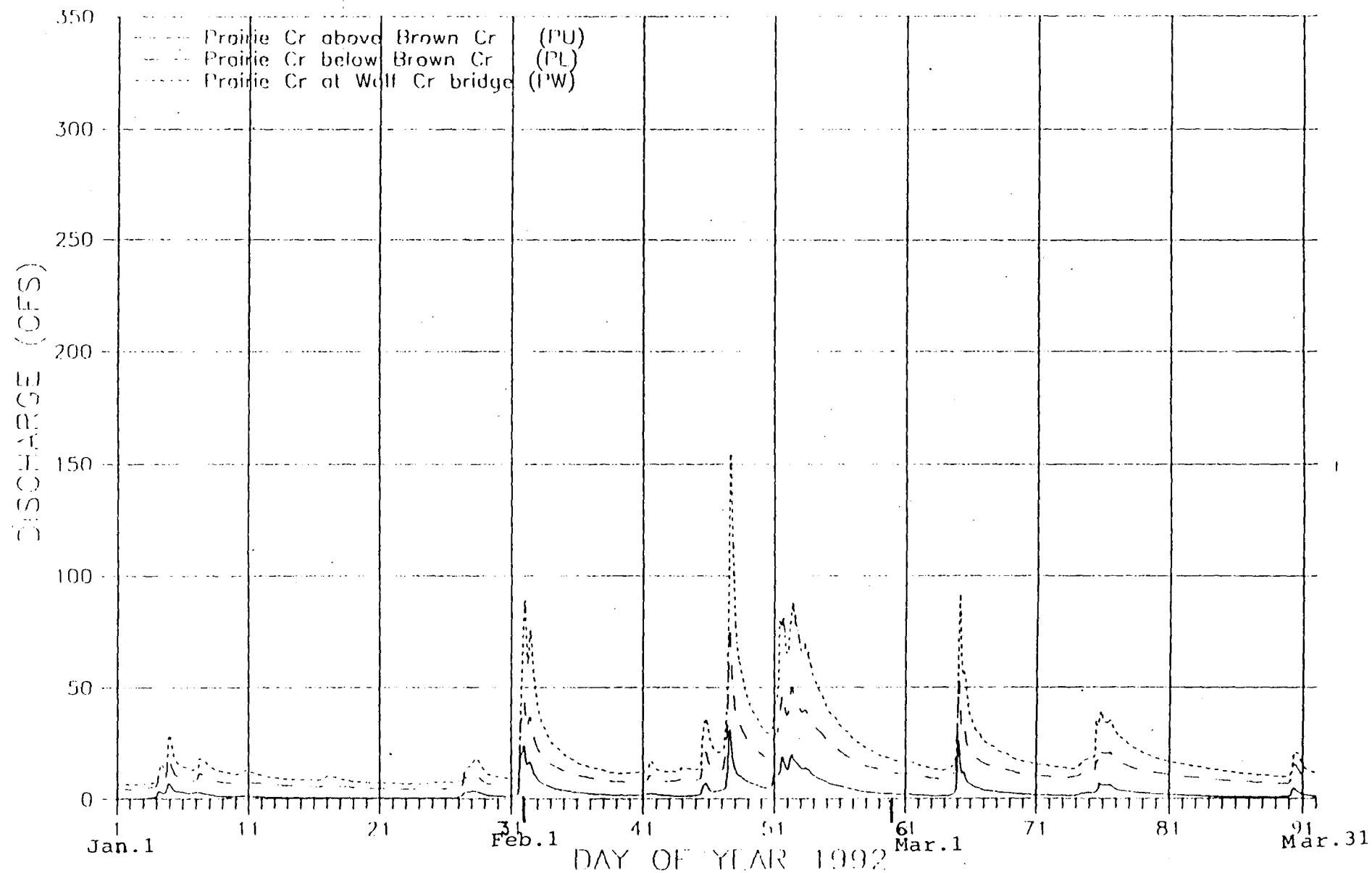
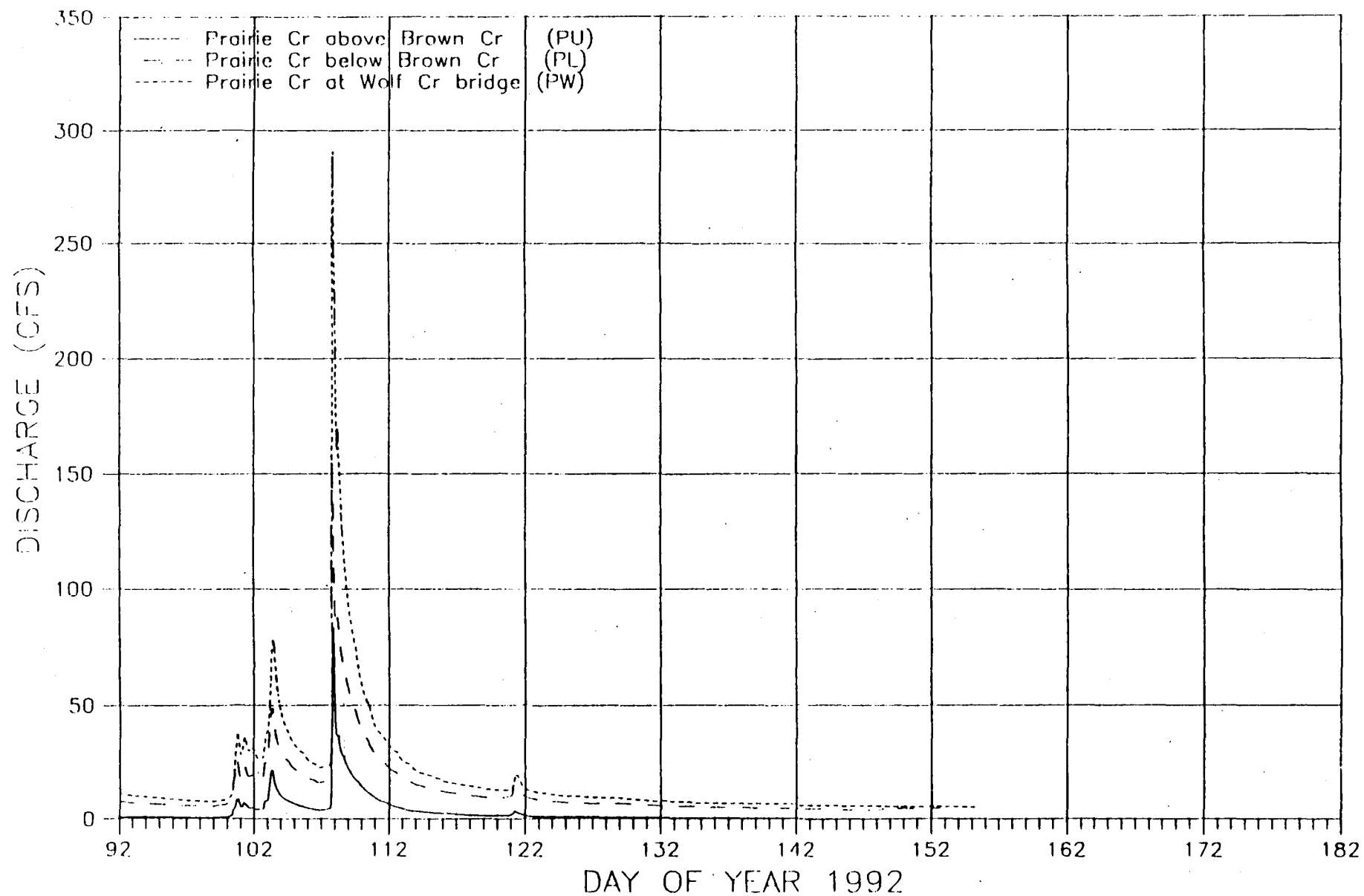


Figure 7c. Water discharge at the Prairie Creek gaging stations, April 1 through June 3, 1992.

REDWOOD NATIONAL PARK Prairie Cr. Bypass Study Hydrograph 04/01/92 - 06/30/92



Suspended sediment.

WY91 Results:

Suspended sediment concentrations varied from storm to storm and throughout the entire WY91 season. Between November 1990 and May 1991, peak suspended sediment concentrations at gaging stations were as follows:

<u>Station</u>	<u>Peak Concentration</u>	<u>Date Measured</u>
PABR	190 mg/l	1/12/91
PBBR	285 mg/l	3/02/91
PAMY	545 mg/l	3/04/91
UB	890 mg/l	1/12/91
LB	1700 mg/l	3/02/91

In contrast, suspended sediment concentration between storm events was less than 3 mg/l (the detection limit of the analysis). Peak suspended sediment concentrations tended to occur just prior to or simultaneously with the hydrograph peak.

Plots of cumulative sediment flux over time for PABR, PBBR, PAMY, and LB gaging stations, show that the bulk of sediment was transported during 2 storm events in WY91 (Figure 8). Over 80% of the sediment at PAMY and PBBR was transported in mid-January and early March. In contrast, 72% of the total sediment transport at PABR occurred during just the January 12 storm.

Total suspended sediment flux for Prairie and Brown Creeks for WY91 is shown in Table 3. Suspended sediment flux between stations may be compared by calculating values of unit flux, expressed in terms of tons per square mile. The annual sediment loads for Prairie Creek included synthesized data to account for unsampled sediment transport in the initial rising and falling limbs of the hydrograph, and they represent maximum annual sediment flux values. In contrast, the annual sediment load for Brown Creek was based on sediment transport only when flow was above threshold, and it represents a minimum value of total annual sediment load. It does not include estimates of sediment transport that occurred in the initial rising and falling limb of the storm hydrograph, when flow was below threshold and, thus, was not sampled.

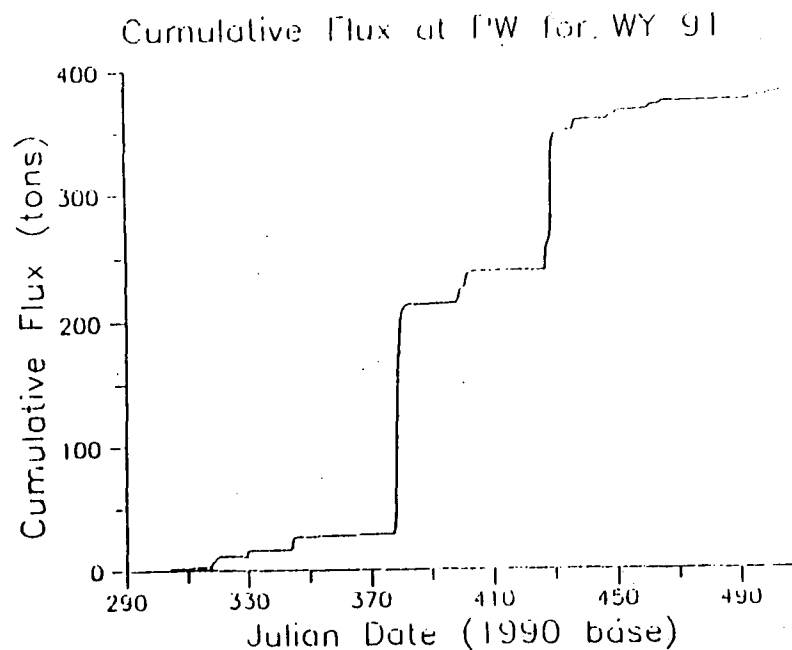
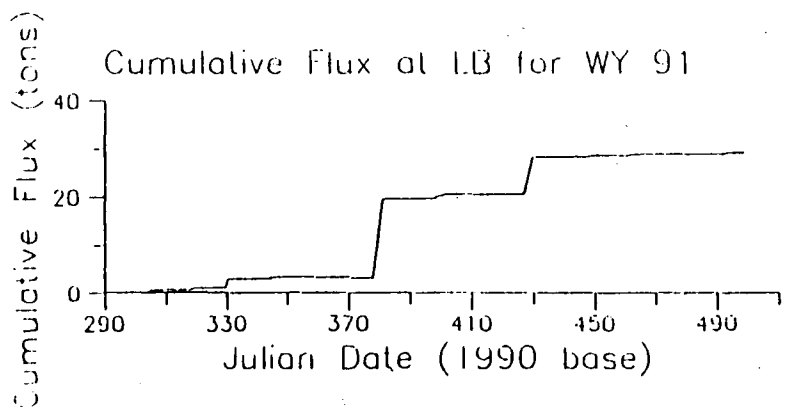
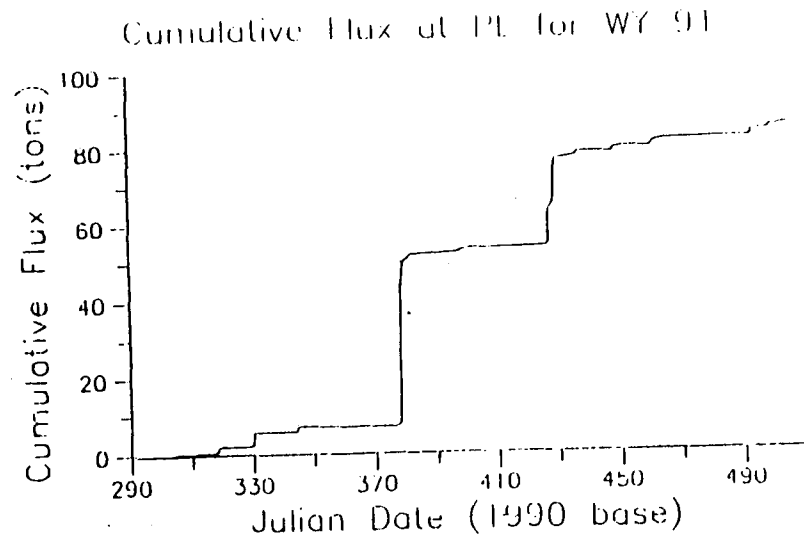
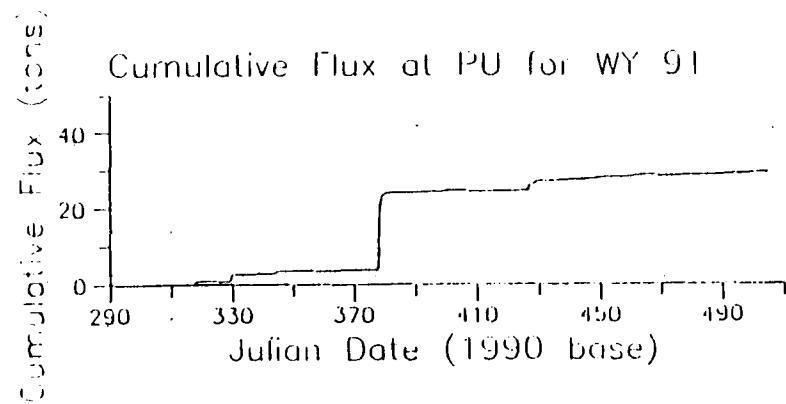


Figure 8. Cumulative sediment flux at PU, PL, PW and LB gaging stations.

Table 3. Annual suspended sediment load for Prairie and Brown Creeks during WY91.

Station	Area	Annual Suspended Sediment Load ^a	
	(mi ²)	(t) (%) ^b	(t/mi ²)
PABR	4.06	28 ^c (18%)	7
PBBR	6.36	80 ^c (35%)	13
PAMY	12.60	374 ^c (27%)	30
UB	0.72	26 ^d (24%)	36
LB	1.40	29 ^d (9%)	21

^a Annual suspended sediment flux is estimated from suspended sediment sampled above threshold flows and from synthesized data for below threshold flows.

^b Values in parenthesis are the percentages of the annual suspended sediment flux that were synthesized.

^c Annual suspended sediment loads for Prairie Creek gaging stations included synthesized data for the initial rising and falling limbs of the hydrograph and represent maximum values for annual sediment flux.

^d Annual suspended sediment loads for Brown Creek gaging stations reflect sediment transport above threshold only and represent minimum values for annual sediment flux.

A sediment balance can be constructed to compare suspended sediment transported past PABR, LB, and south fork of Brown Creek to the annual sediment load for PBBR. During WY91, PABR and LB (north fork of Brown Creek) produced 28 and 29 t of sediment, respectively. If we assume the south fork of Brown Creek reacted similarly to the intensively studied north fork, and the amount of sediment transported is proportional to its drainage area, then the maximum total sediment load for the south fork is 7 t. This estimate is probably high, because the south fork was less impacted by Highway 101 bypass road construction. The total sediment load coming from areas above PBBR equalled about 64 t. In comparison, about 80 t of sediment was transported past PBBR during WY 1991. This leaves about 16 t or 20% of the sediment passing PBBR unaccounted for.

There are several possible sources of error. Some of the difference can be accounted for by the fact that the annual sediment fluxes for Prairie Creek stations were maximum values and the sediment fluxes for Brown Creek stations were minimum values. In addition, the Brown Creek data did not include sediment fluxes for two small storms that were included in Prairie Creek data. Also, the south fork of Brown Creek may have contributed more sediment than we estimated. Finally, a potential sediment source that was not measured was surface sediment in the Brown Creek streambed from LB downstream to PBBR.

WY92 Results:

Figures 9, a through c, show the cumulative suspended sediment flux for the three gaging stations on Prairie Creek for the WY92 season. The largest sediment transport event of that season at all stations occurred on April 17. This event accounted for about 50% of the total suspended sediment transported during the season.

Listed in Table 4 are drainage areas and WY92 unit suspended sediment flux values for the gaging stations on the main channel of Prairie Creek.

Table 4. Suspended sediment load for gaging stations on the main channel of Prairie Creek, WY92.

GAGING STATION	DRAINAGE AREA (mi ²)	UNIT FLUX (tonnes/mi ²)
Prairie above Brown Creek (PABR)	4.1	4
Prairie below Brown Creek (PBBR)	6.4	10
Prairie above May Creek (PAMY)	14.3	13

Streambed mobility. The distance from streambed surface to the buried chain indicates the depth the bed was mobile and the subsequent amount of fill. The net scour or fill which occurred over the 1990-1991 winter at artificial redd sites is reported in Table 5 (for just one of the two chains). All scour chains were exposed on the channel bed or buried under a surface layer of pebbles and cobbles. Field observations, based on scour chains located at artificial redd sites, indicated minor amounts of scour and fill. The maximum depth of net scour in Prairie Creek in WY91 was 19 cm, although most chains showed much less. Maximum depth of net fill was 11 cm.

As in previous years, in WY92 bed mobility was absent or minimal at all locations due to the mild runoff season. At the most, only the upper surface layer of bed sediments was moved by the flows of this season. WY92 results from some scour chains installed in WY91 are summarized in Table 6 (both chains by each redd are shown). These results show minimal channel scour or fill (several centimeters, at most) for two successive years (WY91 and WY92). Table 7 shows scour or fill depths from scour chains installed in WY92, which were also small.

D. Discussion

Results from all phases of this report need to be interpreted in light of the mild storm seasons in WY90, WY91, and WY92. Rainfall in WY91 was 81% of normal, and rainfall in WY90 and WY92 was 67% of normal. In addition, all storm intensities were well below the expected 2-yr recurrence interval.

Figure 9a. Suspended sediment flux at the Prairie Creek gaging stations, October 1 through Dec. 31, 1992.
Prairie Cr. Suspended Sediment Mass Flux 10/01/91 - 12/31/91

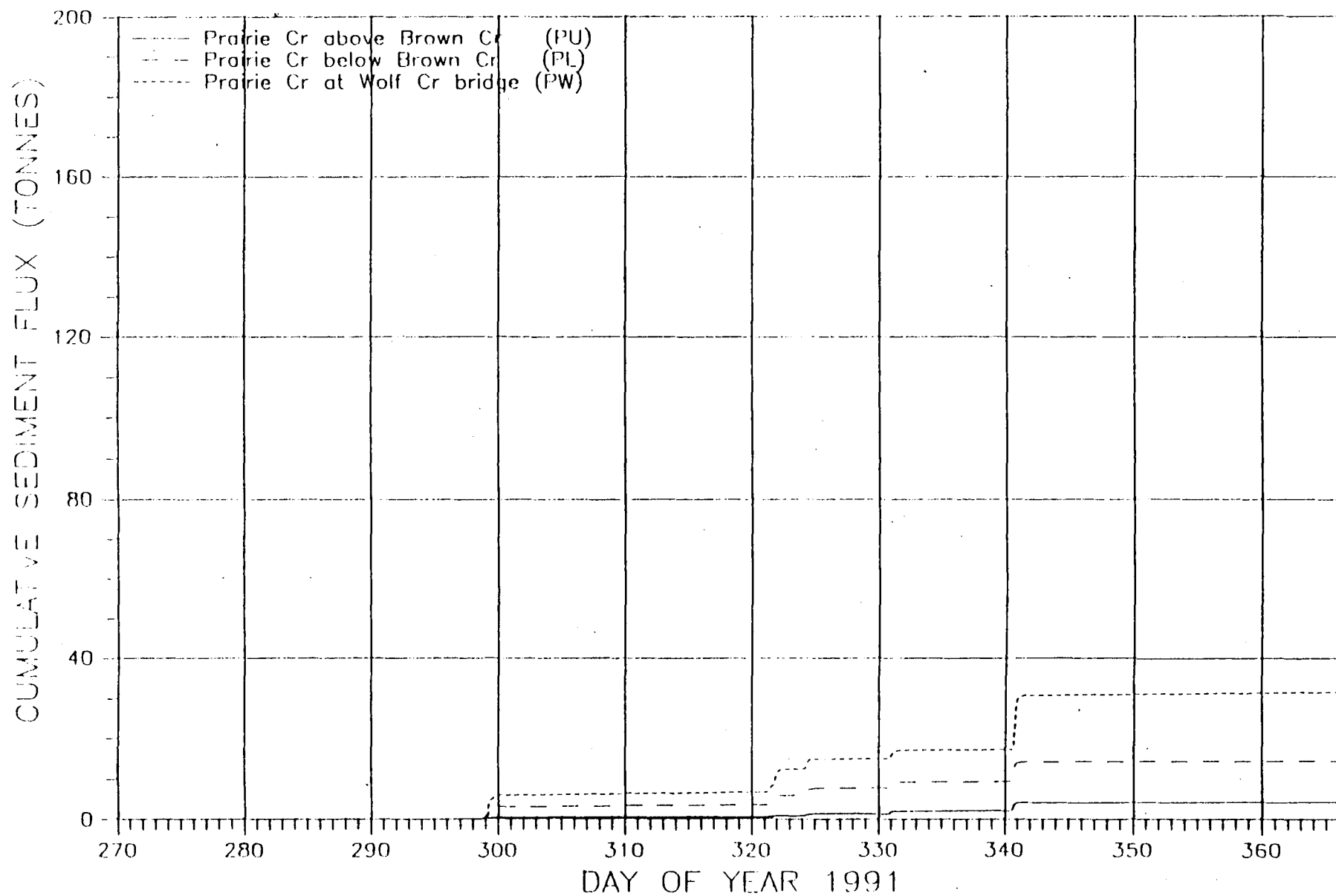


Figure 9b. Suspended sediment flux at the Prairie Creek gaging stations, January 1 through March 31, 1992.
Prairie Cr. Suspended Sediment Mass Flux 1/01/92 - 3/31/92

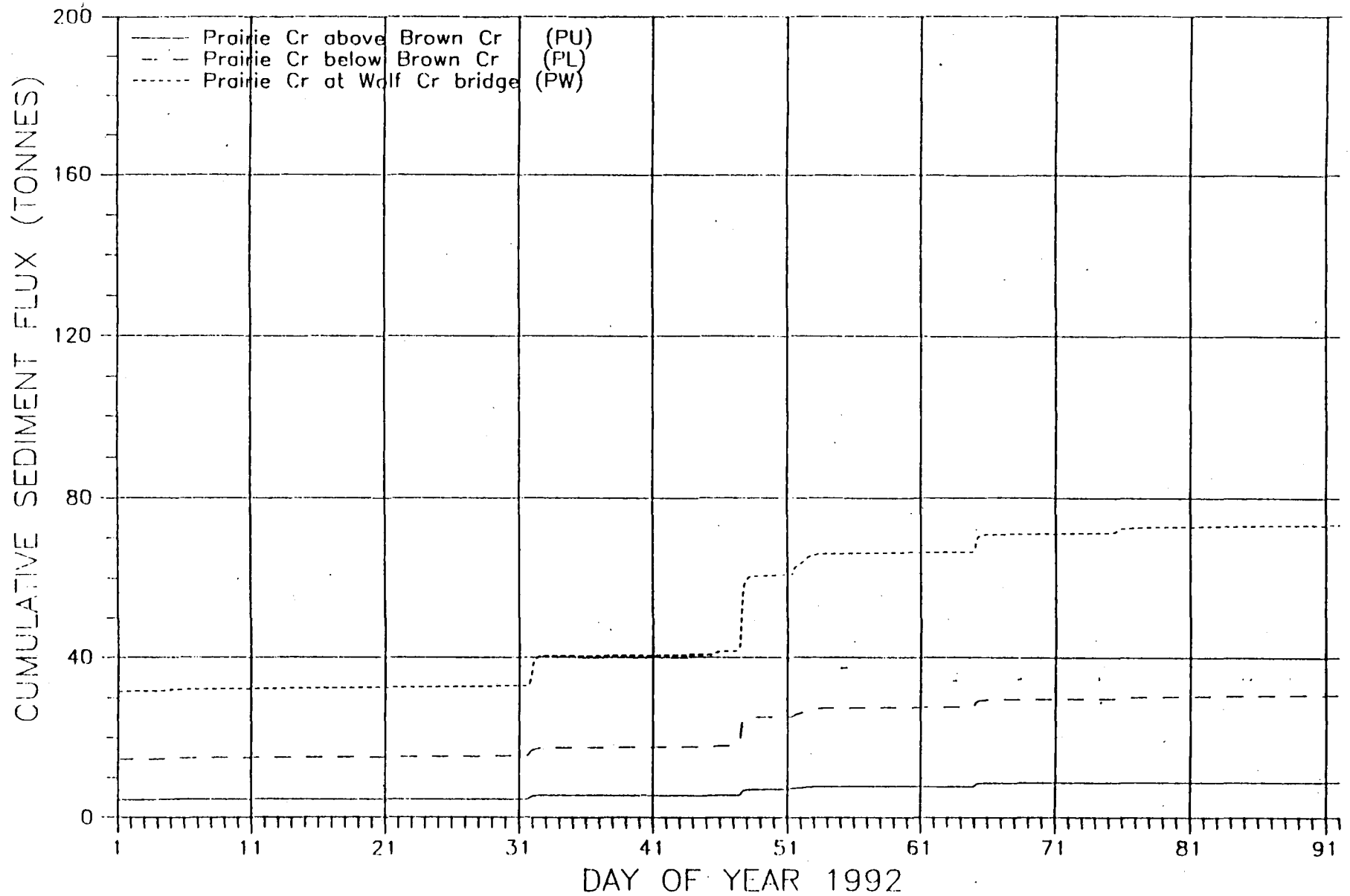


Figure 9c. Suspended sediment flux for the Prairie Creek gaging stations, April 1 through June 3, 1992.
 Prairie Cr. Suspended Sediment Mass Flux 3/31/92 - 6/30/92

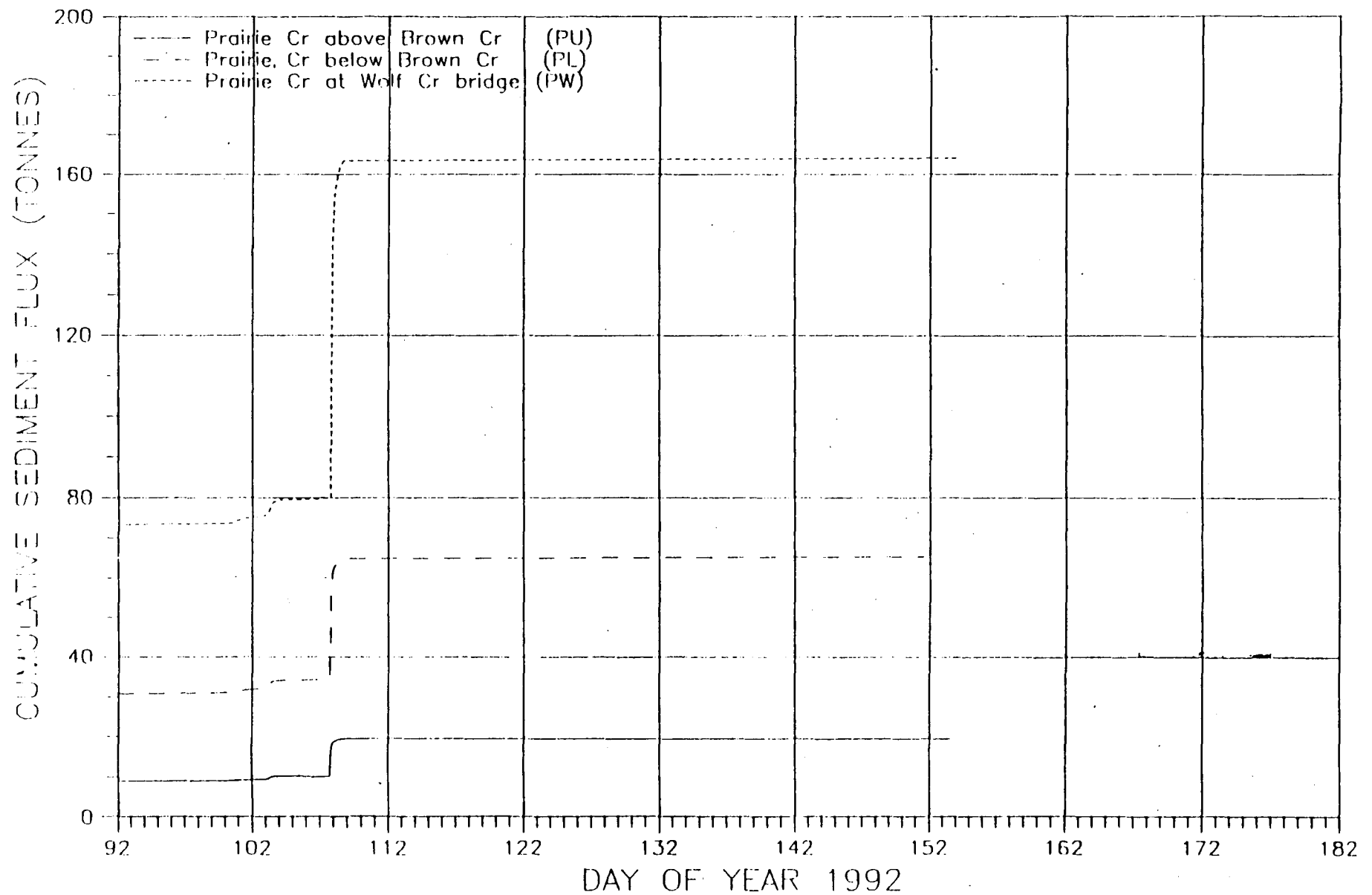


Table 5. Net scour or fill depths at sites on Prairie Creek above (A) and below (B) Brown Creek and at Prairie Creek gaging stations, WY91.

Site #	Distance from Left Monument (m)	EXPOSED CHAIN LENGTH		Net Scour (-) or Fill (+) (cm)
		January 1991 (cm)	August 1991 (cm)	
PABR	3.23	43	37	6
PBBR	8.08	43	44	-1
PAMY	6.95	30	34	-4
A1	3.66	38	35	3
A2	3.75	29	18	11
A3	5.52	29	31	-2
A4	5.18	38	38	0
A5	7.19	47	41	6
A6	7.38	27	29	-2
A7	4.94	38	29	9
A8	6.77	16	13	3
A9	4.94	23	20	3
A10	5.18	18	15	3
B1	6.10	16	35	-19
B2	18.68	21	Not found	---
B3	6.13	17	18	-1
B4	20.12	25	22	3
B5	8.20	30	25	5
B6	5.40	15	Disturbed	----
B7	6.49	25	30	-5
B8	5.24	30	37	-7
B9	6.04	29	34	-5
B10	7.01	40	29	11

Table 6. Scour chain data for WY91 and WY92 at Prairie Creek artificial redds sites. In site number, A = Above Brown Creek, B = Below Brown Creek.

Site #	Date Installed	Distance from Lx	Total Chain Length (cm)	Length of Chain Exposed (cm)					
				WY 91			WY 92		
				1/91	8/91	Net Change	12/91	6/92	Net Change
A1-a	1/91	3.17 m 10.4 ft	78.0	36.5	35.0	1.5	38.5	37.0	1.5
A1-b	1/91	3.66 m 12.0 ft	78.0	38.0	35.5	2.5	38.0	40.0	-2.0
A2-a	1/91	3.05 m 10.0 ft	78.5	35.0	23.0	12.0	38.0	40.0	-2.0
A2-b	1/91	3.75 m 12.3 ft	78.5	29.0	18.5	10.5	19.0	19.0	0.0
A3-a	1/91	6.95 m 22.8 ft	80.0	32.0	36.0	-4.0	26.0	27.0	-1.0
A3-b	1/91	5.52 m 18.1 ft	78.0	29.0	31.0	-2.0	Broken	---	---
B7-a	1/91	4.91 m 16.1 ft	78.0	23.0	18.0	5.0	26.0	21.0	5.0
B7-b	1/91	6.49 m 21.3 ft	78.0	25.0	30.5	-5.5	32.0	32.3	-0.3
B9-a	1/91	4.39 m 14.4 ft	77.5	28.5	33.0	-4.5	34.0	37.4	-3.4
B9-b	1/91	6.09 m 19.8 ft	78.0	29.0	33.5	-4.5	36.0	35.4	0.6
B10-a	1/91	5.79 m 19.0 ft	78.0	39.5	25.5	14.0	Broken	---	---
B10-b	1/91	7.01 m 23.0 ft	77.5	39.5	29.5	10.0	39.5	45.1	-5.6

Table 7. Scour chain data WY92 at Prairie Creek artificial redds sites below Brown Creek.

Site #	Date Installed	Distance from Left Bank	Total Chain Length (cm)	Length of Chain Exposed (cm)		
				WY 92		
				12/91	6/92	Net Change
#1-L	1/92	7.53 m 24.7 ft	80.0	22.0	27.5	-5.5
#1-R	1/92	10.33 m 33.9 ft	80.0	54.0	—	—
#2-L	1/92	4.94 m 16.2 ft	81.0	20.0	18.0	2.0
#2-R	1/92	7.77 m 25.5 ft	80.0	24.0	23.0	1.0
#3-L	1/92	8.35 m 27.4 ft	80.0	23.0	22.8	0.2
#3-R	1/92	12.0 m 39.4 ft	80.0	23.0	21.0	2.0
#4-L	1/92	4.57 m 15.0 ft	80.0	24.0	18.0	6.0
#4-R	1/92	7.32 m 24.0 ft	80.0	19.0	19.0	0.0
#5-L	1/92	2.87 m 9.4 ft	81.5	24.0	26.0	-2.0
#5-R	1/92	4.60 m 15.1 ft	80.0	46.0	44.0	2.0
#6-L	1/92	2.99 m 9.8 ft	80.5	20.0	29.3	-9.3
#6-R	1/92	5.73 m 18.8 ft	80.0	24.0	24.2	-0.2

Comparison of the recorded flood peaks for WY91 and WY92 at the stream gaging stations with the flood frequency estimates in Table 2 illustrates the mildness of stormflow events during the runoff season. The 2-yr recurrence interval peak flows were not attained at any of the gaging sites during the two runoff seasons or during WY90.

Sediment transport in north coastal California is storm dependent. Most sediment is transported at high flows and relatively little is transported at low to moderate flows. Over 80% of the sediment was transported at PAMY and PBBR in WY91 during two storm events in mid-January and early March. In contrast, 72% of the sediment was transported at PABR during one storm event during the mid-January storm. This indicates that erosion occurred throughout the Prairie Creek basin during the mid-January storm. No major sediment transport occurred at PABR during the early March storm, but relatively high transport occurred at LB, PBBR and PAMY. This indicates that erosion must have occurred in the Brown Creek drainage basin and possibly other east-side tributaries of Prairie Creek affected

by the bypass during the March storm.

Because rainfall intensities and flood peaks for storms were well below the 2-yr recurrence interval for WY91, annual suspended sediment loads for Prairie Creek were low and ranged from 7 t/mi² at PABR to 30 t/mi² at PAMY. In comparison, during low flow years annual suspended sediment loads for Little Lost Man Creek, a pristine basin within the Prairie Creek watershed, ranged from 17 to 70 t/mi² with an average of 44 t/mi². However, Little Lost Man Creek is geologically dissimilar to Brown Creek and is not truly comparable. Studies of Lost Man Creek gravel properties is needed to understand and contrast the dynamics of this system with Prairie Creek.

Comparison of sediment transport past gaging stations at PABR in WY90 (not including sediment transported during the October 1989 storm) and WY91 indicate that sediment fluxes were very similar in both years. In contrast, LB and consequently PBBR had about 2.5 times lower sediment load during the WY91 winter storms than in WY90. In WY92 even less sediment was transported past all the gaging stations. This is consistent with the findings documented later in this report indicating sediment previously deposited in Brown Creek remained in place; little sediment was flushed out during winter flows as opposed to WY90 when some flushing of sediment occurred.

It is apparent from these data that suspended sediment yield from the watershed area below Brown Creek (affected by the bypass) is much higher than the relatively pristine area upstream. While there may be scale effects from differences in basin size, these differences are large enough to possibly implicate the bypass as responsible. Without pre-October storm data, however, this could be debated.

Scour chain data indicate insignificant amounts of scour and fill occurred within the streambed in Prairie Creek. Previous bed mobility studies in Prairie Creek using scour chains showed that the channel bed typically scoured up to 30 cm during average winter flows (Dr. Tom Lisle, PSW, personal communication). Results from this study's scour chain data indicate that, in general, only the surface layer of sediment was mobilized during the WY91 and WY92 winter flows and the low flows were not effective in flushing fine sediment from the Prairie Creek streambed. Because movement of the fine sediment presently stored in the streambed is dependent on widespread scour of the bed, fines from the bypass will persist until the present drought ends. The source for suspended sediment transport for both years was probably from local mobilization of surface deposits and new erosion from the bypass right of way.

III. EFFECTS ON SALMONID REPRODUCTION

A. Effects of Fines, Permeability, and Dissolved Oxygen on Coho Salmon Egg Survival

A.1 Study Objective

The objective of this portion of the study was to determine the effects of sediment from the U.S. Highway 101 bypass project on coho salmon egg survival in Prairie Creek. Infiltration of large amounts of fine sediment into salmonid redds has been shown to reduce reproductive success by reducing the gravel permeability (Terhune 1958, McNeil and Ahnell 1964), intragravel water flow (Vaux 1962, Cooper 1965) and, thus, availability of dissolved oxygen (DO). Low dissolved oxygen can cause direct mortality of salmonid embryos (Alderice et al. 1958) or delay development of alevins (Shumway et al. 1964). Fine sediment can also physically trap and prevent salmonid fry from emerging by blocking interstitial pore spaces (Everest et al. 1987). Hence, two life stages were assessed: from fertilized egg to hatching and from fertilized egg to fry emergence. Specifically, we assessed the effects of fine sediment, permeability, and dissolved oxygen on coho salmon eggs planted in artificial redds that were constructed on an impacted reach of Prairie Creek. We compared these results to a Prairie Creek reach that was only minimally impacted. The hypothesis tested was that egg survival would be lower in the impacted reach because of higher fine sediment, lower permeability, and lower dissolved oxygen conditions in the artificial redds.

A.2 Methods

Egg Survival. Procedures for estimating egg survival were adapted from Burton et. al. (1990) and RNP (1991). In WY91, twenty artificial redds were constructed in potential coho salmon spawning sites on Prairie Creek: ten above the confluence of Brown Creek and ten below (Figure 1). Potential sites were selected using depth, velocity, and gravel size criteria documented by Briggs (1953) on Prairie Creek. The reach above Brown Creek was the relatively unimpacted control stream, and the reach below Brown Creek was the impacted (or affected) reach. Results from the previous year's monitoring indicated fines in egg pockets increased in a downstream direction. Therefore, we stratified the reach below Brown Creek into three sections bounded by tributaries. The reach above Brown Creek was also divided into three equal length strata. Sites were randomly chosen within each stratum. Number of redds placed in each stratum were as follows:

<u>Strata</u>	<u>Number of Redds</u>
Prairie Creek above Brown Creek (control)	10
Prairie Creek below Brown Creek	3
Prairie Creek below Big Tree Creek	3
Prairie Creek below Boyes Creek	4

An artificial redd was constructed by digging a large hole (about 1 m x 2 m x 40 cm deep) in the gravel and sifting the gravel clean of fines using a shovel or McLeod. About one-third of the excavated material was cleaned of fines < 4.7 mm using a sieve. The cleaned material was stored on the bank and covered until fish eggs were available. During the interim, two open-ended, 20-L buckets with lids were temporarily placed upright in the hole with a collapsed infiltration bag set in the bottom. The hole was backfilled around the buckets with the shovel-cleaned gravel.

Coho salmon eggs were obtained from the Pacific Coast Federation of Fisherman Associations (PCFFA--more recently called the Pacific Coast Fish, Wildlife, and Wetlands Restoration Association), who, under contract with Caltrans and California Department of Fish and Game (CDFG), trapped fish on Prairie Creek for a streamside hatchbox rearing program. Plastic mesh baskets that were 15-cm tall (25-cm diameter) were filled with 100 recently fertilized eggs and sieved gravel. Baskets of this size were used to test egg survival-to-hatching. Thirty-cm tall baskets were similarly prepared, but were designed to have the top flush with the streambed surface to test egg survival-to-emergence. Aluminum permeability pipes, perforated at the bottom, had been fastened into the center of both sizes of the polyethylene mesh (3.2 mm) basket cylinders. Large cobbles, 64 to 128 mm, were purposely placed at the base of each basket to simulate the egg pocket. Once baskets were filled and mesh tops sewn on, the lids from the 2 buckets in the streambed were removed and each type of basket was placed inside the buckets and buried with sieved gravel. The bucket was then pulled out of the redd, leaving a cylindrical column of sieved gravel directly above the collapsed infiltration bag (Figure 10). The surface of the redd was contoured to mimic a natural redd, with a shallow depression (pot) at the upstream end, and a low-profile mound over the remaining length of the redd. All hatching baskets were installed within two days (January 11 and 12). The emergence baskets were placed in the stream on January 12 and 19. Tests for egg survival-to-hatching were conducted during the same period that natural coho salmon redds were incubating eggs.

Four thousand eggs from three females were used for the WY91 study; each female's eggs were fertilized with sperm from two males. The remaining fertilized eggs from each female (435, 1722, and 2024 eggs) were incubated on trays in hatch troughs at the PCFFA rearing site (Figure 1). These eggs were incubated on a 1/8 inch plastic mesh tray under continuous upwelling flow from a nearby non-sediment impacted tributary of Prairie Creek using standard hatchery practices. These eggs were monitored until they hatched to determine egg infertility and viability. All eggs used in the survival-to-hatching test were fertilized at approximately the same time in mid-January. In the survival-to-emergence experiment, five redds in the control stream contained eggs that were fertilized in mid-January; the rest were fertilized a week later.

Unfortunately, the largest storm of the year fell between January 12 and 19, subjecting half of the control emergence baskets to different conditions from the other half. For this reason, the storm-impacted baskets were separated from the others in some data analyses to test whether this might have had an effect on the results.

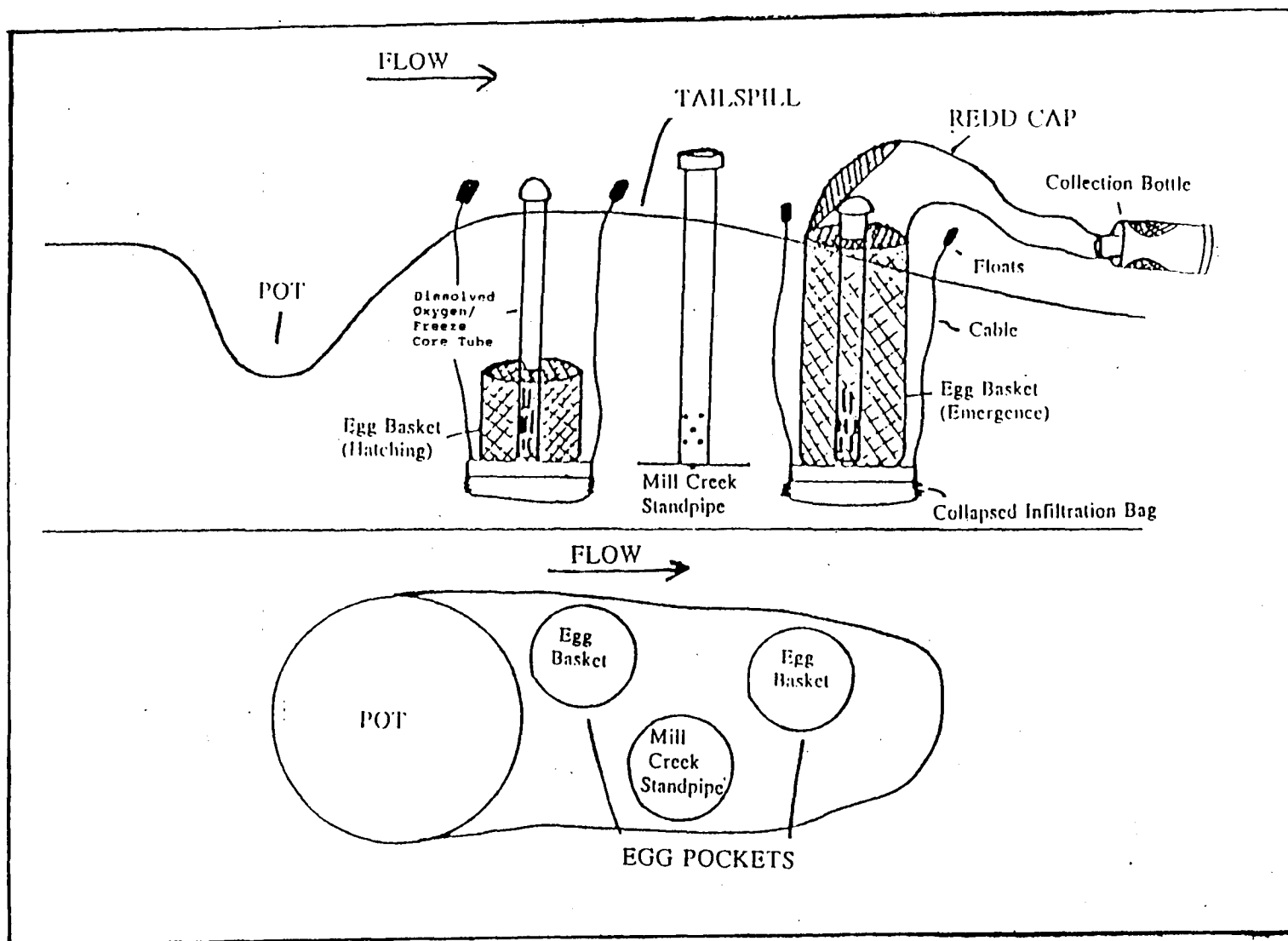


Figure 10. Cross-Section and planimetric view of artificial redds.

To assess handling mortality, a separate basket of eggs was subjected to the same handling procedures as the rest but was placed unburied in an unnamed, unimpacted small tributary of Prairie Creek. This same tributary was used as a water source at the PCFFA site.

Emerging fry were caught in a modified redd cap fitted over emergence baskets after hatching had commenced (Figure 10). Traps were checked at least every other day. Fry were counted, measured and released below the PCFAA downstream migrant traps located on Prairie Creek.

Based on degree days, hatch dates were estimated. Degree days were calculated by totaling the average number of degrees (°F) above freezing for each day over a period of time. Hatching baskets were opened after the estimated hatch date from March 24 to 27. Emergence baskets were opened and removed from May 15 to 22, several days after fry ceased emerging.

Live and dead eggs and alevins found in the baskets upon removal were counted to calculate initial percent survival-to-hatching and complete survival-to-emergence estimation. Survival rates were then adjusted to remove the effect of natural egg infertility and viability.

In WY92, methods followed those used in WY91 except for the following changes:

The results from WY91 suggested that several variables--proximity of redds to tributaries, geometric mean diameter of gravel, streambed slope, streamflow and sediment flux--influence infiltration of fine sediment (fines) into redds. We attempted to hold most of these variables constant when selecting sites for artificial redd construction. However, sediment flux increases in a downstream direction as each tributary deposits more sediment into the mainstem. Sediment flux could not be held constant over the entire system. Therefore, similar to the previous year, sampling effort on Prairie Creek was stratified by reaches bounded by the tributaries: Brown, Big Tree, and Boyes Creeks. Unlike the previous year, however, each reach was split into two groups: (1) areas immediately below the bordering tributary and (2) the rest of the reach. We hypothesized that areas immediately below the tributaries were subjected to greater sedimentation from tributary inputs than areas farther downstream.

An additional control stream was added in WY92 because WY91 results showed the reach above Brown Creek naturally had different gravel framework composition than below Brown Creek, which was correlated to how much fine sediment accumulated. Also, that reach was slightly affected by the bypass sediment inputs from Ten Tapo Creek. Because Lost Man Creek natural redds in WY91 had some success, Lost Man Creek was selected as the second control. Unlike most of Prairie Creek, Lost Man Creek has been subjected to sedimentation from past timber harvest activities. It also differs geologically from Prairie Creek, making it a less than ideal control stream. However, Lost Man Creek was not impacted by the bypass and was the next best control reach available.

Twelve redds were placed in the affected reach on Prairie Creek below Brown Creek, and ten were placed in the control reaches (Figure 2). Number of redds placed in each strata were as follows:

<u>Strata in Control Reaches</u>	<u>Number of Redds</u>
Lost Man Creek	5
Prairie Above Brown Creek	5
<u>Strata in Affected Reach</u>	
Prairie Creek below Brown Creek	2
Prairie Creek below Big Tree Creek	5
Prairie Creek below Boyes Creek	5

Each set of 5 was split into a substratum of 2 redds that were influenced by tributary inputs and a substratum of 3 redds that were not immediately downstream of tributaries. In the Prairie Creek stratum below Brown Creek, numbers of natural redds have historically been low; hence, this stratum was not as intensively sampled. The 2 redds in this strata were placed in the substratum immediately below the tributary to supplement the sample size of tributary-affected redds. Sites were randomly selected within each substratum.

Baskets designed to determine egg survival-to-emergence in the WY91 study were omitted from the WY92 experiment because data in 1991 indicated mortality occurred during the egg stage prior to hatching. Two baskets testing survival-to-hatching, each containing 100 eggs, were placed side-by-side in each redd to achieve replication within redds and avoid effects of one basket being downstream of the other. Baskets were placed in the redds on January 15, 17, and 19 and removed from April 1 to April 9, 1992.

To determine egg mortality due to handling, nine gravel-filled baskets containing eggs from each female salmon used in the study (300 eggs from the fish that ended up having the highest fertility rate and 200 each from the other three fish) were placed in a trough receiving streamflow from an unimpacted tributary of Prairie Creek. These eggs were incubated until the eyed stage, removed, and number of dead eggs were counted.

Approximately 5300 eggs (4400 eggs for artificial redds and 900 for handling mortality estimation) were removed from four female coho salmon between January 15 and 19, 1992. The remaining eggs (650, 1410, 1760, 1500) from each female were incubated in hatch troughs at the PCFFA rearing site (Figure 2). After hatchery personnel estimated all eggs were eyed, fertilization rates of the egg stocks from each fish were calculated through adding the eggs in a rubber hose and counting the number with cellular development. In this WY92 study, we were not able to determine survival to hatching of the control trays due to facility limitations. This was acceptable because the previous year's results indicated the difference between survival to eyeing and survival to hatching at the rearing site was small (< 3%).

Temperature. Campbell recording thermographs were installed at RNP's gaging stations on the stream reaches of Prairie Creek (Figure 1). Peabody-Ryan temperature recorders were also installed at these sites as a backup. Temperature data were used to estimate stage of embryo development during incubation, which helped determine when baskets should be removed.

Percent Fines. To remove the baskets testing survival-to-hatching, we hooked a chain winch attached to a tripod to the cables of the infiltration bags. A 30-cm diameter McNeil core sampler was pushed into the streambed as the bag captured the basket and the surrounding gravel and was winched up through it. Benefits of sampling in this fashion were: (1) it helped to obtain a more complete core sample by preventing sloughing of the sample while winching the infiltration bag upward; (2) it created a zone of slack water above the sample, protecting the sample from the streamflow washing away an unknown amount of fines (as it was, a small plume of fines was observed to bleed into the surrounding streamflow during sample extraction, but the loss of fines from the samples would probably have been much greater otherwise); and (3) it minimized the disturbance to the rest of the redd by preventing the hole from collapsing prior to backfilling. After the sample was removed, the hole was backfilled through the McNeil sampler with gravel collected nearby and the McNeil sampler was then removed.

Baskets testing survival-to-emergence were removed in April, 1991. Prior to removal, we slid a plugged piece of copper tubing into the aluminum permeability pipe to close off the perforations. Then, pressurized carbon dioxide was injected into the aluminum tube to freeze a core of gravel, fines, and water in the basket. The egg basket apparatus was quickly removed using the tripod and infiltration bag. The stratigraphy of the 30-cm core was preserved in a three-chambered tray. The resultant three subsamples were analyzed individually and as a whole for percent fines later in the laboratory.

We wet and dry-sieved all gravel samples to obtain particle size distributions by volume and weight. Since gravel in the egg pockets was cleaned of all fines < 4.7 mm when constructed, we calculated percent fines for < 4.7 mm, < 2.0 mm, < 1.0 mm, and < 0.5 mm. Infiltration bag data were truncated at 128 mm (see Section IV). The largest rocks in the baskets never exceeded 128 mm and were purposely placed at the bottom of baskets to mimic an egg pocket; however gravel outside the basket captured by the infiltration bag occasionally had gravel particles > 128 mm. Wet volumes were converted to dry volumes to remove the bias of smaller size classes toward incorporating more water into the volume estimate. For instance, volume of fines < 0.5 mm was multiplied by 0.70, the next class of 1.0 to 2.0 mm was multiplied by 0.77, and so on (Platts et al. 1983).

When stream gravel samples were sieved to determine proportions in each size class, dark fine-grained organic particulates settled out with fine sediment < 0.5 mm. These non-cohesive organics may not have the same adverse effect on eggs as fine inorganic material. Additionally, more organic matter was introduced by worm excrement and mucous. Thus, the organic/inorganic composition of fines was determined in WY91 to attempt to evaluate

only the impact of the inorganic fine sediment originating from the bypass on fish egg survival. To remove the effect of the organic component, organics were burned off gravel samples and tests rerun on the inorganic component of fines.

Organic matter mostly occurred in the fine sediment fraction < 0.5 mm. This fraction was ignited. We weighed 5-gram subsamples before and after burning at 450°C for 24 hours in a muffle furnace. For the hatching bags, 1 subsample each was taken from the basket itself and one from outside the basket and data for these were averaged. The percent difference in weight was recorded as the percent of organic matter within the subsample. The average percent organic matter for the subsample was applied to the whole sample, and new particle size distribution curves that omitted this fraction were developed for each redd. We then tested for differences in percent of fine inorganic material between the control and affected reaches.

Geometric Mean Diameter and Fredle Index. In WY92, we also calculated the geometric mean diameter and fredle index of the gravel samples in infiltration bags using Everest et al. (1987) equations and truncating at 128 mm. The fredle index is an index of substrate permeability and pore size believed to be correlated to salmonid egg survival. The geometric mean of the gravel framework, which does not include fines < 4.7 mm, was calculated also.

Permeability and Dissolved Oxygen. Intragravel permeability and dissolved oxygen (DO) were measured in the aluminum standpipes within the egg baskets. Perforations at the bottom of the pipe were at the same level as the eggs in the baskets. DO was measured by lowering a probe into the pipe. Measurements were repeated at least three times consecutively to obtain a reliable average.

A similar plastic standpipe, developed by Gangmark and Bakkala (1958) and called a Mill Creek pipe, was installed in the center of each redd several weeks before the egg baskets were buried in the redds. These pipes, provided by Humboldt State University, were used to measure apparent velocity and permeability. During redd construction, the Mill Creek standpipe was placed in between the holes for the baskets at the same depth the baskets would be--30 to 35 cm (Figure 6). The standpipe was offset laterally to keep the salt solution injected into the pipe during apparent velocity measurements from interfering with the downstream basket. Several large cobbles were placed around each standpipe to simulate egg pocket conditions; these were buried with sieved material.

Permeability testing procedures followed those of Terhune (1958), whereby the rate of water inflow was measured in the standpipe following development of a 1-inch head (water level in the pipe was lowered to 1 inch below the free-water surface). This was accomplished by removing the cap from the standpipe, attaching a taller section of pipe which extended above the surface water level, and inserting a length of copper tubing to 1 inch below the free-water surface. The tubing was attached to a vacuum pump via a graduated catchment chamber. After head was established (as indicated by air bubbles entrained in the water being suctioned into the chamber), the volume of inflow into the measuring chamber was

measured 3 times over a known length of time. The test yielded an average rate of water inflow, which correlates directly with permeability.

In WY91, initial permeabilities and DO concentrations were measured in the plastic Mill Creek pipe about two weeks after egg emplacement (January 23-26). To avoid egg disturbance during the sensitive stage, we did not sample DO in the aluminum pipes in the baskets until February 7-11 and permeability until February 13-19, 1993. The final series of measurements in all the pipes were performed just prior to removal of the hatching baskets (March 25-29). Some measurements were taken during the emergence period. However, tests immediately following hatching basket removal showed that the disturbance greatly altered the measurements for the remaining emergence baskets (Appendix B). Thus, these data were not used in the analyses.

In WY92, permeability and DO measurements were taken immediately after placement of baskets in the artificial redd (January 17 to 27) and just before basket removal (March 18 to 25) in all three pipes. It was also measured at similar stream discharges. In WY91, DO was measured after permeability testing, which we found could increase DO up to a few tenths. Thus, DO was measured before permeability in WY92 to avoid disturbing intragravel conditions.

Apparent Velocity. Because of the complex pattern of seepage in stream gravels, true velocity can only be measured at one specific point. This was not possible, so we used the Mill Creek standpipes to measure "apparent" velocity of intragravel water within artificial redds. Apparent velocity was measured at the same time permeability was measured during the incubation period, following the procedures of Gangmark and Bakkala (1958). A salt solution of known concentration was injected into the pipe, and conductivity was measured serially over a specified time period. The rate at which the initial salt solution was diluted can be used to estimate apparent velocity from a calibration curve. Calibration of this data is complex and will not be analyzed for this report. The data is available for analysis at some future date.

Worms. Other factors that may affect egg survival were noted and, if possible, evaluated during this study. Oligochaete worms appeared to adversely affect egg survival in WY90. They were found in two artificial redds below May Creek, which was not part of the study area in WY91 and WY92. Abundance of oligochaete worms found in hatching baskets in WY91 were rated high, medium, low and none. A high rating indicated a very large mass of worms was found filling up the egg pocket. We weighed worm masses to the nearest gram in all emergence baskets.

Data Analysis. Percentage data were adjusted to minimize nonnormality using a square-root arcsine transformation. In WY92, permeability data were transformed using the natural logarithm. For both years, all differences between the control reaches and affected reach were tested for significance using either 2-sample t-tests or analysis of variance (ANOVA) or, when parametric test assumptions were violated, non-parametric statistical equivalents.

To account for the differences in gravel framework between the reaches (see Section IV), the geometric mean of the gravels without fines < 4.7 mm was added as the covariate in an analysis of covariance testing for differences in fine sediment and survival between reaches. This tested for differences between reaches after adjusting for differences in the gravel framework. Redds influenced by tributaries were separated from other redds in some data analyses to remove the tributary effect.

Repeated measures analysis of variance was used to test for differences in DO and permeability in redds over time and between surface and intraredd water. In WY92, the two redds below Brown Creek were excluded in repeated measures analysis to meet the assumption of equal sample sizes between groups. When a two-way interaction term was significant, we tested differences using Scheffe's post-hoc comparison test. Paired t-tests were used to compare values between the hatching and emergence baskets. Non-parametric statistical tests were used for the WY91 emergence basket fine sediment and DO comparisons (Kruskal-Wallis test) and for detecting changes in DO over time (Wilcoxon Sign test). Unless stated otherwise in the results, parametric statistics were used. Relationships between egg survival and the variables measured in the egg pocket were examined for significant correlations. In WY92, baskets with worms were removed from correlations of egg survival with fines, permeability, or DO. Multiple regressions were run using all variables of interest and the stepwise procedure. A difference or correlation was considered significant when $P < 0.05$. All statistical tests were run using SPSS (SPSS Inc. 1988).

Egg survival rates were divided by the parent fish fertility rate (survival to hatching of control eggs)(Hewlett and Plackett 1979) to remove the effect of the parent fish from the data analysis. Monte Carlo simulations were run on WY92 data to test for the effect of variability in these fertility rates on the results of tests between treatment and control reaches (Appendix G).

In WY92 fewer fish spawned in the reach just below Brown Creek, so analyses were conducted with the two baskets below Brown Creek (1) included to represent all strata and (2) excluded to better represent actual spawning areas for the year. We tested for correlations two ways: (1) between variables measured in each basket using each basket as a sample unit, and (2) we averaged basket values using the redd as a sample unit. Basket results were averaged for each redd when testing for differences in means.

Many statistical tests were run on the results using a significance level of 0.05. This means 5% of the tests showing significance may be in error. For this reason, we always listed the actual P value to evaluate probabilities of Type I errors. Use of a smaller significance level with the small sample sizes of this study would increase the likelihood of statistically finding no effect from the bypass when, biologically an effect may exist. To be conservative and protect Prairie Creek aquatic habitat, which is part of a national and state park, we decided to use this confidence level in order to err on the environmentally conservative side.

A.3 Results

WY91 Results:

Egg Survival-to-Hatching. Fertilization rates of the egg stocks from the three female salmon used in WY91 were 92%, 90%, and 68%. Natural viability of these eggs to hatching was estimated to be 92%, 87%, and 67%, respectively. Percentage of eggs surviving to the eyed stage in the basket that tested handling mortality was 98.0%, so handling mortality appeared to be small (2%).

Fertilized eggs were incubated in the hatching baskets from January 11 and 12 to approximately March 27, 1991, a period of 75 days (1148 degree days). The eggs incubated in hatch troughs hatched much earlier, at 60 days (950 degree days) under similar water temperatures.

Mean egg survival-to-hatching was 0.7% (SE = 0.4) in the affected reach (below Brown Creek) and 9.0% (SE = 4.6) in the control reach (above Brown Creek)(Figure 11). The difference between reaches was not statistically significant ($P = 0.09$). Survival-to-hatching ranged from 0 to 3.0% in the affected reach and 0 to 45.0% in the control reach (Appendix C).

Zero egg survival was common (60% of the redds experienced 100% mortality). Seventy percent of the redds below Brown and 50% above Brown (control reach) had 0% survival-to-hatching.

Although not quantified, hatched sac-fry in the affected reach appeared smaller, weaker, and had reduced swimming ability than those in the control reach. Several were still in the egg stage. Many appeared to have just hatched, whereas fry in the control reach appeared more well-developed. Hatching was delayed by at least 13 days (198 degree days) in both reaches when compared to eggs incubated at the PCFFA rearing site. Although not quantified, it appeared that most intact dead eggs had eyed. However, the majority of the eggs originally placed in the basket were missing or were represented by the egg case.

Egg Survival-to-Emergence. A bear destroyed the uppermost emergence basket in the control reach, so only 9 baskets were included in the control data set for survival and fines. Permeability and DO data were collected before the bear destroyed the basket, and were used in the analyses. Fry began emerging in mid-April about the same time in both reaches. Mean egg survival-to-emergence was 12.3% in the affected reach and 23.5% in the control reach. The difference between reaches was not statistically significant ($P = 0.14$). Survival ranged from 0 to 32.0% in the affected reach and from 0 to 60.0% in the control (Figure 12, Appendix D).

Half of the emergence baskets above Brown Creek were placed in the stream just prior to the largest storm of the year (marked sites on Figure 12 plus one destroyed); all other emergence

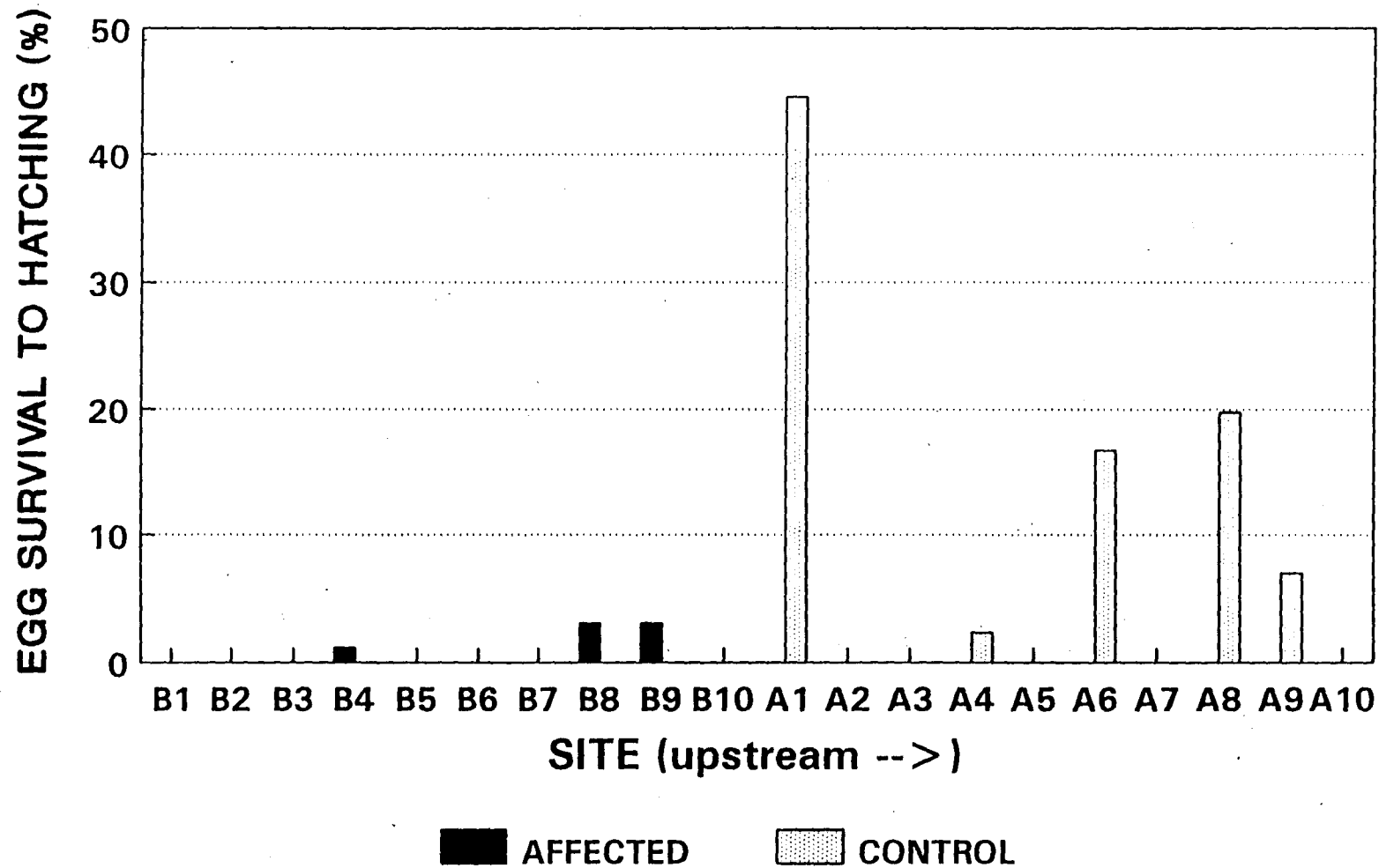


Figure 11. Coho salmon egg survival to hatching in hatching baskets placed in artificial redds in January below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, norther California, March 1991.

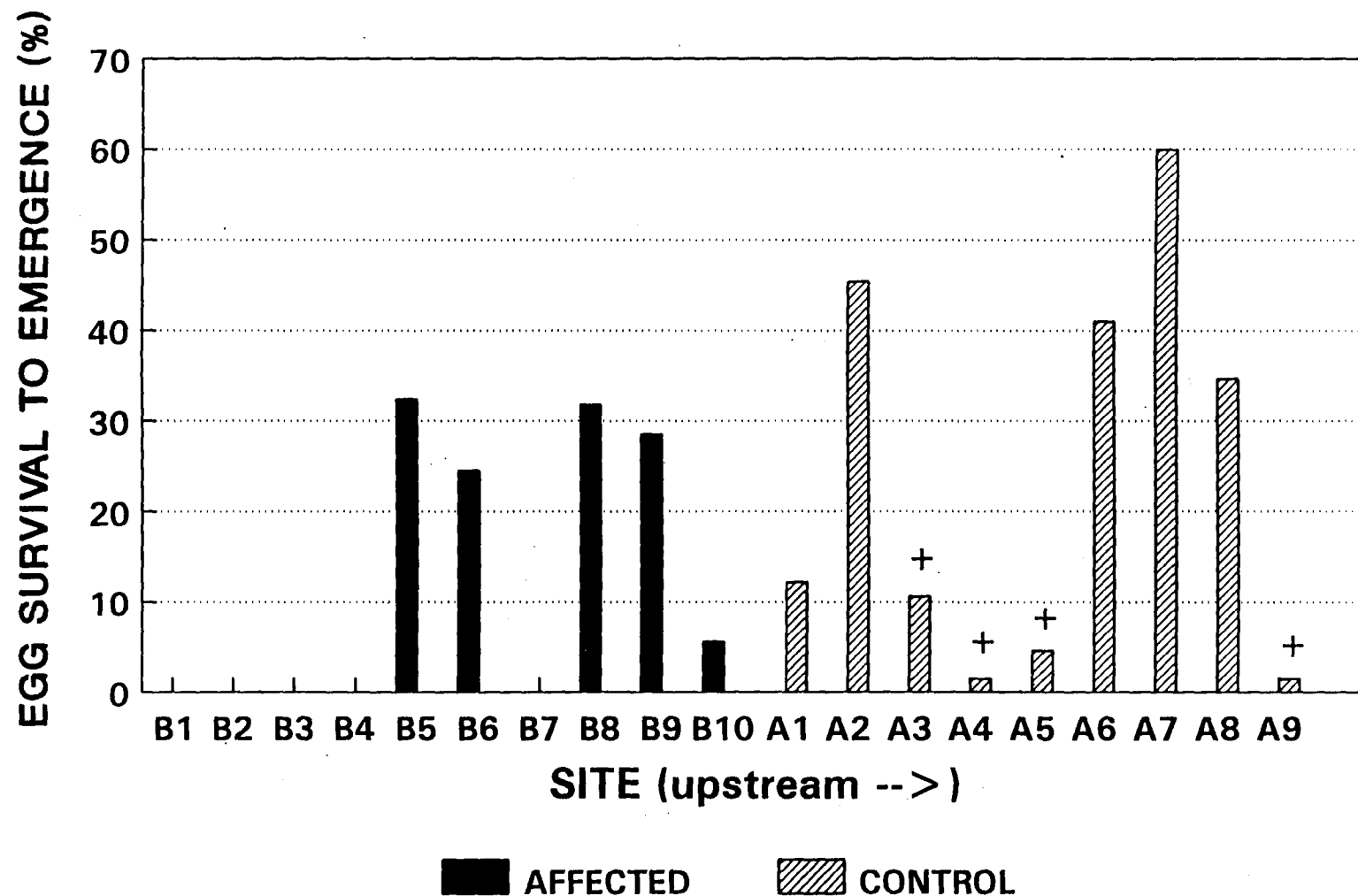


Figure 12. Coho salmon egg survival to emergence in baskets placed in artificial redds in January below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, Northern California, March 1991.

baskets were not in place until soon after the storm because of difficulties in obtaining ripe females. This means that only half of the baskets in the control reach were subjected to the more severe sedimentation conditions that are associated with large storms. As expected, survival rates were lower in these baskets; mean emergence survival in those four baskets exposed to the storm was only 4.0%. Survival was significantly better in the control reach than the affected reach when all baskets were subjected to the same weather conditions. When the four baskets were removed from analysis, mean survival-to-emergence was 38.6% in the control reach vs. 12.3% in the affected reach ($P = 0.009$).

No entrapped or dead sac-fry were found in baskets upon removal. Timing of initial and peak emergence was approximately the same for both reaches. Initial and peak emergence in these reaches occurred after 95 (1462 degree days) and 108 days, respectively. Fry from both reaches generally appeared to be in healthy condition (fry sizes are on file at the Orick RNP office). Because eggs were destroyed during the freezing process, we were unable to observe whether many eggs had eyed before dying.

Overall Egg Survival. Because young were determined to die in the egg stage and not during emergence, egg survival-to-hatching can be compared and averaged between hatching and emergence baskets. Mean egg survival for all the emergence baskets was significantly higher (17.6%, SE = 4.3) than the hatching baskets (4.9%, SE = 2.4) ($P < 0.01$). All hatching baskets and 4 of the control reach emergence baskets were exposed to the January 12 storm. When all baskets were separated by whether they were subjected to the January 12 storm, mean egg survival was higher in those unaffected by the storm (21.1%, SE = 5.1) than those affected (4.8%, SE = 2.1).

Mean survival within redds (averaged between emergence and hatching bags) was significantly lower in the affected reach than the control reach (Table 8, Appendix E). When redds just downstream of tributaries were removed from the analysis, the results did not change much (5.8% in the affected reach vs. 18.3% in the control reach). Survival was not correlated to gravel framework indices, so accounting for local differences in gravel framework did not change the results, either.

Table 8. Mean survival, permeability and fines within artificial redds in the affected and control reaches (standard error in parenthesis), winter 1990-1991.

	Affected Reach Mean (%)	Control Reach Mean (%)	P
Percent Egg Survival	6.50 (2.50)	15.60 (4.40)	0.0300
Percent Change in Inflow Rate (cm ³ /sec)	-26.77 (5.94)	14.34 (8.72)	0.0011
Fine Sediment <4.7 mm (by weight)	6.65 (1.25)	3.83 (0.54)	0.0700

Average egg survival ranked highest in the control reach, and decreased in a downstream direction in the strata within the affected reach (Table 9).

Table 9. Mean egg survival (n = sample size) in individual stream sections, winter 1990-1991. Reaches are listed in order from upstream to downstream.

Percent Egg Survival		
Stream Reach	Mean	S.E. ^a
Prairie Creek above Brown Creek (n = 10)	15.1	4.2
Prairie Creek below Brown Creek (n = 3)	12.0	4.6
Prairie Creek below Big Tree Creek (n = 3)	9.5	4.9
Prairie Creek below Boyes Creek (n = 4)	0.1	0.1

^a Standard error.

Percent Fines in Hatching Infiltration Bags. The volume of fines < 4.7 mm (the size fraction sieved and removed from the redd) that infiltrated back into the redd over the incubation period and captured by the hatching infiltration bag were largely composed of fines < 0.5 mm (82% in the affected reach and 87% in the control). Even after volumetric analyses were corrected for water volume, ratios of weight to volume determined for each bag were variable (Appendix E). Therefore, results for both weights and volumes of fines are presented in this report.

Mean percent fines in hatching bags at the end of the incubation period did not significantly differ by weight or volume between the control and affected reaches (Table 10). Percent fines < 1 mm ranged from 0.9 to 7.0% by weight and from 5.0 to 17.8% by volume in the affected reach. In comparison, fines < 1 mm in the control reach ranged from 1.2 to 4.3% by weight and from 3.9 to 21.7% by volume (Figures 13 and 14).

When data were adjusted for local variations in the geometric mean (based on weight) of the gravel framework, percent fines by weight was significantly higher in the affected reach than the control reach for fines < 4.7 mm ($P = 0.041$; $r = 0.68$, $P = 0.007$). Differences were not significant for the other two size classes ($P = 0.183$ and 0.281).

Due to laboratory error, organic matter content was not obtained for one site in the control reach and one site in the affected reach. Organic content within the fine fraction < 0.5 mm was similar between the reaches in the redd gravel. When the organic matter was removed, inorganic fines < 0.5 mm still did not significantly differ between reaches (Table 11). Sites with worms did not have significantly greater amounts of organic material, either.

Percent Fines in Emergence Infiltration Bags. Similar to hatching bags, fine sediment < 0.5 mm dominated the fine fraction < 4.7 mm in the emergence bags, comprising 73% and 79% of the volume in the affected and control reach, respectively. Ratios of weight to volume determined for each bag were variable and similar to hatching bags (Appendix E).

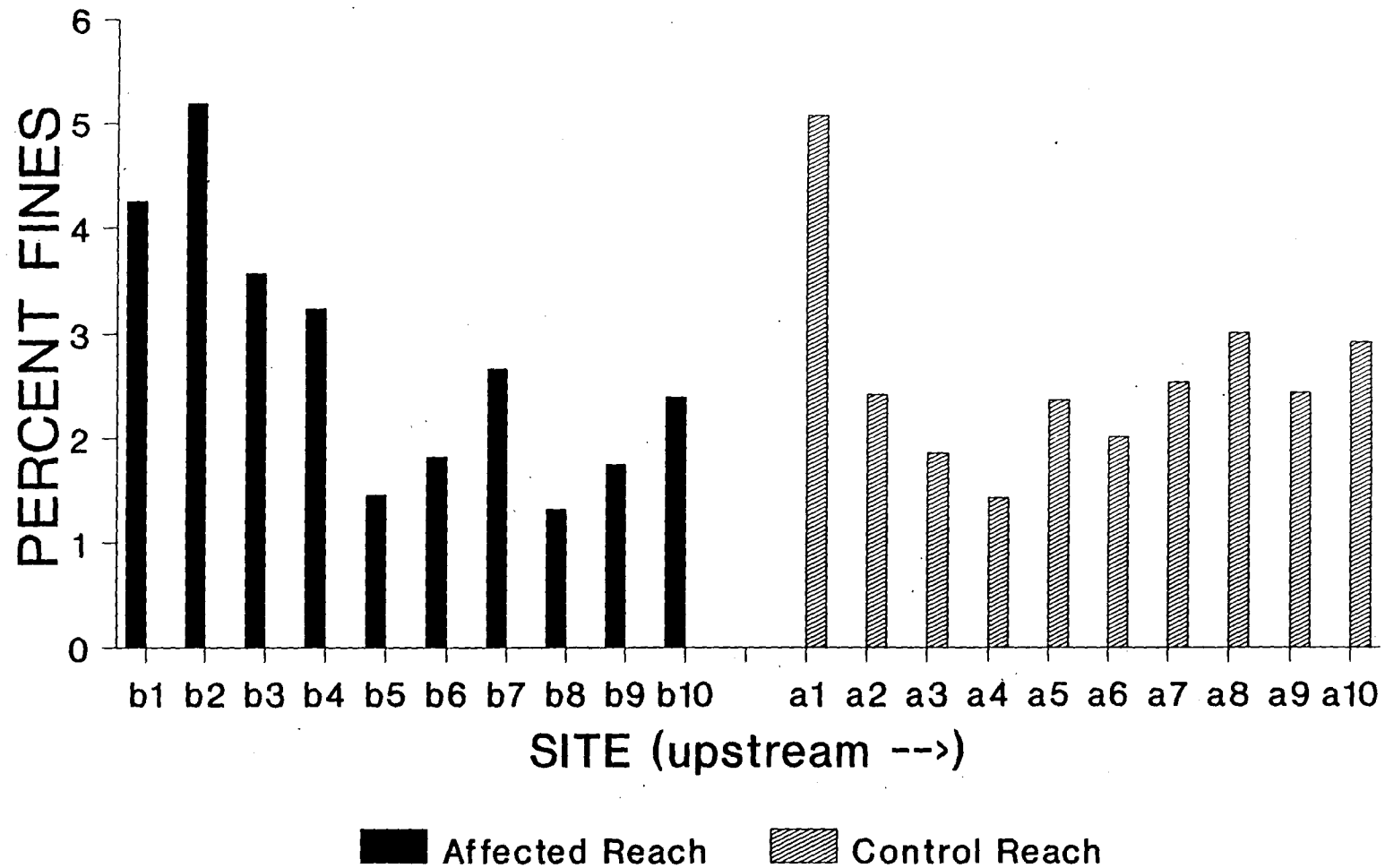


Figure 13. Percent fines (< 1mm) by weight from coho salmon hatching baskets placed in artificial redds in January below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, March 1991. Above the Brown Creek confluence is the control reach; below is the affected reach.

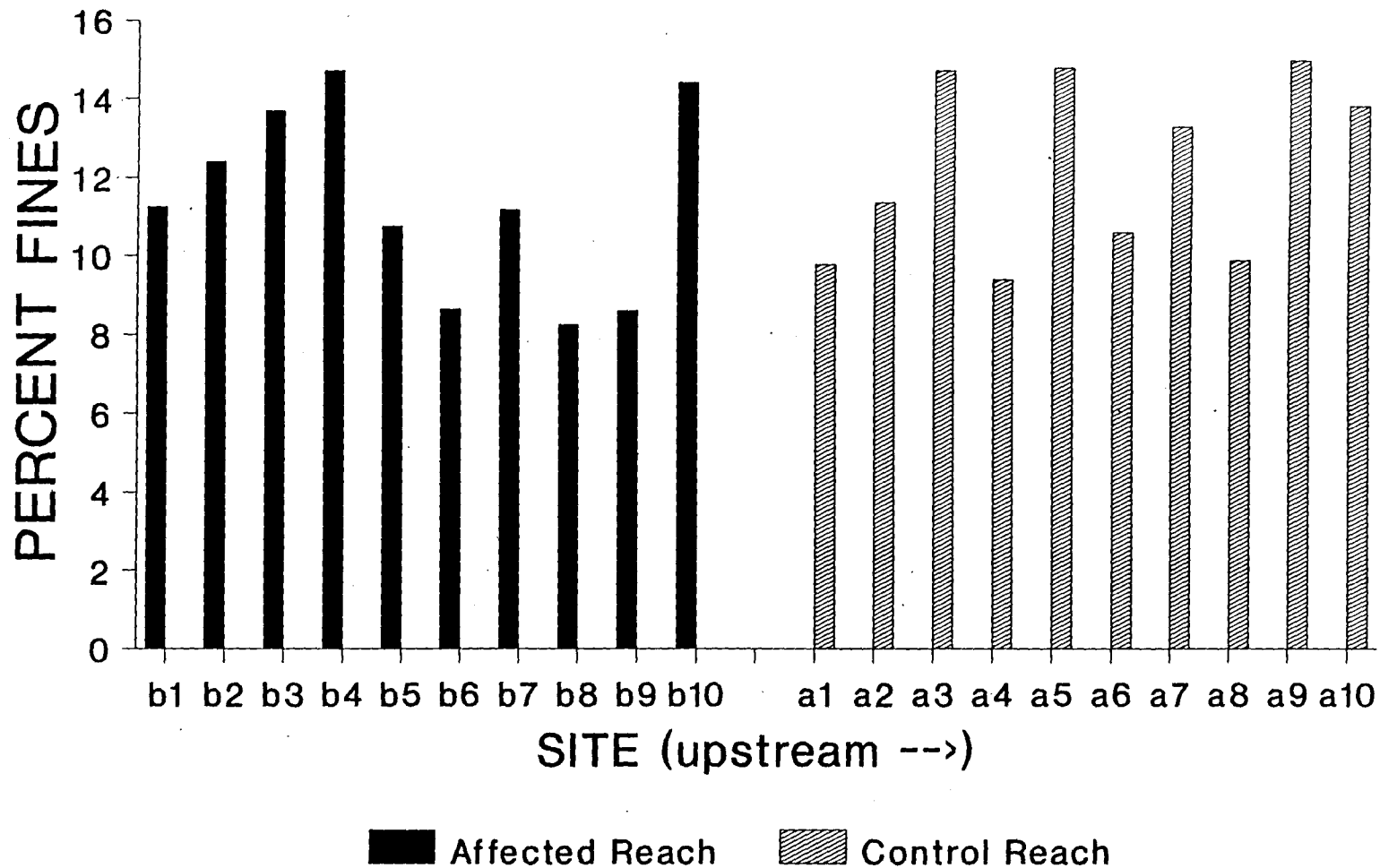


Figure 14. Percent fines (< 1mm) by volume from coho salmon hatching baskets placed in artificial redds in January below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, March 1991. Above the Brown Creek confluence is the control reach; below is the affected reach.

Table 10. Comparison of percent fines in hatching bags after eggs had hatched in the affected (below Brown) and control (above Brown) reaches of Prairie Creek, winter 1990-1991.

FINE SEDIMENT (%)					
PARTICLE SIZE(mm)	MEAN AFFECTED REACH	S.E.	MEAN CONTROL REACH	S.E.	P*
BY WEIGHT					
< 4.7	4.81	0.65	4.04	0.60	0.258
< 1.0	2.77	0.41	2.50	0.22	0.683
< 0.5	1.91	0.34	1.81	0.12	0.847
BY VOLUME					
< 4.7	13.12	0.86	13.48	0.74	0.741
< 1.0	11.38	0.76	12.25	0.72	0.414
< 0.5	10.76	0.71	11.71	0.76	0.377

* Significance level--less than 0.05 was considered a significant difference between means in this report.

Table 11. Comparison of percent of fines containing organic matter and percent of total gravel sample composed of inorganic fine sediment in artificial redds in affected and control reaches of Prairie Creek, 1990-1991.

< 0.5 (mm)	Affected Reach		Control Reach		P
	Mean (%)	S.E.	Mean (%)	S.E.	
Organic Content Hatching Bag	12.3	1.40	13.6	1.54	0.514
Organic Content Emergence Bag	10.8	5.30	16.0	3.30	0.023
Inorganic Fines Hatching Bag	1.8	0.36	1.5	0.17	0.825
Inorganic Fines Emergence Bag	2.7	1.30	1.4	0.40	0.010

Mean fines by weight in emergence bags were significantly greater in the affected reach than the control reach, but the difference was not significant by volume (t-test for weight, K-W test for volume) (Table 12; Figures 15 and 16). When adjusted for gravel framework, weight of fines was still significantly greater in the affected reach for all three size classes ($P = 0.002, 0.006, 0.012$).

Table 12. Comparison of percent fines in emergence bags after fry had emerged in the affected (below Brown) and control (above Brown) reaches of Prairie Creek, winter 1990-1991.

EMERGENCE FINES (%)					
PARTICLE SIZE(mm)	MEAN AFFECTED REACH	S.E.	MEAN CONTROL REACH	S.E.	P
BY WEIGHT					
< 4.7	8.48	1.93	3.96	0.66	0.051
< 1.0	4.51	0.90	2.29	0.39	0.048
< 0.5	2.81	0.43	1.70	0.14	0.033
BY VOLUME					
< 4.7	16.75	1.62	14.27	2.31	0.22
< 1.0	13.58	0.97	12.18	1.67	0.22
< 0.5	12.35	0.81	11.25	1.27	0.46

Control sites impacted by the January storm ($n = 4$, all in the control stream) had similar levels of fines in emergence baskets as control sites not storm impacted ($P > 0.28$). The < 1.0 mm mean for storm-impacted control sites was 2.0% by weight and 12.4% by volume ($SE = 0.09$ and 2.22); for other control sites it was 2.5% by weight and 12.0% by volume ($SE = 0.71$ and 2.66).

Only 12 freeze cores (6 from each reach) were successfully extracted from the 19 intact emergence baskets. Three cores failed due to improper technique, and four were incomplete samples because the gravel did not uniformly freeze. Most of the fine sediment was located in the bottom stratum where the egg pocket was located. Mean weight percentages < 1.0 mm in this stratum were almost significantly greater in the affected reach than the control reach ($P = 0.05$, K-W test) (Table 13).

Organic content of the fine sediment fraction < 0.5 mm in the emergence bag was higher in the control reach than the affected reach. Inorganic fines < 0.5 mm were significantly greater in the affected reach than the control reach (Table 11). Emergence bags with worms had no more organic material than bags without worms.

In the affected reach only, fine sediment loads in the emergence bags were significantly greater than the hatching bags for all 3 fine size classes except volume < 0.5 mm (from small to large size classes, $P = 0.004$, 0.012 , and 0.026 by weight and 0.186 , 0.090 , and 0.039 by volume). When sediment loads were averaged between emergence and hatching bags, fine sediment did not significantly differ between reaches, although the mean by weight was twice as high in the affected reach (Table 8). Volume of sediment < 1.0 mm was 12.5% ($S.E. = 0.67$) in the affected reach and 12.1% ($S.E. = 0.85$) in the control reach.

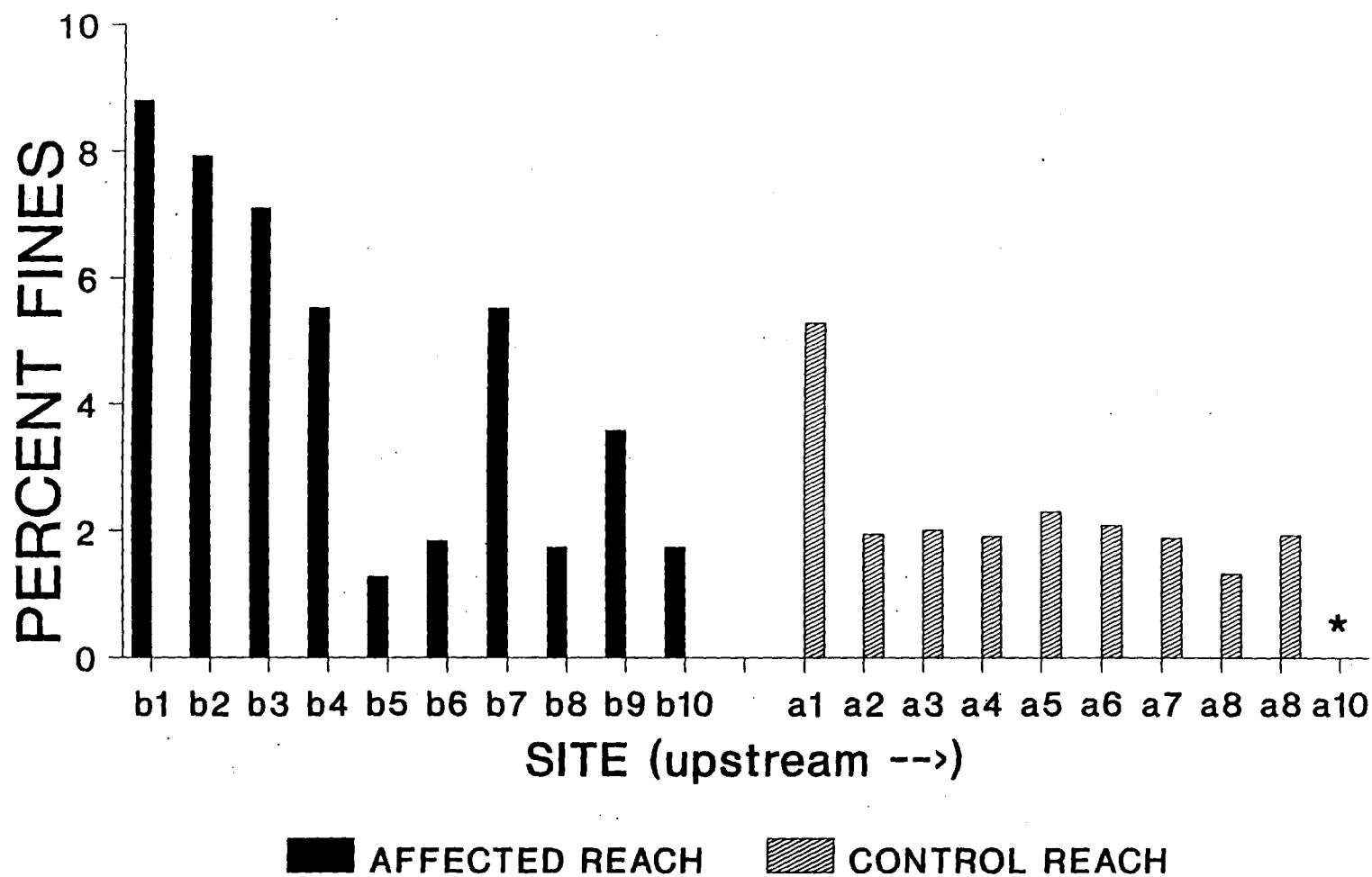


Figure 15. Percent fines (< 1mm) by weight from coho salmon emergence baskets placed in artificial redds in January below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, March 1991. Above the Brown Creek confluence is the control reach; below is the affected reach. * = site damaged by bear.

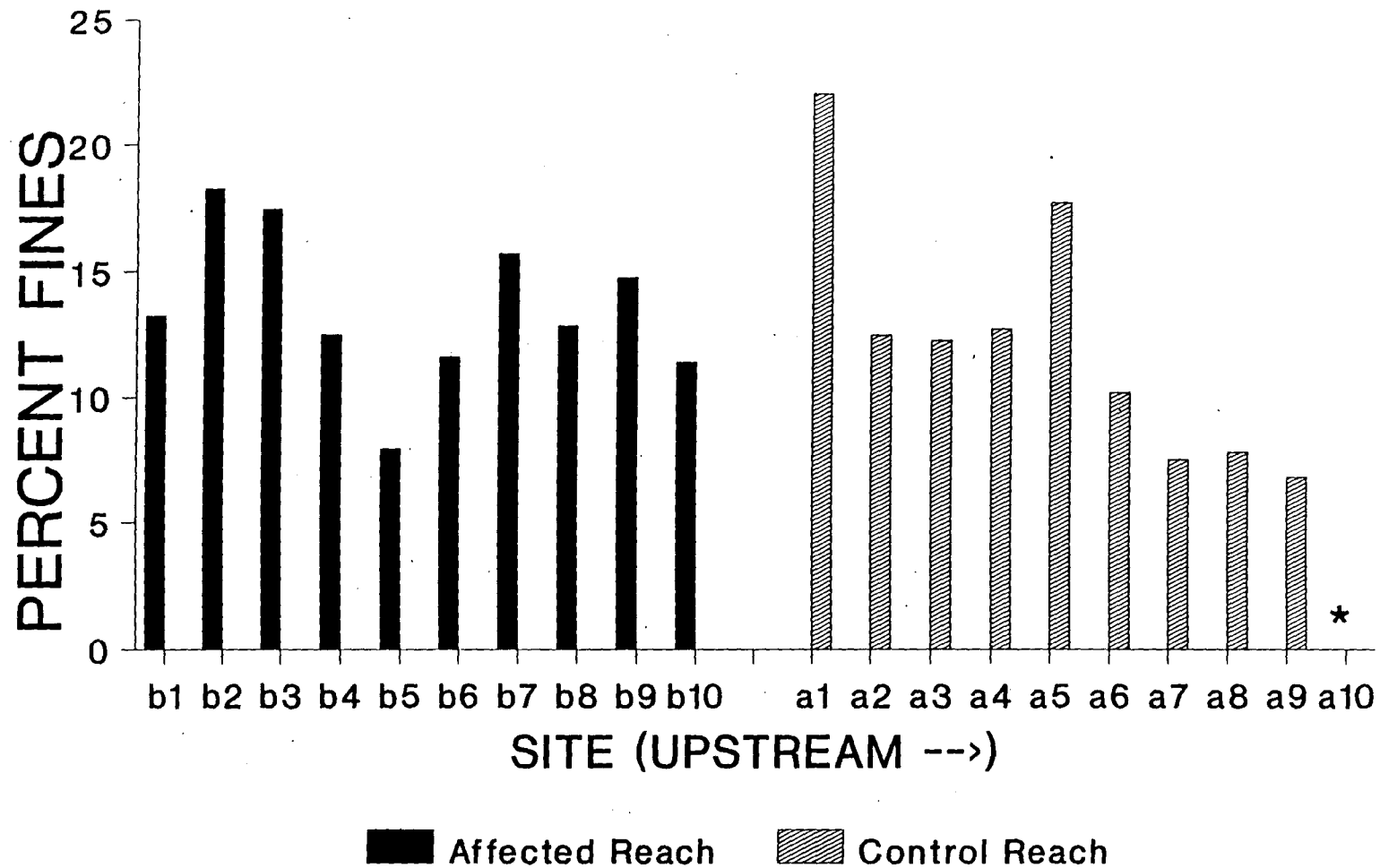


Figure 16. Percent fines (< 1mm) by volume from coho salmon emergence baskets placed in artificial redds in January below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, March 1991. Above the Brown Creek confluence is the control reach; below is the affected reach. * = site damaged by bear.

Table 13. Fine sediment < 1.0 mm by depth within freeze-cores sampled within emergence baskets in artificial redds on affected and control reaches of Prairie Creek, winter 1990-1991.

PERCENT OF FINES < 1.0 mm BY WEIGHT						
SITE NUMBER	Percent of stratum composed of fine sediment < 1.0 mm			Distribution (%) of total core fines across all strata		
AFFECTED REACH	BOTTOM 20-30 cm	MIDDLE 10-20 cm	TOP 0-10 cm	BOTTOM 20-30 cm	MIDDLE 10-20	TOP 0-10
B1	8.96	5.98	6.33	42.13	28.11	29.76
B2	6.83	0.59	0.06	91.31	7.89	0.80
B6	2.22	0.21	0.00	91.36	8.64	0.00
B7	4.08	1.14	1.57	60.08	16.79	23.12
B9	3.28	1.38	*	*	*	*
B10	0.81	0.10	0.03	86.17	10.64	3.19
Mean	4.36	1.57	1.60	74.21	14.41	11.37
CONTROL REACH	BOTTOM	MIDDLE	TOP	BOTTOM	MIDDLE	TOP
A4	3.09	0.06	*	*	*	*
A5	2.04	0.13	*	*	*	*
A6	1.70	0.09	*	*	*	*
A7	0.52	0.36	0.23	46.85	32.43	20.72
A8	0.74	0.34	0.14	60.66	27.87	11.48
A9	2.41	0.14	*	*	*	*
Mean	1.75	0.20	0.19	53.76	30.15	16.10

* The top stratum did not freeze properly in the sample.

When adjusted for geometric mean in an analysis of covariance, the weight of fines < 4.7 mm became significantly higher in the affected reach ($P = 0.002$, $r = 0.76$ and P (for r) = 0.01). Results were similar for weight of fines < 1.0 and < 0.5 mm. Volume of fines still did not significantly differ between reaches.

The reach on Prairie Creek below Boyes Creek ranked the highest for percent fines < 1.0 mm (averaged between emergence and hatching bags), and Prairie below Brown Creek had the lowest amount of fines accumulating in the redds (Table 14).

Table 14. Mean percent fines < 1 mm by weight in individual stream sections, winter 1990-1991. Reaches are listed in order from upstream to downstream.

Percent Fine Sediment < 1.0 mm		
Stream Reach	Mean	S.E.
Prairie Creek above Brown Creek (n = 10)	2.43	0.35
Prairie Creek below Brown Creek (n = 3)	2.09	0.58
Prairie Creek below Big Tree Creek (n = 3)	2.43	0.89
Prairie Creek below Boyes (n = 4)	5.18	0.49

Permeability. Permeability was measured and analyzed during the same time period for both hatching and emergence baskets (Figure 17 and 18). Mean inflow rates (used as an index for permeability) at the end of the incubation period were lower than beginning rates in hatching baskets in the affected reach, but not the control reach (significant interaction of $P = 0.048$). The average change in inflow rate over time in hatching baskets was negative in the affected reach and positive in the control reach, and the changes in the reaches significantly differed ($P = 0.048$). The same was true for the emergence baskets ($P = 0.008$) (Table 15). When the five emergence baskets in the control reach subjected to the January storm were removed from the analysis, initial permeability tended to be higher, but the new mean change over time for the control did not change much ($+9.8 \text{ cm}^3/\text{sec}$, $\text{SE} = 16.7$, $n = 5$) and still differed significantly from the affected reach ($P = 0.041$).

When hatching and emergence baskets were averaged, loss in permeability was significantly greater in the affected reach than the control reach (Table 8). Final permeabilities ranked lowest in Prairie Creek below Boyes, and this reach had the greatest loss in permeability over the incubation period (Table 16).

Dissolved Oxygen. Dissolved oxygen concentrations were high and similar in the affected and control stream reaches (Figures 19 and 20). In all locations tested within the artificial redd, DO did not significantly differ between the control and affected reaches ($P > 0.34$, repeated measures ANOVA) (other tests, see Appendix H). Mean DO was higher in the overlying surface water than in the hatching or emergence baskets in January and March ($P < 0.004$, repeated measures ANOVA).

In either the control or affected reaches, Mean DO also did not differ in any of the pipes before and after the incubation period ($P > 0.05$). However, below Brown Creek, mean DO significantly increased in the overlying surface water, although the change was small. DO was measured three times during the incubation period, and at no time did concentrations drop below 9.6 ppm. DO was not negatively and significantly correlated with fine sediment of any size class in the egg baskets in either reach or in the reaches combined; nor was it positively correlated to egg survival-to-hatching or emergence or ending permeability in the baskets. Mean DO was similar between individual creek strata (Table 17).

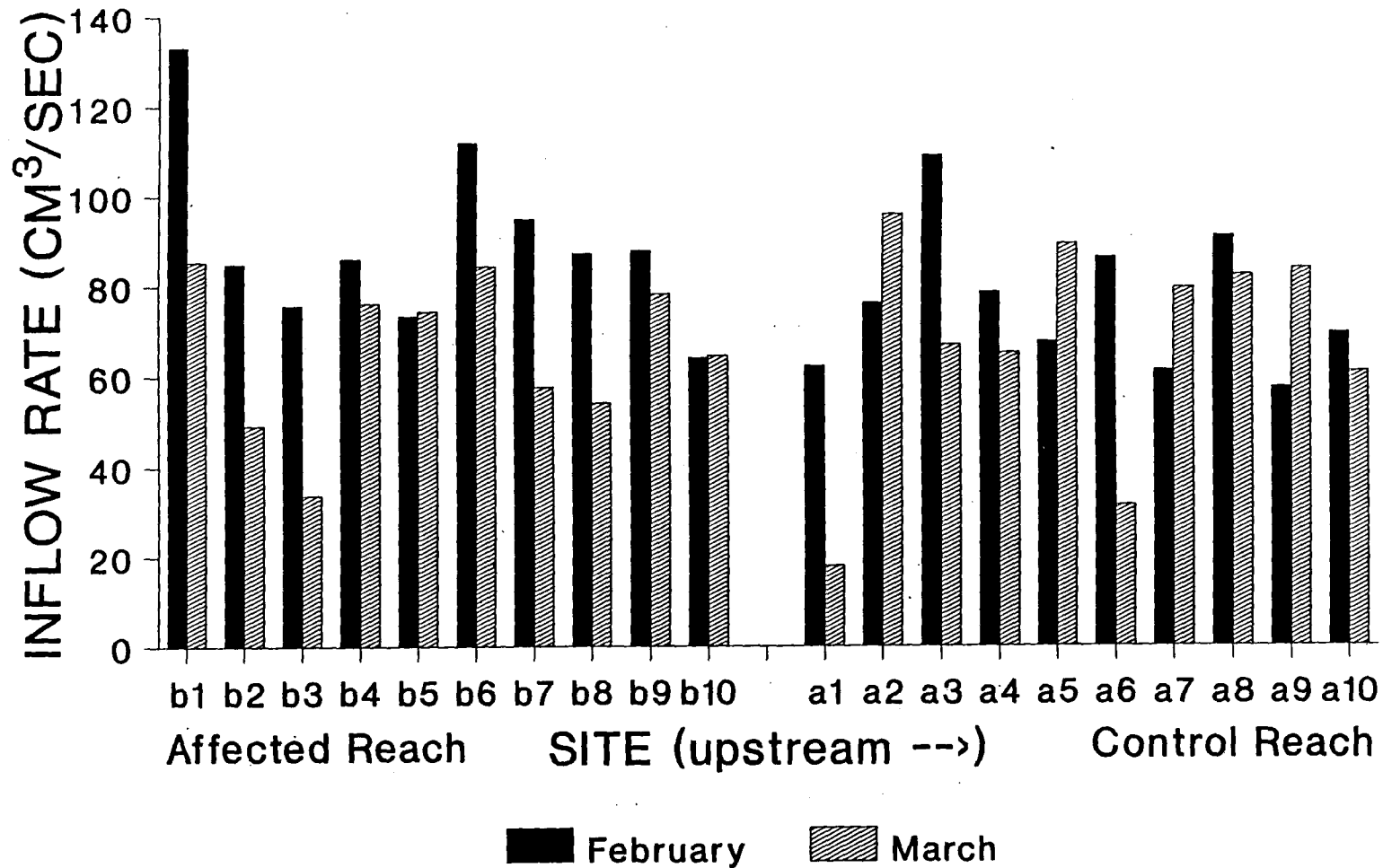


Figure 17. Comparison of inflow rates of standpipes within coho salmon hatching baskets placed in artificial redds below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, 1991. Rates were measured at the beginning (February) and ending (March) of the incubation period. Above Brown Creek confluence is the control reach; below is the affected reach.

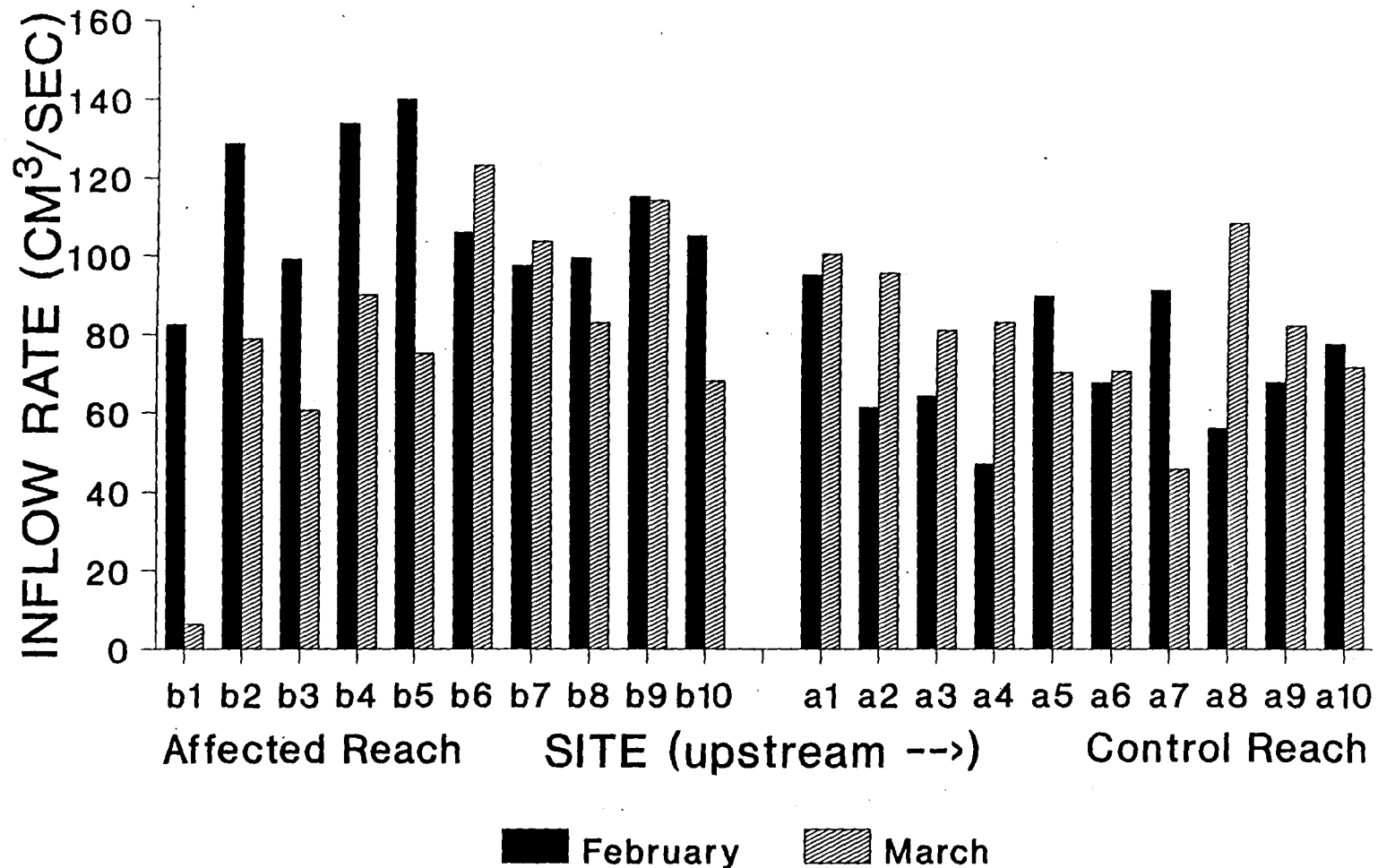


Figure 18. Comparison of inflow rates of standpipes within coho salmon emergence baskets placed in artificial redds below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, 1991. Rates were measured near the beginning (February) and ending (March) of the incubation period. Above the Brown Creek confluence is the control reach; below is the affected reach. + = eggs placed in redds one week prior to the other sites which, unlike the others, were exposed to the year's major storm.

Table 15. Comparison of mean inflow rates in hatching and emergence baskets in artificial redds in the affected and control reaches of Prairie Creek using repeated measures ANOVA. Mean change in inflow rate was compared using the t-test, winter 1990-1991.

	Hatching Baskets		Emergence Baskets	
Permeability (cm ³ /sec)	AFFECTED	CONTROL	AFFECTED	CONTROL
	Mean(S.E.)	Mean(S.E.)	Mean(S.E.)	Mean(S.E.)
Initial February Rate	89.8 (6.3)	75.8 (5.0)	110.8 (5.8)	71.7 (5.4)
Final March Rate	65.7 (5.3)	77.2 (7.3)	80.2 (10.9)	80.9 (6.0)
P* (all sites - initial vs. final)	< 0.05		< 0.005	
Mean Change in Rate	-24.1 (5.7)	+1.4 (10.6)	-30.5 (9.8)	+9.1 (9.1)

* Scheffe's post-hoc comparison test was used for P values.

Table 16. Mean final inflow rate and inflow rate change over the incubation period in individual stream sections, winter 1990-1991. Reaches are listed in order from upstream to downstream.

Stream Reach	Final Inflow Rate (cm ³ /sec)		Change in Inflow Rate (cm ³ /sec)	
	Mean	S.E.	Mean	S.E.
Prairie Creek above Brown Creek (n = 10)	74.1	4.7	+5.3	6.2
Prairie Creek below Brown Creek (n = 3)	77.0	9.6	-16.2	5.7
Prairie Creek below Big Tree Creek (n = 3)	98.9	9.5	-17.6	7.8
Prairie Creek below Boyes (n = 4)	60.0	8.7	-43.0	7.2

Worms. Over half of the hatching baskets were infested with oligochaete worms (*Haplotaxia ichthyophagous*). Worms infested the affected reach sites more than the control sites. Large masses of several hundred worms were found surrounding dead eggs and sac-fry. Mean survival-to-hatching was lower in worm-infested redds than in redds without worms, although the difference was not significant. When worm-infested redds were excluded, mean survival in redds in the affected reach about doubled and in the control reach increased about 50% (Table 18).

Worms had a significantly negative impact on egg survival in the emergence baskets. Average worm mass weight per emergence basket was 22.0 g in the affected reach and 14.8 g in the control reach (averaging about 0.3 g/worm). The majority of the emergence basket

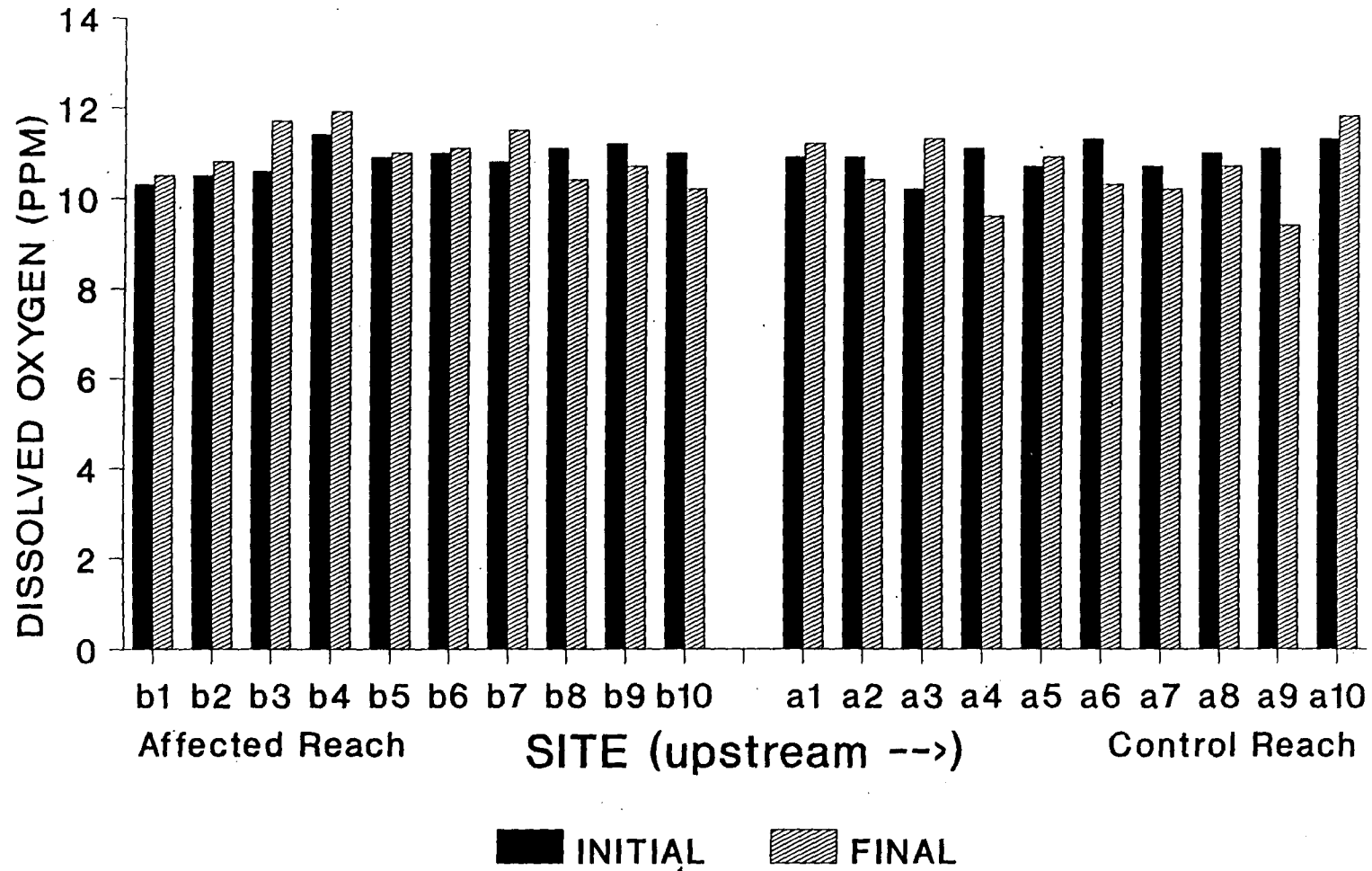


Figure 19. Comparison of dissolved oxygen (DO) rates within standpipes within coho salmon hatching baskets placed in artificial redds below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, 1991. DO was measured near the beginning (February) and ending (March) of the incubation period.

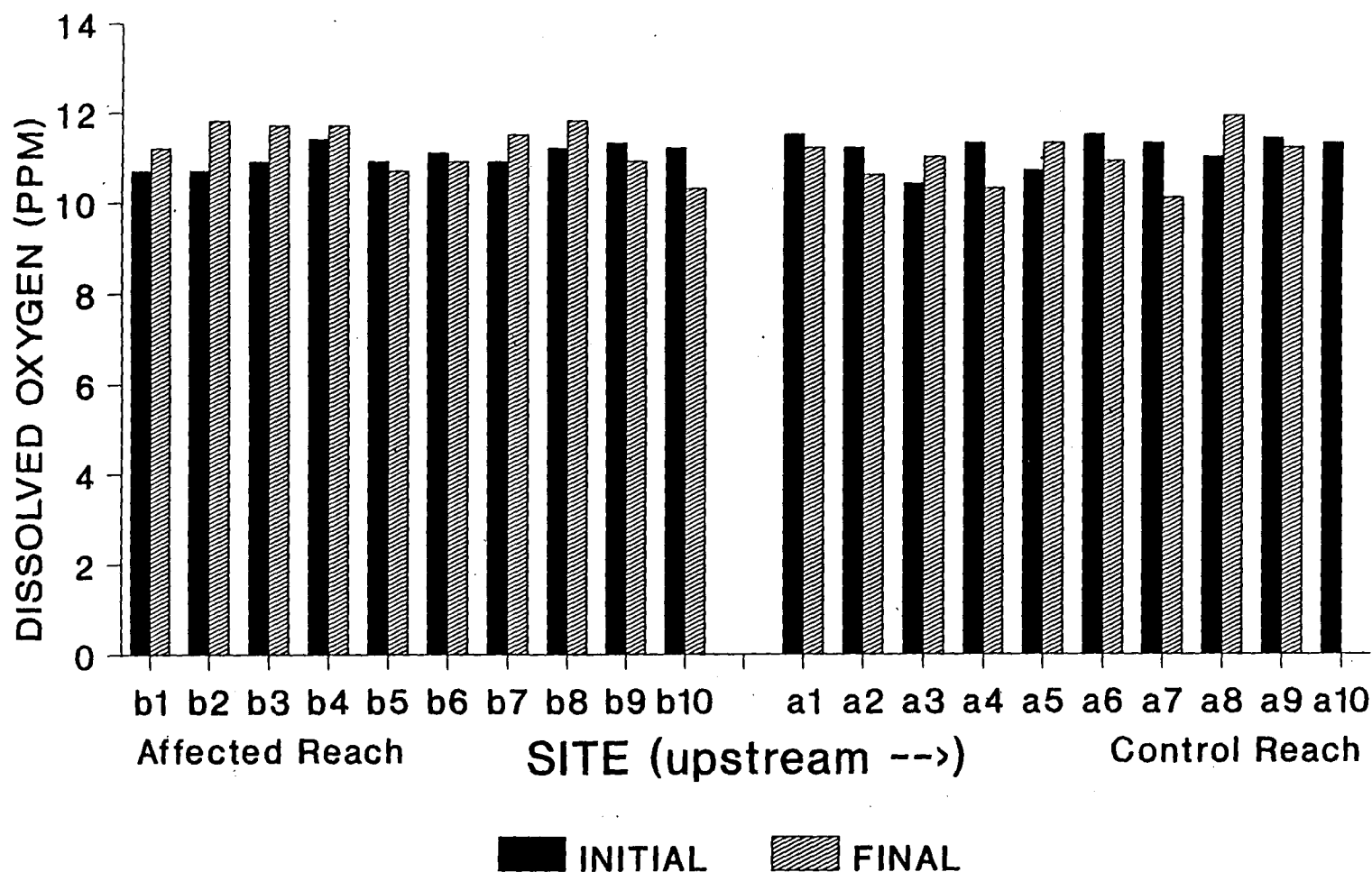


Figure 20. Comparison of dissolved oxygen (DO) rates within standpipes within coho salmon emergence baskets placed in artificial redds below (b1-10) and above (a1-10) the Brown Creek confluence on Prairie Creek, northern California, 1991. DO was measured near the beginning (February) and ending (March) of the incubation period.

Table 17. Mean final dissolved oxygen in individual stream sections, winter 1990-1991. Reaches are listed in order from upstream to downstream.

Final Dissolved Oxygen (ppm)		
Stream Reach	Mean	S.E.
Prairie Creek above Brown Creek (n = 10)	11.1	0.2
Prairie Creek below Brown Creek (n = 3)	10.7	0.2
Prairie Creek below Big Tree Creek (n = 3)	11.1	0.2
Prairie Creek below Boyes (n = 4)	11.4	0.2

Table 18. Percent worm infestation and mean percent egg survival in sites with and without worms by reach, winter 1990-1991. Standard error is in parenthesis.

	% WORM INFESTED	MEAN % EGG SURVIVAL	MEAN % EGG SURVIVAL WITH WORM INFESTATION	MEAN % EGG SURVIVAL WITHOUT WORM INFESTATION	P WITH VS. WITHOUT
PRAIRIE CREEK, ALL SITES					
ALL	62	11.1 (2.6)	7.3 (2.6)	17.1 (5.2)	0.130
HATCH	55	4.9 (2.4)	2.0 (1.6)	8.5 (5.0)	0.144
EMERGENCE	68	17.6 (4.3)	11.9 (4.3)	30.0 (8.7)	0.047*
PRAIRIE CREEK ABOVE BROWN CREEK (CONTROL)					
ALL	47	15.6 (4.4)	11.1 (4.8)	19.3 (7.1)	0.770
HATCHING	40	9.0 (4.6)	4.2 (4.2)	12.3 (7.1)	0.359
EMERGENCE	56	23.5 (7.3)	18.5 (8.1)	29.8 (13.7)	0.544
PRAIRIE CREEK BELOW BROWN CREEK (AFFECTED)					
ALL	75	6.5 (2.7)	4.4 (2.6)	12.7 (7.2)	0.130
HATCHING	70	0.7 (0.4)	0.6 (0.4)	1.0 (1.2)	0.754
EMERGENCE	80	12.3 (4.7)	7.8 (4.6)	30.2 (1.6)	0.062

*Significant

were infested. When worm-infested baskets were excluded, mean egg survival-to-emergence more than doubled in the affected reach and increased 20% in the control reach (Table 18).

In the control stream, worm infestation was only slightly higher in emergence and hatching baskets subjected to the storm (50%) than those not subjected to the storm (40%). In the affected reach, 70% of all baskets exposed to the storm were infested versus 80% of all baskets not exposed to the storm.

A larger percentage of emergence baskets were infested than hatching baskets. However, numbers of worms appeared greater in hatching baskets that contained worms. This general observation was not quantified because weights of worms in the hatching baskets were not measured. Worm infestation was greatest in the stream reach below Boyes Creek (Table 19).

Table 19. Proportion of artificial redds infested with worms in individual stream sections, winter 1990-1991. Reaches are listed in order from upstream to downstream.

Proportion of Redds with Worms	
Prairie Creek above Brown Creek (n = 10)	Half
Prairie Creek below Brown Creek (n = 3)	Two-thirds
Prairie Creek below Big Tree Creek (n = 3)	Half
Prairie Creek below Boyes (n = 4)	All

Fines were not significantly higher in baskets with worms than baskets without worms ($P > 0.55$). However, volume of fines, not weight, in hatching baskets was significantly greater in baskets with large masses of worms ($P < 0.03$).

Correlations of Variables in Redds. Analysis of averaged redd data (data shown in Appendix D) showed that weight of fines was significantly and negatively correlated to egg survival, change in permeability was significantly and negatively correlated to weight of fines < 4.7 mm, and correlations were the strongest in the affected reach (Table 20). When the effect of the differences in the geometric mean of the gravel framework was removed, the partial correlation of change in permeability with weight of fines < 4.7 mm for all sites increased from -0.49 to -0.73. The partial correlation for survival with fines when the gravel framework effect was removed increased only slightly from -0.49 to -0.54. Survival was positively correlated to change in permeability for all sites ($r = 0.50$, $P = 0.015$) and the affected reach sites ($r = 0.52$, $P = 0.06$), but was not correlated in the control reach. In the control reach, worm abundance was negatively correlated to change in permeability ($r = -0.63$, $P = 0.034$, $n = 9$) (meaning more worms were in sites that had reduced permeability), but a similar correlation was not apparent in the affected reach. Over all sites, worms were weakly, but significantly correlated to the smallest fraction of fine sediment. Worms were not significantly correlated to egg survival, however. Appendix F presents correlation coefficients for hatching and emergence baskets analyzed separately. Correlations were strongest in the emergence baskets. In stepwise multiple regression, sediment flux alone was selected as the best predictor of survival (multiple $r = 0.65$, $P =$

Table 20. Correlation coefficients (r) and significance for variables sampled in redds using data averaged between the hatching and emergence baskets in artificial redds in Prairie Creek, winter 1990-1991.

	% SURVIVAL	PERMEABILITY		WORM ABUNDANCE
		% ▲ INFLOW	ENDING RATE	
PRAIRIE CREEK ABOVE AND BELOW BROWN CREEK (all sites pooled)				
BY WEIGHT				
< 4.7 mm	-0.49**	-0.49*	-0.32	0.06
< 1.0 mm	-0.50**	-0.42*	-0.26	0.02
< 0.5 mm	-0.58**	-0.44*	-0.29	0.09
BY VOLUME				
< 4.7 mm	-0.50*	-0.28	-0.17	0.16
< 1.0 mm	-0.54**	-0.18	-0.10	0.30
< 0.5 mm	-0.58**	-0.15	-0.11	0.45*
PRAIRIE CREEK ABOVE BROWN CREEK (CONTROL)				
BY WEIGHT				
< 4.7 mm	0.52	0.32	0.52	-0.27
< 1.0 mm	0.40	0.38	0.62*	-0.34
< 0.5 mm	0.07	0.41	0.66*	0.32
BY VOLUME				
< 4.7 mm	-0.05	0.18	0.48	0.12
< 1.0 mm	-0.33	0.04	0.32	0.32
< 0.5 mm	-0.56	-0.13	0.09	0.53
PRAIRIE CREEK BELOW BROWN CREEK (AFFECTED)				
BY WEIGHT				
< 4.7 mm	-0.87**	-0.76**	-0.60*	0.26
< 1.0 mm	-0.86**	-0.71*	-0.54	0.23
< 0.5 mm	-0.82**	-0.69*	-0.50	0.27
BY VOLUME				
< 4.7 mm	-0.76*	-0.68*	-0.43	0.21
< 1.0 mm	-0.60	-0.44	-0.01	0.27
< 0.5 mm	-0.35	-0.18	0.33	0.33

* P < 0.05 ** P < 0.01 *** P < 0.001

0.0026, 39% of variance accounted for); when worm abundance and ending permeability were added, 51% of the variance was accounted for. Percent fines by weight < 4.7 mm was highly correlated with sediment flux ($r = 0.81$, $P = 0.0001$) and less correlated with geometric mean of gravel framework ($r = -0.48$, $P = 0.03$). In a multiple regression, the latter two variables accounted for 73% of the variance in fines (multiple $r = 0.88$, $P = 0.0001$).

WY92 Results:

Egg Survival. After an average of 35 days (± 2) or 522 temperature units (degree days)(± 14), fertilization rates in WY92 (survival of unhandled eggs to eyed stage) were determined to be 75%, 60%, 18% and 62% for the four control trays representing each fish. Yet, fertilization rates for the handled eggs in the control baskets testing handling mortality were higher at 92%, 69%, 53% and 87%, respectively. Fungus problems were evident on the trays and may have accounted for the poorer survival of the unhandled eggs. Because handling mortality was probably minimal, similar to WY91, mean egg survival rates in the handling mortality baskets were used as fertilization rates to adjust egg survival rates in the artificial redds, rather than the more unreliable rates of the control trays.

WY92 eggs were incubated in each stream reach in water temperatures ranging between 7° and 11° C (Figure 21) and hatched after an average of approximately 79 days (1275 degree days) following fertilization. Eggs from female salmon incubated at the PCFFA site hatched at an average of 48 days (731 degree days) under similar (slightly colder) water temperatures.

Egg survival-to-hatching did not significantly differ between reaches using a t-test. This result was supported after running 1,000 Monte Carlo t-test simulations, each using different fertility rates randomly selected from beta distribution curves developed from the handling mortality control basket results (Appendix G).

Egg survival ranged from 10.6% to 68.8% in the affected reach and from 10.6% to 58.0% in the control reach (Figure 22, Appendix D). Mean egg survival did not significantly differ (1) between affected and control reaches when separated into tributary and non-tributary influenced groups (2) between the two control reaches, Prairie Creek above Brown Creek and Lost Man Creek, nor (3) between sites located just downstream of tributaries and other sites when analyzed in the affected reach or over all reaches combined. When the two redds just below Brown Creek were removed from the analysis, mean survival in the affected reach still did not significantly differ from the control reach (Table 21). The majority of the eggs that died had not eyed and commonly half of the eggs were missing.

Mean survival was highest in the reach below Brown Creek and next highest below Big Tree Creek; both were higher than the most downstream Prairie Creek reach and Lost Man Creek (Table 22).

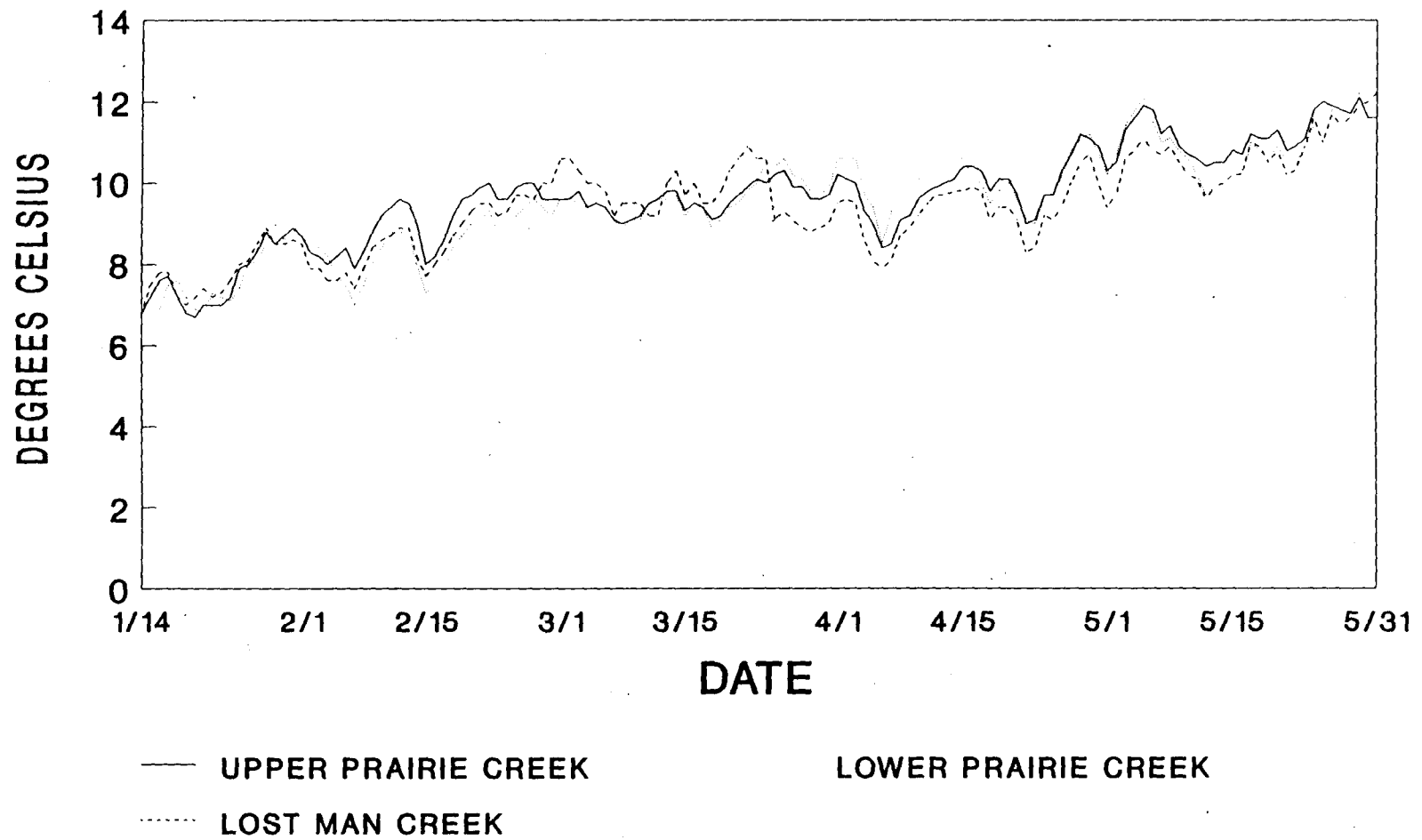


Figure 21. Stream temperatures in Prairie Creek and Lost Man Creek from January to May, 1992.

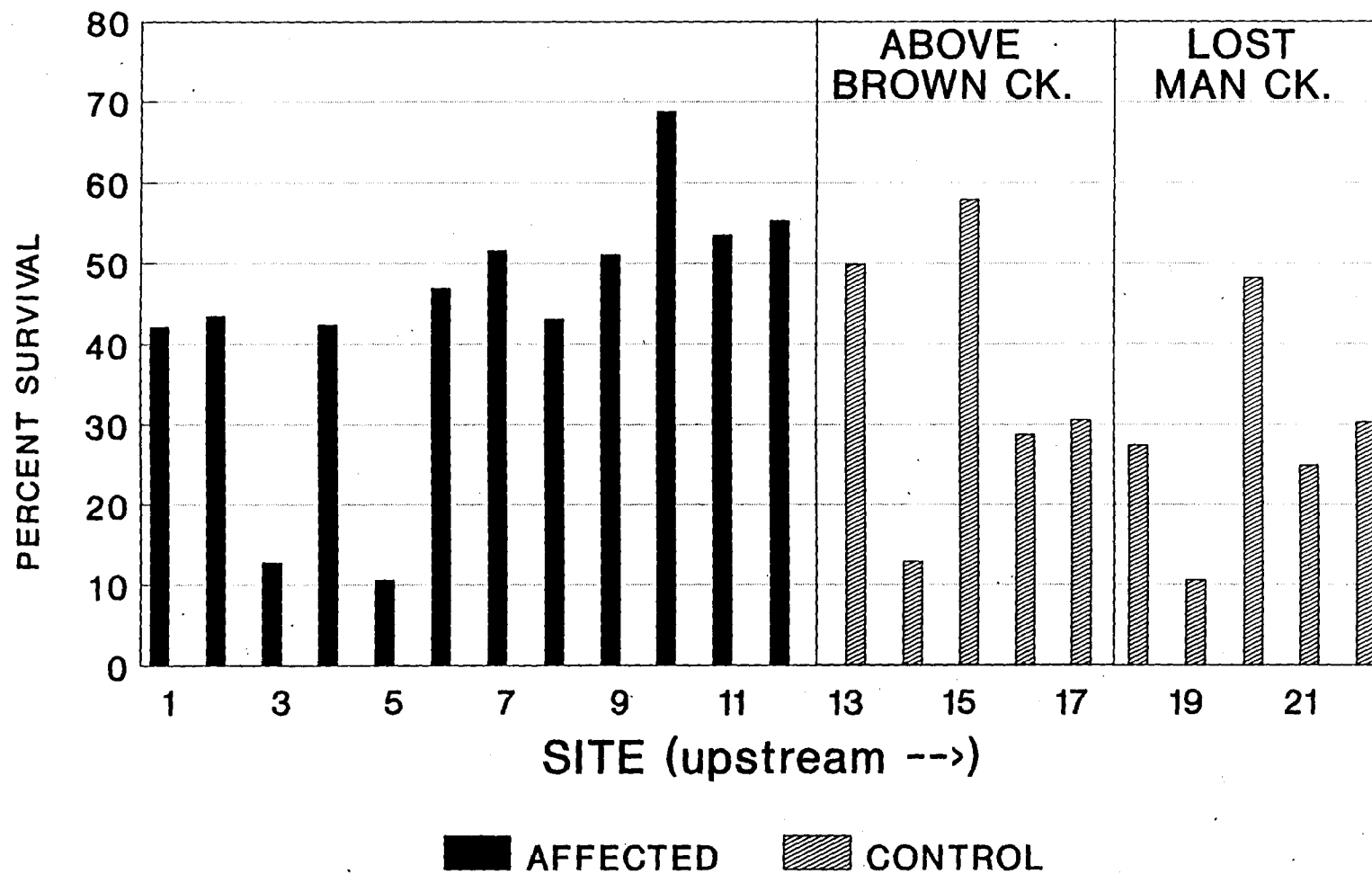


Figure 22. Percent of coho salmon eggs placed in artificial redds surviving to hatching in Prairie Creek and Lost Man Creeks, northern California March 1992. Prairie Creek below Brown Creek (sites 1-12) is the affected reach.

Table 21. Comparison of egg survival means in artificial redds on treatment and control reaches of Prairie and Lost Man Creeks, winter 1991-1992.

Sites	Egg Survival				
	Mean (%)	S.E.	Mean (%)	S.E.	P ^a
	Affected Reach		Control Reach		
All Sites (n = 12,10)	43.5	4.8	32.2	4.9	0.139
No Worms (n = 11,n = 9)	43.6	3.3	32.4	5.5	0.183
Removal of redds below Brown Creek (n = 10,10)	41.3	5.5	32.2	4.9	0.264
	Above Brown Creek Control		Lost Man Creek Control		
Control Sites (n = 5,5)	36.0	8.0	28.3	6.0	0.482
	Tributary-affected		Not tributary-affected		
All Sites (n = 10,12)	39.6	5.6	42.6	7.1	0.183
Affected Sites (n = 6,6)	47.0	8.1	40.0	5.6	0.549

^a P < 0.10 is considered a significant difference between means.

Table 22. Mean egg survival in individual stream sections, winter 1991-1992. Prairie Creek reaches are listed in order from upstream to downstream.

Percent Egg Survival		
Stream Reach	Mean ^a	S.E.
Lost Man Creek	28.3	6.0
Prairie Creek above Brown Creek	36.0	8.0
Prairie Creek below Brown Creek	54.4	0.9
Prairie Creek below Big Tree Creek	52.3	4.4
Prairie Creek below Boyes Creek	30.3	7.6

^a For each reach, n = 5 except below Brown Creek, which was n = 2.

Worms. Only 5% of baskets in the affected reach, control reach, and over all reaches were infested with oligochaete worms in WY92. Two baskets, one in the control reach in Lost Man Creek, and one in the affected reach below Boyes Creek, were infested (Appendix D). The basket in the affected reach had 22 grams of worms; all the eggs in that basket died. Yet, the adjacent basket in the same redd had no worms and very high survival (84.8%).

The infested basket in the control reach had 11 grams of worms and survival was 15.3%. The adjacent basket had no worms and 45.4% survival. Worm-infested baskets had much lower mean survival (7.7%, SE = 7.63) than non-infested baskets (38.5%, SE = 3.9). Egg survival in redds did not change much for the affected or control reach when infested redds were removed from the analysis (Table 21).

Other Effects on Survival. Because the survival rates were adjusted for fertility differences, the fish grouping was expected to have a minimal effect on survival rates. However, a small significant correlation existed between survival and fertilization rates ($r = 0.35$, $P = 0.012$ when baskets with worms were excluded). Using the analysis of covariance test, we removed the effect of parent fish fertilization rates, but results still showed no significant differences in egg survival between the affected and control reaches.

Percent Fines. Fine sediment < 4.7 mm that infiltrated into the baskets was composed of 89% fines < 0.5 mm by volume in the affected reach and 84% in the control reach. Of < 1.0 mm fines, 98% and 97% were < 0.5 mm by volume in the affected and control reach, respectively.

Levels of fine sediment that accumulated in the redds over the incubation period were very low (Figure 23, Table 23). Fines in all size classes tested by weight were significantly lower in the affected reach than in the control reaches. When mean percent fines were measured by volume rather than weight, the difference was not significant, although the trend of lower fines in the affected reach was still present. When differences in geometric mean of the gravel framework were accounted for, differences in fines (and survival) were not significant ($P > 0.05$).

The control reach on Lost Man Creek had significantly higher levels of fines by weight ($P < 0.03$ for all size classes) and volume ($P < 0.0074$) than the control reach on Prairie Creek above Brown Creek and all other strata ($P < 0.05$, Table 24). When Lost Man Creek results were removed from the analysis, differences between the affected and control reach on Prairie Creek disappeared ($P > 0.32$).

In both reaches, redds immediately below tributaries had significantly greater fines < 4.7 mm by weight than other redds, although the difference was not significant ($P = 0.07$; 2.5% vs. 1.53% in affected reach; 5.3% vs. 2.9% in control). Tributary redds in the control reaches had higher fine sediment levels than tributary redds in the affected reaches ($P < 0.03$). No significant differences existed between the affected and control reaches for redds unaffected by tributaries ($P > 0.11$).

Geometric Mean and Fredle Index. The average geometric mean and mean fredle index in redds after the incubation period did not significantly differ between individual stream reaches ($P = 0.26$). Differences between the gravel geometric mean before and after sediment infiltration were largest below Boyes Creek and in Lost Man Creek. Lost Man Creek tended to have the lowest values followed by Prairie Creek below Boyes Creek. The

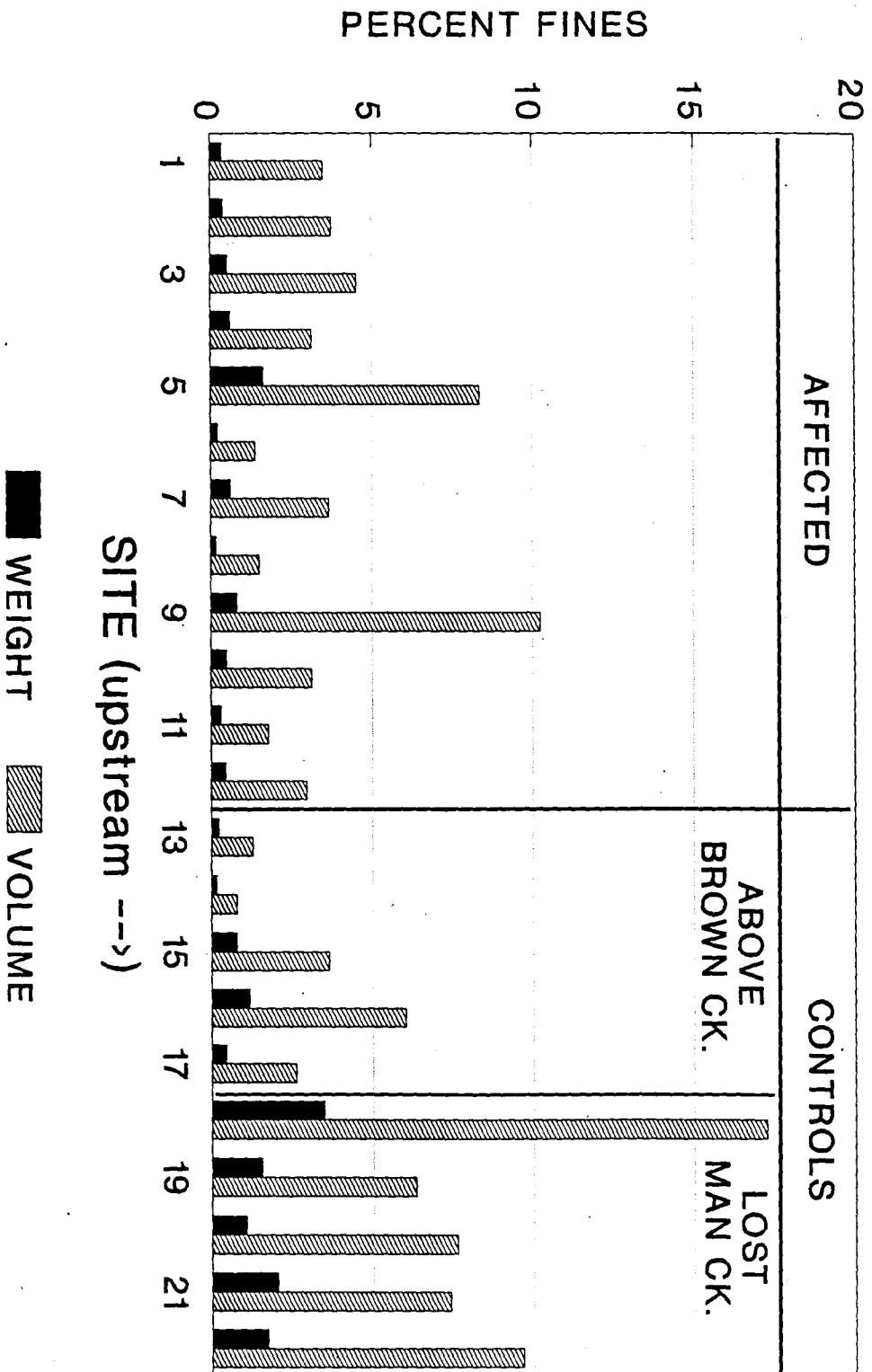


Figure 23. Percent fines (<1 mm) by weight and volume from coho salmon hatching baskets placed in artificial redds in January in Prairie and Lost Man Creeks, northern California, March 1992. Lost Man Creek (18-21) and above Brown Creek (13-17) are the control reaches. Below Brown Creek (1-12) is the affected reach.

Table 23. Comparison of percent fines in hatching baskets of artificial redds on the affected and control reaches of Prairie and Lost Man Creeks, winter 1991-1992 (redds below Brown included^a).

HATCHING BASKET FINES (%)					
	AFFECTED REACH n = 12		CONTROL REACH n = 10		
PARTICLE SIZE (mm)	MEAN	S.E.	MEAN	S.E.	P
BY WEIGHT					
< 4.7	2.01	0.28	3.86	0.70	0.022
< 1.0	0.92	0.12	1.75	0.28	0.015
< 0.5	0.73	0.08	1.27	0.20	0.025
BY VOLUME					
< 4.7	10.03	0.81	11.73	1.44	0.061
< 1.0	8.95	0.70	12.15	1.49	0.083
< 0.5	8.76	0.67	14.08	1.74	0.095

^a Results were very similar when 2 redds below Brown were excluded.

Table 24. Mean percent fine sediment < 1.0 mm by weight in artificial redds in individual stream sections, winter 1991-1992. Prairie Creek reaches are listed in order from upstream to downstream.

PERCENT FINES		
STREAM REACH	MEAN ^a	S.E.
Lost Man Creek	2.46	0.40
Prairie Creek above Brown Creek	1.03	0.23
Prairie Creek below Brown Creek	0.77	0.11
Prairie Creek below Big Tree Creek	0.55	0.09
Prairie Creek below Boyes Creek	1.20	0.20

^a For each reach, n = 5 except below Brown Creek, where n = 2.

highest values were on Prairie Creek below Brown and Big Tree Creeks (Table 25). The geometric mean and fredle index were strongly correlated ($r = 0.98$). For fines correlations, geometric mean was most strongly correlated to weight of fines < 4.7 mm ($r = -0.85$);

Table 25. Geometric mean and mean fredle index for infiltration bag gravel samples in artificial redds in Prairie Creek and Lost Man Creek, winter 1991-1992. Prairie Creek reaches are listed in order from upstream to downstream.

STREAM REACH	GRAVEL FRAMEWORK GEOMETRIC MEAN		GEOMETRIC MEAN (mm)		FREDLE INDEX (mm)	
	MEAN	S.E.	MEAN ^a	S.E.	MEAN	S.E.
Lost Man Creek	34.2	3.6	30.8	3.6	18.1	3.2
Prairie Creek above Brown Creek	38.5	3.6	35.6	4.0	23.9	3.8
Prairie Creek below Brown Creek	43.6	2.5	41.7	3.1	28.7	3.5
Prairie Creek below Big Tree Creek	40.2	2.0	39.0	2.0	25.5	2.2
Prairie Creek below Boyes Creek	39.2	2.1	35.2	1.4	22.0	1.2

^a For each reach, n = 5 except below Brown Creek, which was n = 2.

fredle index was most strongly correlated to volume of fines < 4.7 mm ($r = -0.81$).

Permeability. In the affected and control reaches, the inflow rate decreased significantly over the incubation period (Figure 24, Table 26). Initial, final, and mean change in inflow rates did not significantly differ between the affected and control reaches. The rate of change over time was similar between affected and control reaches (insignificant interaction, $P = 0.106$; Figure 3). Mean final permeabilities in the individual stream reaches were similar, although change over time tended to be lowest below Big Tree Creek and highest in Lost Man Creek (statistically insignificant difference, however)(Table 27).

Table 26. Comparison of mean inflow rates (cm^3/sec) in artificial redds in the affected and control reaches using repeated measures (2 redds below Brown excluded, $n = 10, 10$)^a and mean change in inflow rate using the t-test (all redds included $n = 12, 10$), winter 1991-1992.

	AFFECTED REACH		CONTROL REACH		P
	Mean	S.E.	Mean	S.E.	
Permeability (cm^3/sec)					
Initial January Rate	106.6	3.6	111.0	3.9	0.739
Final March Rate	96.4	2.9	90.9	2.9	
P (initial vs. final)	<0.001				
Mean Change in Rate	-10.2	4.1	-20.2	3.7	0.157

^a Means were very similar with redds below Brown included.

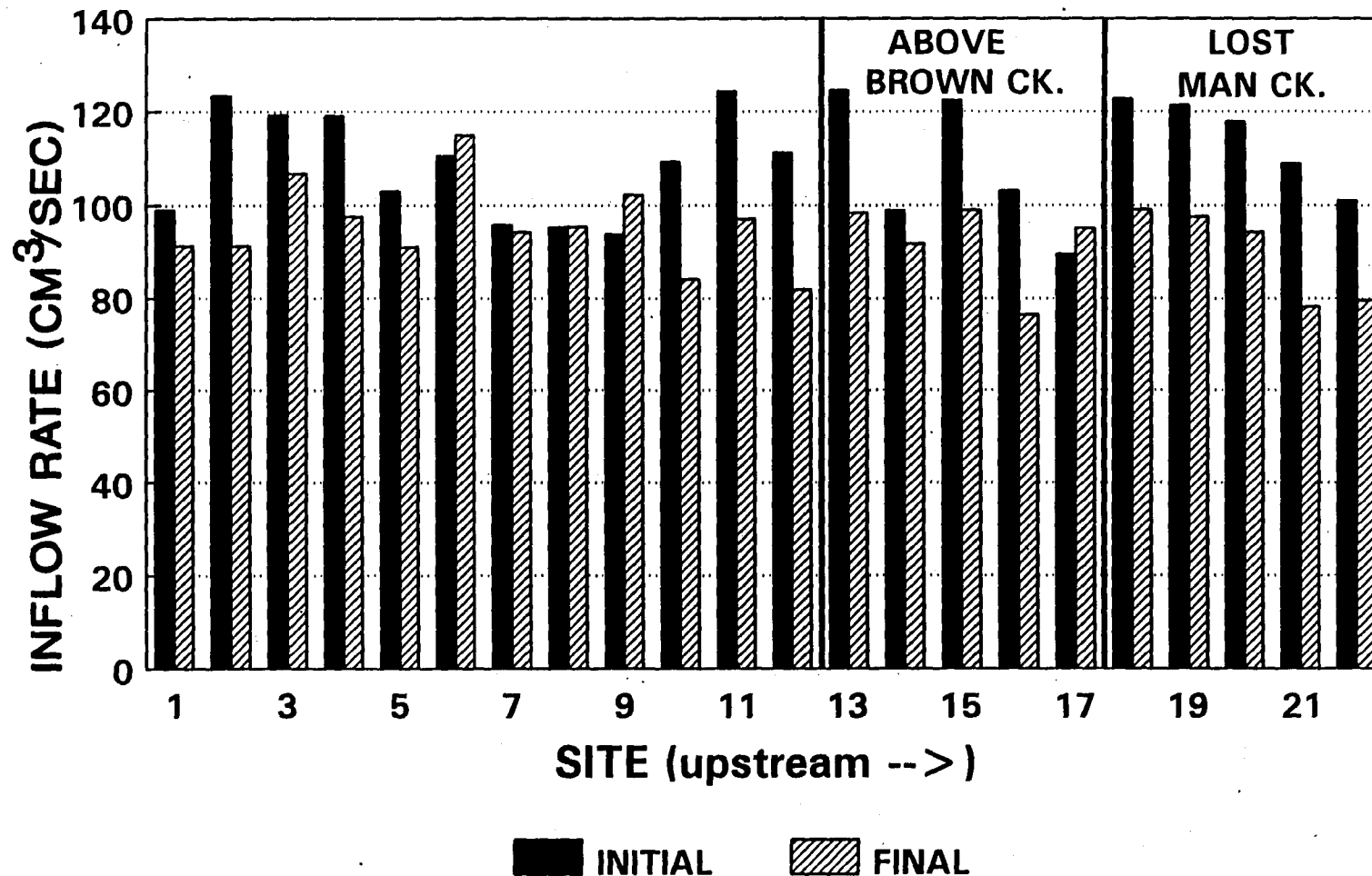


Figure 24. Comparison of inflow rates of standpipes within coho salmon hatching baskets placed in artificial redds in Prairie Creek and Lost Man Creek, 1992. Rates were measured at the beginning (January) and ending (March) of the incubation period. Prairie Creek below Brown Creek (sites 1-12) is the affected reach and Prairie above Brown Creek and Lost Man Creeks are the control reaches.

Table 27. Mean final inflow rate and change in inflow rate over the incubation period in artificial redds in individual stream sections, winter 1991-92. Prairie Creek reaches are listed in order from upstream to downstream.

STREAM REACH	FINAL INFLOW RATE (cm ³ /sec)		CHANGE IN INFLOW RATE (cm ³ /sec)	
	MEAN ^a	S.E.	MEAN	S.E.
Lost Man Creek	89.4	4.2	-25.4	4.2
Prairie Creek above Brown Creek	91.2	4.8	-15.0	4.8
Prairie Creek below Brown Creek	89.3	7.4	-23.2	4.4
Prairie Creek below Big Tree Creek	97.1	5.2	-6.2	5.2
Prairie Creek below Boyes Creek	95.6	3.1	-17.1	4.4

^a For each reach, n = 5 except below Brown Creek, which was n = 2.

Dissolved Oxygen. Mean DO in the buried redd baskets did not significantly differ from the adjacent surface water initially; but it dropped lower than the surface water DO in both reaches by the end of the incubation period, although the decrease was small and not statistically significant (significant interaction of $P = 0.038$; Table 28). DO significantly decreased in redds in both reaches over time, but did not differ between the affected and control reaches (insignificant interaction of $P = 0.207$, Table 29) (Figure 25). DO was similar between individual stream sections (Table 30). DO never dropped below 10.0 ppm in any redd basket.

Correlations with Egg Survival and between Variables. Egg survival was very weakly negatively correlated with percent fines by weight and not at all with volume. Percent fines and final and change in inflow rate were weakly negatively correlated, also (Table 31). When separated by reach, no relationships were significant in the affected reach and only ending permeability was significantly correlated with fines < 4.7 mm by weight in the control reach ($r = -0.39$, $P = 0.044$). Adjustments for gravel framework did not improve the correlations.

Individual stream reaches were ranked in order from highest to lowest for egg survival as follows: (1) Prairie below Brown and Prairie below Big Tree, (2) Prairie above Brown, (3) Prairie below Boyes, and (4) Lost Man Creek. These stream reaches had the reverse ranking for fine sediment, which corroborates the inverse relationship between fines and survival. The survival rankings also matched the rankings for geometric mean and fredle index. When Prairie below Brown is excluded, the highest to lowest permeability decrease over time followed the same ranking as fine sediment. DO was only consistent in that the highest DO was in Prairie above Brown and the lowest was in Lost Man Creek.

Table 28. Comparison of affected and control reach mean dissolved oxygen concentrations (ppm), initially and after the incubation period in artificial redds and adjacent surface water (n = 10,10) of Prairie Creek, winter 1991-92. Redds below Brown were excluded^a.

INITIAL DISSOLVED OXYGEN (ppm)					
REACH	REDD	S.E.	SURFACE	S.E.	P
AFFECTED	12.0	0.1	11.9	0.1	0.908
CONTROL	12.3	0.2	12.4	0.3	
P (Affected vs. Control)	0.189				
FINAL DISSOLVED OXYGEN (ppm)					
REACH	REDD	S.E.	SURFACE	S.E.	P
AFFECTED	10.7	0.1	11.2	0.1	<0.10 ^b
CONTROL	10.6	0.1	11.5	0.1	
P (affected vs. control)	>0.50				

^a Means were very similar with redds below Brown included.

^b Scheffe's comparison test used for final DO comparisons.

Table 29. Comparison of mean dissolved oxygen concentrations (ppm) measured in artificial redds (n = 10,10) of Prairie and Lost Man Creek, winter 1991-92. Redds below Brown were excluded for repeated measures analysis.

DISSOLVED OXYGEN (ppm)					
TIME	AFFECTED	S.E.	CONTROL	S.E.	P
INITIAL	12.0	0.1	12.3	0.2	0.395
FINAL	10.7	0.1	10.6	0.1	
P (initial vs. final)	<0.001				

Worm weight was weakly negatively correlated to egg survival ($r = -0.42$, $P = 0.002$). Neither final inflow rates nor change in inflow rates nor final DO ($r = 0.079$, $P = 0.352$) were correlated to egg survival ($P > 0.28$). Geometric mean and the fredle index were not correlated to egg survival, either. They were weakly correlated to change in permeability ($r = 0.34$, $P = 0.048$), but not ending permeability ($r = 0.37$, $P = 0.065$).

In stepwise regression, only sediment flux was selected ($r = 0.67$, $P = 0.0085$, 41% of variance accounted for).

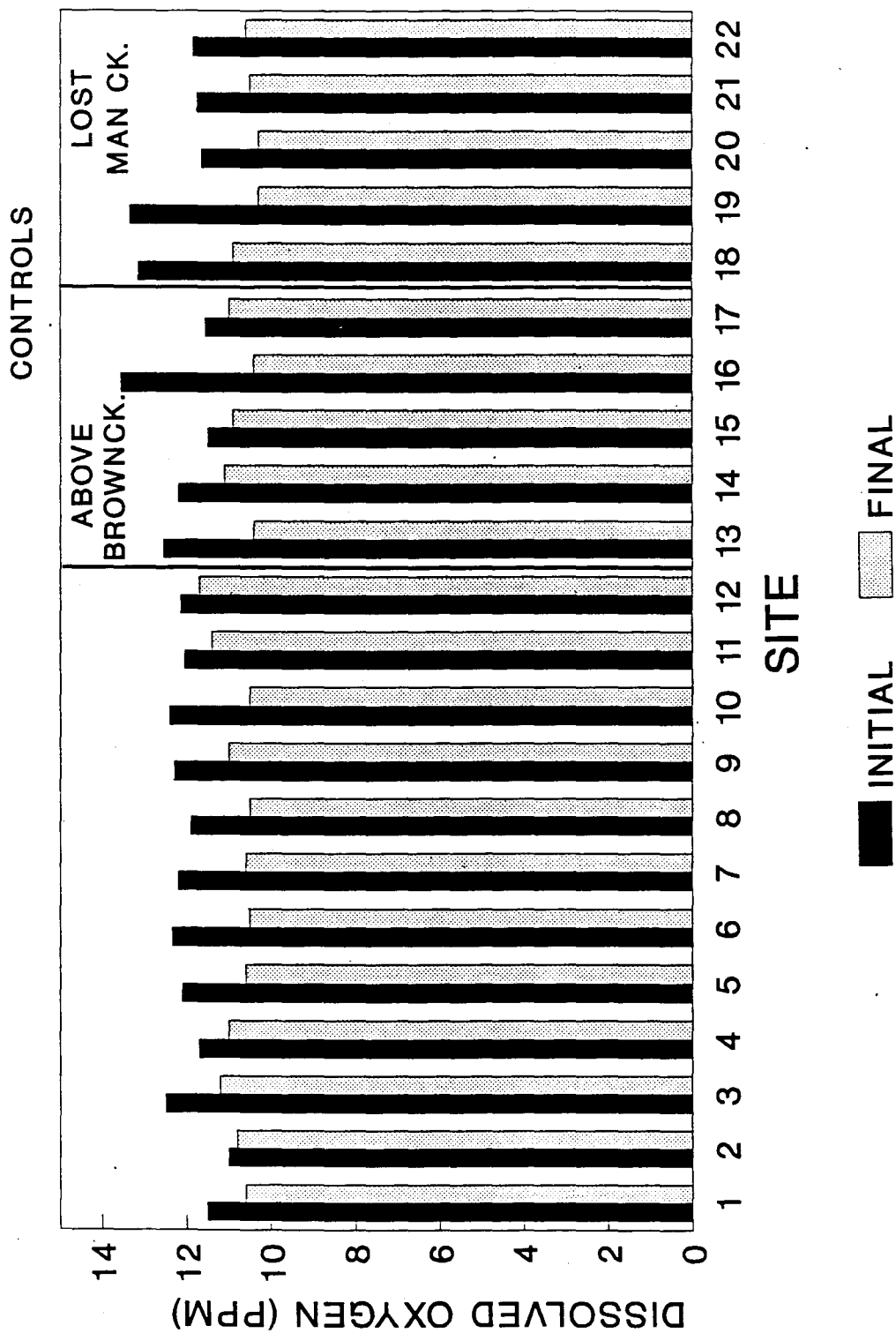


Figure 25. Comparison of dissolved oxygen in standpipes within coho salmon hatching baskets in artificial redds in Prairie Creek and Lost Man Creek, 1992. Rates were measured at the beginning (January) and ending (March) of the incubation period. Prairie Creek below Brown Creek (sites 1-12) is the affected reach and Prairie above Brown Creek and Lost Man Creeks are the control reaches.

Table 30. Mean dissolved oxygen taken in redds after the incubation period in individual stream sections, winter 1991-92. Prairie Creek reaches are listed in order from upstream to downstream.

FINAL DISSOLVED OXYGEN (ppm)		
STREAM REACH	MEAN ^a	S.E.
Lost Man Creek	10.5	0.1
Prairie Creek above Brown Creek	10.7	0.5
Prairie Creek below Brown Creek	11.6	0.2
Prairie Creek below Big Tree Creek	10.7	0.1
Prairie Creek below Boyes Creek	10.8	0.1

^a For each reach, n = 5 except below Brown Creek, which was n = 2.

Table 31. Correlation coefficients (r) and significance levels (*) between percent fines and other variables measured in artificial redds in Prairie Creek, winter 1991-1992.

PERCENT FINES	% EGG SURVIVAL	FINAL INFLOW RATE	CHANGE IN INFLOW RATE
Prairie Creek and Lost Man Creek (n=44)			
By Weight			
< 4.7 mm	-0.14	-0.32*	-0.22
< 1.0 mm	-0.26*	-0.30*	-0.30*
< 0.5 mm	-0.28*	-0.28*	-0.29*
By Volume			
< 4.7 mm	-0.08	-0.25*	-0.24*
< 1.0 mm	-0.09	-0.21	-0.23
< 0.5 mm	-0.08	-0.20	-0.22

* P < 0.05

Variability was high within a redd. Right and left basket values were not significantly correlated for any variables except (1) fines, which had r = 0.77 to 0.79 by volume and r = 0.83 to 0.88 by weight (P < 0.001) and (2) permeability (r = 0.31, P = 0.077).

A.4 Discussion

Effect of Bypass Sediment. As storms transport fines downstream during the incubation period, the amount of water seepage (permeability) usually declines in cleansed redds, even in pristine streams. However, turbulence of water over redds can also remove fines and improve seepage. The result may be a fluctuating pattern of seepage throughout the incubation period (McDonald and Shepard 1955).

We wanted to test whether the bypass-derived sediment would infiltrate cleansed artificial redds and decrease gravel permeability and delivery of dissolved oxygen to salmonid eggs more than natural levels of fine sediment. Because we did not have a completely unimpacted control stream, however, we were only able to test whether the sediment infiltration over the incubation period was greater in the heavily impacted reach than the slightly impacted control reach on Prairie Creek and the logging-impacted Lost Man Creek. We hypothesized that we would find greater fine sediment levels, lower permeability, lower dissolved oxygen and lower egg survival in the artificial redds in the affected reach than the control reaches. Egg survival would be positively correlated to permeability and dissolved oxygen; fine sediment would be negatively correlated to these variables. These relationships would be the strongest in the affected reach. The finest class of sediment (especially when measured by volume) might be expected to block oxygen flow and affect embryo survival (McNeil and Ahnell 1964, Koski 1966), whereas coarser fine sediment might seal the surface of a redd, preventing fry from emerging (Phillips et al. 1975, Lantz 1967, Hall and Lantz 1969, Phillips and Koski 1969).

WY91 results showed that, once local variations in gravel framework were accounted for, the amount of fine sediment infiltration was higher in the affected reach than the control reach. Even before adjusting for framework differences, the results showed 93% confidence that sediment was higher in the affected reach. Gravel permeability decreased more in the affected reach, and the majority of fish embryos died, all prior to hatching. More died in the affected reach than the control reach. The volume of sediment infiltrating into the redds was mostly composed of fines < 0.5 mm, and was not coarse enough to entrap emerging fry. If an egg hatched, the fry was able to emerge. Fine sediment was negatively correlated to egg survival, particularly in the affected reach. This relationship was not present in the control reach. Weight of total fines infiltrating back into the redd was negatively correlated to permeability in the affected reach; fines appeared to have an effect on permeability especially when local variations in gravel framework were accounted for. Egg survival was also weakly positively correlated with permeability in the affected reach, but not the control reach. Fines were highest in the bottom of the baskets, where the eggs resided.

The averaged values for the two sample baskets or bags in each WY91 redd had the best correlations with egg survival. Correlations of variables with fines measured within the hatching bags alone were much weaker. The hatching bags (which had the smaller hatching baskets) had coarser gravel than the emergence bags. This was because larger rocks would fit in the bag space above the basket than in basket. The volume of the emergence bag was

almost completely filled by the much larger emergence basket, making these bags contain smaller gravels on average and more representative of the gravels in the egg baskets. We found more sediment infiltrated into finer gravel frameworks, possibly explaining why more fines were found in the emergence baskets in the affected reach.

The amount of suspended sediment moving through the water over the redds (sediment flux), was the best predictor of egg survival. Permeability and fine sediment measured at the end of the incubation period probably do not reflect redd conditions at the time of egg mortality as well as sediment flux does.

WY92 values for egg survival, fine sediment, permeability, and dissolved oxygen in redds were similar between the slightly impacted Prairie Creek reach and the reach heavily impacted by the bypass. Except for fine sediment, these values were similar to the Lost Man control reach, also. Fine sediment was actually higher than Prairie Creek in the Lost Man control reach in the riffle crests (see Section IV) and in the artificial redds. Lost Man Creek has had more fine sediment inputs from past logging activities than the studied reach of Prairie Creek, and thus, would be expected to have higher sediment loads than Prairie Creek would have had before bypass construction. The fact that survival was similar suggests that, in WY92, fish that spawned in Prairie Creek were at least as successful as those spawning in Lost Man Creek.

In WY92, the control reach, Prairie above Brown Creek, had similar fines levels to the affected reach except for below Boyes Creek. Natural reproduction in Prairie Creek above Boyes Creek may have been fairly successful in WY92. Lowest survival and greatest loads of fines and worms in redds for Prairie Creek were found on the reach below Boyes Creek, similar to WY91 (and for fines in WY90). Although the upper Prairie Creek reaches may be improving over time, this reach probably is producing relatively few fish.

Correlations between survival and fines or permeability were weak to non-existent in WY92, likely due to the lower levels of fines, which have a more minimal effect at the low ranges. We did not find correlations between survival and geometric mean or the fredle index because the gravel indices did not approach detrimental ranges in WY92. Survival of salmonids decreased when fredle indices were < 11 (Lotspeich and Everest 1981) and geometric mean was < 26 (Shirazi and Seim 1979).

DO was relatively high in the redds in both years and did not differ between reaches. DO in the pipes always remained high enough for good egg survival; it usually must drop to below 2 ppm to cause widespread egg mortality (Chapman 1988). Either lack of DO was not the cause of the egg mortality, or, more likely, measuring DO in pipes is not an adequate representation of the microenvironment under which the eggs were actually exposed. Also, intragravel velocities may have been too low to efficiently deliver the available oxygen to the eggs and remove metabolic wastes. Further analysis of DO with microprobes and analysis of the apparent velocity data is needed to assess this possibility.

These results suggest sediment infiltration into redds may have increased in the affected reach in WY91 as a result of the bypass, and for that year salmonid egg survival was adversely impacted by the October 1989 storm sediment inputs. Survival was much less impacted by sediment in WY92, particularly above Boyes Creek where average survival exceeded 50%. However, in WY91, egg survival was low even in the control reach. Also, geometric means did not drop below 30 in Prairie Creek in WY91 (Appendix C). Worms, in addition to fines accumulation, may have been responsible for the low egg survival found throughout Prairie Creek in WY91. Worm-infested baskets tended to have lower mean egg survival. The redds with heavy infestation of worms in the WY90 egg survival study had 0% egg survival. In that study, worms were largely restricted to below May Creek, an area impacted by channelization activities. Their widespread representation throughout Prairie Creek in WY91 was unexpected.

Even in the late 1940's, Briggs (1953) found that abundant worm infestation (more than 5 individuals) reduced salmonid egg survival in natural redds from an average of about 86% to 45%. In his 1948 and 1951 studies, worms were present in redds from February to May and infested 27% of coho salmon redds, 54% of steelhead trout redds, and 0% of chinook salmon redds (chinook spawned before worms became abundant) in Prairie Creek (31% of all the salmonid redds he examined). Thus, worms are a natural source of egg mortality in Prairie Creek. As a side note: Drought years may force fish to spawn later and suffer greater worm-caused mortality.

Egg survival rates were much higher in Briggs' study than in both years of this study, suggesting that Prairie Creek conditions, even in the control reach, have degraded since that time. A hypothesis may be that the widespread new fine sediment from the October 1989 storm allowed worms to multiply and spread throughout Prairie Creek over a year's time, even to the control reach, which received some bypass sediment from Ten Tapo Creek. The worms sought out fish eggs and directly or indirectly killed them. In this study, fine sediment was highest in the reach below Boyes Creek and worms were found in every basket in that section. Much work on the life history and distribution of these worms is needed before this hypothesis could be tested. Consequently, this study's results are inconclusive as to whether the bypass is responsible for the low survival.

The relationships between worm abundance, fine sediment, and egg survival in the baskets were not that strong, probably because worms are mobile. They may have left the basket by the time the baskets were removed from the stream.

This study was not designed to test and separate from other factors the effect of worms on egg survival. As a consequence, part of the variance in egg survival was not explained by the multiple regressions. Some index to maximum number of worms that had been present in a basket is needed to quantify their effect. Additionally, other variables not tested probably affected survival including, but not limited to, stream slope, local velocities, lateral placement in the stream, redd superimposition and disturbance by external factors including other wildlife. If these factors could be held constant, and apparent velocity and some worm

index were added to the multiple regressions, the statistical relationships might further improve.

In WY91, the data suggested fine sediment infiltration was higher and egg survival lower immediately below impacted tributaries on Prairie Creek (see Section IV). This was tested in WY92. Although fine sediment tended to be higher just below impacted tributaries in WY92 (Section IV), egg survival was not affected and stratifying by proximity to tributaries did not change the results. Sediment infiltration may have been too low that year to show a direct effect.

Adequacy of Sampling Methods. When percent fines were calculated on samples pulled directly from the baskets, rather than from the entire infiltration bag, mean percent fines decreased by about 50% in WY92, but changed little in WY91. It is safest to always calculate fines using an infiltration bag around the basket to capture the fines, which was done for this study's results in WY91 and WY92.

Results for fine sediment were not always consistent between gravimetric and volumetric analyses. Sediment is believed to affect egg survival by plugging interstitial spaces or volumes within gravel. Thus, egg survival would be expected to be more correlated to volume than weight of fines. Our results generally disagreed with this. However, fines < 0.5 mm were a large component of infiltrating sediment. One speculation may be that Prairie Creek's combination of coarser sands blocking water flow and fines < 0.5 mm smothering eggs and providing worm substrate are responsible for the low egg survival rates in WY91 (worms were most correlated with fines < 0.5 mm).

In future studies, all three size classes by weight and volume should continue to be sampled. If only one can be used, weight should be selected because it gives stronger and more consistent correlations. Sampling just the "egg pocket" should not be necessary, however. Although the majority of fines quickly settled in the bottom stratum of the artificial redd in the egg pocket, we found sampling the entire infiltration bag was adequate to represent changes in fines.

Separating out the organic content made little difference in the fine sediment results. Its relationship to worm excrement and mucus and its effect on permeability need to be determined and separated from one another in another study to determine its importance.

Comparison Between Years. Average salmonid egg survival-to-hatching in WY91 was much lower than WY90 (1/10 as low) and WY92 (1/6 as low). However, the WY90 study used eyed rather than fertilized eggs. Fortunately, that year we experimentally placed two redds containing fertilized steelhead eggs in the affected reach above Boyes Creek. Survival-to-hatching rates in those were 49% (range 44 to 56%) and 73% (range 69 to 80%). Had these rates been corrected for infertility, they would have been slightly higher. Thus, WY90 rates still far exceeded even the maximum rate in the affected reach obtained in WY91 for hatching baskets (3%) and emergence baskets (32%).

The difference in egg survival between years could be partly attributed to stream discharge. Eggs in the WY91 baskets were exposed to at least one of the two largest stormflows of the year, which together transported 85% of the total sediment mobilized that winter. The two stormflows had peak flows 33% and 20% of a 2-year recurrence-interval flow. In contrast, WY90 eggs missed the largest storms and were only exposed to a small stormflow, 9% of a 2-yr recurrence-interval flow. WY92 eggs also missed the largest storm of the year, which came on April 17, and was 15% of a 2-year recurrence interval flow. Likewise, egg survival of fertilized eggs in WY90 were within the range of WY92 values.

The smaller storms of WY90 and WY92 were unable to move much sediment into the redds. In the affected reach, mean percent volume of fine sediment < 1 mm around eggs in WY90 and WY92 was less than 1/4 and 2/3 (28% by weight for WY92) of that in WY91, respectively. With the additional impact of worms present throughout the study area in WY91, egg survival was severely compromised that year. Yet compared to historical records, the WY91 storms were small. Had the 1991 water year not been a drought year, egg survival might have been even more reduced.

Of note, even with the lower flows, volume of fine sediment in the control reach on Prairie Creek in WY92 was similar to WY91. The fine sediment was lighter in weight, however (42% of WY91 levels), and did not attract any worms. Egg survival was 2 1/4 times higher in this reach in WY92 than in WY91. As we found before, weight of fines appears to be a better predictor of egg survival than volume of fines.

The relationship between fines and storm size as they affect egg survival is not straightforward and must take into account many other variables. In WY91, egg survival was poorer in baskets exposed to the 1991 January storm than those placed in the stream after the storm, but fines were not significantly different. The March storm of that same year may have deposited additional fines into the baskets that missed the first storm, but caused less mortality because the eggs were in the more resistant eyed stage by then. Also, another fish may deposit fines on top of redd when it superimposes its own redd. In WY91 four artificial redds (one on the control stream) were superimposed by a natural redd on Prairie Creek, but none were affected on Prairie Creek in WY90 (although two on the Lost Man Creek control stream were superimposed).

With lower fines levels in WY92, came not only higher egg survival rates, but little worm infestation. In WY91, worms were likely a major cause of the poor egg survival that year. Although worm amounts were not strongly correlated with survival or fines in baskets because of their mobility, the relative lack of worms in WY92 supports the hypothesis that worms follow fine sediment. An alternate hypothesis is that worms increased with the drought conditions. The results from this study do not support that hypothesis because WY92 had less rainfall than WY91 but very few worm-infested redds. A third hypothesis is that worms normally undergo population cycles and WY91 was a peak year.

The composition of fine sediment did not change from WY91 to WY92, suggesting even

finer < 0.5 mm are not being flushed out any faster than the coarser fine sediment. Fine sediment differences between right and left baskets were not very different in WY92, unlike the difference found between hatching and emergence baskets found in WY91. The change to placement of similar-sized baskets side by side may have helped minimize differences.

Average permeability in redds did not drop as low in WY92 as it did in WY91. The exception was the reach below Big Tree Creek, which remained relatively high in WY91. Values were relatively high in all reaches in WY92. In WY92, initial measurements were taken immediately after egg emplacement in the streambed and before any large storms occurred, whereas many of the WY91 baskets had been exposed to a storm before initial measurements. Initial permeabilities were higher in WY92 than WY91, except for the WY91 emergence baskets, that were not exposed to a storm before initial measurements. As a consequence, change in permeability is not as comparable between years as the ending permeability values. Dissolved oxygen rates were similar between years, only slightly lower in WY92. The slight change in the methodology of measuring DO before instead of after permeability testing may be responsible for this difference.

Fines levels in Prairie Creek in WY91 artificial redds were higher than those freeze-cored in natural redds in Freshwater Creek, Humboldt County, a creek that had been impacted by logging in the early 1900's (Barnard 1992). The Freshwater study was conducted in 1988, which was also a drought year. Volume of fines < 1 mm averaged 6% in post-emergence natural redds for that creek and its tributaries (3% for the mainstem only), compared to 9 to 15% for < 1 mm in artificial redds on Prairie Creek in WY91 and 5 to 11% in WY92. Thus, Prairie Creek fines levels in redds for a drought year may presently be high, particularly for sections of stream that were relatively pristine before the highway was built.

Estimated number of degree days until hatching were greater in WY92. The fry were two to three weeks old, however, when the baskets were opened in WY92. The fry had just hatched when the hatching baskets were opened in WY91. When this difference is taken into account, timing is similar between years. Compared to the hatchbox facility, hatching in the creek was delayed by at least 15 days.

The WY91 results strongly suggest that reproduction of coho salmon in Prairie Creek was severely reduced in the winter of 1990-1991. Chinook salmon spawned during the period similar to the coho salmon that year (Haux and Anderson 1991), and were probably equally impacted. Even steelhead redds, most of which were constructed after the January storm, were probably severely impacted by the worms.

Below Boyes Creek, spawning gravels were in good condition before the October storm, usually better than on a site above Brown Creek (RNP 1991a). During this study, the reach below Boyes had the most fines, greatest loss in permeability, and lowest survival on Prairie Creek. Thus, it appears this section is now a poor spawning area for fish even in a drought year. During a drought year, the upstream portions of Prairie Creek appear to provide some good spawning habitat.

During spawning surveys on Prairie Creek in WY92, 76% of the redds were located in the stream reach on Prairie Creek below Boyes Creek, 17% were between Brown Creek and Boyes Creek, and 6% were above Brown Creek. Because egg survival was relatively low below Boyes Creek where most fish spawned, salmonid production was probably low even in WY92 in Prairie Creek.

Under natural conditions, salmonid egg survival-to-hatching in most streams is fairly high, ranging from 50 to 90% (Hobbs 1940, Carl 1940, Shapavalov and Berrian 1940, White 1930). In the late 1940's, Briggs (1953) found average egg survival-to-hatching for coho salmon on Prairie Creek and its tributaries was 74%, for steelhead trout it was 65%, and for chinook salmon, 86%. This study's averages of 7% and 44% on the affected reach are much lower for coho salmon.

Additional study on a small scale was conducted in WY93 and needs to be compared to these results (Meyer et al 1994). Following a year when stormflows scour substantial amounts of sediment from the streambed, we recommend repeating the study at full scale after that year to determine if fines infiltration and egg survival have improved.

B. Emergence Success of Natural Redds

B.1 Study Objective

Success of emerging fry from natural redds was estimated using fry traps. The objectives were to determine natural spawning success, fine sediment levels in natural redds, and timing of emergence. These results were compared between bypass-affected reaches and control reaches and with the artificial redd results to help further evaluate the effect of the bypass sediment on egg survival.

B.2 Methods

As part of RNP's regular fisheries monitoring, spawning surveys were conducted on Prairie and Lost Man Creeks from December to March. Redds that appeared to be coho salmon redds based on fish presence and redd size were dated and marked; length of the female, when present, was recorded. In a few cases, exact date of construction was unknown. The date for these was estimated conservatively based on the last time the particular reach was surveyed.

In WY91, emergent fry traps (Figure 26) were placed on ten of the redds on Prairie Creek. Seven traps were placed below the confluence of Brown Creek (at least two below each affected tributary), and three were placed in the control reach above the confluence. An additional three fry traps were installed over coho salmon redds on Lost Man Creek, which served as a separate control stream (Figure 1). More traps would have been placed on the control reaches, but too few known coho salmon redds were available. Fry traps were provided by the Cooperative Fisheries Unit at Humboldt State University and were adapted

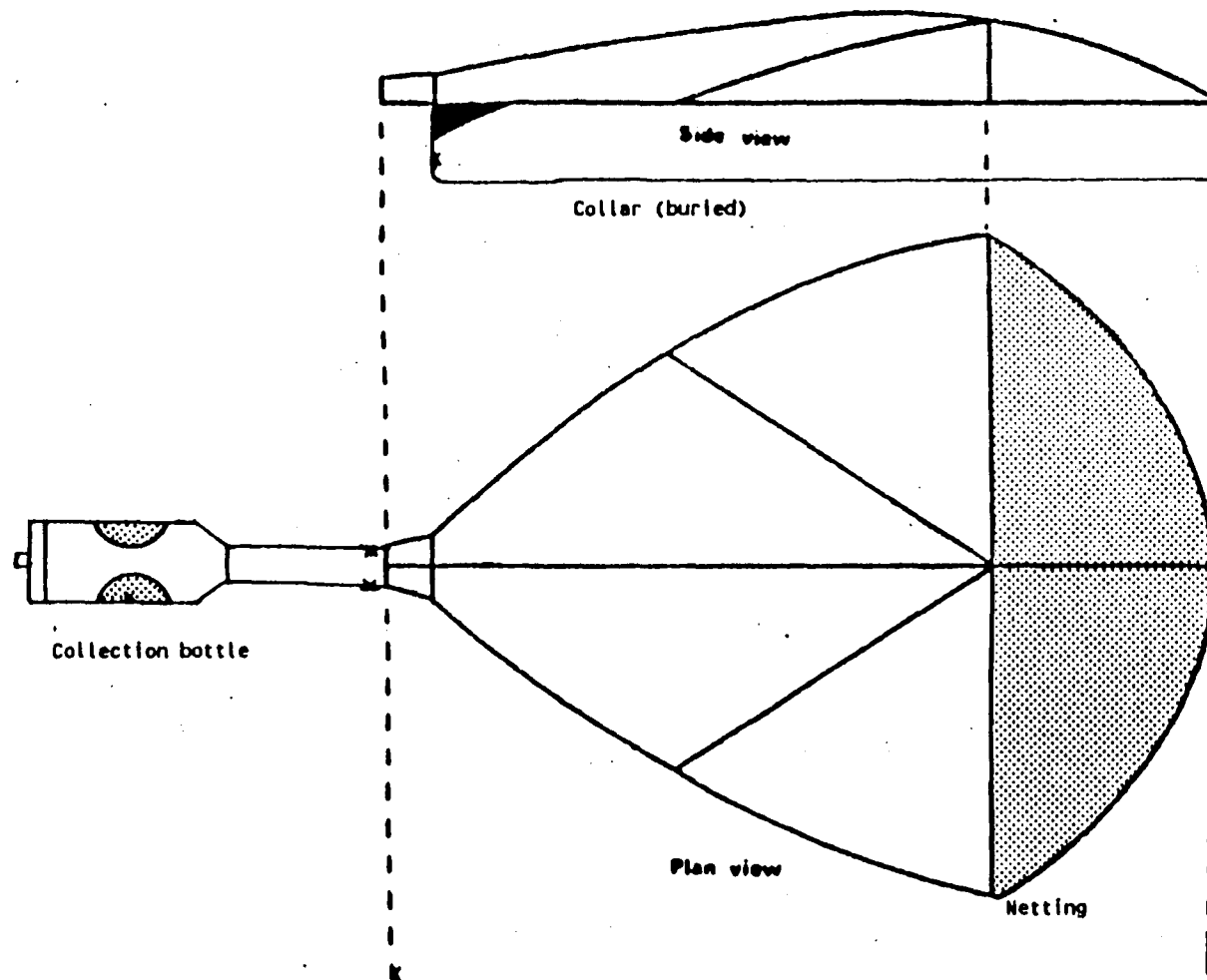


Figure 26. Diagram of emergent fry traps used for capturing fry emerging from natural redds. Measurements are in centimeters. Design was adapted after Field-Dodgson (1983) and Porter (1973).

from designs by Field-Dodgson (1983) and Porter (1973).

In WY92, ten fry traps were placed on Prairie Creek natural coho salmon redds and nine were placed on Lost Man Creek natural coho salmon redds (Figure 2). Three of the redds on Prairie Creek were in the control reach above Brown Creek.

In March and April 1991, fry traps were installed on the marked redds a couple weeks prior to estimated time of emergence based on degree days. They were monitored at least every other day for emerging fry. Numbers, species and fork lengths of emerging fry were recorded. In WY92, traps were placed on the redds throughout the months of February, over a month earlier than they were capped in WY91 to avoid having another redd superimposed on top of the studied redd.

When fry stopped emerging, traps were removed. Thirty-cm diameter 30-cm deep McNeil core samples were taken from the WY91 redds in areas approximated to contain the egg pocket and were analyzed by weight and volume (without data truncation) for particle size distribution. Means were compared using the non-parametric Kruskal-Wallis test. We noted if worms were present in the gravel sample. Gravel samples were not taken in WY92.

B.3 Results

WY91 Results:

In the winter 1990-1991, 69% of spawning on Prairie Creek took place below the Boyes Creek confluence, 27% took place in the reach between Boyes and Brown Creek confluences, and 4% took place above the Brown Creek confluence. Redds trapped on Prairie and Lost Man Creek represented 9.1% and 10.7% of the respective salmonid redds counted during 1990-1991 surveys. Most redds capped were found in the third week in January, although a few were found in mid-February.

Only one trap of ten on Prairie Creek produced significant numbers of fry (Figure 27). Three traps on Prairie Creek below Brown Creek produced 3,671, 37, and 2 fry, for a total of 3,710 fry. No traps above Brown Creek produced fry. All three traps on Lost Man Creek produced fry (804, 219 and 208, respectively), for a total of 1,231 fry. The redds producing the most fry on Prairie and Lost Man Creeks were each superimposed by a steelhead's redd, and probably produced both coho salmon and steelhead fry. The size of the fry were too small to differentiate the species. One fry trap (pc3) was blown out and reestablished four times, which may account for its lack of fry.

Except for the redd producing only 2 fry, fry began to emerge approximately the same time (after 94 days in mid-April) and number of degree days (1604) in natural redds on Prairie Creek as they did in artificial redds on Prairie Creek. The redd producing only 2 fry was first found about 3 weeks after the other redds, and consequently fry emerged several weeks later in this redd than the other Prairie Creek redds. Peak emergence at 66 days on Lost

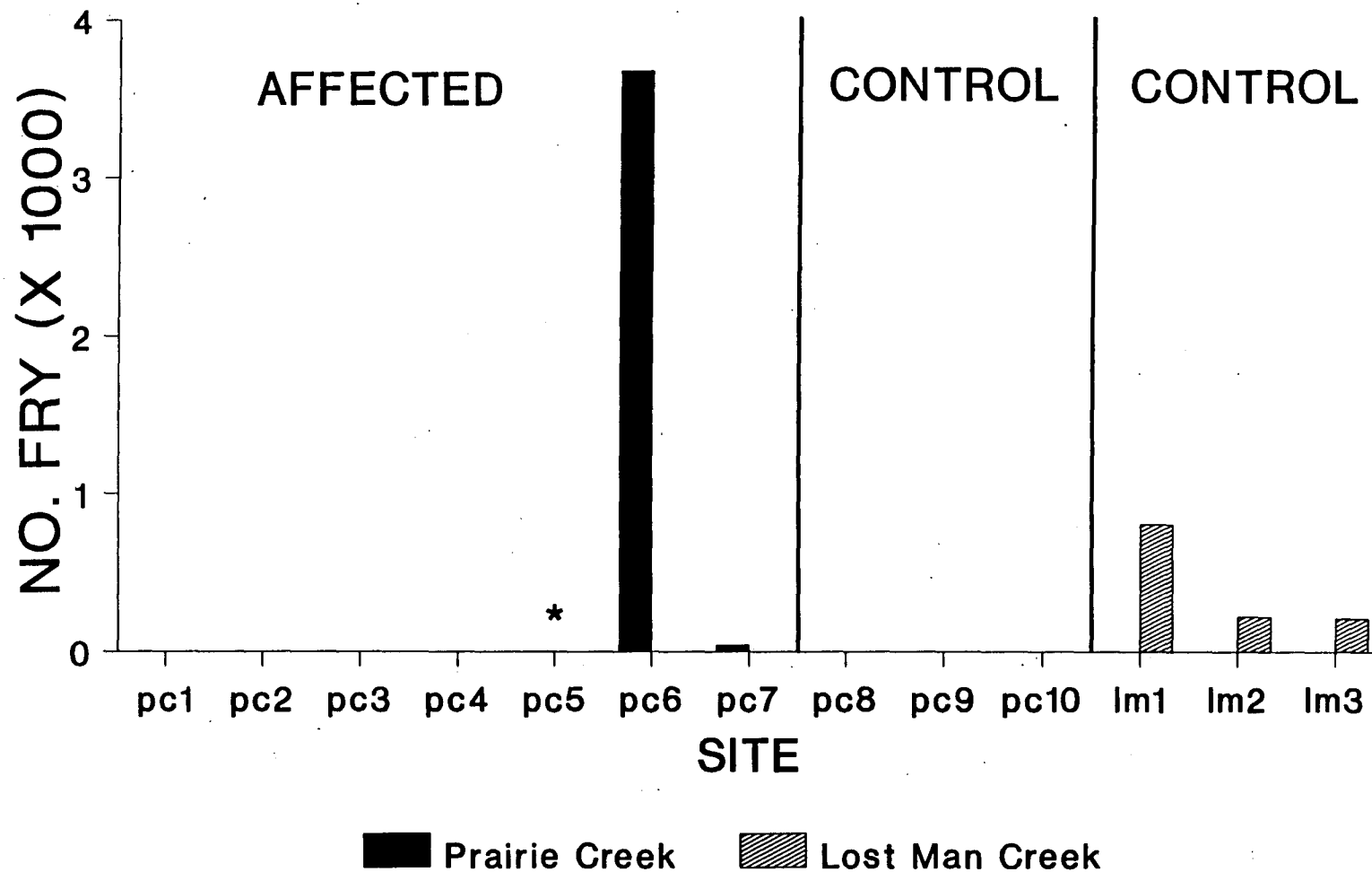


Figure 27. Numbers of coho salmon fry emerging from fry traps placed over natural redds in Prairie Creek (pc) and Lost Man Creek (lm), northern California, April to June 1991. Pc 7-9 were located above Brown Creek and were monitored as control sites within Prairie Creek. Lost Man Creek was used as a separate control stream. * = two fry.

Man Creek redds, redds created near the same time as the January Prairie Creek redds, occurred 28 days earlier than the peak on Prairie Creek. These redds were created near the same time as the January Prairie Creek redds.

Size distribution of fry emerging from natural redds was variable because some fish stayed underneath the trap's netting for a while and grew in size before swimming into the capture bottle. As a consequence, these data are difficult to interpret and are not reported here. They are available at the Arcata office.

One trap that produced no fry (just above Boyes Creek - pc4) was not sampled for fine sediment. Instead, we dug it up on May 22 to thoroughly search for worms and eggs. No eggs were found, but a few worms were uncovered. A trap on Lost Man Creek (lm3) was removed on May 29, but we found living sac-fry still in the gravel. Thus, the rest of the traps on both creeks were not removed until mid-July. All redds were sampled for sediment in mid to late July.

Mean fine sediment amounts from the redds did not significantly differ among the affected and control reaches for any size classes ($P > 0.10$, K-W)(Table 32). Weight of fines < 4.7 mm was negatively, but not significantly, correlated with number of fry produced in the affected reach ($r = -0.60$, $P = 0.076$, $n = 7$), and it was not significantly correlated in the control reaches $P = 0.3$ to 0.4). Correlations with other size classes and by volume were not significant either.

Table 32. Percentages of fine sediment found in natural redds after fry emerged on the affected Prairie Creek reach (below Brown Creek) and control reaches (Prairie above Brown and Lost Man Creek), winter 1990-1991.

PERCENTAGE OF FINE SEDIMENT							
	PRAIRIE BELOW Brown Creek (n = 6)		PRAIRIE ABOVE BROWN Creek (n = 3)		LOST MAN CREEK (n = 3)		
SIZE CLASS	MEAN	S.E.	MEAN	S.E.	MEAN	S.E.	P
By Weight							
< 4.7 mm	15.4	3.3	11.3	5.8	17.4	4.6	0.891
< 1.0 mm	4.8	3.0	4.1	2.2	4.6	0.2	0.852
< 0.5 mm	3.2	1.0	2.8	1.4	3.2	0.1	0.707
By Volume							
< 4.7 mm	18.8	4.1	16.8	7.7	17.1	4.5	0.655
< 1.0 mm	9.2	2.6	8.1	3.3	10.1	1.4	0.655
< 0.5 mm	8.0	2.5	6.6	2.6	9.2	1.5	0.482

Due to high variability (Figure 28), percentage of fines by weight in natural redds in the Prairie Creek reaches above and below Brown Creek were not significantly different from the results for the artificial redds ($P > 0.09$). (Compare Tables 10 and 12 to Table 32). Weight of fines values in the natural redds were closer to the emergence basket values.

However, volume of fines < 1.0 mm (Figure 29) were lower in natural redds than emergence baskets ($P = 0.001$) in the affected reach. In the Prairie Creek control reach, volume of fines < 0.5 mm were lower in natural redds compared to the hatching ($P = 0.024$) baskets. Percent of fines < 4.7 mm composed of fines < 0.5 mm (by volume) was lower than the artificial redds: 42% in the affected reach, 59% in the Prairie Creek control reach, and 44% in the Lost Man Creek reach, whereas percentages in the artificial redds ranged from 73% to 87%.

Some worms were found in the McNeil samples of two redds above Brown Creek (pc8 and pc10) that produced no fry, and in one Lost Man Creek redd (lm2) that produced fry. When the fry trap was first installed, worms were seen on the redd that produced 2 fry on Prairie Creek (located below Big Tree Creek - pc5).

As a side note, juvenile tailed frogs were common in the tube of the fry traps (as well as the emergence basket tubes) in Lost Man Creek and from above Boyes Creek to above Brown Creek on Prairie Creek. None were found below Boyes Creek. Giant pacific salamanders, juvenile lampreys, and sculpins were also occasionally in the traps.

WY92 Results:

In WY92, two redds out of seven produced fry on the affected reach on Prairie Creek, all three produced fry on the control reach on Prairie Creek, and five out of nine produced fry on Lost Man Creek. However, number of fry exceeded 3 individuals in only the control reaches: one redd on Prairie Creek and one redd on Lost Man Creek (Figure 30). Numbers of fry produced were generally low in all redds. Fry emerged after an average of 62 days (1057 degree days) on Prairie above Brown Creek, 89 days (1377 degree days) on Prairie below Brown Creek, and 94 days (1456 degree days) on Lost Man Creek.

The capped redds were constructed in December, January, and February. Fry began emerging in Lost Man Creek first, on March 25, for two redds constructed in late December and early January. Peak emergence on this creek was during the second week in April. Fry began emerging in Prairie Creek on March 31 from a redd constructed below Big Tree Creek in mid-January. On Prairie Creek just above Boyes Creek, fry emerged on April 13 from a redd constructed in mid-January. All redds in the Prairie Creek control reach were constructed in mid-February and emergence began in the second and third week of April. Too few fish emerged on Prairie Creek to determine peak emergence. Fry stopped emerging at all sites by mid-May.

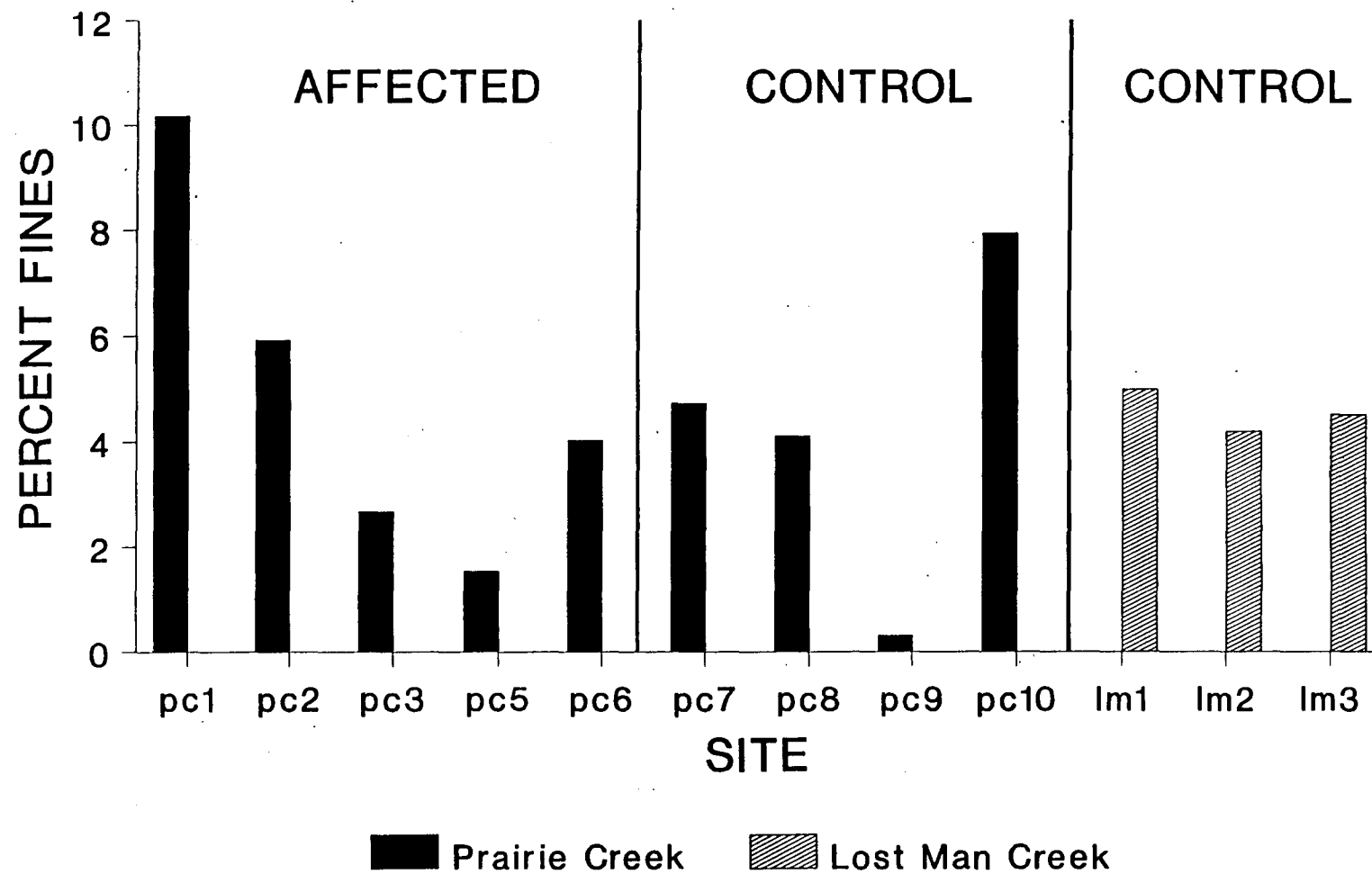


Figure 28. Percent fines (< 1mm) by weight from natural redds on Prairie and Lost Man Creeks, 1991.

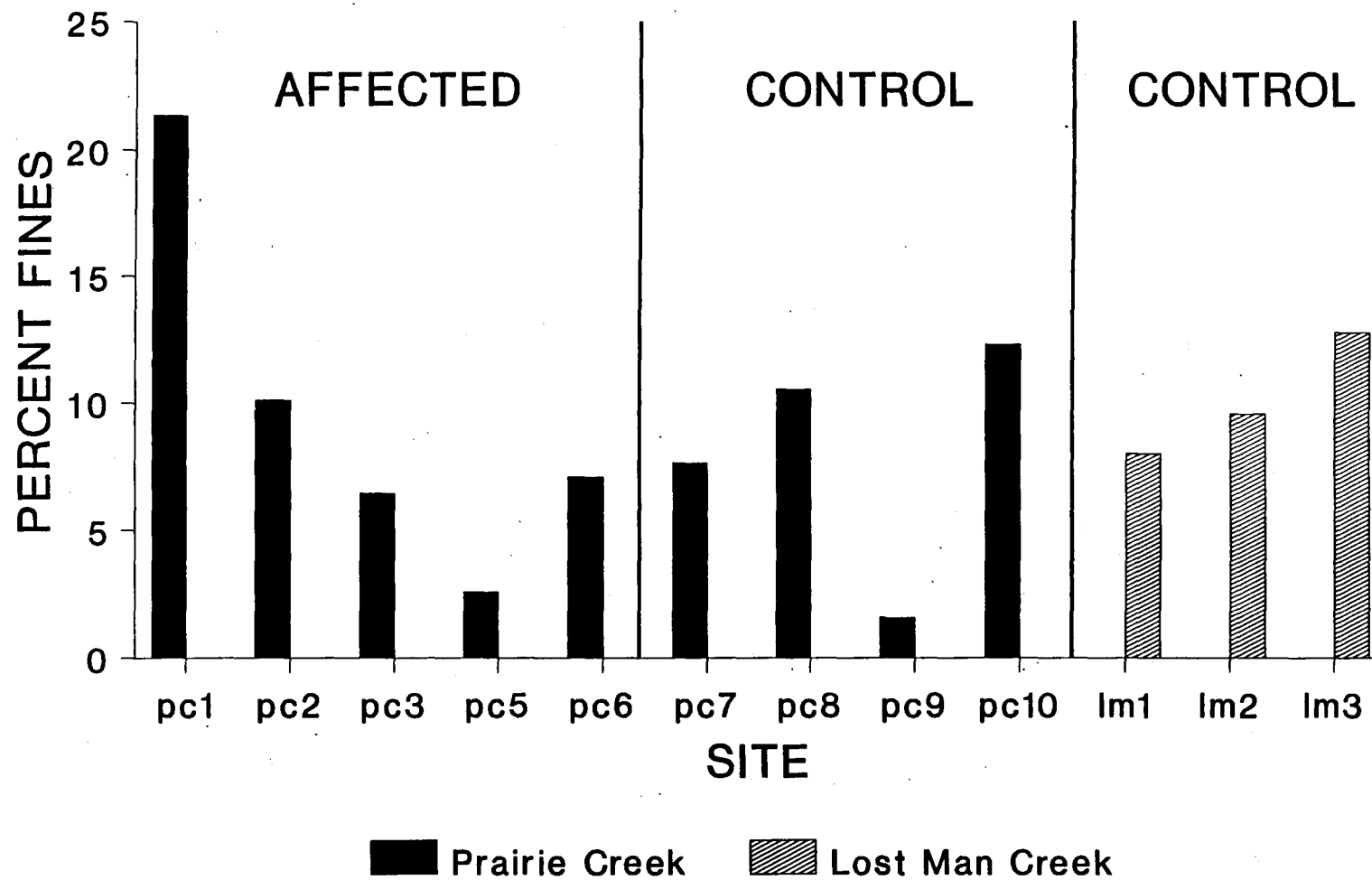


Figure 29. Percent fines (< 1mm) by volume from natural redds on Prairie and Lost Man Creeks, 1991.

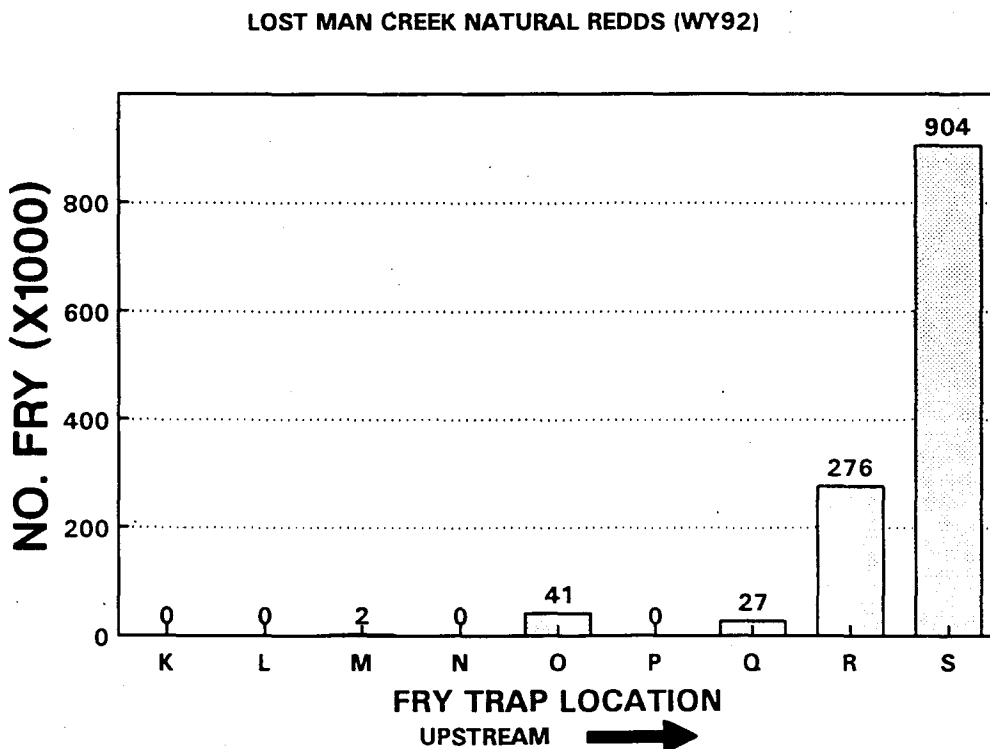
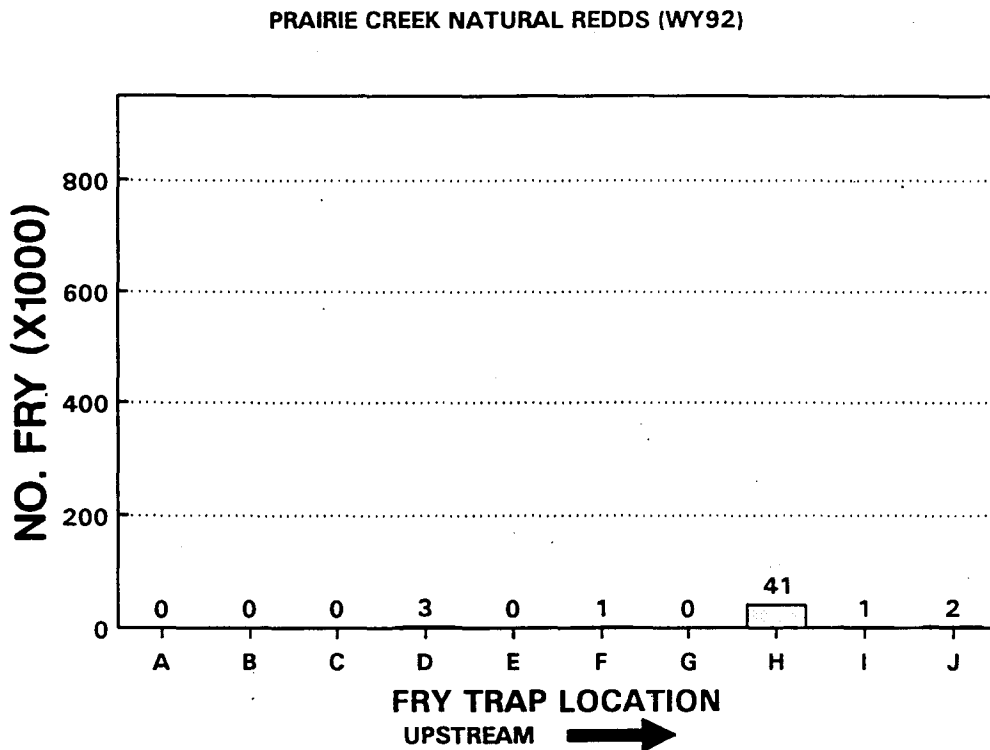


Figure 30. Numbers of salmonid fry emerging from fry traps placed over natural redds in Prairie Creek and Lost Man Creek, 1992. Sites H-J (above Brown Creek) and K-S were on control reaches.

B.4 Discussion

It is not known whether all redds were 'true' redds (ie., fish actually deposited eggs) or whether eggs were fertilized. Briggs (1953) estimated a 50% to 75% false redd rate when digging up redds on Prairie Creek. In this study, we assumed the false redd rate would be similar between reaches.

In WY91, all trapped redds produced hundreds of fry on the Lost Man control stream, whereas only 11% of the trapped redds produced substantial numbers of fry on Prairie Creek. This corroborates the findings of low survival in the artificial redds, indicating coho salmon egg survival-to-emergence was probably poor in Prairie Creek in WY91. Of note, however, is that the Lost Man redds had relatively low numbers of emerging fry compared to the thousands of eggs typically laid, and thus, were not highly successful, either. It is possible that some fish escaped from under the traps, and that there were losses from amphibian predation. Pacific giant salamanders were found in four fry trap tubes (pc3, pc5, pc8, pc9) up to 3 different times. They may have consumed some fry in the tubes and under the traps. However, one was found in a tube coexisting with 510 live fry. It is unlikely they could have been responsible for the loss of 1,000s of fry.

Redds exposed to the January storm may have had lower egg survival. However, it is unknown how many of the 1991 January redds on Prairie Creek missed the large mid-January storm. Fry traps pc5, pc9, and pc10 were known to have missed the January storm. On Lost Man Creek, two redds (lm1 and lm2) first observed on January 31 missed the mid-January storm. Fish frequently come up into streams during the storms of the year and spawn afterward. It is quite likely that most of the natural redds capped were not exposed to the largest storm of the year, and yet survival was still poor.

In WY92, no redds produced substantial numbers of fry in the affected reach and only a few fry were produced on the control reach of Prairie Creek. Emergence success was better on Lost Man Creek, but only in the upper reach, where logging impacts have been less.

Some of the natural redds in WY92 were subjected to the April 17 storm, which carried the highest loads of sediment for the year. This sediment, especially after being caught under the traps, may have adversely affected egg survival-to-emergence. The two redds able to produce over 100 emerging fry were created in the third week in December and began emergence well before the April storm. Of note, however, is that the three redds constructed early enough (in late December) to avoid the storm on Prairie Creek still had no egg survival. These were all below Boyes Creek, however, the reach that had the lowest egg survival and the highest fine sediment in the artificial redds on Prairie Creek.

The finding that fry emergence occurred late in WY91 in Prairie Creek agreed with our not finding large amounts of young-of-the-year fry in Prairie Creek during stream surveys and trap checking until approximately the same time fry began emerging in the traps. Moreover, emergence on Lost Man Creek peaked a month earlier than on Prairie Creek, which did not

appear to be solely due to water temperature differences.

Timing of emergence of natural and artificial redds in WY91 were generally similar: 95 days (1462 degree days) for artificial redds, 94 days (1604 degree days) for natural redds. Timing of emergence in artificial redds was not determined in WY92. Fry emerged after an average of 1320 degree days (83 days) in natural redds. Fry found in the WY92 hatching baskets in the artificial redds had all hatched by 79 days and 1275 degree days. Exact hatching dates of artificial redd fry were probably earlier, since some fry appeared to be two to three weeks old when the baskets were opened. It is possible that the fry in the baskets emerged after about the same number of degree days as the fry in the natural redds, if not later (it usually takes 20 to 30 days for fry to absorb the yolk-sac and emerge). Overall, artificial redds appear to be a good indicator of natural redd success, and are probably better than using the fry trap method, which unnaturally accumulates sediment, suffers amphibian predation losses, and may not capture all emerging fry.

The poor success of natural redds agreed with the artificial redd data in WY91, but not WY92. In WY92, we noticed large amounts of sediment accumulated under the fry traps over the months the traps were on the redds. Unlike the previous year in which the traps were on the redds for no more than a couple weeks before emergence began, traps were placed on redds at least a month and up to two months before emergence began. The Lost Man Creek redds that had the best egg survival were capped the latest (February 27). Thus, the traps may have increased egg or sac-fry mortality by increasing sediment accumulation in the redds.

The nets on the WY91 traps may have trapped additional fine sediment under the frames, but the amount probably was minimal that late in the WY91 season when sediment flux was found to be low (See Section II). Future trapping should occur no more than two weeks before estimated time of emergence. Overall, artificial redds appear to be a good indicator of natural redd success, and are probably better than using the fry trap method, which unnaturally accumulates sediment.

In WY91, survival in natural redds was very poor (0%) on Prairie Creek above the Brown Creek confluence. Yet in WY92, 100% of the redds in this control reach produced at least one fry. Briggs (1953) found egg survival in salmon redds in the control reach was never lower than 71%.

In contrast to the artificial redd results, egg survival was worse in the affected reach than the control reach in WY92. This may have been because more bypass sediment was available in Prairie Creek to accumulate under the fry traps. The results may represent what would have happened during a higher stormflow year. Additional sampling with later placement of the fry traps on the redds during a high stormflow year is needed to determine this.

Fines levels in natural redds in WY91 were similar between the affected and control reaches, including Lost Man Creek. In WY92, Lost Man Creek artificial redds and riffle crests had

higher fine sediment levels than Prairie Creek. The fact that Prairie Creek natural redd fines were similar to Lost Man Creek in WY91 may indicate that Prairie Creek fines levels in redds were unnaturally high that year.

A greater percent of fine sediment in the natural redds was between 1.0 and 4.7 mm than the artificial redds. All particles < 4.7 mm were completely removed from the artificial redd baskets. In natural redds, fish are probably not as efficient, particularly with the coarser fines.

Similar to the correlation results for the emergence baskets, natural redd fines (measured by weight) tended to have some adverse effect on survival in the affected reach. Worms may have increased mortality also. Determining their presence was difficult because most redds were not dug up and the traps were not removed until July when the worms could have already dispersed. Worms were present in one natural redd in Lost Man Creek in WY91. Because we had limited samples in this creek that year, it is unknown whether they were as common in Lost Man Creek as in Prairie Creek in WY91. The better survival in Lost Man Creek could have been due to less worm infestation.

Post-emergence fines levels in natural redds were higher in WY90 than WY91. Natural redd fines < 1.0 mm in the affected reach ranged from 15% to 31% by volume in the WY90 study (mean = 20%), whereas they ranged from 4% to 20% by volume in the WY91 study (mean = 9%). Fines were more similar between years in the Prairie Creek control reach (10% in WY90, 8% in WY91). Peak stormflows were similar between years, although some redds were not exposed to the largest storm of the year. Worms were generally absent in WY90, however, so overall fish survival was likely higher in WY90 than WY91.

Despite the exposure to low flows, these results further support that fish production was very poor in Prairie Creek in WY91. Results from both the WY91 natural redd study and the artificial redd study indicate that, in the stream section used by 96% of the spawners (below Brown), egg survival was zero in 16 of 27 (59%) monitored natural redds or egg baskets (compared to 8 of 23 (35%) that had zero survival in control reaches). In those having some survival in the affected reach, rates were extremely low. Below Boyes Creek, which has received greater spawning use in recent years due to the drought and the PCFFA weir, only 1 of 11 of the redds or egg baskets had any survival.

In WY92, egg survival was higher and zero survival much less common. Only 6 out of 31 (19%) monitored natural redd or egg baskets in the affected reach and 4 of 32 (13%) in the control reaches had zero survival. However, of the redds and baskets below Boyes Creek, 29% had zero survival. Because egg survival was relatively low below Boyes Creek where 76% of the fish spawned in WY92, salmonid production was likely still low in WY92 in Prairie Creek.

Because the data do not support that egg survival is adequate to maintain viable populations of salmon in Prairie Creek, the streamside hatchbox and rearing program was continued after

this study. Monitoring of the persistence of the fine sediment continued in WY93 and WY94 and a small-scale egg survival study was completed in WY93. The results from this report are compared to those results in Meyer et al (1994).

IV. PROPERTIES OF GRAVEL IN REDDS

A. Gravel Framework Size, Fines Infiltration, and Permeability in Artificial Redds

A.1 Study Objective

The process of sediment infiltration into the gravel framework of the streambed is driven by complex interactions between streamflow, depth of sediment, sediment transport rates and size properties, hydraulic channel geometry, and substrate composition. Add to this list the substrate modifications caused by spawning fish, and it becomes obvious that detecting impacts solely from the October, 1989, storm is a complex task. The limited literature on the topic of fines infiltration suggests that the size of framework gravels affects (1) the size and amounts of fines infiltrating into the streambed and (2) the vertical distribution of infiltrated fines (Beschta and Jackson 1979, Lisle 1989, Diplas and Parker 1990). Because the overall objective of this study was to determine the impact of fines from a single event, it is important to measure other factors that might affect fines infiltration, so impacts from the bypass can be distinguished from the natural variability in the stream system.

This section reports on physical properties measured in redds constructed in streambeds of Prairie and Brown Creeks, which contain sediments composed of two primary components: (1) coarse gravel framework, and (2) finer matrix material which occupies a portion of the interstitial space between the framework particles. In a natural state, streambed sediments consist mostly of what is referred to as open framework gravels, in which a small percentage of the interstitial space is occupied by fines, or matrix materials. Open framework gravels exhibit high permeability, thus providing a healthy environment for streambed organisms by allowing relatively free movement of intragravel water. Excessive infiltration of fine sediment causes more of the interstitial space to be occupied by fine sediment and may thereby restrict intragravel flow to levels detrimental to streambed organisms, including salmonid eggs.

The objectives for measuring physical properties of the streambed redds were: (1) to characterize the physical processes controlling fines infiltration; (2) to use this characterization to help determine if erosion and sedimentation from the bypass during the October, 1989, storm has caused significant and persistent impacts in the affected reach of Prairie Creek; and (3) to study Brown Creek fines infiltration as representative of a tributary response to the bypass sediment. To this end, the affected reach of Prairie Creek was contrasted to the control reach above Brown Creek. As stated earlier we believed this upstream section had been relatively unaffected by the large sediment input in comparison to downstream tributaries, where much bypass-derived sediment was delivered.

A.2 Methods

Gravel Framework Size and Fines Infiltration. As mentioned earlier, twenty artificial redds were constructed in the main channel of Prairie Creek in WY91, with ten each in the control

and the affected reaches (Figure 1). In addition to being used for the egg survival study (see Section III), these redds were used to measure physical characteristics of the streambed that affect infiltration of fines into redds.

In WY92, gravel characteristics were also measured at streambed locations near four of the five gaging stations: three on Prairie Creek and one on lower Brown Creek. These sites were added to complement the data collected at the gaging sites. Because both sediment transport and water discharge exhibit large spatial variability within the stream network, fines infiltration and permeability may not be well explained by sediment transport measured some distance away. Recognizing this, gravels were sampled and permeability was measured in riffles adjacent to the gaging stations to elucidate relationships.

At the stream sites near gaging stations a pit was dug (one meter wide by one and one-half meter long by one-half meter deep), two infiltration bags and permeability standpipes (Mill Creek variety) were set into the pit, the excavated gravel was sieved down to 4.7 mm, and the sediment coarser than 4.7 mm was backfilled into the pit. The sediment finer than 4.7 mm was wet-sieved and weighed in the laboratory.

Particle size distributions were derived for gravel samples from infiltration bags withdrawn from Prairie Creek artificial redds (see Section III for description of redd construction and infiltration bag placement). This section deals only with WY91 infiltration bags that contained hatching baskets, which were removed for analysis between March 24 and 27, 1991, and WY92 infiltration bags placed near the gaging stations. For the latter bags, D_{50} and percent fines < 4.7 mm were calculated in January before sieving and bag placement and in June, after the end of the seasonal rains.

Samples from the Prairie Creek redds were wet sieved in the laboratory. The following sieve sizes were used (except for two samples, from which the 45, 22, and 11 mm sieves were omitted): 256, 128, 64, 45, 32, 22, 16, 11, 8, 5.6, 4.7, 4, 2, 1, and 0.5 mm. Following separation by wet sieving, volumes of the individual size fractions were measured by water displacement (for fractions coarser than 0.5 mm) and by settling in Imhoff cones (for the fraction finer than 0.5 mm). The sample fractions were then oven dried at 100° C and weighed.

PSW also determined particle size distributions for Brown Creek "artificial redds". Gravel samples were extracted from Brown Creek using infiltration bags. A McNeil core sampler was used to remove gravel from four riffles and three pools between October 17 and December 5, 1990. Each sample was wet sieved in the field, and the sample was returned to the streambed with the < 2 mm fraction removed and discarded. Prior to filling the hole with the sieved gravel, a collapsed infiltration bag was placed in the bottom of the hole. In WY91 three bags were placed in upper Brown Creek and four bags in lower Brown Creek (same reaches as in the WY90 study). The infiltration bag was winched out of the streambed on May 15, 1991, without the aid of the McNeil sampler. The Brown Creek samples were wet sieved in the field using the following sieves: 256, 128, 64, 32, 16, 8, 4, 2, 1, and 0.5

mm sieves. In WY92, 2 bags were placed in one redd in lower Brown Creek. The gravel at this site was cleaned of fines < 4.7mm.

Sieve data were analyzed by calculating the percent of the sample weights finer than each of the sieve sizes used. Particle size distribution curves were constructed, whereby cumulative percent finer was plotted against sieve size. A computer program was then used to determine several indices of gravel size from the data: (1) percent fines less than 2 mm and 4.7 mm; (2) various percentile particle diameters (D_{10} , D_{16} , D_{25} , D_{50} (median diameter), D_{75} , D_{84} , and D_{90}); (3) geometric mean diameter (D_g), and 4) graphic mean diameter (mg), calculated as:

$$mg = [(D_{16})(D_{50})(D_{84})]^{0.33}$$

For the percentile diameters, the subscript number represents the percent of the sample less than the particle diameter value. For example, D_{16} is the particle size diameter at which 16% of the gravel sample is finer. Median (D_{50}), geometric mean (D_g), and graphic mean (mg) diameter are three measures of central tendency commonly used to describe size characteristics of gravel samples.

In WY92, relationships between fine sediment in riffle crest gravel just before artificial redd construction and the amount of fine sediment in the gravel at the end of the incubation period were explored. Gravel samples by the gaging stations were extracted with a McNeil sampler and volume of fine sediment < 4.7 mm, < 4.0 mm, < 1.0 mm, and < 0.5 mm was calculated.

Permeability. Permeability was tested in the Mill Creek standpipes using the method described in Section III. Only results from the Mill Creek pipes, which were in the center of the redd and were not in the egg baskets, will be discussed in this section. In addition to the tests performed on the standpipes placed in the artificial redds in WY91, tests were also repeated on fifteen pipes installed in four clusters in WY90 that were still in place (RNP 1991), and on the WY92 pipes within the sieved gravels adjacent to the gaging stations.

Data Analysis. For gravel size analyses that focus on the amount and effects of fine sediments, Kondolf (1988) recommends truncation of the sieve analysis data to numerically exclude very coarse particles. Particles which are very large in relation to the sample size tend to skew the sample data such that it does not represent the population from which it came. Several methods are available for selecting the cutoff particle size for truncating data, depending on the size of sample taken (Kondolf 1988). Based on the sample sizes in this study (mean = 44 kg), a size cutoff of 64 mm or 128 mm seemed appropriate using Kondolf's method. Two of the twenty samples from Prairie Creek, and four of the seven samples from Brown Creek contained particles coarser than 128 mm. Accordingly, all gravel size indices were calculated on the fraction of the total sample finer than 128 mm diameter for WY91 samples. WY92 were also truncated at 64 mm for comparison.

Percent fines were calculated using two particle diameters to define the upper size limit of fines. These were 2.0 and 4.7 mm. Because gravel size indices (D_g , mg, and percentile diameters) are affected by the entire size distribution of a sediment sample, including fines in their calculation would result in the indices being partially dependent on fines content. This condition would violate the assumption of independence of these variables for statistical analyses. In addition to truncating sample size distributions at the coarse end, it was therefore necessary to also truncate the data at the lower end (at 4.7 mm for Prairie Creek and 2.0 mm for Brown Creek) for calculations of size indices of the framework gravel. The lower limits differed between Prairie and Brown Creeks in WY91 because the redds were field sieved by different investigators using different sieve sizes.

For WY91 data, two series of regression analyses were performed on the physical data from artificial redds. In the first series, percent fines (< 2.0 mm) was treated as the dependent variable. Three gravel size indices (D_{50} , D_g , and mg) and suspended sediment flux (see Section II) were used to explain percent fines infiltration variation. This analysis included data from the 20 artificial redds in Prairie Creek as well as the four sites in Brown Creek. Because of interdependence, only one gravel size index at a time was used in the regression analysis.

In the second series of analyses, the permeability (inflow rate) at the end of the study period was the dependent variable. Independent variables used to explain permeability variation were percent fines and the same set of gravel size indices used in the first series.

Regressions were performed using the Lotus spreadsheet program for WY91 and SPSS for WY92.

T-tests (and Kruskal-Wallis tests when assumptions of the t-test were not met) were used to test for differences in percent fines and percent change in permeability between the control and impacted reaches and tributaries. The tests were performed using the SPSS statistical software. All tests were considered significant at $P < 0.05$. Sample sizes for WY92 infiltration bags by gaging stations were too small for statistical analysis. Trends were evaluated.

A.3 Results

WY91 Results:

Gravel Framework Size and Fines Infiltration. Particle size distribution curves were developed from the WY91 sieve analyses by weight and volume for both the infiltration bags and for egg hatching baskets, which were subsamples of the infiltration bags. Appendix H shows an example of one of these distributions. The rest of the data is on file at Redwood National Park. Appendix I shows the complete data set of percentile diameters, geometric mean diameters, and percent fines by weight for hatching baskets. Two outliers had excessively high fines. These were B2 (in the impacted reach) and A1 (in the control reach). Spawning surveys documented natural redd construction immediately upstream and partly on

top of these two sites, which probably was at least partially the cause of the unusually high levels of fines in these samples (although B1 and A5 had superimposition, also). Summary data for the sieve analyses are shown in Table 33. Percent fines are also summarized for the Prairie Creek reaches with the two anomalous samples (A1 and B2) deleted. Both percent fines (< 4.7 mm) and D_g are plotted against stream distance in Figure 31.

Percent fines by weight in the hatching bags did not differ significantly between the control and impacted reaches of Prairie Creek (see Section III). Without the two anomalous observations (A1 and B2), there was still no significant difference. In Brown Creek, infiltration of fines < 2 mm into cleansed riffles was about twice as high as in the Prairie Creek hatching baskets, although this difference was not statistically significant ($P = 0.26$, K-W). Mean fines infiltration in Brown Creek bags was similar to the emergence bags in the affected Prairie Creek reach (Table 33).

Table 33. Particle diameter (D_x , x = percent, D_g = geometric mean) at which a given percent of the gravel sample has smaller particle diameters. Percent of infiltrated fine sediment in the sample is also given. Data are means of hatching basket gravel samples from each reach of Prairie and Brown Creeks and morphologic type (pools and riffles). Numbers in parentheses are based on data sets excluding sites A1 and B2.

PARTICLE DIAMETER									PERCENT FINES	
SITE	D_{10}	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{90}	D_g	$< 2\text{mm}$	$< 4.7\text{mm}$
Brown Creek Pools	5.4	9.3	15.7	47.2	62.6	68.5	74.5	33.8	6.5	*
Brown Creek Riffles	4.2	4.9	6.6	22.9	40.6	47.4	52.4	17.5	6.5	*
Prairie Creek Redds above Brown Creek	12.4	17.5	25.6	46.2	62.6	70.2	75.1	40.5	3.3 (2.9)	4.1 ¹ (3.5)
Prairie Creek Redds below Brown Creek	15.2	22.0	31.7	52.9	65.7	70.6	74.8	46.3	3.6 (3.3)	4.8 ¹ (4.4)

* denotes no data; this sieve size was not used in these samples.

¹ Percent fines < 4.7 mm in emergence infiltration bags in redds was 4.0% in Prairie Creek above Brown and 8.5% in Prairie Creek below Brown.

Permeability. Table 34 shows permeability test results for the Mill Creek standpipes installed in WY91, along with percent decreases for the study period. Table 35 shows selected test results from the standpipes installed in WY90 for both water years. Table 36 shows mean inflow rates and change in inflow rates over time.

Changes in inflow rates were highly variable from redd to redd. Initial inflow rates, which were measured right after the January storm, were not significantly lower in the control reach than the affected reach ($P = 0.065$); differences between reaches were not significant in February or March either ($P = 0.116$).

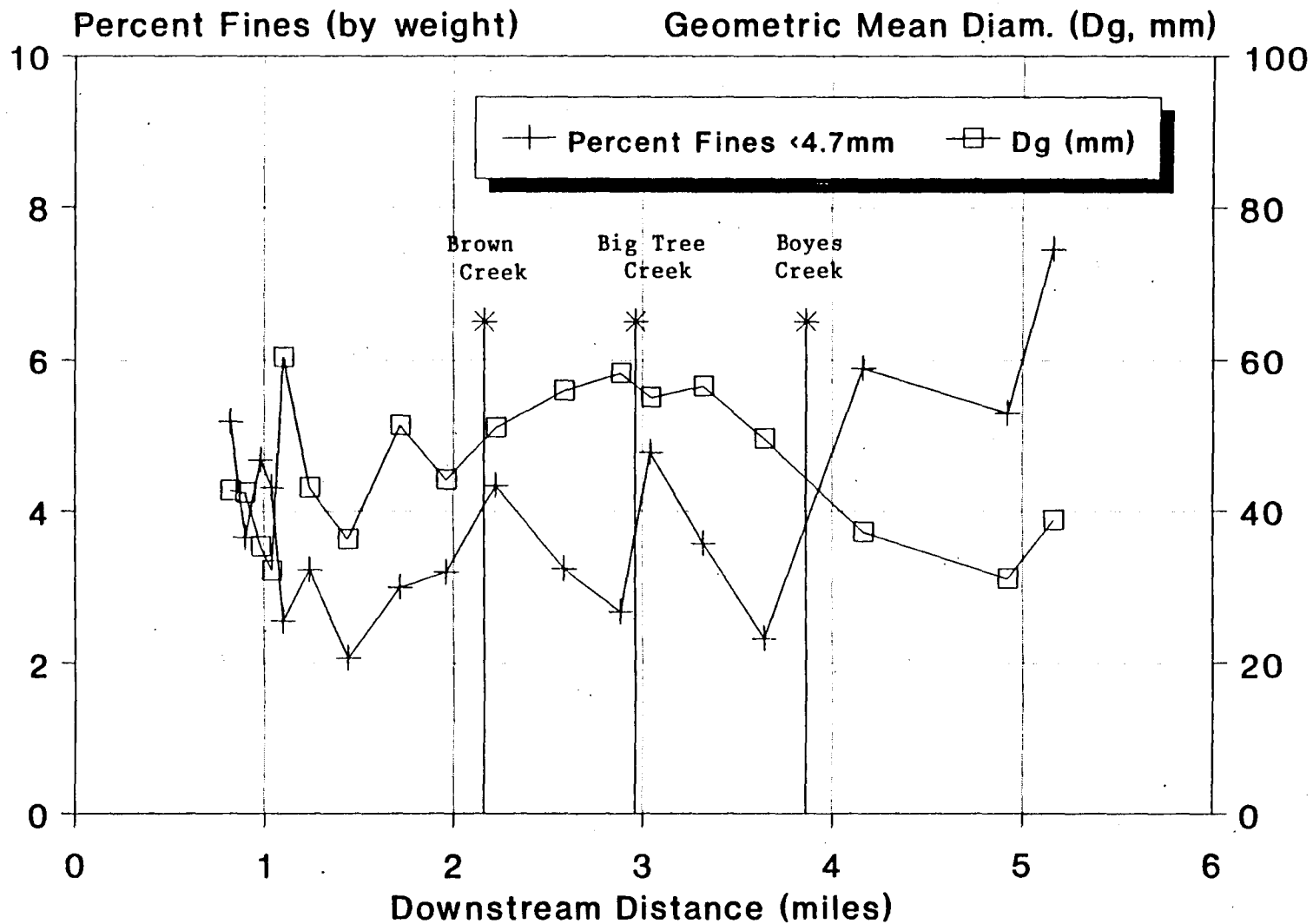


Figure 31. Percent fines and geometric mean diameter plotted versus stream distance for the study reach. The three impacted tributaries are shown in their respective positions.

Table 34. Permeability (inflow rate) test results from WY91 in Mill Creek standpipes installed in WY91 on artificial redds in the main channel of Prairie Creek. Sites are listed in downstream order. A = above Brown Creek, B = below Brown Creek.

SITE	JAN. 23-26	FEB. 13-19	MAR. 25-29	PERCENT CHANGE
PRAIRIE CREEK RIFFLES ABOVE BROWN CREEK				
A10	50.2	109.1	101.9	+103
A9	104.2	107.2	97.4	-7
A8	102.5	117.1	115.8	+13
A7	113.8	127.1	116.1	+2
A6	87.2	95.5	97.9	+12
A5	86.1	96.7	82.0	-5
A4	149.7	103.0	101.5	-32
A3	137.0	105.6	98.2	-28
A2	91.4	64.3	75.4	-18
A1	87.9	60.8	60.0	-32
PRAIRIE CREEK RIFFLES BELOW BROWN CREEK				
B10	83.9	110.7	73.6	-12
B9	No data	118.4	102.7	-13
B8	88.8	110.5	99.6	+12
B7	95.2	113.5	104.4	+10
B6	65.5	92.6	78.7	+20
B5	51.8	80.2	61.7	+19
B4	86.2	116.7	100.7	+17
B3	82.2	97.8	40.0	-51
B2	62.9	62.9	58.2	-7
B1	62.3	76.8	75.2	+21

Mean percent change in inflow between late January and March did not significantly differ between reaches: +0.8% on the control reach and +1.6% on the affected reach ($P > 0.56$). When the changes between February and March were compared, mean change in inflow rates almost significantly differed between reaches ($P = 0.055$) (Table 36). All 20 sites were included for these tests.

WY92 final inflow rates and change in inflow rates were compared between the three permeability pipes (including the larger Mill Creek pipe) in each artificial redd (Appendix B). The Mill Creek pipe appeared to have higher ending inflow rates than the averaged rates

Table 35. Permeability test results from WY90 and WY91 in Mill Creek standpipes installed in WY90 in cleaned gravels on the main channel of Prairie Creek. Data are means of multiple tests on several pipes at each site. Sites are listed in downstream order.

SITE	INFLOW RATE (cm ³ /sec)					
	BEGINNING WY90	ENDING WY90	% CHANGE	BEGINNING WY91	ENDING WY91	% Change
PABR*	101.9	83.6	-18	42.4	26.2	-38
PBBR	56.6	37.5	-34	24.0	25.0	+4
PBBY	47.3	35.1	-26	30.1	27.6	-8
PAMY	66.8	54.2	-19	44.4	47.7	+7

* PABR: above Brown, PBBR: below Brown, PBBY: below Boyes, PAMY: above May

Table 36. Comparison of mean inflow rates and change in inflow rates in Mill Creek pipes in the affected and control reaches of Prairie Creek, winter 1990-1991.

PERMEABILITY	AFFECTED REACH	CONTROL REACH
INFLOW RATE (cm ³ /sec)	MEAN (S.E.)	MEAN (S.E.)
January 23-26	79.7 (6.2)	101.0 (8.9)
February 13-19	98.0 (6.1)	101.6 (5.5)
March 25-29	79.5 (7.0)	94.6 (5.6)
Mean Change in Rate (January - March)	-0.3 (5.8)	-6.6 (9.2)
Mean Change in Rate (February - March)	-18.5 (5.3)	-0.6 (6.9)

of the two basket pipes. Change in inflow rate over time was similar between the affected and control reaches for the Mill Creek pipe and left basket. Right basket pipes, however, had greater decreases in inflow in the control reaches than the affected reach.

Regressions. The two anomalous observations (A1 and B2) were deleted from the data set. The regression analysis of the independent variables on percent fines was then run using gravel samples from both Prairie and Brown Creeks. The gravel index which explained the most variability in percent fines was geometric mean diameter (D_g), $r^2 = 0.71$. Percent fines was also regressed on suspended sediment flux in two forms: total tons transported over the study period (Q_{ss}) and unit suspended sediment flux ($Q_{ss/sq.mi.}$) in tons per mi². Unit suspended sediment flux explained the greater variation in percent fines, $r^2 = 0.78$. These two variables were then used together in a multiple regression, resulting in the equation:

$$Y = 4.42 - 0.04869 D_g + 0.08126 Q_{ss/sq.mi.}$$

which explained 86% of the variability in percent fines ($r^2 = 0.86$).

Gravel size indices and percent fines in hatching bags vs. ending permeabilities in Mill Creek pipes did not correlate significantly. However, ending permeability was significantly correlated to % weight of fines < 4.7 mm averaged between emergence and hatching bags ($r = -0.44$, $p = 0.031$). Also, the gravel framework index and unit suspended sediment flux explained 67% of the variance in change in inflow rates, whereas the gravel framework with percent fines < 4.7 mm only accounted for 52% of the variance.

WY92 Results:

Gravel Framework Size and Fines Infiltration. Gravel size indices and percent fines are shown for infiltration bags placed near gaging stations in WY92 in Table 37 along with the permeability data. Indices were calculated with truncation at 64 mm and 128 mm for comparison. All other data from infiltration bags in this report were truncated at 128 mm. Given the size of the infiltration bags, 64mm may be a more appropriate truncation boundary (Kondolf 1988).

Permeability. Four measurements of permeability were made on the pipes during the WY92 season. The initial (January) and final (June) measurements are shown in Table 37. On average, permeabilities decreased by 35% in these eight sites near the gaging stations. Of the six sites in the main channel of Prairie Creek, the two in the control reach (PABR-A and PABR-B) averaged 28% while the four in the affected reach (PBBR-A, PBBR-B, PAMY-A, PAMY-B) averaged 42% decrease in permeability.

Correlations with Riffle Crest Fines. The volume of fines in the gravel before redd construction in WY92 was correlated to the volume of fines that infiltrated into the gravel at the end of the incubation period, particularly for fines < 1.0 mm ($r = 0.69$, $P = 0.001$). Mean volume of fine sediment < 4.7 mm at the riffle crests before redd construction was 17.5 % (S.E. = 1.32, $n = 10$) in the affected reach, 9.6% (S.E. = 2.62, $n = 4$) in the Prairie Creek control reach, and 29.8% (S.E. = 0.20, $n = 3$) in Lost Man Creek. These means were derived by truncating out gravel volume > 128mm and are not comparable to the riffle crest fines weight truncated at 64mm sampled in January near the gaging stations.

Regressions. Similar to WY91, the gravel index that explained the most variability in percent fines in the 22 artificial redds in WY92 (< 4.7 mm) was geometric mean diameter of the gravel framework, $r^2 = 0.45$ ($p = 0.0052$). Sediment flux added little to the multiple regression.

A.4 Discussion

Gravel Framework Size. As shown in Table 33, gravel framework sizes were generally coarser in Prairie Creek than in Brown Creek. Interestingly, gravel in pools sampled in Brown Creek was coarser than in riffles. Also, gravel in Prairie Creek below Brown Creek

Table 37. Gravel sample particle size and permeability data for infiltration bag sites near gaging stations, WY92.

Site #	Gravel Size Data (by weight)							Permeability		
	January, 1992 ¹		June, 1992 ²					(inflow rate, ml/sec)		
	D ₅₀ (mm) ³	% Fines < 4.7 (mm) ³	D ₅₀ (mm) ³	D ₅₀ (mm) ⁴	% Fines < 4.7 (mm) ³	% Fines < 4.7 (mm) ⁴	D _g (mm) ⁵	Jan. 1992	June 1992	% Change
PABR-A	28.0	15.7	31.2	65.5	3.2	1.5	41.6	110	61	35
PABR-B	32.9	13.0	32.6	52.2	2.3	1.4	35.7	112	90	20
PBBR-A	33.1	18.2	34.6	42.1	2.9	2.3	35.7	127	74	42
PBBR-B	29.6	20.9	33.3	53.3	3.6	2.2	39.2	> 135	80	41
PAMY-A	13.9	29.0	14.7	18.9	7.6	6.2	22.6	107	62	42
PAMY-B	13.4	28.2	20.3	28.8	6.8	5.5	25.8	133	78	41
BROWN-A	15.2	23.5	25.1	37.9	8.7	6.4	30.3	104	78	25
BROWN-B	15.1	21.1	33.8	68.9	8.1	2.8	55.3	123	82	33

¹ before sieving and infiltration bag placement.

² end of study period.

³ material coarser than 64 mm truncated out prior to calculation.

⁴ material coarser than 128 mm truncated out prior to calculation.

⁵ material coarser than 128 and finer than 4.7 mm truncated out prior to calculation (geometric mean was 1 to 3 mm smaller without truncation at < 4.7 mm).

(the impacted reach) was coarser than that above Brown Creek (the control reach). These two results contradict the normal trends of particle sizes in most stream systems. Typically, pools exhibit finer gravels than riffles, and gravels become finer in a downstream direction.

In Figure 31, a streamwise trend is apparent in D_g. In the control reach (above Brown Creek), D_g is quite variable. Near the mouth of Brown Creek, gravel size becomes more consistent in a trend of downstream coarsening. From Big Tree Creek downstream, particle sizes become increasingly finer, a tendency more typical of streams. The variations in gravel framework sizes are probably a function of local hydraulic characteristics such as active channel slope, width, and depth. Gravel framework sizes are important to this study insofar as they affect the propensity of a redd to be infiltrated with fines from the available sediment load, which is discussed in the next section.

Fine Sediment Infiltration. As shown in Table 33, percent fines infiltrating into the hatching baskets of the cleansed artificial redds during the egg incubation period in Prairie Creek were slightly higher below Brown Creek than above, but this difference was not statistically significant. Distinct trends in fines infiltration are apparent in Figure 29. As with D_g , infiltrated fines were quite variable in artificial redds in the control reach (above Brown Creek). However, a sharp increase in fines was observed below each of the three impacted tributary mouths. Fines infiltration amounts dropped off with increasing distance downstream of each tributary.

Surface sediment was greatest in the tributaries in WY90; in that year, fine sediment < 2 mm in infiltration bags averaged 6.7% within Brown Creek riffles compared to 3.4% in Prairie Creek below Brown Creek (RNP 1991). These means significantly differed ($P = 0.03$ K-W). In WY91 fine sediment in Brown Creek bags was not significantly different from the Prairie Creek infiltration bags. However, infiltrating levels did not change much in Brown Creek (around 6%) or Prairie Creek (around 3%) from WY90 to WY91. The gravel in these sites were exposed to similar peak stream discharges both years. Lower Brown Creek appeared to have lower fines in WY92 than WY91 (range 3 to 6% fines < 4.7 mm vs. 6 to 7% fines < 2 mm). This is consistent with findings on Prairie Creek in general and is probably stream flow related. This supports earlier conclusions that there probably has been little change in subsurface sediment over the three years. The fact that Brown Creek generally has higher fines than Prairie Creek suggests that the bulk of the sediment from the bypass is in the tributaries.

The regressions of percent fines on gravel framework size (D_g) and suspended sediment flux ($Q_{ss/sq.mi.}$), both separately and together, provide important insights into factors controlling the process of infiltration of fines derived from bypass erosion. Because percent fines was negatively correlated with D_g , it is inferred that riffles composed of finer gravels have a higher propensity for fines infiltration. Another possibility is that riffles with finer gravels often have gentler slopes, and it is really the slope of the riffle which controls fines infiltration. Because slopes were not measured, this relationship cannot be explored with the present data set.

The linear relationship between $Q_{ss/sq.mi.}$ and percent fines found in WY91 but not WY92 demonstrates that the dependence of fines infiltration on availability of fines occurs only when sediment flux is at higher levels. Because of the use of unit suspended sediment flux (tons per square mile), this variable alone may be useful for predicting fines infiltration for a variety of locations in the Prairie Creek drainage during years of high sediment discharge. In WY91, the multiple regression using both D_g and $Q_{ss/sq.mi.}$ explained the largest variation in percent fines. Use of D_g in the regression tends to account for differences between the control and impacted reaches in terms of geomorphic dissimilarity, which affects their respective propensities for fines infiltration.

About half of the variance in fine sediment in WY92 was explained by the amount of fine sediment in the riffle crest before the redd was constructed. Thus, a combination of

sediment flux, gravel framework, and fines available locally probably affect the amount of fines infiltrating into redds over the winter.

The spatial trends shown in Figure 31 demonstrate elevated fines infiltration immediately downstream of the three impacted tributaries. Therefore, the artificial redd data set was stratified based on proximity to tributary mouths in WY92, to detect any differences between the two reaches (results reported in Section III).

Compared to the WY92 artificial redds, which avoided the April 17 storm, the WY92 infiltration bags near the gaging stations received greater loads of sediment and had a greater loss in permeability on Prairie Creek. These gravels were subjected to the April storm and gained more fine sediment and lost more permeability in the affected reach than the control reach on Prairie Creek. This collaborates higher stormflows deliver more sediment into redds.

Permeability. As shown in Table 34 and Appendix B, large apparent changes in permeability occurred in the Mill Creek pipes within the artificial redds during the WY91 study period. These changes occurred in both directions; some sites showed large increases in permeability while others showed large decreases. Only three sites exhibited permeability changes less than 10% in absolute value.

Although groundwater permeability is often considered to be independent of stream discharge, stream discharge probably affects gravel permeability rates in fast flowing streams with a coarse gravel framework like Prairie Creek. Permeability was measured at different flows in the stream reaches in WY91. Initial permeability was measured in the Mill Creek pipes at low flows in late January after the year's big storm. In the affected reach, the next two sets of measurements were taken in mid-February and late March at slightly higher flows than January (see Figure 6). In the control reach, flows during measurements in January and February were very similar. March flows were higher than February flows during measurement periods for all sites. Thus, January permeability estimates in the affected reach would have to be adjusted higher to be comparable to February and March values. This may explain why values in late January in the Mill Creek pipes were lower than in mid-February in all the affected sites, yet this did not hold true for the control sites. Inflow changes between February and March (Table 28) are probably more comparable than between January and March. Comparison of the basket pipe results in Table 15 with the Mill Creek pipe results shows permeability changed in the same direction in most pipes, particularly in the affected reach, where inflow rate decreased over time in almost every redd.

Ending permeability in Mill Creek pipes was correlated significantly with percent fines < 4.7 mm found in the artificial redds. These findings are consistent with the cause and effect model, in which fines infiltration causes decreases in permeability. Correlations of fines with permeability can probably be improved when gravel framework variability is accounted for and levels of sedimentation are high enough.

A more severe winter runoff season, which probably would cause greater levels of fines infiltration, could produce larger, more consistent trends in streambed permeability. For this reason, measurement of permeability was continued in future work.

While the data from two years of permeability testing on artificial redds constructed in January, 1990 (Table 35), are not representative of conditions in salmonid redds (because they span two years), they provide insights into changes in the impacted streambed over more than one year. Permeability in the control reach (PABR) decreased less during the first winter than at the three sites (PBBR, PBBY, PAMY) in the impacted reach; ending permeability was also higher in the control reach. During the second year, permeability at PABR decreased by 38% to about the same ending permeability as two of the lower sites (PBBR and PBBY). It is inferred from these results that, given sufficient time, redds in both the control and impacted reaches would attain similar permeabilities. However, the redds in the impacted reach appear to arrive at the lower permeability sooner, even within such a short a time as the length of an incubation period.

Results from the standpipes at PAMY also showed consistently declining permeability that seemed to stabilize in the beginning of WY91, similar to the behavior at PBBR and PBBY. However, no explanation for the higher ending permeability at PAMY can be given at this time. When monitoring of these sites is discontinued, these gravels will be sampled and sieved, giving data on gravel framework size and amount of fines. These data may help to explain the permeability results observed over the study period.

The large differences in sediment flux between the control reach and the other monitored locations in the creek were likely due to effects of the bypass. Redds constructed adjacent to sediment gaging stations in WY92 reflected the greater flux by having greater infiltration of fines and greater decrease in permeability in the affected reaches (including Brown Creek). However, natural redds were probably less affected because their eggs hatched before the storm that contributed most of the sediment occurred.

In summary, these results indicate that slope, proximity to a tributary mouth, geometric mean diameter, fines present in the riffle crest, and sediment flux contribute to the variability in the amount of fines infiltration in the redds. This information was used in the egg survival study to separate out natural variability in sediment from bypass-induced effects. However, larger storms than those that occurred during this study are needed to assess the full impacts of the bypass-derived sediment on fish redds.

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VI. APPENDICES

APPENDIX A: SEDIMENT FLUX CALCULATIONS

A.1 Sediment Flux Calculation for Prairie Creek.

Sediment flux for storms at Prairie Creek gaging stations was calculated at each point in which the net change in water discharge was more than one cfs or when a sediment sample was measured. The sediment flux for each point was summed to get the total sediment load for the storm. Sediment flux calculations for periods above threshold were based on both measured and estimated suspended sediment concentrations. For points above threshold in which no sediment data were available, sediment concentrations were estimated based on linear interpolation from the adjacent ISCO sediment sample data. When discharge was below threshold and no samples were taken, suspended sediment concentrations were synthesized for the initial rising and falling limbs of the hydrograph. It was assumed that no sediment transport occurred between storms.

A.2 Sediment Flux Calculation for Brown Creek.

Sediment flux for each storm was calculated by multiplying the mean sediment concentration of the sample stratum by the length of the stratum and summing the sediment flux for each stratum over the entire storm. Sediment flux was calculated for storm flows above threshold only. It was assumed that no sediment transport occurred between storms.

A.3 Comparison of Sediment Flux Techniques

Sediment flux for WY91 was calculated using a different technique for Brown Creek stations than Prairie Creek gaging stations. To compare techniques, sediment flux was calculated both ways using the same sediment data and the results compared.

Techniques used to determine sediment flux for the previous year, WY90, were slightly different than used for WY91 data. To compare the results of the different sediment flux methods used in WY90 versus WY91, sediment load for WY90 was recalculated using the current technique at Prairie Creek gaging stations.

As described above, a different method was used to calculate the sediment flux at Brown Creek stations than for Prairie Creek stations. A comparison of the two methods for calculating sediment flux indicated a difference of less than 1.5%.

The WY91 sampling thresholds were set independently at all of the gaging stations. Stations set at low thresholds sampled more of the storm flow than stations set at higher thresholds. As a result, the relative contribution of sediment flux above versus below threshold can vary between stations. The total sediment load transported above threshold during storm flow was 82% for PABR, 73% for PAMY, and 65% for PBBR. The remainder of the sediment transport was synthesized for below threshold in the rising and falling limb of the storm hydrograph. The relatively higher percent of the sediment transport, which was synthesized

for below threshold at PBBR, was due to higher sampling thresholds at PBBR than at PAMY and PABR. As a result, several small storms at the beginning of the season were not sampled at PBBR that were sampled at the other gaging stations.

The technique for calculating sediment flux in WY90 differed from the technique used for WY91 in this report. Sediment flux for WY90 at Prairie Creek gaging stations was recalculated using the current technique (method 2, Appendix A) for Prairie Creek gaging stations (Table 4). Our results indicate that the method used in WY90 (method 1) overestimated the annual sediment flux by 9.0% at PBBR and 0.4% at PABR; PAMY was not gaged in WY90. Estimates of total annual sediment flux changed from 555 tons to 510 tons at PBBR and from 129 tons to 128.5 tons at PABR.

Table A-1. Comparison of sediment load for WY 90 using two different methods. Method 1 used the earlier sediment flux calculation technique (RNP 1991), and Method 2 used the current sediment flux technique for Prairie Creek gaging stations.

Station	Time Period	Sediment Load WY 91 (tons)		Percent Diff.
		Method 1	Method 2	
PABR	October, 1989	100	100.0	---
	Jan.-June, 1990	29	28.5	+2.0
	TOTAL	129	128.5	+0.4
PBBR	October, 1989	325	325.0	-----
	Jan.-June, 1990	230	185.0	+24.0
	TOTAL	555	510.0	+9.0

Suspended sediment data, a discussion of the specific techniques used to compute sediment flux and the sediment flux calculations are on file in Redwood National Park's Arcata office.

APPENDIX B

Permeability Rates

Table B-1. Inflow rates on hatching baskets, emergence baskets, and Mill Creek pipes in Prairie Creek artificial redds, Winter 1990-1991.

IN-FLOW RATE (CM3/SEC)				
DATE	SITE#	HATCHING	MILL CREEK	EMERGENCE
01/24/91	B1		62.26	
02/14/91	B1	132.97	76.77	82.42
03/27/91	B1	85.29	75.21	6.18
05/02/91	B1		78.97	23.67
05/09/91	B1		72.88	28.33
01/24/91	B2		62.88	
02/13/91	B2	84.84	62.93	128.70
02/26/91	B2	65.33	60.30	80.67
03/27/91	B2	49.21	58.23	78.69
05/02/91	B2		62.92	46.98
05/09/91	B2		69.59	87.55
01/24/91	B3		82.23	
02/13/91	B3	75.60	97.77	99.08
03/14/91	B3	68.35	104.04	60.53
03/25/91	B3	33.72	39.95	
03/25/91	B3		102.47	
05/06/91	B3		99.92	
01/24/91	B4		86.24	
02/14/91	B4	85.94	116.65	133.86
02/26/91	B4	86.87	95.94	106.63
03/11/91	B4	52.52	71.02	76.35
03/25/91	B4	76.05	100.67	89.99
03/25/91	B4		87.67	94.92
04/30/91	B4		54.42	60.84
05/09/91	B4		66.37	71.44
01/24/91	B5		51.78	
02/14/91	B5	73.28	80.16	140.07
03/29/91	B5	74.27	61.66	75.12
04/30/91	B5		67.31	84.73
05/17/91	B5		61.36	104.72
01/24/91	B6		65.51	
02/14/91	B6	111.86	92.61	106.00
03/14/91	B6	91.45	65.35	108.49
03/28/91	B6	84.35	78.69	123.11
05/17/91	B6		44.84	104.46
01/24/91	B7		95.19	
02/14/91	B7	94.77	113.49	97.47
03/14/91	B7	25.82	80.05	52.06
03/28/91	B7	57.47	104.44	103.64
01/24/91	B8		88.80	
02/14/91	B8	87.07	110.51	99.42
03/14/91	B8	76.01	80.82	74.30
03/29/91	B8	54.02	99.59	82.87

Table B-1 . continued

02/14/91	B9	87.81	118.41	115.30
03/14/91	B9	68.41	78.18	108.86
03/28/91	B9	78.13	102.69	114.25
01/23/91	B10		83.91	
02/14/91	B10	63.97	110.70	105.16
02/27/91	B10	28.77	112.23	101.70
03/13/91	B10	80.19	63.35	91.03
03/28/91	B10	64.48	73.56	68.00
01/25/91	A1		87.93	
02/15/91	A1	62.14	60.79	95.12
02/27/91	A1	57.32	73.46	70.12
03/13/91	A1	25.45	73.00	108.88
03/28/91	A1		60.04	100.47
01/25/91	A2		91.40	
02/15/91	A2	76.21	94.31	61.26
02/27/91	A2	66.03	80.19	67.62
03/11/91	A2	80.30	73.49	83.74
03/12/91	A2	84.83	85.08	69.72
03/13/91	A2	66.92	92.48	87.23
03/27/91	A2	95.86	75.37	95.68
01/25/91	A3		137.03	
02/19/91	A3	108.90	105.16	64.27
03/29/91	A3	66.87	98.18	80.95
05/15/91	A3		67.97	81.17
01/25/91	A4		149.70	
02/19/91	A4	78.51	103.01	47.01
03/26/91	A4	65.11	101.50	82.95
03/26/91	A4		116.30	87.29
01/26/91	A5		86.09	
02/19/91	A5	67.52	96.73	89.74
02/26/91	A5	88.90	94.83	59.65
03/11/91	A5	84.21	80.82	28.60
03/12/91	A5	91.86	94.83	82.24
03/13/91	A5	81.53	91.08	79.60
03/28/91	A5	89.21	82.03	70.25
04/24/91	A5		64.98	71.76
01/25/91	A6		87.24	
02/19/91	A6	86.15	95.49	67.67
03/15/91	A6	62.18	87.56	68.03
03/26/91	A6	31.30	97.91	70.54
03/27/91	A6		113.92	77.73
01/25/91	A7		113.77	
02/15/91	A7	61.11	127.06	91.26
03/15/91	A7	39.58	101.90	67.14
03/26/91	A7	79.40	116.08	45.65
03/27/91	A7	117.92	57.72	
01/25/91	A8		102.48	
02/15/91	A8	90.87	117.05	55.98
03/26/91	A8	82.31	115.82	108.37

Table B-1 continued

05/15/91	A8		84.36	95.09
01/25/91	A9		104.20	
02/19/91	A9	57.26	107.16	67.72
03/13/91	A9	85.54	91.02	77.89
03/29/91	A9	83.71	97.40	82.12
04/24/91	A9		83.98	70.01
01/25/91	A10		50.15	
02/19/91	A10	69.31	109.12	77.40
03/11/91	A10	73.57	86.56	74.07
03/12/91	A10	78.93	103.77	95.99
03/13/91	A10	69.67	108.00	98.42
03/29/91	A10	60.76	101.90	71.62
03/29/91	A10		84.72	106.03

Table B-2. Mean change in inflow rate between different locations sampled within each redd on the affected and control reaches of Prairie and Lost Man Creeks, winter 1991-1992.

Location of Pipe	Mean Change in Inflow Rate (cm ³ /sec)	
	Affected Reach	Control Reach
Average of Both Baskets in each Redd	-10.2	-20.2
Left Basket	-11.1	-10.6
Right Basket	-13.6	-30.3
Mill Creek Pipe	-15.7	-16.7

Table B-3. Mean final inflow rate and change in inflow rate over the incubation period in artificial redds individual stream sections, winter 1991-92. Prairie Creek reaches are listed in order from upstream to downstream.

Stream Reach	Mean Final Inflow Rate (cm ³ /sec)		Mean Change in Inflow Rate (cm ³ /sec)			
	Redds ^a	Mill Creek Pipe	Redds	Mill Creek Pipe	Left Basket	Right Basket
Lost Man Creek	89.4	90.4	-25.4	-19.7	-16.2	-34.8
Prairie Creek above Brown Creek	91.2	103.5	-15.0	-13.6	-4.5	-25.3
Prairie Creek below Brown Creek	89.3	104.5	-23.2	-13.9	-32.3	-14.1
Prairie Creek below Big Tree Creek	97.1	104.5	-6.2	-11.6	2.0	-8.6
Prairie Creek below Boyes Creek	95.6	106.1	-17.1	-20.2	-11.1	-18.2

^a For each reach, n = 5 except below Brown Creek, which was n = 2.

APPENDIX C
Percentile Particle Diameters

Table C. Percentile particle diameter and geometric mean (D_g) diameters and percent fines of infiltration bag gravel samples for WY91. Diametric indices were calculated with truncation at both 2 and 128 mm. Percent fines were calculated with truncation at 128 mm only. Sample sites are listed in downstream order.* denotes no data.

Site	Particle Diameter (mm)								Percent Fines	
	D_{10}	D_{16}	D_{25}	D_{50}	D_{75}	D_{84}	D_{90}	D_g	< 2 mm	< 4mm
Brown Creek Pools										
UBP1	3.9	5.1	7.2	20.6	38.9	47.7	57.3	18.4	8.8	*
UBP2	8.4	17.5	32.2	69.1	77.3	81.6	85.6	52.7	6.0	*
LBP3	4.0	5.4	7.8	51.9	71.6	76.2	80.5	30.2	4.7	*
Brown Creek Riffles										
UBR1	5.6	7.0	10.5	38.4	65.0	69.9	74.6	29.1	5.7	*
UBR2	3.8	4.3	5.7	11.9	30.3	38.9	47.5	13.5	7.0	*
LBR3	3.8	4.3	5.5	32.5	54.7	65.9	70.7	18.9	6.3	*
LBR4	3.6	3.9	4.8	8.7	12.5	14.9	16.7	8.4	6.9	*
Prairie Creek Riffles above Brown Creek										
AB10	16.4	20.8	28.1	46.7	62.3	68.0	72.8	41.5	4.1	5.2
AB09	10.3	13.9	20.4	52.2	71.4	76.0	80.3	41.4	2.8	3.7
AB08	8.9	11.5	16.6	45.7	61.2	67.4	72.2	34.2	3.5	4.7
AB07	10.2	15.3	18.8	35.2	46.0	64.5	69.4	31.3	3.5	4.3
AB06	15.8	29.0	47.6	67.5	75.9	80.3	84.4	59.8	2.3	2.6
AB05	13.4	18.3	26.7	48.2	66.3	71.2	75.8	42.5	2.8	3.2
AB04	11.1	15.5	21.0	39.4	60.8	67.7	72.4	35.8	1.7	2.1
AB03	12.3	20.0	36.9	61.1	71.8	76.4	80.7	50.4	2.4	3.0
AB02	16.9	20.9	28.1	45.1	66.3	71.1	75.7	43.6	2.8	3.2
AB01	8.2	9.5	12.0	21.2	43.8	59.5	67.7	24.4	7.1	8.7
Prairie Creek Riffles below Brown Creek										
BB10	16.5	25.1	35.9	54.5	69.9	74.5	79.0	49.1	3.0	4.3
BB09	16.7	24.4	37.4	64.9	73.5	78.0	82.3	54.3	2.2	3.2
BB08	19.3	29.3	38.9	65.8	74.3	78.7	82.9	56.9	1.9	2.7
BB07	25.4	33.0	40.1	56.2	69.3	74.0	78.5	53.5	3.8	4.8
BB06	15.8	24.6	38.3	65.4	74.0	78.5	82.7	54.7	2.5	3.6
BB05	13.9	20.7	33.3	56.8	70.8	75.4	79.8	48.7	1.8	2.3
BB04	10.3	14.3	20.9	39.1	59.4	67.2	72.0	35.9	4.5	5.9
BB03	10.7	13.6	18.9	33.5	37.7	39.9	42.0	30.3	4.3	5.3
BB02	11.8	18.3	29.8	50.0	67.5	72.3	76.7	43.2	6.7	8.6
B01	11.5	16.5	23.3	42.4	60.5	67.3	72.1	36.7	5.4	7.0

APPENDIX D

Raw Data for Egg Survival Study

Table D-1. Averaged data collected from hatching and emergence infiltration bags within artificial redds on Prairie Creek, CA 1991.

SITE	SURVIVAL (%)	WORM ABUND. (RANK)	FINES <0.5 mm VOLUME (%)	FINES <0.5 mm WEIGHT (%)	FINES <1.0 mm VOLUME (%)	FINES <1.0 mm WEIGHT (%)	FINES <4.75 mm VOLUME (%)	FINES <4.75 mm WEIGHT (%)	% OF <4.75 mm FRACTION <1.0 mm, VOLUME	CHANGE IN INFLOW (cm ³ /sec)	BEGINNING INFLOW (FEBRUARY) (cm ³ /sec)	ENDING INFLOW (MARCH) (cm ³ /sec)
B1	0.00	1.0	9.90	3.68	12.25	4.53	18.39	13.42	70	-64.18	107.70	45.73
B2	0.00	1.0	13.43	3.92	15.34	4.11	19.07	11.10	81	-40.43	106.77	63.95
B3	0.00	2.0	14.07	3.08	15.57	3.67	19.52	10.46	82	-47.15	87.34	47.12
B4	0.58	3.0	12.88	2.99	13.60	2.89	15.86	8.13	86	-22.14	109.90	83.02
B5	16.21	2.0	9.24	1.18	9.35	0.71	10.16	2.46	92	-22.51	106.68	74.69
B6	12.23	1.0	9.82	1.41	10.14	1.02	11.30	3.15	89	-4.23	108.93	103.73
B7	0.00	1.0	12.13	2.49	13.45	2.88	15.76	6.73	86	-16.52	96.12	80.56
B8	17.42	0.0	10.34	1.29	10.55	0.95	11.37	2.46	92	-27.30	93.25	68.44
B9	15.78	1.0	11.20	2.03	11.68	1.88	13.25	4.43	88	-5.96	101.56	96.19
B10	2.79	1.0	12.52	1.53	12.91	0.97	14.71	4.14	88	-17.27	84.57	66.24
A1	28.38	0.0	12.02	2.26	15.90	2.78	21.35	7.87	76	47.70	78.63	109.20
A2	22.69	0.0	11.66	1.83	11.92	1.06	12.96	2.90	73	40.99	68.74	95.77
A3	5.33	3.0	13.21	1.62	13.50	1.09	14.50	3.01	94	-6.32	86.59	73.91
A4	1.93	1.0	10.78	1.35	11.06	1.02	11.92	2.56	93	29.68	62.76	74.03
A5	2.28	3.0	15.92	1.95	16.24	1.24	17.10	3.29	95	5.21	78.63	79.73
A6	28.85	1.0	10.02	1.63	10.40	1.12	11.37	3.00	92	-29.72	76.91	50.92
A7	29.97	2.0	9.52	1.44	10.41	1.04	12.28	4.62	84	-10.02	75.19	62.53
A8	27.22	1.0	8.46	1.71	8.86	0.76	10.44	3.86	85	42.07	73.43	95.34
A9	4.26	0.0	10.65	1.91	10.90	1.06	11.85	3.42	93	33.72	62.49	82.92
A10	*	*	*	*	*	*	*	*	*	-9.90	67.33	66.19

B = below Brown Creek confluence (affected reach) A = above Brown Creek (control reach)

* = bear destroyed emergence bag

Table D-2. Summary of data collected from hatching infiltration bags within artificial redds on Prairie Creek, CA 1991.

SITE	SURVIVAL (%)	WORM ABUND. (RANK)	FINES <0.5 mm VOLUME (%)	FINES <0.5 mm WEIGHT (%)	FINES <1.0 mm VOLUME (%)	FINES <1.0 mm WEIGHT (%)	FINES <4.75 mm VOLUME (%)	FINES <4.75 mm WEIGHT (%)	% OF <4.75 mm FRACTION <1 mm, VOLUME	CHANGE IN INFLOW (cm ³ /sec)	BEGINNING INFLOW (FEBRUARY) (cm ³ /sec)	ENDING INFLOW (MARCH) (cm ³ /sec)
B1	0.00	1	10.41	3.11	11.25	4.25	13.92	7.45	81	-47.68	132.97	85.29
B2	0.00	1	10.67	2.83	12.41	5.19	15.29	8.58	81	-35.63	84.84	49.21
B3	0.00	3	12.96	2.60	13.69	3.57	15.13	5.29	90	-41.88	75.60	33.72
B4	1.17	3	14.06	2.32	14.70	3.24	16.90	5.89	87	-9.89	85.94	76.05
B5	0.00	3	10.60	1.22	10.74	1.46	11.56	2.31	93	0.98	73.28	74.27
B6	0.00	0	8.24	1.25	8.64	1.82	10.11	3.57	85	-27.51	111.86	84.35
B7	0.00	0	10.43	1.71	11.17	2.67	12.98	4.77	86	-37.30	94.77	57.47
B8	3.04	0	8.02	1.03	8.24	1.32	9.39	2.67	88	-33.05	87.07	54.02
B9	3.04	2	8.30	1.37	8.59	1.75	9.97	3.23	86	-9.67	87.81	78.13
B10	0.00	1	13.87	1.65	14.40	2.40	15.98	4.33	90	0.52	63.97	64.48
A1	44.58	0	8.21	2.65	9.76	5.07	12.14	8.67	80	55.72	62.14	17.92
A2	0.00	0	11.03	1.95	11.35	2.42	12.12	3.20	94	19.65	76.21	95.86
A3	0.00	3	14.44	1.56	14.70	1.86	15.72	2.98	94	-42.04	108.90	66.87
A4	2.33	0	9.13	1.13	9.38	1.43	10.00	2.02	94	-13.41	78.51	65.11
A5	0.00	3	14.32	1.77	14.77	2.37	15.53	3.22	95	21.70	67.52	89.21
A6	16.74	2	10.20	1.55	10.59	2.02	11.09	2.54	95	-54.85	86.15	31.30
A7	0.00	3	12.71	1.62	13.27	2.54	14.72	4.30	90	18.29	61.11	79.40
A8	19.78	0	9.43	2.47	9.87	3.01	11.39	4.67	87	-8.56	90.87	82.31
A9	7.00	0	14.56	2.13	14.96	2.44	16.32	3.65	92	26.45	57.26	83.71
A10	0.00	0	13.02	1.87	13.80	2.92	15.74	5.18	88	-8.55	69.31	60.76

B = below Brown Creek confluence (affected reach) A = above Brown Creek (control reach)

Table D-3. Summary of data collected from emergence infiltration bags within artificial redds on Prairie Creek, CA 1991.

SITE	SURVIVAL (%)	WORM WEIGHT (GRAMS)	FINES <0.5 mm VOLUME (%)	FINES <0.5 mm WEIGHT (%)	FINES <1.0 mm VOLUME (%)	FINES <1.0 mm WEIGHT (%)	FINES <4.75 mm VOLUME (%)	FINES <4.75 mm WEIGHT (%)	% OF <4.75 mm FRACTION <1.0 mm, VOLUME	CHANGE IN INFLOW (cm ³ /sec)	BEGINNING INFLOW (JANUARY) (cm ³ /sec)	ENDING INFLOW (MARCH) (cm ³ /sec)
B1	0.00	0.69	9.39	4.24	13.24	8.79	22.86	19.38	57.92	-76.24	82.42	6.18
B2	0.00	1.00	16.19	5.01	18.27	7.93	22.84	13.62	79.99	-50.01	128.70	78.69
B3	0.00	2.00	15.17	3.55	17.45	7.11	23.90	15.63	73.01	-38.55	99.08	60.53**
B4	0.00	121.00	11.69	3.66	12.49	5.53	14.81	10.36	84.33	-43.87	133.86	89.99
B5	32.42	3.90	7.89	1.13	7.96	1.27	8.76	2.61	90.87	-64.95	140.07	75.12
B6	24.46	50.30	11.40	1.57	11.63	1.84	12.49	2.73	93.11	17.11	106.00	123.11
B7	0.00	41.50	13.82	3.27	15.72	5.53	18.53	8.69	84.84	6.17	97.47	103.64
B8	31.79	0.00	12.66	1.54	12.85	1.74	13.34	2.24	96.33	-16.55	99.42	82.87
B9	28.52	0.00	14.09	2.68	14.77	3.58	16.52	5.63	89.41	-1.06	115.30	114.25
B10	5.59	0.23	11.17	1.41	11.42	1.74	13.43	3.95	85.03	-37.17	105.16	68.00
A1	12.17	0.00	15.83	2.44	22.04	5.29	30.56	8.91	72.12	5.35	95.12	100.47
A2	45.38	0.00	12.29	1.70	12.48	1.94	13.79	2.60	90.50	34.43	61.26	95.68
A3	10.65	55.50	11.97	1.67	12.29	2.00	13.28	3.03	92.55	16.69	64.27	80.95
A4	1.52	0.23	12.42	1.57	12.73	1.90	13.83	3.09	92.05	35.93	47.01	82.95
A5	4.57	76.00	17.52	2.13	17.70	2.29	18.66	3.36	94.86	-19.50	89.74	70.25
A6	40.95	0.60	9.83	1.70	10.20	2.07	11.64	3.46	87.63	2.87	67.67	70.54
A7	59.95	0.00	7.13	1.26	7.54	1.87	9.84	4.94	76.63	-45.61	91.26	45.65
A8	34.66	0.92	7.48	0.95	7.84	1.31	9.48	3.04	82.70	52.38	55.98	108.37
A9	1.52	0.00	6.74	1.69	6.83	1.92	7.38	3.18	92.55	14.40	67.72	82.12
A10	*	*	*	*	*	*	*	*	*	-5.77	77.40	71.62

B = below Brown Creek confluence (affected reach) A = above Brown Creek (control reach)

* = bear destroyed emergence bag

** = Measurement taken in mid-March (3/14), not late March when basket was removed.

Table D-4. Averaged data collected from infiltration bags within artificial redds in Prairie Creek basin, CA 1992. Sites 1-12 were below Brown Creek; sites 13-17 were above Brown Creek; sites 18-22 were on Lost Man Creek.

SITE	SURVIVAL (%)	WORM WEIGHT (GRAMS)	FINES <0.5 mm VOLUME (%)	FINES <0.5 mm WEIGHT (%)	FINES <1.0 mm VOLUME (%)	FINES <1.0 mm WEIGHT (%)	FINES <4.75 mm VOLUME (%)	FINES <4.75 mm WEIGHT (%)	% OF <4.75 mm FRACTION <1.0 mm, VOLUME	CHANGE IN INFLOW (cm ³ /sec)	BEGINNING INFLOW (JANUARY) (cm ³ /sec)	ENDING INFLOW (MARCH) (cm ³ /sec)
1	42.09	0	11.34	0.86	11.47	1.00	12.78	2.36	89.75	-7.66	98.90	91.24
2	43.51	0	8.30	0.67	8.32	0.69	8.65	1.02	96.18	-32.15	123.47	91.32
3	12.71	0	9.56	0.93	9.64	1.02	10.16	1.55	94.88	-12.45	119.26	106.81
4	42.39	22	10.70	0.92	11.23	1.47	13.77	4.11	81.55	-21.47	119.10	97.63
5	10.59	0	11.27	1.42	11.70	1.84	13.40	3.50	87.31	-12.04	103.02	90.98
6	46.92	0	5.22	0.37	5.31	0.46	6.18	1.29	85.92	4.37	110.60	114.97
7	51.63	0	11.73	0.76	11.96	1.00	12.99	2.07	92.07	-1.52	95.87	94.35
8	43.12	0	4.47	0.33	4.51	0.37	5.08	0.91	88.78	0.17	95.28	95.45
9	51.09	0	8.29	0.61	8.40	0.72	9.16	1.47	91.70	8.50	93.76	102.26
10	68.83	0	7.77	0.67	8.08	0.96	9.42	2.28	85.77	-25.17	109.25	84.08
11	53.53	0	7.68	0.56	7.77	0.66	8.43	1.40	92.17	-27.27	124.32	97.05
12	55.38	0	8.83	0.67	9.04	0.88	10.33	2.21	87.51	-29.40	111.22	81.82
13	49.87	0	7.24	0.53	7.39	0.68	8.27	1.56	89.36	-26.18	124.57	98.39
14	12.88	0	3.50	0.30	3.53	0.33	3.84	0.60	91.93	-6.98	98.81	91.83
15	57.95	0	10.12	0.75	10.58	1.22	12.94	3.66	81.76	-23.48	122.38	98.90
16	28.80	0	11.85	1.05	12.28	1.51	14.36	3.69	85.52	-26.68	103.10	76.42
17	30.59	0	11.18	1.11	11.48	1.43	12.94	2.93	88.72	5.56	89.55	95.11
18	27.45	0	15.71	2.03	16.38	2.82	17.78	4.46	92.13	-23.66	122.72	99.06
19	10.55	0	10.22	1.25	10.62	1.70	11.54	2.71	92.03	-23.82	121.37	97.55
20	48.25	0	17.11	1.95	17.39	2.28	19.21	4.37	90.53	-23.48	117.83	94.35
21	24.88	0	11.55	1.74	12.46	2.75	17.21	8.01	72.40	-30.72	108.91	78.19
22	30.32	11	18.78	1.99	19.42	2.75	22.70	6.61	85.55	-21.38	101.00	79.62

Table D-5. Data collected from left baskets within artificial redds in Prairie Creek basin, CA 1992. Sites 1 - 12 were below Brown Creek; sites 13-17 were above Brown Creek; sites 18-22 were in Lost Man Creek.

SITE	SURVIVAL (%)	WORM WEIGHT (GRAMS)	FINES <0.5 mm VOLUME (%)	FINES <0.5 mm WEIGHT (%)	FINES <1.0 mm VOLUME (%)	FINES <1.0 mm WEIGHT (%)	FINES <4.75 mm VOLUME (%)	FINES <4.75 mm WEIGHT (%)	CHANGE IN INFLOW (cm ³ /sec)	BEGINNING INFLOW (JANUARY) (cm ³ /sec)	ENDING INFLOW (MARCH) (cm ³ /sec)
1	49.41	0	11.90	0.82	12.09	1.02	13.99	3.03	6.92	106.5	99.5
2	60.13	0	9.10	0.72	9.12	0.74	9.39	1.02	31.01	123.7	92.4
3	19.63	0	8.08	0.72	8.15	0.79	8.57	1.22	14.54	127.8	113.1
4	84.78	11	11.90	0.97	12.48	1.58	15.57	4.80	7.73	115.1	107.6
5	1.93	0	11.97	1.57	12.47	2.05	14.44	3.98	19.34	107.6	88.4
6	57.47	0	5.68	0.46	5.81	0.58	7.02	1.73	5.55	106.6	112.1
7	49.65	0	12.66	0.72	12.73	0.80	13.23	1.31	12.78	108.6	95.9
8	36.23	0	3.97	0.31	4.00	0.34	4.46	0.79	6.97	97.0	104.0
9	33.67	0	9.65	0.70	9.77	0.82	10.84	1.89	30.45	84.8	115.1
10	50.57	0	6.81	0.58	7.12	0.95	8.68	2.42	20.55	104.5	84.3
11	57.00	0	6.77	0.52	6.83	0.60	7.48	1.36	31.31	124.2	91.9
12	49.77	0	8.98	0.65	9.07	0.75	9.81	1.50	33.48	100.5	72.3
13	36.21	0	7.24	0.55	7.42	0.74	8.45	1.73	37.66	133.8	96.5
14	5.90	0	4.32	0.35	4.35	0.38	4.59	0.61	22.32	77.8	100.0
15	69.17	0	8.52	0.64	8.81	0.93	10.14	2.26	11.41	108.6	97.5
16	34.78	0	11.35	0.96	11.70	1.33	13.50	3.22	6.51	94.9	88.4
17	19.25	0	9.24	0.98	9.43	1.16	10.26	2.00	9.95	87.4	97.5
18	35.58	0	18.77	2.51	19.30	3.17	20.32	4.44	41.92	131.8	89.9
19	13.48	0	9.25	1.13	9.56	1.48	10.25	2.22	8.58	109.1	100.5
20	59.54	0	17.69	1.72	18.00	2.09	20.30	4.80	12.63	119.7	107.1
21	35.49	0	10.77	1.58	11.77	2.68	17.27	8.71	7.57	98.5	90.9
22	15.26	5.5	23.63	2.48	24.32	3.35	28.32	8.38	9.75	93.9	84.3

Table D-6. Data collected from right baskets within artificial redds in Prairie Creek basin, CA 1992. Sites 1-12 were below Brown Creek; sites 13-17 were above Brown Creek; sites 18-22 were in Lost Man Creek.

SITE	SURVIVAL (%)	WORM WEIGHT (GRAMS)	FINES <0.5 mm VOLUME (%)	FINES <0.5 mm WEIGHT (%)	FINES <1.0 mm VOLUME (%)	FINES <1.0 mm WEIGHT (%)	FINES <4.75 mm VOLUME (%)	FINES <4.75 mm WEIGHT (%)	CHANGE IN INFLOW (cm ³ /sec)	BEGINNING INFLOW (JANUARY) (cm ³ /sec)	ENDING INFLOW (MARCH) (cm ³ /sec)
1	34.78	0	9.31	0.90	9.38	0.98	11.60	1.73	-8.43	87.36	83.32
2	26.89	0	7.61	0.62	7.63	0.65	8.01	1.02	-33.48	124.23	89.90
3	5.80	0	11.44	1.21	11.54	1.31	12.18	1.99	-8.74	108.07	100.49
4	0.00	11	9.68	0.87	10.16	1.37	12.25	3.53	-35.20	117.16	87.87
5	19.25	0	10.60	1.27	10.97	1.64	12.39	3.04	-5.85	103.02	93.93
6	36.36	0	4.79	0.29	4.84	0.34	5.39	0.88	3.18	113.63	118.17
7	53.60	0	10.61	0.81	11.04	1.23	12.70	2.95	6.92	82.31	89.90
8	50.00	0	5.07	0.34	5.13	0.39	5.84	1.07	-6.97	82.31	81.31
9	68.50	0	6.88	0.52	6.96	0.60	7.42	1.05	-16.51	107.57	86.35
10	87.08	0	8.68	0.75	8.91	0.94	10.13	2.15	-30.35	118.17	83.32
11	50.06	0	8.78	0.61	8.89	0.73	9.58	1.44	-23.89	123.72	101.51
12	60.99	0	8.68	0.69	9.00	1.01	10.85	2.90	-4.19	97.47	88.37
13	63.53	0	7.24	0.51	7.35	0.63	8.09	1.38	-9.24	118.68	106.10
14	19.86	0	2.73	0.26	2.76	0.28	3.13	0.60	-34.74	123.72	81.31
15	46.74	0	11.58	0.85	12.20	1.50	15.49	2.73	-40.55	135.85	95.45
16	22.83	0	12.32	1.14	12.82	1.68	15.17	4.13	-47.07	110.09	64.14
17	41.93	0	12.88	1.23	13.29	1.67	15.29	3.79	4.70	92.41	96.45
18	19.06	0	12.91	1.62	13.71	2.51	15.46	4.49	-12.63	114.64	101.00
19	7.63	0	11.11	1.37	11.59	1.91	12.73	3.17	-40.30	151.50	97.97
20	36.97	0	16.53	2.17	16.79	2.46	18.15	3.98	-34.34	116.15	81.81
21	14.27	0	12.25	1.89	13.09	2.82	17.16	7.37	-53.88	117.16	65.65
22	45.38	5.5	14.60	1.61	15.19	2.29	17.85	5.24	-32.98	107.06	75.25

Table D-7. Data collected from natural redds on Prairie and Lost Man Creeks, CA WY1991.

SITE	REACH	SURVIVAL (# fry)	WORMS FOUND	FINES <0.5 mm VOLUME (%)	FINES <0.5 mm WEIGHT (%)	FINES <1.0 mm VOLUME (%)	FINES <1.0 mm WEIGHT (%)	FINES <4.75 mm VOLUME (%)	FINES <4.75 mm WEIGHT (%)	% OF <4.75 mm FRACTION <1 mm, VOLUME
PC1	AFFECTED	0.00	NO	19.74	7.83	21.36	10.17	37.61	29.92	0.57
PC2	AFFECTED	0.00	NO	8.61	3.97	10.10	5.92	16.16	12.52	0.63
PC3	AFFECTED	0.00	NO	5.85	1.80	6.46	2.68	15.31	12.70	0.42
PC4	AFFECTED	0.00	NO	-	-	-	-	-	-	-
PC5	AFFECTED	2.00	YES	1.90	0.66	2.58	1.53	12.35	11.16	0.20
PC6	AFFECTED	3671.00	NO	5.97	2.51	7.10	4.03	9.39	6.71	0.76
PC7	AFFECTED	37.00	NO	5.93	2.47	7.65	4.73	21.93	19.44	0.35
PC8	CONTROL	0.00	YES	7.91	2.87	10.54	4.11	26.33	13.79	0.40
PC9	CONTROL	0.00	NO	1.58	0.30	1.58	0.30	1.58	0.30	0.10
PC10	CONTROL	0.00	YES	10.25	5.10	12.32	7.94	22.50	19.78	0.55
LM1	CONTROL	804.00	NO	6.64	3.05	8.02	4.99	17.87	16.93	0.45
LM2	CONTROL	219.00	YES	9.08	3.52	9.58	4.20	16.50	9.83	0.58
LM3	CONTROL	208.00	NO	11.85	3.17	12.81	4.52	30.50	25.57	0.42

APPENDIX E.

Table E. Ratio of weight to volume of fine sediment in hatching and emergence infiltration bags on Prairie Creek, winter 1990-1991.

RATIO OF WEIGHT TO VOLUME OF FINE SEDIMENT		
PARTICLE SIZE	MEAN FOR HATCHING BAGS (RANGE)	MEAN FOR EMERGENCE BAGS (RANGE)
< 4.7 mm	0.17 (0.12 - 0.30)	0.19 (0.12 - 0.45)
< 1.0 mm	0.23 (0.14 - 0.52)	0.26 (0.14 - 0.66)
< 0.5 mm	0.33 (0.19 - 0.71)	0.38 (0.17 - 0.85)

For winter 1991-1992, the mean ratio of weight to volume of fine sediment < 1.0 mm was 0.118 which was much lower than 1990-1991. This may be because the lower flows of WY92 carried smaller particles within the size range of 0 to 1 mm.

APPENDIX F

Correlations with Egg Survival-to-Hatching and Egg Survival-to-Emergence

Correlations with Egg Survival-to-Hatching. Egg survival-to-hatching was weakly negatively correlated with volume < 0.5 mm (but not weight) of fines in infiltration bags over all sites and in the control reach, but not in the affected reach (Table F-1). When volume of fines < 0.5 mm, geometric mean of the gravel framework, and sediment flux were regressed on survival, the regression was significant ($r = 0.62$, $P = 0.0471$, 27% of variance explained).

When all sites were combined, egg survival-to-hatching was weakly correlated with percent change in inflow rate ($r = 0.38$, $P = 0.048$), but not actual change in inflow rate ($r = 0.34$, $P = 0.071$) or ending inflow rate. When separated by reach, correlations between survival and inflow rate were not significant. Permeability was not correlated to volume of fines or with weight of fines in the affected reach. However, in the control reach, permeability increased with increasing weight of fines (Table F-1).

Amount of worms in hatching baskets were ranked none, low, medium, or high. Amount of worms and hatching survival were not significantly correlated ($r = -0.31$, $P = 0.09$). Worms were weakly correlated to fines for the smallest size classes in the control reach only (Table F-1). Percent of organic matter in fines was negatively correlated to egg survival ($r = -0.85$, $P = 0.004$, 68% of variance accounted for) in the control reach, but not the affected reach.

Using all sites, percent volume of fines < 0.5 mm, and percent change in inflow were selected in a stepwise regression. Egg survival-to-hatching was the dependent variable, and $r = 0.60$, $P = 0.038$, and variance accounted for (adjusted r) was 28%. When percent organic matter was substituted for percent volume of fines, the statistics were almost identical ($r = 0.60$, $P = 0.034$, 29%). When worms or other variables were added to the multiple regression, little additional variance was explained.

When this same analysis was run on the separate reaches, the stepwise procedure did not select any variables for the affected reach. Only percent volume of fines < 0.5 mm was selected for the control reach ($r = 0.66$, $P = 0.05$, 37%).

Correlations with inorganic fines < 0.5 mm were almost identical to results for correlations with all fines < 0.5 mm.

Correlations with Egg Survival-to-Emergence. Correlations found between egg survival and fines or permeability in the emergence baskets were stronger than the hatching baskets. Volume of fines < 0.5 mm was strongly and negatively correlated to survival over all sites and just in the affected reach. No significant correlations existed for sites above Brown Creek (Table F-2).

Correlations with fine percentages in the bottom strata (egg pocket) were almost identical to

correlations with fine percentages for the entire sample. Different from the hatching bag results, percent organics in emergence bags were positively correlated to egg survival in the affected reach ($r = 0.71$, $P = 0.01$).

Permeability was not significantly correlated to egg survival-to-emergence for all sites or when separated by reach ($P > 0.10$).

Change in inflow rate (percent change and actual change had similar results) for all emergence baskets was significantly and negatively correlated to the percent of fine sediment by weight (but not volume) found in these baskets. Separated by stream reach, this correlation was only significant below Brown Creek for fines < 4.7 mm. Most fines vs. ending flow rate correlations were not significant, except for < 4.7 mm below Brown Creek (Table F-2).

Weight of worms in emergence baskets was not correlated to egg survival-to-emergence. Unlike hatching basket results, worm abundance did not significantly correlate with percentage of fines in the emergence baskets (Table F-2).

Stepwise regression selected weight of fines < 0.5 mm and percent of fines < 0.5 mm composed of organic material when egg survival-to-emergence was the dependent variable ($r = 0.77$, $P = 0.0007$, accounting for 55% of the variance). When data for hatching and emergence bags were combined for all sites, correlations between survival and fines, permeability, and worms were very weak, but significant ($r = -0.29$ to -0.33 , $P < 0.05$ for fines, $r = 0.30$, $P = 0.03$ for percent change in permeability, $r = -0.31$, $P = 0.3$ for worms). Weight of fines < 4.7 mm slightly negatively affected permeability ($r = -0.33$, $P = 0.02$). Amount of worms were not correlated to permeability. Stepwise multiple regression with survival as the dependent variable selected (1) volume of fines < 1 mm and (2) percent change in inflow rate, accounting for 14% of the variance (multiple $r = 0.43$, $P = 0.02$).

Table F-1. Correlation coefficients (r) and significance for variables sampled in hatching bags in artificial redds in Prairie Creek, winter 1990-1991.

	% SURVIVAL	PERMEABILITY		WORM ABUNDANCE
		% ▲ INFLOW	ENDING RATE	
PRAIRIE CREEK ABOVE AND BELOW BROWN CREEK (all sites pooled)				
BY WEIGHT				
< 4.7 mm	0.05	0.05	0.11	-0.10
< 1.0 mm	0.09	0.07	0.08	-0.04
< 0.5 mm	0.05	0.01	0.07	0.02
BY VOLUME				
< 4.7 mm	-0.33	0.14	-0.04	0.37
< 1.0 mm	-0.37	0.13	-0.10	0.45*
< 0.5 mm	-0.42*	0.10	-0.12	0.49*
PRAIRIE CREEK ABOVE BROWN CREEK (CONTROL)				
BY WEIGHT				
< 4.7 mm	0.45	0.62*	0.58*	-0.29
< 1.0 mm	0.53	0.65*	0.63*	-0.32
< 0.5 mm	0.40	0.45	0.51	-0.37
BY VOLUME				
< 4.7 mm	-0.49	0.21	0.11	0.39
< 1.0 mm	-0.63*	0.06	-0.05	0.50
< 0.5 mm	-0.70*	-0.06	-0.14	0.51
PRAIRIE CREEK BELOW BROWN CREEK (AFFECTED)				
BY WEIGHT				
< 4.7 mm	-0.39	-0.46	-0.17	0.00
< 1.0 mm	-0.45	-0.49	-0.27	0.11
< 0.5 mm	-0.41	0.46	-0.20	0.25
BY VOLUME				
< 4.7 mm	-0.45	0.04	-0.27	0.39
< 1.0 mm	-0.44	0.05	-0.32	0.48
< 0.5 mm	-0.38	0.15	-0.27	0.54

* P < 0.05

Table F-2. Correlation coefficients (r) and significance for variables sampled in emergence baskets in artificial redds in Prairie Creek, winter 1990-1991.

	% SURVIVAL	PERMEABILITY		WORM WEIGHT
		% ▲ INFLOW	ENDING RATE	
PRAIRIE CREEK ABOVE AND BELOW BROWN CREEK (all sites pooled)				
BY WEIGHT				
< 4.7 mm	-0.64**	-0.58*	-0.45	0.03
< 1.0 mm	-0.68**	-0.51*	-0.31	0.10
< 0.5 mm	-0.72***	-0.49*	-0.24	0.21
BY VOLUME				
< 4.7 mm	-0.51*	-0.32	-0.14	0.03
< 1.0 mm	-0.47*	-0.17	0.09	0.15
< 0.5 mm	-0.40	-0.07	0.22	0.25
PRAIRIE CREEK ABOVE BROWN CREEK (CONTROL)				
BY WEIGHT				
< 4.7 mm	0.03	-0.43	0.03	-0.21
< 1.0 mm	-0.21	-0.33	0.19	-0.02
< 0.5 mm	-0.46	-0.38	0.03	0.33
BY VOLUME				
< 4.7 mm	-0.22	-0.17	0.28	0.21
< 1.0 mm	-0.33	-0.14	0.26	0.38
< 0.5 mm	-0.38	-0.11	0.17	0.56
PRAIRIE CREEK BELOW BROWN CREEK (AFFECTED)				
BY WEIGHT				
< 4.7 mm	-0.87**	-0.58*	-0.60	0.03
< 1.0 mm	-0.86**	-0.44	-0.46	0.08
< 0.5 mm	-0.82**	-0.34	-0.32	0.15
BY VOLUME				
< 4.7 mm	-0.76*	-0.33	-0.43	-0.19
< 1.0 mm	-0.60	0.09	-0.01	-0.12
< 0.5 mm	-0.35	0.39	0.33	-0.06

* P < 0.05 ** P < 0.01 *** P < 0.001

APPENDIX G

Monte Carlo Simulations.

Problem

The number of unfertilized eggs in each control basket testing handling mortality varied, which indicates fertility rates in the individual baskets within the artificial redds probably varied, also. This variability could change the outcome of the statistical tests by random chance. The effect of random chance on selecting different variability rates needed to be determined to understand the reliability of the results. For this reason, Monte Carlo simulations were run using data from the handling mortality baskets. The control tray results were not used because the data were unreliable. Fungus spread rapidly throughout some of the trays, killing many eggs that may have survived if they had been separated by gravel in the baskets.

Methods

The 9 control baskets testing for handling mortality had the following egg survival rates for each fish:

	Basket 1	Basket 2	Basket 3
Fish 1:	89%	96%	90%
Fish 2:	72%	66%	-
Fish 3:	55%	51%	-
Fish 4:	78%	95%	-

Beta distribution curves (Figure 8) were developed for each fish using the means and standard deviations of these data. The beta distribution was selected over the normal distribution because the beta curve is appropriate for percent values clumping close to 100%, and it prevents egg survival values from exceeding 100%. These curves represented the expected distribution of fertility rates for each fish. During one Monte Carlo simulation, fertility rates were randomly selected for each basket in an artificial redd based on the probabilities represented by the curves. Egg survival percentages in each basket were divided by the selected fertility rates, averaged between the two baskets in each redd, and then transformed using arcsine square-roots. A t-test was run to detect differences between the resulting transformed egg survival mean in the affected and control reaches. The Monte Carlo simulations were run 1,000 times giving 1,000 t-test results.

Results

The mean from 1,000 runs in the affected reach for egg survival was 44.0% in the affected reach and 32.2% in the control reach. These numbers were almost identical to those obtained using the average egg survival rates from the handling mortality baskets (43.5% in the affected reach and 32.2% in the control reach). Egg survival rates did not significantly

differ between the two reaches 858 out of 1000 runs when $P < 0.10$. When $P < 0.05$, the difference was insignificant 100% of the time. Thus, taking in account the random variability in fertility rates that may have occurred in each basket, the results still did not strongly support a significant difference in egg survival between the affected and control reaches.

APPENDIX H

Dissolved Oxygen Values for WY91

Table H-1. Comparison of mean dissolved oxygen (ppm) in artificial redds and overlying surface water between the control (above Brown) and affected (below Brown) reaches of Prairie Creek, winter 1990-91.

INITIAL MEAN DISSOLVED OXYGEN (ppm)						
PIPE LOCATION	STATISTICAL TEST	AFFECTED REACH	S.E.	CONTROL REACH	S.E.	P
HATCHING BASKET	T-Test	10.8	0.1	10.9	0.1	0.791
EMERGENCE BASKET	Kruskal-Wallace	11.0	0.1	11.2	0.1	0.170
MILL CREEK PIPE	T-Test	11.1	0.1	11.2	0.1	0.229
SURFACE WATER	T-Test	11.2	0.1	11.3	0.1	0.644
FINAL MEAN DISSOLVED OXYGEN (ppm)						
PIPE LOCATION	STATISTICAL TEST	BELOW (Affected)	S.E.	ABOVE (Control)	S.E.	P
HATCHING BASKET	Kruskal-Wallace	11.0	1.8	10.4	0.2	0.111
EMERGENT BASKET	Kruskal-Wallace	11.3	0.2	10.9	0.2	0.305
MILL CREEK PIPE	Kruskal-Wallace	11.3	0.2	11.3	0.1	0.435
SURFACE WATER	T-Test	11.6	0.1	11.4	0.2	0.224

Table H-2. Comparison of dissolved oxygen (ppm) in artificial redds and overlying surface water before and after the incubation period in the control (above Brown) and affected (below Brown) reaches of Prairie Creek, winter 1990-91.

MEAN DISSOLVED OXYGEN (ppm)						
PIPE	STATISTICAL TEST	INITIAL	S.E.	FINAL	S.E.	P
HATCHING BASKET (below)	Wilcoxon's Sign	10.8	0.1	11.0	0.2	0.575
HATCHING BASKET (above)	Paired T-Test	10.9	0.1	10.4	0.2	0.184
MILL CREEK PIPE (below)	Paired T-Test	11.1	0.1	11.3	0.2	0.242
MILL CREEK PIPE (above)	Wilcoxon's Sign	11.2	0.1	11.3	0.1	1.000
EMERGENCE BASKET (below)	Wilcoxon's Sign	11.0	0.1	11.3	0.2	0.292
EMERGENCE BASKET (above)	Wilcoxon's Sign	11.2	0.1	10.9	0.2	0.441
SURFACE WATER (below)	Paired T-Test	11.2	0.1	11.6	0.1	0.012
SURFACE WATER (above)	Paired T-Test	11.2	0.1	11.4	0.2	0.620

APPENDIX I

An Example of a Particle Size Distribution Curve

Site BB1H - Below Brown Creek

