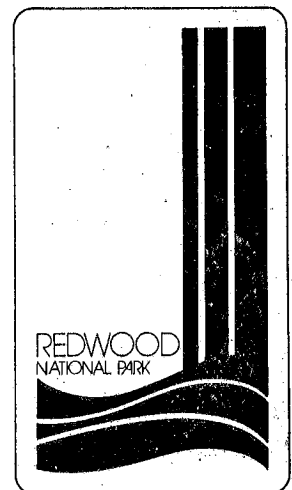


Vicki Ozaki

**MONITORING THE IMPACTS
AND PERSISTENCE OF FINE
SEDIMENT IN THE
PRAIRIE CREEK WATERSHED
1989-1990**

March, 1991
REDWOOD NATIONAL PARK



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LIST OF ABBREVIATIONS

cfs	cubic feet per second
DO	Dissolved Oxygen
FEIS	Final Environmental Impact Statement
ft	feet
g	gram
LBR	Lower Brown Creek Monitoring Site
mi	miles
mg/l	milligrams per liter
m	meters
ntu	nephelometric turbidity units
NRWQCB	Northcoast Regional Water Quality Control Board
PABR	Prairie Creek above Brown Creek Monitoring Site
PBBR	Prairie Creek below Brown Creek Monitoring Site
PBBY	Prairie Creek below Boyes Creek
PP	Photo-Point
ppm	parts per million
PSW	U.S. Forest Service Pacific Southwest Forest and Range Experiment Station
Q	discharge
r^2	coefficient of variation
RI	recurrence interval
t	tons
UBR	Upper Brown Creek Monitoring Site
WY	Water Year
X/S	cross section
yr	year

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

EXECUTIVE SUMMARY

The October, 1989 storm delivered fine sediment from the U.S. Highway 101 Bypass directly into the Prairie Creek watershed. Redwood National Park and U.S. Forest Service scientists instituted a monitoring program to determine the effects of the fine sediment on the physical and biological habitat in Prairie Creek and selected tributaries and evaluated the persistence of fine sediment deposited in these streams from the October storm. A summary of the findings is as follows:

1. **Hydrologic season:** Total rainfall for the 1989-1990 winter season was 29% below normal. Consequently, the runoff season was minimal and all peak stormflows were smaller than the estimated two year recurrence interval discharge. It is important to interpret the results of this study within the context of the mild 1989-90 winter runoff season.
2. **Suspended sediment:** The October storm transported 30 times the amount of sediment than later storms of a similar magnitude. During the monitoring period from January to June, most sediment was transported during the first storm in January and little sediment moved during low flows. Average annual sediment loads in 1989-90 were five times higher in Brown Creek and two times higher in Prairie Creek (below Brown Creek) than the average annual sediment load measured in a control stream (Little Lost Man Creek). Suspended sediment concentrations in Prairie Creek and Brown Creek were up to 20 times higher than the control.
3. **Surface deposition:** A light-colored fine sediment from the October storm was deposited on streambed surfaces primarily in quiet water areas, such as pools, backwater channels, eddies and on emergent gravel bars. Average depth of this surface fine sediment ranged from 0.3 to 5.0 cm. Other, higher velocity areas exhibited a thin coating of silt. Over the 1989-90 monitoring period, sand and gravel in the channel bed moved locally, but no widespread mobilization of the bed surface occurred. In Brown Creek, the most intensively studied of the Prairie Creek tributaries, surface fine sediment from the October storm decreased in the upper study reach by 28%, while in the lower reach, they increased by 3%. Extrapolation to the entire length of Brown Creek showed a net decrease of about 11% in the surface fine sediment deposited by the October, 1989 storm. However, in an impacted tributary, Boyes Creek, and in Prairie Creek, the volume and depth of fine sediment on streambed surfaces remained about the same, or increased locally throughout the season. In Prairie, and the tributaries, Ten Tapo, Brown and Boyes Creeks, percent embeddedness of spawning gravels remained about the same from October to June. It is likely that future high flows will remove fine sediment more readily from the higher velocity areas than from the quiet water areas where fine sediment will be the most persistent.

4. **Subsurface fine sediment:** Fine sediment deposited within streambed gravels and below the streambed surface comprise the bulk of fine sediment still in the stream system. Fine sediment generally remained in place throughout the winter due to the lack of flows capable of mobilizing the streambed. The < 1 mm size fraction which infiltrated artificially cleaned riffles (measured by infiltration bags) was significantly higher in affected streams: one and one half times higher in Prairie Creek than in the control stream (Lost Man Creek), and three times higher in Brown Creek riffles. Natural and artificial salmonid redds in Prairie Creek also showed sizable increases in fine sediment (measured by McNeil samples), but at levels not statistically different from Lost Man Creek. At the end of the winter, mean percent (by volume) of the < 1 mm size fraction was 10.5% in natural redds in Prairie Creek upstream of Brown Creek which was significantly lower than the 23% for Prairie Creek redds downstream of Brown Creek. In comparison, the value for natural redds in Lost Man Creek was 19% at the end of the winter.

In Prairie and Boyes Creeks riffles, where subsurface fine sediment was not artificially cleaned, the volume of fine sediment (measured by McNeil samples) generally did not change over the winter (average volume was about 25%). Of interest, the < 1 mm size fraction in a few uncleaned riffles in lower Brown Creek decreased significantly by about 12% (from an initial average volume of 33%). More fine sediment infiltrated into pools in Brown Creek than in riffles.

Freeze-core sampling showed that although the top five cm of the Brown Creek streambed had relatively few fines, the percent fine sediment increased with depth to 40 cm below the streambed surface. In Prairie Creek, freeze-core sampling before and after the October storm did not detect an increase in the < 1 mm size fraction. However, the freeze-core technique appears to underestimate the < 1 mm size fraction and is not sensitive enough to monitor changes in fine sediment. We found McNeil sampling to be more sensitive to change in the < 0.5 mm size fraction and is recommended over freeze-core sampling in future studies of short-term impacts of very fine sediment.

In Brown Creek, over 70% of the < 2 mm size fraction presently in the stream system is stored subsurface. The proportion of this material resulting only from the October storm cannot be accurately determined. However, the color and texture of this fine sediment resembles nearby surface deposits which are known to be a direct result of the October storm. This suggests that a large proportion of subsurface fine sediment in Brown Creek has infiltrated the streambed as a direct result of the October, 1989 storm. The large reservoir of fine sediment stored subsurface in Brown Creek will probably remain in place until the streambeds are significantly mobilized, probably by at least a 10-year recurrence interval flood.

5. **Permeability and dissolved oxygen:** Permeability (measured as inflow rates into standpipes) in artificial redds in Prairie Creek decreased steadily throughout the winter, especially below Brown and Boyes Creeks. Inflow rates in Prairie Creek below Brown Creek were only half those

measured in Prairie Creek above Brown Creek. Dissolved oxygen was lower in the intragravel water (ranging from 7.7 to 11.7 ppm) than in the surface water (ranging from 8.6 to 12.4 ppm) in these same artificial redds. The greatest difference in surface and intragravel dissolved oxygen was found downstream of the mouth of Brown Creek.

6. **Steelhead egg survival:** Survival of eyed steelhead eggs to hatching was determined by monitoring eggs in baskets placed within artificial redds from February to April. It is important to note that no storms (and thus no significant flows) occurred during this period. Survival to hatching in Prairie Creek was relatively high (71%) and not significantly different than the control stream, Lost Man Creek (85%). Worms appeared to be responsible for some egg mortality; when their effect was removed, survival was 88% in Prairie Creek and 86% in Lost Man Creek. These worms, rather than sediment, were associated with the only high mortality (100%) found in two artificial redds in Prairie Creek. After hatching, mean percent volume of fine sediment (< 1 mm) in the egg baskets was low, 3% in Prairie Creek and 4% in Lost Man Creek. Winter flows were insufficient to transport sediment into the cleaned redds. These results do not indicate whether the eggs would have survived if exposed to a large flow event. Nor did we test whether the surviving sac-fry would have been able to emerge from the gravels. Further study of survival to emergence and oxygen delivery in redds during a typical rainfall year with larger flows is needed.

In general, much of the fine sediment delivered to the tributaries of Prairie Creek in the October, 1989 storm remains in the stream system. Although the total amount of sediment delivered to Brown Creek was less than the amount estimated in the Final Environmental Impact Statement (FEIS), the percent of fine sediment found in redds was much higher than predicted by the preparers of the FEIS. The amount of fine sediment anticipated to infiltrate into the streambed was so low in Brown Creek and upper Prairie Creek that no impact to fisheries was predicted; however, this study has demonstrated significant infiltration of fine sediment into the gravel bed of these streams and a corresponding decrease in streambed permeability. This sediment is expected to move through the system episodically, as a function of future streamflow magnitudes. Because sediment movement is highly weather dependent, the persistence of this sediment is difficult to project. Also, the biological impacts of the sediment may persist longer than the sediment itself, owing to the life histories of affected species.

Although the sediment can be found throughout Prairie Creek, the greatest amounts still reside in the tributaries. Impacts to salmonid reproduction were likely greatest in these tributaries. Spawner surveys on Prairie Creek indicates spawning was not inhibited in winter 1989-1990. Our monitoring also indicates that effects to the main channel of Prairie Creek during the 1989-90 winter season were probably not catastrophic for steelhead egg survival. However, it is unknown what the effects were on salmon egg survival. Impacts to the Prairie Creek ecosystem are expected to increase for an unknown period of years as the affected tributaries flush themselves of fine sediment. Continued monitoring is essential for tracking conditions through time so that the downstream propagation of impacts can be followed and the need for further

measures to artificially sustain fish reproduction (beyond the normal operation of the Humboldt County Prairie Creek Fish Hatchery) can be evaluated.

It is important to recognize that all projections of the persistence of both the fine sediment and its effects are based on the assumption that future erosion from the bypass will be minimal. If this is not the case, and high erosion rates from the bypass continue or recur, effects from fine sediment will be both more intense and more persistent. In addition, fine sediment from the October, 1989 storm will be indistinguishable from later material, which will further complicate the task of assessing impacts solely from the October storm.

Recommendations for continued monitoring:

1. Continue to monitor suspended sediment discharge in Prairie and Brown Creeks, but restrict sampling to higher discharges to reduce sampling intensity and associated costs.
2. Conduct an egg survival to emergence experiment with coho salmon eggs during the next two fall seasons. Measure infiltration of fine sediment, permeability, apparent velocity and dissolved oxygen (solute transport) at egg basket locations. This will facilitate interpretation of results and reduce costs by consolidating various measurements to fewer locations, and provide a greater range of flow conditions for the study.
3. Repeat spawning surveys on Prairie Creek.
4. Repeat cross section surveys, sediment probing, photographs, and McNeil sampling after a high discharge (5-year storm, for example).

I. INTRODUCTION

A. Background

Construction of the U.S. Highway 101 Bypass construction project has been in progress since 1984. The second phase of this project (grading and earth work) has been underway since 1985 and will be completed in 1990. The site encompasses about 500 acres and spans parts of the Klamath and Prairie Creek watersheds.

The Final Environmental Impact Statement (FEIS) of the U.S. 101 Bypass Project predicted short-term (four to eight years) and long-term (20 years) sediment yields and resultant short-term fishery losses from the Bypass construction site. Sediment losses were predicted by the Universal Soil Loss Equation. An internal document produced by Caltrans District 1 Engineering Services (Mark Moore, personal communication) separated these estimates by watershed, as follows:

	Predicted Sediment Loss (tons)		Predicted Short-term Fishery Losses
	<u>Short-term</u>	<u>Long-term</u>	
Prairie Creek	3586	1076	13.6% (Co, S, Ch)**
Big Tree Creek*	2638	40	0
Ten Tapo Creek*	497	7	0
May Creek	3170	951	75-100% (Co, S)
Boyes Creek South Fork	2152	1077	} 25-45% (Co, S, Ch)
Boyes Creek North Fork	1470	441	
Brown Creek	1138	341	0

* The sediment loss for these creeks is included in Prairie Creek estimates.

**Co=coho, S=steelhead, Ch=chinook

The construction contract between Caltrans and the contractor, as well as the waste discharge requirements issued by the Northcoast Regional Water Quality Control Board (NCRWQCB) limited construction activities to the period between May 15 and October 15. Both agencies also required that all erosion control facilities be installed by October 15 and maintained throughout the rainy season.

B. The Problem

In September, 1989 Caltrans drafted a change order in the contract which extended the October 15 cutoff date for construction activities to November 17, 1989. The NCRWQCB, California Department of Fish and Game, Department of Parks and Recreation, and Redwood National Park were notified of this action. The purpose of the change order was to allow the contractor to complete much of the remaining earthmoving work for the project. In response, the contractor continued construction activities past October 15 and failed to complete erosion control facilities along a several-mile long segment of the project under construction.

Between October 20 and October 27, 1989, 3.73 inches of rainfall were recorded at Orick, approximately seven miles south of the construction project. The resultant runoff caused extensive erosion throughout the unprotected construction project. Erosion control structures would have dispersed and directed runoff into sediment basins or drainage ditches. Without them, runoff was allowed to run uncontained for distances up to 3/4 mile, eventually finding routes down embankment faces and unprotected ditchlines. Embankment faces, which were not protected by mulch and filter fabric fences, were subject to extensive surface erosion and gullying which generated numerous mud flows. Several hundred cubic yards of soil were eroded from the project site, and much of this fine-grained material was deposited in Ten Tapo, Brown, Big Tree, Boyes, May and Prairie Creeks.

In response to the discharge permit violation and damage resulting from this fall storm, the NCRWQCB issued Cleanup and Abatement Order No. 89-146, directing Caltrans to mitigate for the resultant impacts. Although many of the impacted streams have been monitored for several years to document highway construction related impacts, the nature of the monitoring was insufficient to adequately assess the acute nature and persistence of the impacts from the October 20-27 storm. This was because: (1) the monitoring techniques were not designed to measure the extremely fine-grained nature of the deposited material (silt and finer), (2) the number of monitoring sites was too small for a problem of this nature, and (3) the type of monitoring was designed to document much larger and longer-term physical changes in stream morphology.

To determine mitigation related to the October storm, Caltrans proposed to supplement the existing monitoring with studies to determine the extent of impacts and persistence of materials deposited in streambeds in October. In Caltrans' Phase 1 Compliance Plan under the North Coast Water Quality Control Board Order No. 89-146, Caltrans proposed additional monitoring to predict residence times for project-derived sediments. "This additional monitoring will include additional freeze-core substrate sampling, invertebrate sampling, stream reach mapping, gravel permeability sampling, suspended sediment and bedload movement analysis, and other work as determined to be appropriate." Redwood National Park and the U.S. Forest Service, Pacific Southwest Forest and Range Experiment Station (referred to herein as PSW) were funded by Caltrans to implement studies to determine the nature and longevity of October storm impacts on Prairie Creek and its tributaries.

C. Life History of Salmonids

A brief description of salmonid life histories is required to understand potential impacts that fine sediment from the bypass may have in the Prairie Creek system. Four salmonid species reproduce in Prairie Creek and its tributaries: chinook salmon (Oncorhynchus tshawytscha) (also called king salmon), coho salmon (Oncorhynchus kisutch) (also called silver salmon), steelhead trout (Oncorhynchus mykiss), and coastal cutthroat trout (Oncorhynchus clarki). These species are anadromous, spending part of their life cycle in the ocean. Chinook salmon typically return to Prairie Creek from the ocean to spawn between November and early January. Coho salmon

arrive between November and early February. Steelhead trout enter the system the latest, between January and April. Chinook salmon primarily spawn in the mainstem, whereas coho salmon and steelhead trout spawn in the tributaries as well. Although little is known about the life histories of cutthroat trout, they are often found in the Redwood Creek estuary in the summer before their upstream migration into the Prairie Creek tributaries to spawn. A few resident (non-migratory) populations of cutthroat trout inhabit the tributaries.

The larger the salmonid, the larger the gravels the fish uses to construct a redd (egg nest). Females of the largest salmonid species, chinook salmon, may deposit between 4,000 to 7,500 eggs in a redd in Prairie Creek (Steve Sanders, personal communication). The female constructs a redd using her tail to hydraulically lift the gravels, sifting them free of fine sediment as they drift downstream. In this manner she creates a hole for eggs and piles a mound of gravel, called the tailspill, downstream. Side by side the male and female deposit some of their sperm (milt) and eggs into the hole (egg pocket). The female fills the hole by digging a new one upstream. Again, the pair deposit their eggs and sperm into the new hole. This process is repeated until the female has released all her eggs. Depending on the water temperature, the eggs hatch in 6 to 11 weeks. The alevins (sac fry) remain in the gravel 2 to 8 weeks longer. When the yolk sac is absorbed, these fry emerge from the gravel to feed on available stream invertebrates.

When spring arrives, chinook salmon smolt migrate downstream to rear in the Redwood Creek estuary before entering the ocean in the fall. Coho salmon typically remain in the streams for one year before migrating downstream in the spring to enter the ocean. Steelhead juveniles rear in the stream for one to four years before migrating downstream and entering the ocean. Chinook salmon usually return to freshwater after three to four years, although two year old male spawners are commonly observed. The majority of coho salmon return at age three and most steelhead trout return to spawn at age four.

All Pacific salmon die after spawning; however, steelhead can survive to spawn again for several years. Steelhead carcasses are rarely found in Prairie Creek. One implication of the salmonid life cycle is that poor spawning and recruitment in one year will result in a depressed salmonid population three to four years later. Thus, poor reproduction in a stream four years in a row can be devastating. The studies in this report address the effects of bypass-derived sedimentation on the reproductive portion of the salmonid life cycle in Prairie Creek.

D. Goals and Purpose

The goals of this study were to define where sediment was deposited, how much was deposited, how deeply sediment infiltrated the streambed, how infiltrated sediment affected flow of oxygenated water to redds, how long fine-grained sediment will remain in the creeks, and how the fine sediment affects fish reproduction, specifically spawning habitat, egg survival, and the food base (benthic macroinvertebrates).

E. Study Sites

Figure 1 shows the locations of study sites in the Prairie Creek watershed. The north fork of Brown Creek was intensively monitored by PSW staff. Sediment behavior in Brown Creek is probably similar to other tributaries affected by erosion and sedimentation, and Brown Creek results will be used to interpret processes in Boyes, Big Tree and Ten Tapo Creeks. Redwood National Park and Prairie Creek Redwoods State Park personnel set up intensive monitoring stations on Prairie Creek upstream and downstream of Brown Creek to assess the impact of known sediment input (from Brown Creek) on Prairie Creek. Lost Man Creek was used as a control stream for several aspects of this study. Lost Man Creek was previously logged, so natural erosion processes have been affected, but it has not been impacted by bypass construction. Little Lost Man Creek, a pristine old-growth redwood watershed, was also used for comparison purposes. Miscellaneous study sites were chosen for specific phases of the project, and will be described in the appropriate sections below.

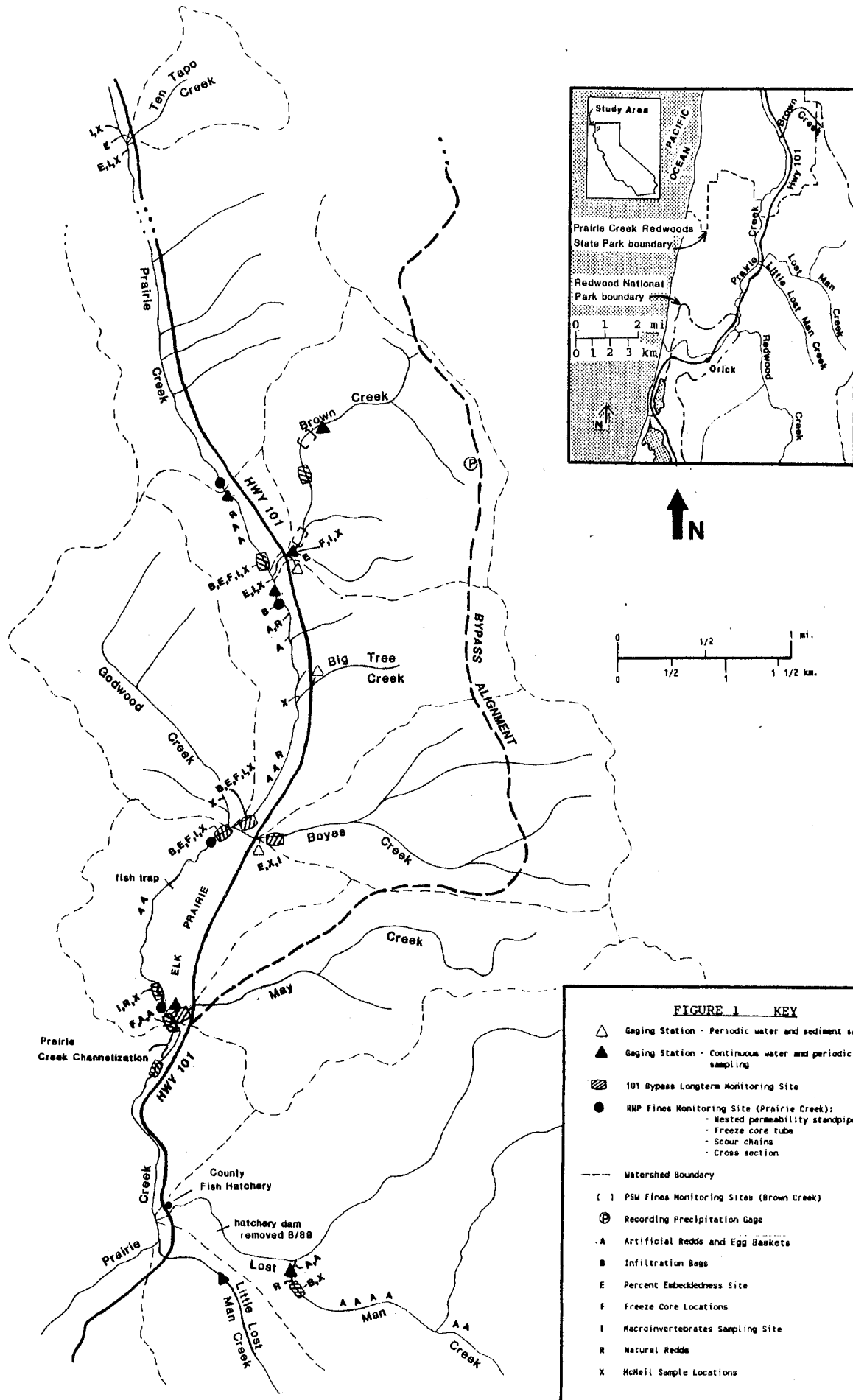


Figure 1. Location Map

II. SEDIMENT TRANSPORT AND DEPOSITION

The definition of "fines" in previous stream studies varies, and few previous studies have addressed the impacts of very fine sediment (< 0.5 mm), such as was deposited in Prairie Creek. The purpose of this study was to quantify the amounts of this fine sediment transported and deposited after the October storm and to determine the persistence of this material over the winter period. To do this, the amount of water and sediment entering and leaving affected streams must be quantified. Then a sediment balance is constructed for the affected reach, where the difference between sediment coming in and sediment leaving the reach equals the amount of sediment deposited in the streambed. Several factors, including precipitation, water discharge, and suspended sediment discharge, must be quantified to construct this balance.

A. Precipitation

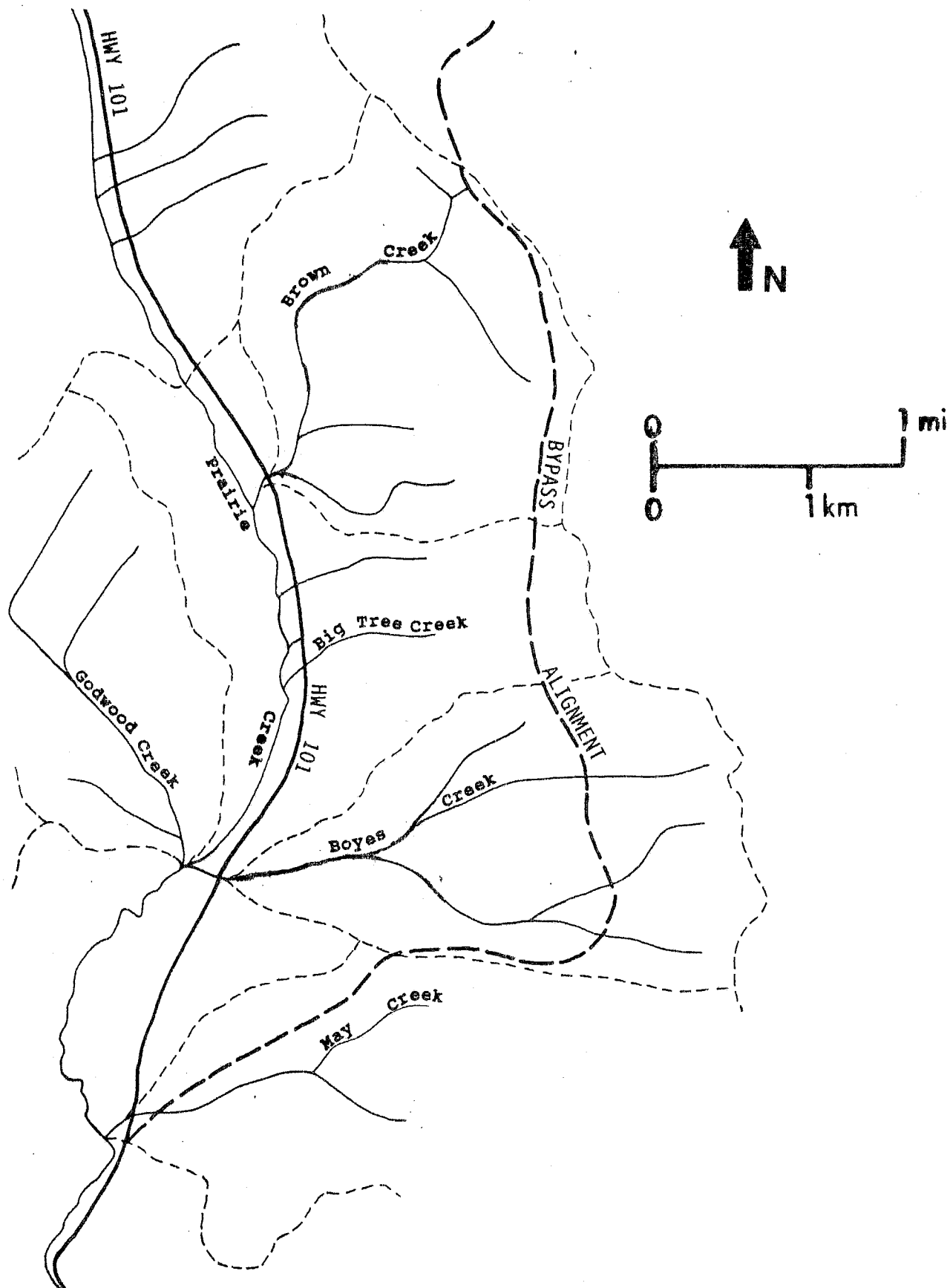
A.1 Study Objective

Both intensity and duration of rainfall affect how much erosion occurs during a given storm event. For example, an intense rainfall of 2 inches in 6 hours may cause more erosion than 4 inches in two days. Therefore, our objective was to quantify both the depth and intensity of rainfall during the October storm and over the winter of 1989-90.

A.2 Methods

Several sources of information were used to estimate rainfall in the Prairie Creek basin. On February 1, 1990 a raingage (tipping-bucket assembly with an electronic data logger) was installed on the bypass right-of-way in the headwaters of Brown Creek to continuously record the amount of rain received in the upper watershed. Rainfall data before this date was collected from five other sources. Prairie Creek Redwoods State Park and Redwood National Park at the Orick South Operations Center both maintain daily storage raingages. The Humboldt County Prairie Creek Fish Hatchery has collected daily rainfall data for the last 19 years (Steve Sanders, personal communication). Redwood National Park also maintains continuously recording raingages at Requa (19 miles north of Orick) and on the L-line road (seven miles south of Prairie Creek). This information was used to estimate rainfall in the study site, although rainfall depths and intensities may vary locally.

To estimate rainfall on the bypass right-of-way for the period preceding installation of the recording raingage, a regression analysis was performed on data from the bypass raingage and from the L-line raingage, which is located in a topographically similar area. Rainfall depths for numerous simultaneous



time periods were tabulated for both gages, and bypass rainfall depths were regressed on the L-line depths.

The following equation ($r^2 = .95$):

$$Y = 1.504 * X$$

where: Y = Bypass rainfall depth

X = L-line rainfall depth

was derived and used to synthesize cumulative rainfall from January 1 to February 1, 1990 (the beginning date of records at the study site).

A.3 Results

Average annual rainfall is about 67 inches at the Humboldt County Prairie Creek Fish Hatchery, and at least 80% falls during moderately intense winter storms between October and March (Fig. 2). Rainfall during summer months is infrequent. During the winter of 1989-1990, the Prairie Creek watershed experienced below normal rainfall. With the exception of January and May, monthly rainfall in the Prairie Creek watershed was below normal, and as of May 1990 total winter rainfall was 45.02 inches, or 29% below normal for that time period.

Figure 3 shows the cumulative precipitation curve from January 1 to June 6, 1990 generated from the bypass gage and synthesized rainfall data.

Besides the low seasonal total, the Prairie Creek watershed experienced low rainfall intensities during the winter of 1989-1990. Every two years, between 2 - 2.6 in of rain can be expected to fall within a 6-hour period in the Redwood Creek watershed (Janda et al., 1975). Table 1 lists the depth-duration data for 2- and 6-hour durations recorded at the Requa weather station from October 1989 to May 1990. During the winter of 1990, the highest rainfall depth in a 6-hour period was only 1.79 inches on April 23, 1990.

Monthly Rainfall at Prairie Creek Fish Hatchery

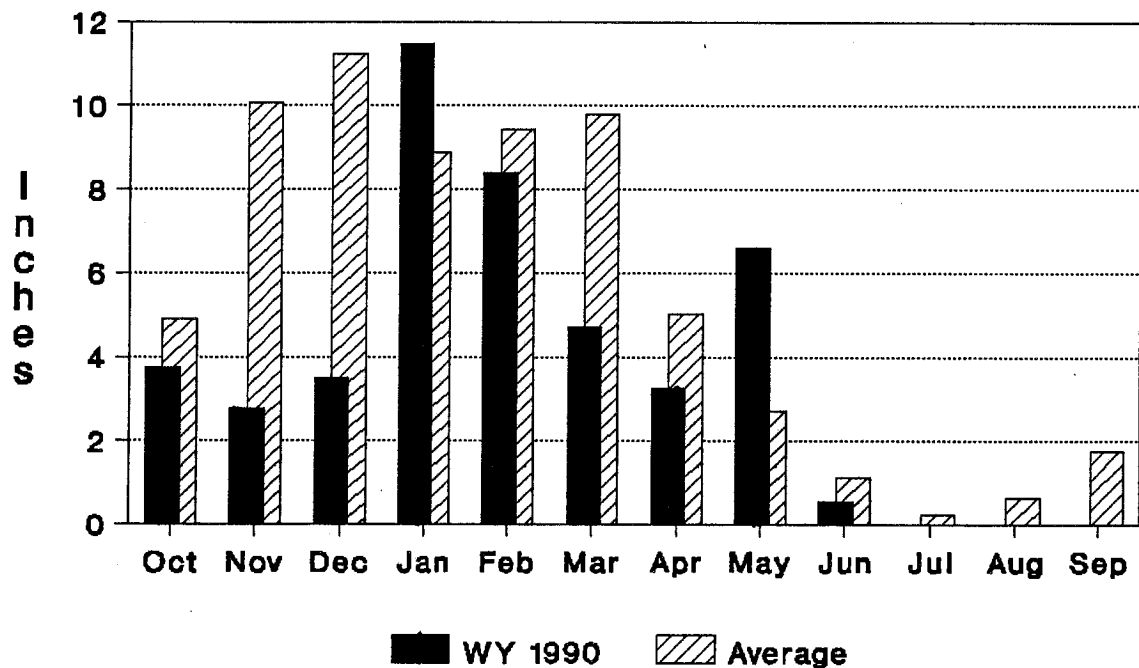


Figure 2. Monthly rainfall at the Prairie Creek Fish Hatchery. Water Year 1990 monthly rainfall is compared to the average monthly rainfall for the last 19 years.

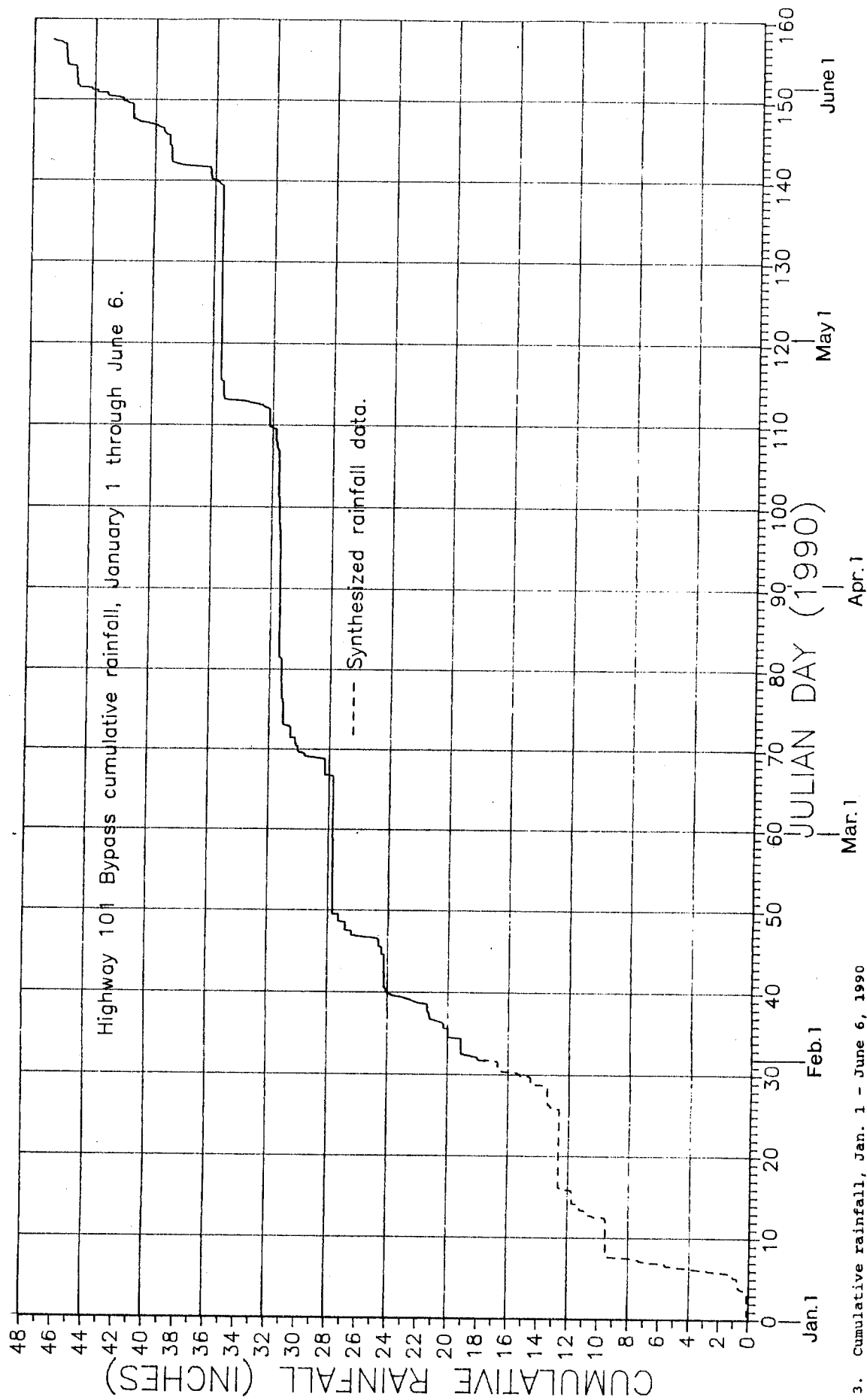


Figure 3. Cumulative rainfall, Jan. 1 - June 6, 1990

Table 1. Maximum rainfall depths at 2- and 6-hour durations at Requa, California, 1989-90.

Date	Rainfall Depth (in)	
	2-hour duration	6-hour duration
10-26-89	0.63	1.41
11-23-89	0.42	0.79
12-04-89	0.68	1.59
01-01-90	0.29	0.62
01-07-90*	0.57	1.18
01-12-90*	0.45	0.67
01-28-90*	0.46	0.73
02-15-90*	0.44	0.87
03-10-90	0.38	0.97
04-23-90*	0.74	1.79
05-27-90*	0.34	0.66

* Stream discharge measurements and suspended sediment samples were taken during these storms on Prairie Creek.

Depth-duration data for the period of record for the bypass raingage is listed in Table 2. Comparison of Tables 1 and 2 reveals wide differences in maximum rainfall depths between the two locations and that seasonal maximums occurred during different storms. This illustrates the importance of using site-specific rainfall (and runoff) data in hydrologic analyses.

Table 2. Maximum rainfall depths at 2- and 6-hour durations for the bypass raingage in Brown Creek headwaters, 1989-90.

Date	Rainfall Depth (in)	
	2-hour duration	6-hour duration
1-08-90*	0.62	1.58
2-01-90	0.27	0.80
2-03-90	0.51	0.84
2-15-90	0.57	1.01
4-23-90	0.57	1.36
5-21-90	0.62	1.46
5-28-90	0.35	0.78
5-30-90	0.68	0.90
5-31-90	0.68	0.82

* Calculated from synthesized data.

A.4. Discussion

Results from all phases of this monitoring report need to be interpreted in light of the 1989-1990 storm season. The season was mild, with rainfall 29% below normal. All storm intensities were well below the expected 2-year recurrence interval.

B. Water Discharge

B.1 Study Objective

Sediment discharge is dependent upon both water discharge and sediment concentration. Objectives of this study element were: (1) to obtain continuous water discharge data for the January to June 1990 storm season, (2) to estimate runoff volume for the October 1989 storm, and (3) estimate flood peak magnitudes at various recurrence intervals for stream monitoring sites.

B.2. Methods

(a) Discharge data collection

Methods used to measure water and 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 four gaging sites in the Prairie Creek watershed. Two gaging stations were located in Brown Creek (PSW study sites) and two stations were located in Prairie Creek upstream and downstream of the Brown Creek confluence (Fig. 1). The gaging stations will be referred to as:

- Upper Brown Creek (UBR)
- Lower Brown Creek (LBR)
- Prairie Creek above Brown Creek (PABR)
- Prairie Creek below Brown Creek (PBBR)

At these stations, water stage was recorded continuously with pressure transducers and data recorders. Shelters were built to house automatic recording equipment. Bridges were built to allow us to measure high flows on Brown Creek, and a cableway was installed on Prairie Creek below Brown Creek for the same reason.

Water discharge can be directly correlated with stage and a relationship between water depth or stage and discharge can be developed for each station.

Stage observations were recorded manually, electronically, and mechanically. Manual stage observations were made by reading staff plates and crest stage gages mounted on streambanks. Crest stage gages were made of 3/4 inch PVC with a 1/2 inch wide PVC graduated dipstick. The lower end of the PVC pipe was perforated and covered with a single layer of filter cloth to prevent

clogging with fine sediment. After each observation, ground cork was applied to the bottom of the dipstick. As stage rises, the cork floats and leaves a high water mark on the dipstick, which is correlated to the gage datum at the site.

Electronic stage observations used submerged pressure transducers to sense stage fluctuations and recorded stage on Campbell 21X or ENMOS data loggers. Transducers were housed inside a 4 - 6 inch diameter PVC perforated pipe. Pipe interiors were lined with filter fabric to deter fine sediment from clogging pipes. Data loggers were battery powered and housed in waterproof containers. Stage, date, and time data were recorded at 10-minute intervals.

Mechanical stage observations at Prairie Creek above May Creek used a Belfort strip chart stage recorder and required chart changes about every eight days. The recorder is mechanically driven by a spring, which is wound during each chart exchange. All stage readings have an approximate precision of +/- 0.02 feet.

Actual water discharge was measured over a range of stages to establish a stage-discharge rating curve. We measured discharge with a pygmy velocity meter or larger Price AA meter, depending on flows.

Additional discharge data were collected periodically at the following stations: Lost Man Creek, Little Lost Man Creek, Prairie Creek at Wolf Creek Bridge, Brown Creek at Highway 101, and Boyes and Big Tree Creeks.

(b) Hydrograph synthesis

Because stage recorders were not installed at the upper and lower Prairie Creek gaging sites until February 15, 1990, hydrographs for several storms preceding this date were synthesized from other sites to estimate sediment flux. An ENMOS data logger recorded stages at the PABR site from January 11 through February 15. Regression analysis performed on data from later overlapping periods indicated a strong relationship ($r^2 = .99$) between PBBR and PABR. The equation:

$$Q_{PBBR} = (1.636 * Q_{PABR}) + 6.3$$

where: Q_{PBBR} = discharge at Prairie Creek below Brown Creek site in cfs

Q_{PABR} = discharge at Prairie Creek above Brown Creek site in cfs

cfs = cubic feet per second (cfs)

was used to synthesize flows at PBBR from the records at PABR from January 11 through February 15, 1990.

For the period of January 1 - 11, 1990 (encompassing the largest storm of the season), no instrumentation existed at either PABR or PBBR. A continuous recorder was operating on Lost Man (LM) Creek during this period for a separate project. After adjusting data from this recorder for a lag time

difference between Prairie Creek and Lost Man Creek, a good fit ($r^2 = .95$) was obtained between LM and PABR using the following regression equation:

$$Q_{PABR} = (1.686 * Q_{LM}) - 83.4$$

where: Q_{LM} = discharge at Lost Man Creek in cfs

This equation was used to synthesize hydrographs for PABR from LM records for the period of January 1 - 11, 1990. For the January 7 - 9 storm, regression analysis of flow measurements taken during the storm at PABR and PBBR indicated a non-linear relationship between these two sites during high flow conditions. A good fit (percent residuals about mean explained = 100), was obtained using a second degree polynomial equation:

$$Q_{PBBR} = 7.32 + (1.287 * Q_{PABR}) + (.0089 * Q_{PABR}^2)$$

This equation was used to synthesize the PBBR stormflow hydrograph from that estimated for PABR. Although the PBBR data were derived from a second generation synthesis (from PABR synthesized data), good agreement was found between measured and synthesized data.

(c) October storm runoff volume

Streamflow estimates for the October 22, 1989, rainstorm are needed to estimate sediment flux at the gaging sites. However, no continuous streamflow gages were installed on Prairie Creek or its tributaries during this time period. Since no gaging stations were operating during the October storm, no streamflow data exist to synthesize suitable discharge data either directly or by transposition. We chose to estimate runoff volume for this storm by using a rainfall/runoff ratio calculated from a storm which occurred later in the season (one for which continuous discharge data exists).

An event which occurred on April 22 through 23, 1990, was selected for estimating the rainfall/runoff ratio to be used to estimate the October, 1989, storm runoff volume. Although this storm occurred late in the runoff season and was of smaller magnitude than the October storm, it was selected for two reasons: 1) it was a discrete storm, isolated in time from other events, and 2) antecedent soil moisture conditions were similar to the October storm. Runoff volume for the October storm was calculated by multiplying the October rainfall volume (rainfall depth (ft) x basin area (ft²) = rainfall volume (ft³)) by the rainfall/runoff ratio for the particular site.

(d) Flood frequency estimates

We have mentioned that the 1990 runoff year was exceptionally mild with respect to peak stormflows. To help put the relative severity of the past year's storms in perspective, flood peaks recorded from last winter can be compared with long-term flood frequency estimates for the gaging sites. To estimate peak flow rates of various recurrence intervals, unit peak flow rates (cfs/square mile) were calculated from USGS annual exceedence probability distributions for two gaged tributaries to Prairie Creek. 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 3.46 and 0.40 square miles, respectively. Unit peak flows for these two basins were remarkably similar, and so 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.

B.3 Results

Figure 4 shows the hydrographs for Prairie Creek gaging sites from January 1 to June 6, 1990, which were plotted from both synthetic and measured data. The largest storm of the season occurred from January 7 - 9, 1990. Maximum recorded discharge was 93 cfs at PABR and 205 cfs at PBBR. Recorded discharge for the UBR station ranged from 52.6 to 2.5 cfs and the mean discharge for the storm season was 6 cfs. At LBR gaging station, recorded discharge ranged from 67.4 to 0.7 cfs with a mean discharge of 10.9 cfs for the winter.

Calculated rainfall/runoff ratios for the April storm were 0.107 for PABR and 0.224 for PBBR. These ratios were then multiplied by rainfall volumes for the October storm, yielding storm runoff volumes of 5.54×10^6 ft³ for PABR and 1.82×10^7 ft³ for PBBR. Storm runoff volumes combined with suspended sediment concentrations from the October storm were then used to estimate sediment flux.

Table 3 shows the calculated flood peaks for the 2-, 5-, 10-, 25-, and 50-year recurrence intervals, along with recorded flood peaks for the 1990 Water Year (WY).

Table 3. Flood frequency estimates for various recurrence intervals at gaging sites in Prairie Creek and Brown Creek.

Site	Area (mi ²)	Peak flow WY 90	Peak flow rates (cfs) at various recurrence intervals				
			2-yr	5-yr	10-yr	25-yr	50-yr
<u>Prairie Ck:</u>							
Above Brown Ck	4.06	93	327	581	727	1031	1234
Below Brown Ck	6.36	205	512	909	1138	1615	1933
At Wolf Ck Bridge	12.60	N/M*	1014	1802	2255	3200	3830
<u>Brown Ck:</u>							
Upper	0.72	52.6	58	103	129	183	219
Lower	1.40	67.4	113	200	251	356	426

* not measured.

DISCHARGE AT PRAIRIE CR. GAGING SITES FOR JANUARY 1 THROUGH JUNE 6, 1990.

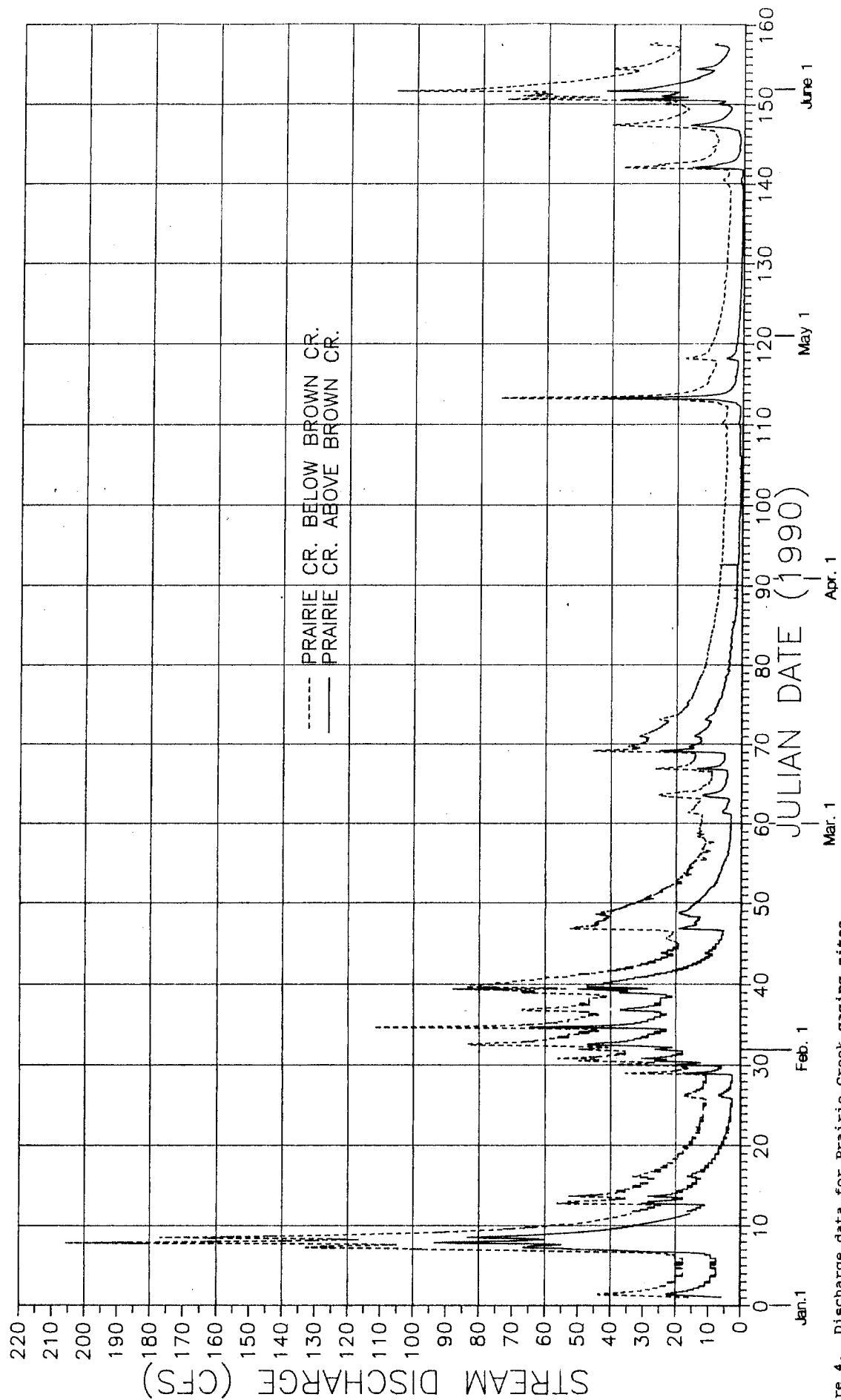


Figure 4. Discharge data for Prairie Creek gaging sites, Jan. 1 - June 6, 1990

B.4 Discussion

Comparison of the recorded flood peaks of 1990 at the gaging sites with the flood frequency estimates in Table 3 illustrates the mildness of stormflow events during the runoff season. At none of the gaging sites were the 2-year recurrence interval peak flow estimates attained during the 1989-90 runoff season. Only at one site, Upper Brown Creek, did the largest recorded flow even approach the two year event.

C. Suspended Sediment Discharge

C.1 Study Objective

Suspended sediment discharge measurements are required to calculate tonnage of sediment introduced in the Prairie Creek system during the October storm. These discharge estimates also are an indicator of the quantities of finer sediment being flushed through the system over the winter period. These data, together with changes in surface and subsurface sediment quantities, provide an estimate of persistence of fine material in Prairie Creek. The objective of this study was to estimate tons of sediment introduced into the Prairie Creek system during the October storm and to determine sediment transport rates of this material during the winter.

C.2 Methods

Forty suspended sediment samples were collected during the October storm by California Department of Fish and Game at several locations along Prairie Creek and on selected tributaries. We estimated sediment loads from Prairie and Brown Creeks during the October storm by combining the synthesized storm hydrograph data (Section II. B.2) with average concentrations in Prairie Creek (below Brown Creek) and in Brown Creek during the storm. Suspended sediment concentrations and loads were compared with those in a control stream, Little Lost Man Creek.

In early January suspended sediment was sampled with a hand-held depth-integrated sampler during storm flows. Beginning in late January, suspended sediment concentrations were measured with automatic pumping samplers at the four gaging stations (Fig. 1).

The samplers were set to automatically collect suspended sediment when the stream's stage passed a particular threshold or height. Samplers automatically shut off during times of low flow when virtually no sediment was being transported.

Model 2700 ISCO water samplers were permanently installed in sheds at UBR, LBR, PABR and PBBR. Samplers were programmed to take 24 discrete 300-350 ml water samples. Sampler inlets were placed at 0.6 water depth with a rod and float depth proportional sampler intake device anchored to the streambed (Eads and Thomas, 1983). On 1/25/90 and 1/31/90 streams were sampled at one hour intervals. After 2/1/90, methodology changed slightly, and we used unique computer generated random sampling schemes to program sets of 24 samples at 6, 12, 24 or 48-hour durations. When creek stage exceeded a preset threshold,

the Campbell 21X micrologger activated the ISCO sampler clock. This began the time countdown to the first preprogrammed sample interval. When stage dropped below the threshold, the Campbell 21X deactivated the sampler.

We occasionally collected depth-integrated samples in order to calibrate automatic samplers. Hand samples were taken with a DH-48 sampler according to USGS methods. Periodic hand samples were collected from all stations during storms throughout the winter.

Between 1/25/90 to 6/6/90, a total of 600 suspended sediment water samples were collected from PABR and PBBR, and about 800 samples from Brown Creek. Both DH-48 manual and ISCO automatic water samples were analyzed by North Coast Laboratories, Arcata, CA. Depending on concentrations, samples were analyzed by the filtration or evaporation method.

Suspended sediment discharge was calculated by multiplying sediment concentration by water discharge. A record of suspended sediment discharge during floods was constructed. The total amount of sediment transported in a 10-minute interval (the sediment flux) was calculated for each time a sediment sample was collected, and sediment fluxes were averaged over intervening time periods when no samples were collected. Sediment loads carried by Brown and Prairie Creeks were calculated for the four gaging stations from January through June. Suspended sediment data and sediment flux calculations are on file in Redwood National Park's Arcata office.

C.3 Results

Suspended sediment concentrations varied widely from storm to storm and for the entire season. Between January and June, suspended sediment concentrations at PABR ranged from < 3 mg/l to 120 mg/l (measured on January 1, 1990) and at PBBR from < 3 mg/l to 310 mg/l (measured on January 7, 1990). Concentrations for the upper reach in Brown Creek ranged from a low of < 3 mg/l to a high of 2210 mg/l on January 7, 1990. Concentrations for the lower reach in Brown Creek ranged from a low of < 3 mg/l to a high of 1398 mg/l. May Creek had a suspended sediment concentration of 12,100 mg/l in the October storm, the highest concentration measured this winter, but was not considered in this study because damage to May Creek was predicted in the FEIS, and mitigated. The control stream, Lost Man Creek, had concentrations ranging from only 0.8 to 1.2 mg/l during the same period. No sediment data are available from November and December 1989; however, low flows during this time period suggest minimal sediment transport occurred. Suspended sediment loads for Prairie Creek and lower Brown Creek from October, 1989 and from January to June, 1990, are estimated as follows:

Station*	Time Period	Sediment Load (tons)	
PV PABR :	October, 1989 -	100	
	Jan. 1 - 10, 1990 -	13	> 29
	Jan. 10 - June, 1990 -	<u>16</u>	
	Total =	129	= 32 t/mi ² /yr
PL PBBR :	October, 1989 -	325	
	Jan. 1 - 10, 1990 -	154	7 230
	Jan. 10 - June, 1990 -	<u>76</u>	
	Total =	555	= 87 t/mi ² /yr
LB LBR :	October, 1989 -	200	
	Jan. - June, 1990 -	<u>87</u>	87
	Total =	287	= 205 t/mi ² /yr

* UBR was not included. No sediment data were available for the October storm

The October flood transported 78%, 59% and 70% of the 1989-90 annual suspended load for PABR, PBBR and LBR, respectively. In comparison, the early January flood transported only 10% of the 1989-90 suspended sediment load for PABR, and 28% for PBBR. Relatively little sediment was transported from February to June. The above data shows that the October storm carried at least 30 times the amount of sediment than later storms of equivalent size in 1990. High sediment loads in Prairie Creek during the October flow were obvious from the turbidity of the streamflow (Fig. 5). Suspended sediment loads from January to June, 1990 were 74 tons at UBR (PSW, unpublished data) and 87 tons at LBR.

We compared results of suspended solids, turbidity and settleable solids from 40 water samples in seven streams collected during the same time period. They were analyzed by the California Department Fish and Game. There is only a rough relationship between turbidity and total sediment in a sample (suspended and settleable solids) ($r^2=38\%$), over a range of turbidity values between 0.8 and 2500 ntu. If only suspended sediment and turbidity are used, the relationship is stronger ($r^2=72\%$). We recommend that turbidity be used only with caution as a substitute for suspended sediment until more samples over a greater range are tested.



Figure 5. Confluence of Prairie Creek (left) with Redwood Creek during the October storm.

C.4 Discussion

Sediment transport in north coastal California is very storm dependent. Most sediment is transported at high flows, and relatively little is transported at low and moderate flows. For example, in Little Lost Man Creek half the suspended sediment load over a four-year period (1985-88) occurred during one four-day storm period in February, 1986. The February 1986 flow was rated as a 10-year recurrence interval flood for Little Lost Man Creek. Winter sediment concentrations in Little Lost Man ranged from 10 to 107 mg/l (the highest being measured during the February, 1986 storm). In contrast, concentrations over 2200 mg/l were measured in Brown Creek in 1990. Annual suspended sediment loads in Little Lost Man are 17 - 70 t/mi² (average 44 t/mi²) in low flow years, similar to the 1989-90 flow year. Annual suspended sediment loads for gaging stations on affected streams were much higher ranging from 32 t/mi² at PABR to 205 t/mi² at LBR. The October flood transported two-thirds to three-fourths of the annual load, and later floods of similar magnitude carried much less sediment. Estimates of October sediment loads are subject to the most error, due to the sporadic sediment sampling, and estimated rather than measured runoff volume.

In Brown Creek, sediment concentrations dropped sharply in a downstream direction. For example, on Jan. 7, 1990 a water sample taken in the headwaters of Brown Creek just downstream of the bypass alignment had a concentration of 8600 mg/l, whereas a water sample at lower Brown on the same day was 1400 mg/l. Dilution by other tributaries contributes to the decrease in concentrations, but deposition of sediment in the stream likely accounts for some of the decrease as well.

In future sampling, the threshold at which suspended sediment samples are collected should be set higher because low to moderate flows carry little sediment. Fewer samples taken at higher flows will still assess the major sediment loads, at a lower cost and effort.

D. Sediment Deposition and Storage on Surface of Streambeds

D.1 Study Objective

The October 20 storm deposited silt, sand and clay on gravel bed surfaces. Fine sediment deposited along exposed streambanks and gravel bars in October was highly visible in Prairie Creek and its tributaries. The objective of this study was to quantify the changes in depth, volume, and texture of surface fine sediment over the winter to examine changes in storage of this material. Surface coverage of fine sediment on potential spawning riffles was also estimated by measuring gravel embeddedness.

D.2 Methods

Surface deposition was documented in the following three ways.

(a) Fine sediment surveys and probes

To track the movement of fine sediment in Brown and Boyes Creeks, several cross sections were established downstream of steeper headwater reaches (Fig. 6). Monitoring sites (17 on Brown Creek and 16 on Boyes Creek) sampled a variety of geomorphic environments within the streams.

Depths of fine sediment at each cross section and monitoring site on Brown and Boyes Creeks were measured by stretching a tape across the channel between fixed endpoints and probing through the fine sediment with a thin (0.63 cm diameter) metal rod. Depths of fine sediment were recorded at each cross section, and the sediment stratigraphy and texture described. All survey sites were photographed.

Fine sediment in Brown Creek was probed several times during the rainy season. Initial surveys were conducted within two weeks of the October 20 storm, and repeated after January and February storm periods and at the close of the season in June. Boyes Creek was surveyed in early November and again in June.

The volume of fine sediment on streambed surfaces for two 200-meter long study reaches (PSW sites, Fig. 1) was also measured in December and again in April. Each Brown Creek study reach was divided into five meter segments. Surface sediment volumes for each segment were then visually estimated. Using a thin wire sediment probe, volumes for 20% of reach segments were intensively measured. Segments were sampled according to a statistical procedure, with probability of segment selection proportional to total estimated sediment volume. Total volume of surface sediment for each reach and standard error were estimated using SALT (Thomas 1985).

At several survey sites, small (35 ml) core samples of the recently deposited fine sediments were taken in order to evaluate bulk density, porosity and other properties.

(b) Deposition tiles

Clean, unglazed clay tiles were installed flush with the channel bed in a variety of geomorphic units (pools, riffles, gravel bars, backwater and eddy environments) along the same portion of Brown Creek where cross sections were established. Tiles were emplaced on January 22 and 23, 1990. The accumulated fine sediment was retrieved for gross weight and particle size analysis on February 27 and 28, 1990, and on June 13, 1990 (Fig. 7). The former date followed the late January through February storm period. Unfortunately, the sampling period missed the maximum seasonal discharge recorded between January 8-12, 1990. The latter sampling interval encompassed the spring season which is represented by less frequent storms and generally lower discharges. However, the storm period of May 22 - June 6 is included in this period.

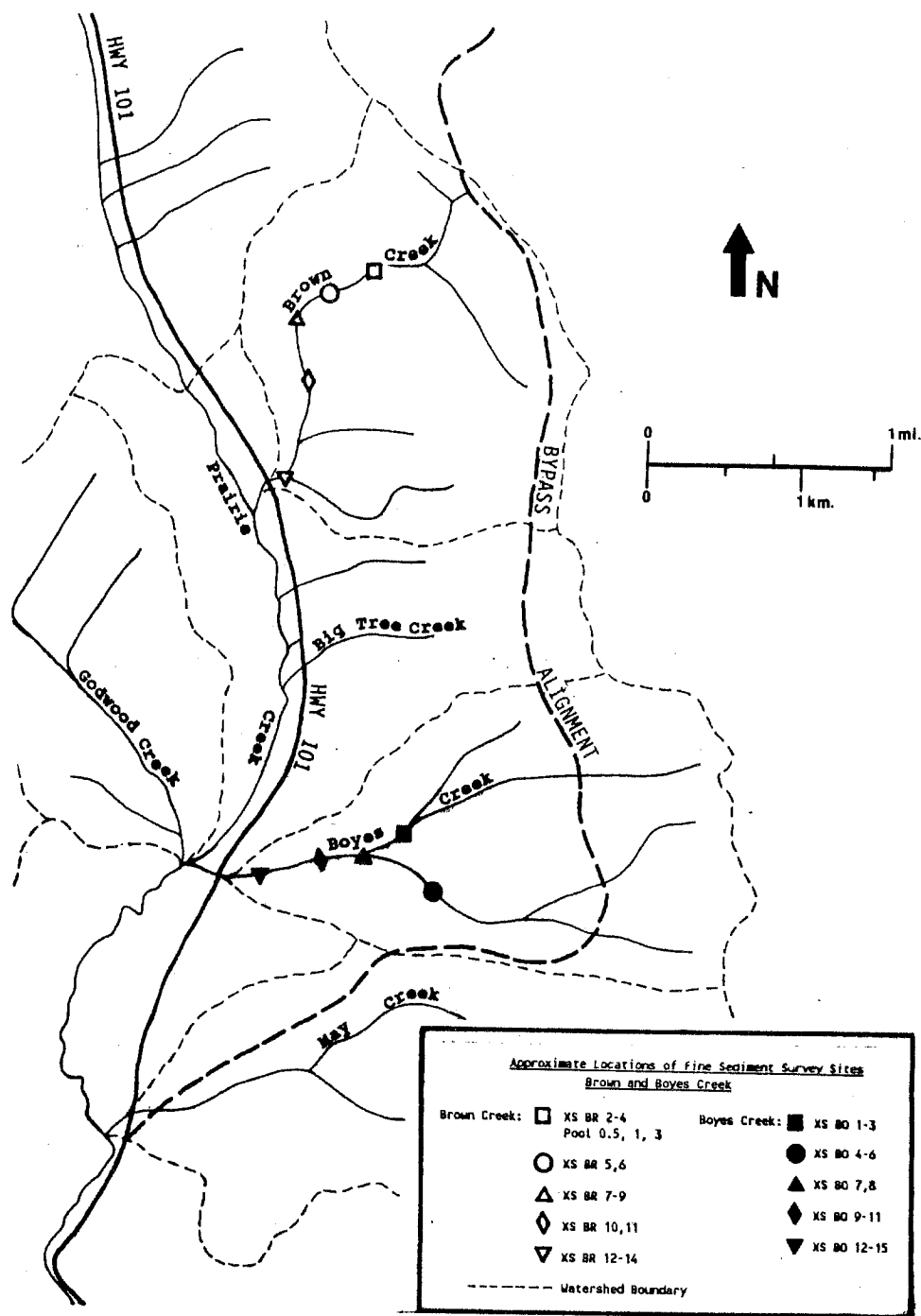


Figure 6. Location of Brown and Boyes Creek surface deposition survey sites and cross sections.



Figure 7. Deposition of sand and silt on tile, Brown Creek.

(c) Visual estimate of embeddedness and depth of fine sediment cores.

Embeddedness measures the percentage of surface gravels buried in fine sediment (Platts et al. 1983). A few days after the October storm, we visually estimated percent embeddedness of spawning gravels within Prairie Creek and on tributaries near their confluences (Fig. 1). At these same locations (non-randomly selected), we measured the depth of the fine sediment recently deposited along the streambank using a small soil core sampler. The boundary between bypass-derived sediment and pre-existing sediment was distinct and marked by a sharp change in color and texture from a dark brown sandy substrate below to a light brown silty clay substrate above (Fig. 8). Measurements were repeated at the same locations in June, 1990.

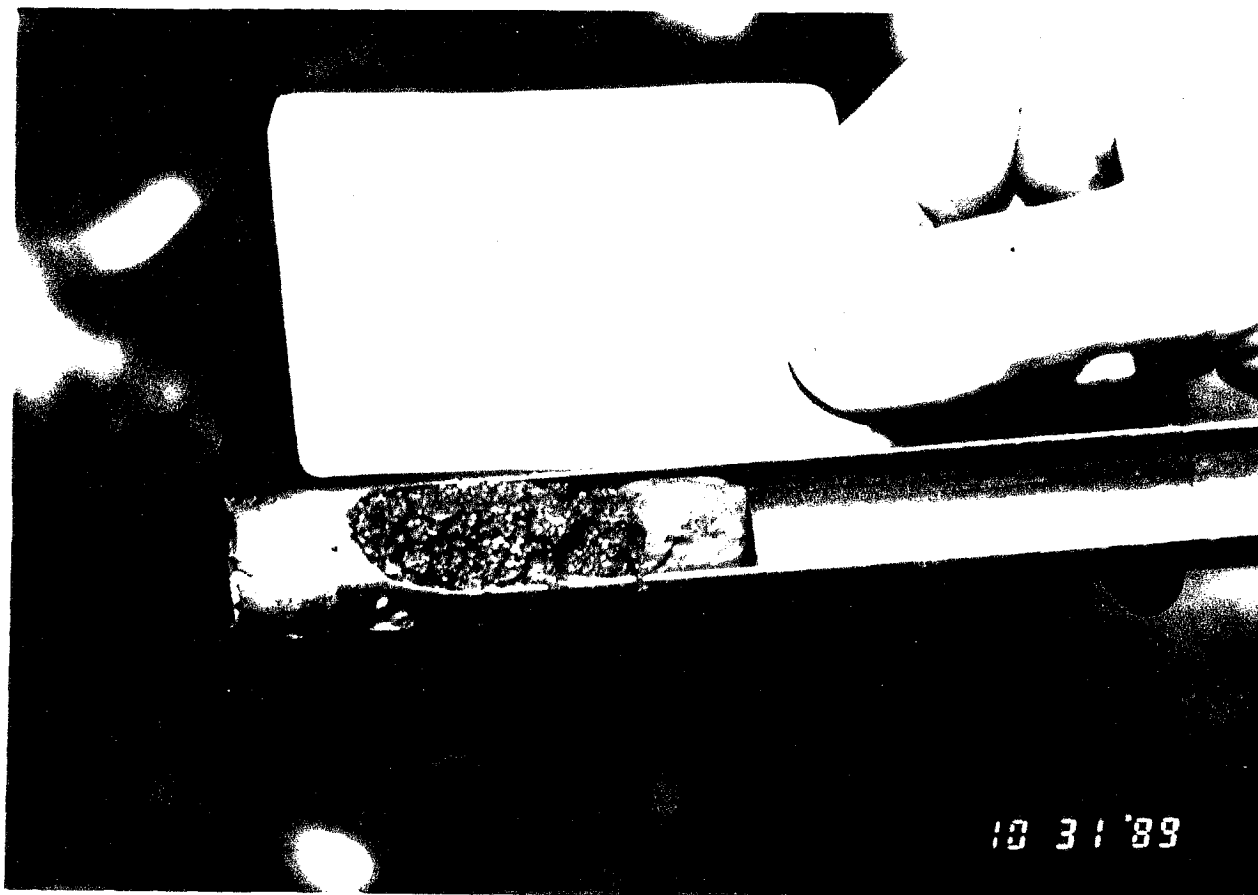


Figure 8. October, 1989 deposition of finer sediment of a lighter color over coarser channel bed material in Prairie Creek.

D.3 Results

Channel description, sediment depth and texture of fine sediment deposited at each cross section on Brown and Boyes Creeks have been compiled and tabulated. Complete tables as well as photographic documentation are on file at the Arcata office of Redwood National Park. Both Boyes and Brown Creeks exhibited similar trends in sediment storage and movement and will be discussed jointly. Surface sediment had bulk mass densities of $1.1 - 1.3 \text{ g/cm}^3$ and porosities averaged 45%. These data were used to determine total sediment by weight (tons) deposited in these streams and in Prairie Creek during the winter of 1989-90.

Following the October 20 storm, sediment coverage of active channel in upper Boyes and Brown Creeks was pervasive, averaging 80%-100%. Deposition tiles indicated the average depth of fine sediment on channel surfaces ranged from 0.3 cm to 5 cm in early November. However, sediment survey probes in some areas of Boyes Creek received more than 27 cm of fine sediment. Depths of surface fine sediment in the active channel of lower Ten Tapo and Boyes Creeks near their confluences with Prairie Creek were about equal (0.7 to 0.8 cm). The greatest depth of fine sediment (2.0 cm) in lower tributary reaches was on Brown Creek. In Prairie Creek, depth of surface fine sediment ranged from only a trace above the Brown Creek confluence to 0.5 cm above the Boyes Creek confluence.

In upper Boyes and Brown Creeks, pools and glides typically had a trace to 0.6 cm of fine sediment, but locally 100% coverage was recorded in November. Riffles typically showed only a trace of surface deposition with less than 10% coverage. Interstitial deposition of fine sediment was commonly observed within cobble and gravel surfaces. Silt-coated cobbles in the active channel, extremely turbid water, and interstitial subsurface fine sediment were evident in both streams.

Repetition of surveys in January, February and June documented minor sediment removal. Fine sediment accumulated in low energy environments, particularly behind organic debris traps and on emergent bar surfaces. Surficial fine sediment decreased on most active channel surfaces (high velocity areas). However, sediment plumes were generated in riffles when the bed was disturbed indicating the persistence of fine sediment within the gravels, even in high energy environments. Such plumes were still evident at most sites in Prairie, Boyes and Brown Creeks in June, 1990.

Bypass-derived sediment observed in the streams was composed primarily of fine sand, silt and finer particles. The proportion of sand in bar deposits increased over the season. Several sites on upper Brown Creek showed sand overlying finer sediments. Other sites, particularly a reach in lower Boyes Creek, exhibited an increase in sediment depths accompanied by a textural change from mostly silt to poorly sorted gravel, sand and silt. As a result of continued deposition and some reworking, the boundary between newly deposited sediment on streambed surfaces and pre-existing stream sediments (deposits from the October storm) was indistinguishable by June. Therefore, changes in depth of the specific sediment layer (October storm deposits) could not be determined over the winter.

Estimates of surface sediment volumes for Brown Creek study reaches are listed in Table 4. The upper reach showed a 28% decrease in surface fine sediment volume. An unknown portion of the decrease is due to compaction of fine sediment over the winter. Estimates for the two 200-m study reaches were extrapolated to the upper and lower reaches of Brown Creek (a total length of 2730 m) to estimate total surface sediment volume in the north fork of Brown Creek (Table 5). Using bulk densities measured on fine sediment samples (which averaged 1.2 tons per m³ with appropriate conversions), we converted volumes to weights of surface sediment deposited in Brown Creek (Table 5).

Sediment deposition on tiles is summarized in Table 6. In all cases, tiles placed in high flow velocity areas remained clean. Deposition occurred at low flow velocity sites such as pools, back eddies and on emergent gravel bars. The origin of the sediment is unclear. Sediment deposited on tiles may have been reworked and redeposited from upstream channel deposits or may be sediment newly deposited in the stream. Table 7 summarizes total weight and particle size analysis of the sediment. Sediment in all size classes were deposited, but was primarily composed of ≤ 2 mm size fraction. The amount of fine sediment differed greatly among tiles, and ranged from 59 to 640 g in lower Brown Creek. In upper Brown Creek (near X/S BR 6 in Fig. 6) fine sediment weight for tiles in pools ranged from 19 to 653 g while fine sediment weights for tiles in eddies ranged from 5 to 344 g.

Table 4. Estimates of initial (December) and final (April) surface fine sediment volume in the upper and lower study reaches of the North Fork of Brown Creek, California, 1990.

Reach	Initial Volume Estimate (m ³)	Standard Error (m ³)	Final Volume Estimate (m ³)	Standard Error (m ³)	Percent Change
Upper	6.52	2.55	4.68	2.16	-28
Lower	14.17	3.76	14.61	3.82	+ 3

Table 5. Estimates of initial (December) and final (April) surface fine sediment volumes and weights for the North Fork of Brown Creek (extrapolated and converted from data in Table 4).

Reach	Initial Volume (m ³)	Initial Weight (tons)	Final Volume (m ³)	Final Weight (tons)	Percent Change
Upper	38.9	46.7	27.1	32.5	-30
Intervening	48.1	57.7	44.4	53.3	-8
Lower	<u>44.4</u>	<u>53.3</u>	<u>45.6</u>	<u>54.7</u>	+3
Total	131.4	157.7	117.1	140.5	-11

Table 6. Summary of depositional record for Brown Creek tiles, 1990.

Tile Location	Site Description	Date Inspected	Status
X/S BR 4	a) Upper right bank gravel bar, downstream of riffle	2-27-90	5/8" max. deposition on LB* ds corner of tile; pea gravel over sand, silt; tile cleaned, replaced.
	b) Lower right bank gravel bar, downstream of riffle	6-13-90	no significant deposition; Tile left in place.
		2-27-90	1" max. deposition on RB edge of tile; Pea gravel over sand, silt; tile cleaned, replaced.
	c) Right bank gravel bar adjacent to riffle crest	6-13-90	No significant deposition; Tile left in place.
Photo-Point 9 (above X/S BR 7)		2-27-90	1/2" max. deposition on RB u/s corner; Sands; Tile cleaned, replaced.
		6-13-90	No significant deposition; Tile left in place.
	d) In channel, riffle crest	2-27-90	No deposition; Tile left in channel
		6-13-90	No deposition; Tile left in channel.
Photo-Point 15 C (between X/S 11 and 12)	Left bank backwater eddy bar, original composition: sands	2-28-90	3/4" max. deposition on LB d/s corner; Coarse sands over silty/clayey sands; Cleaned, replaced.
	Right bank emergent gravel bar	6-13-90	Tile undercut, no surface deposition; Tile left in place.
		2-28-90	7/16" max. deposition on LB d/s corner; Poorly sorted clayey silty sand w/ pebbles, overlain by 1/4" sands; Tile cleaned, replaced.
		6-13-90	Very low % cover of fine sediment and gravel; Tile left in place.
Photo-Point 15 C (between X/S 11 and 12)	a) Right bank slackwater pool, isolated from channel	2-28-90	Uniform cover of silt and clay; Basal fine sediment lighter color (buff) overlain by darker (med. brown) fine sediment; Tile cleaned replaced.
		6-13-90	Uniform 3/8" cover of brown silt, clay; No textural, or color variation; Tile cleaned, replaced.
	b) Right bank high flow cobble bar, isolated from channel, behind large organic debris	2-28-90	No deposition; Accumulated organic litter suggests no flow during sample interval; Bed surface lower than tile surface; Tile left in place.
		6-13-90	Tile disturbed, no data recorded; Bed lower than tile surface; Tile located and replaced.

* LB = left bank, RB = right bank, d/s = downstream, u/s = upstream

Table 7. Particle size analysis of sediment on Brown Creek deposition tiles in 1990.

Site	Sampling Period	Percent by Weight in Each Size Class					Total Wt mm (g)
		< 0.5	0.5-1	1-2	2-4	4-32	
X/S BR 4-a	Jan-Feb	14.5	8.96	16.5	29.6	30.5	618.9
X/S BR 4-b	Jan-Feb	28.5	14.0	15.4	23.8	18.3	239.5
X/S BR 4-c	Jan-Feb	35.1	49.4	14.0	1.5	0	164.7
Photo-Pt 9	Jan-Feb	30.4	25.6	28.5	11.2	4.3	645.5
Photo-Pt 15C-a	Jan-Feb	100	0	0	0	0	59.0
Photo-Pt 15C-b*	Feb-June	100	0	0	0	0	58.6

* Only tile which had new sediment deposition at the end of this period.

Percent embeddedness immediately after the October storm ranged from categories less than 5% on Prairie Creek above Brown Creek confluence to 25 - 50% in downstream locations and just below the Ten Tapo Creek confluence (Table 8). Of the tributaries, Boyes Creek had the greatest percent embeddedness (50 - 75%) and Ten Tapo Creek had the least (5 - 25%).

Table 8. Percent embeddedness in various locations along Prairie Creek and its tributaries near their confluences during October, 1989 and June, 1990.

Stream	Percent Embeddedness	
	October	June
<u>Prairie Creek:</u>		
Below Ten Tapo Ck	25-50	25-50
Above Brown Ck	< 5	< 5
Below Brown Ck	5-25	5-25
Above Boyes Ck	25-50	5-25
Below Boyes Ck	25-50	25-50
<u>Tributaries:</u>		
Ten Tapo Ck	5-25	5-25
Brown Ck	25-50	25-50
Boyes Ck	50-75	50-75

D.4 Discussion

Surface fine sediment in Prairie Creek and its tributaries increased as a result of the October storm. The distinct change in substrate color and texture of newly deposited sediment made it easy to quantify depths of fine sediment. Depths and embeddedness of this material were greatest in tributaries (Boyes and Brown Creeks), although a layer of sediment was deposited in mainstem Prairie Creek.

Surface fine sediment was transported during the winter, but much still remains in the creeks. Extrapolation from the two PSW Brown Creek study reaches to all of Brown Creek indicated that 157 tons were deposited on the bed surface by the October storm (Table 5). April surveys indicated that 141 tons of this sediment still remained, yielding a net decrease in stored sediment of 11% over the winter season.

Fine surface sediment derived from the October, 1989 storm appears to have been locally remobilized and redeposited after mixing with pre-existing fine sediment in Prairie Creek and its tributaries. However, analyses of the Brown Creek fine surface sediment surveys indicate fine sediment persisted over the rainy season in low-energy environments such as pools, exposed bars and organic debris traps. In some sites, particularly in lower stream reaches of tributaries, a small amount of additional aggradation of fine sediment occurred during the winter. A landslide in Boyes Creek delivered large woody debris to the stream near one site. This resulted in new sediment traps and accelerated aggradation. Total volume of surface fine sediment in storage appears to have changed little from November to June in Boyes or Brown Creek. The combination of small storm magnitudes and numbers and the deposition of sediment in low energy environments accounts for the small observed net sediment transport out of study reaches in Brown and Boyes Creeks.

Deposition tiles do not record the entire depositional history, only the net aggradation at their locations over the sample interval. Some trends are evident, however. First, pea gravel, sand and finer sediments were transported in middle and upper study reaches during the storm period between January 22 and February 27, 1990 (Table 6). In some samples (X/S BR 4 and Photo-Point 9) coarser materials overlaid finer sediments. This stratification suggests that finer sediments were deposited from upstream or mobilized in the vicinity of tiles and redistributed to cover the tiles' surfaces prior to deposition of coarser materials from upstream onto the tiles. This is supported by visual field observations of many relatively low flow velocity sites in both Brown and Boyes Creek which changed very little in overall sediment storage over the season, but in which fine sediment was redistributed to more homogeneous textures. Compaction was observed where tile surfaces were emergent or tiles appeared undercut (Table 6). Compaction may account for an unknown proportion of the apparent fine sediment volume reductions observed during the 1990 hydrologic year.

Almost no accumulation of sediment on tiles was recorded for the second sampling interval encompassing much of the late winter and spring, except for one tile located in a slackwater pool some distance from the main channel (Photo-Point 15C). Because this pool was a considerable reservoir for very fine sediment (silt and clay) prior to the beginning of the tile study, it is likely that sediment was locally redistributed and deposited on this tile. Lack of sediment accumulation on tiles in the second sampling interval

indicates little overall sediment transport during this period. This conclusion is supported by fine sediment probing surveys, which show that most fine sediment deposited in Brown and Boyes Creek in October, 1989 remains and will not be transported significantly further until higher flows occur.

E. Bed Mobility

E.1 Study Objective

The rate at which fine sediment is flushed from a stream system depends on the frequency and degree of streambed scour. The assumption is that as the bed scours, all fine sediments within the streambed down to the depth of scour are released into the flow and carried away. The objective of this study was to determine depth and frequency of streambed scour.

E.2 Methods

Scour chains and channel cross sections were used to measure bed mobility in Prairie and Brown Creeks. Cross sections and scour chains were established at each of four fine sediment monitoring sites on Prairie Creek. Cross sections were surveyed with a self-leveling level and stadia rod. Distances were measured with a tape.

Three scour chains were inserted vertically into the streambed along each cross section. Figure 9 illustrates how the scour chain methods works. Aluminum chains 80 cm long were anchored into the streambed with a dowel attached to the lower end. The chain and anchor 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.

Channel cross sections were surveyed before and after the winter season and the net amount of scour, fill and change in thalweg elevation were calculated. After the winter storm season, scour chains were excavated.

E.3 Results

Channel changes at cross sections on Prairie Creek were minimal and are reported in Table 9. The distance from streambed surface to the buried chain indicates the depth the bed was mobile and the subsequent amount of fill. All scour chains were buried under a surface layer of pebbles. Maximum depth of net scour in Prairie Creek was 9.3 cm and maximum depth of net fill was 12.6 cm (Table 10). In Brown Creek, storage of fine sediment in the bed subsurface appears to be consistent with Prairie Creek. Field observations, based on scour chains located at the infiltration bag sites, indicate minor amounts of scour and fill.

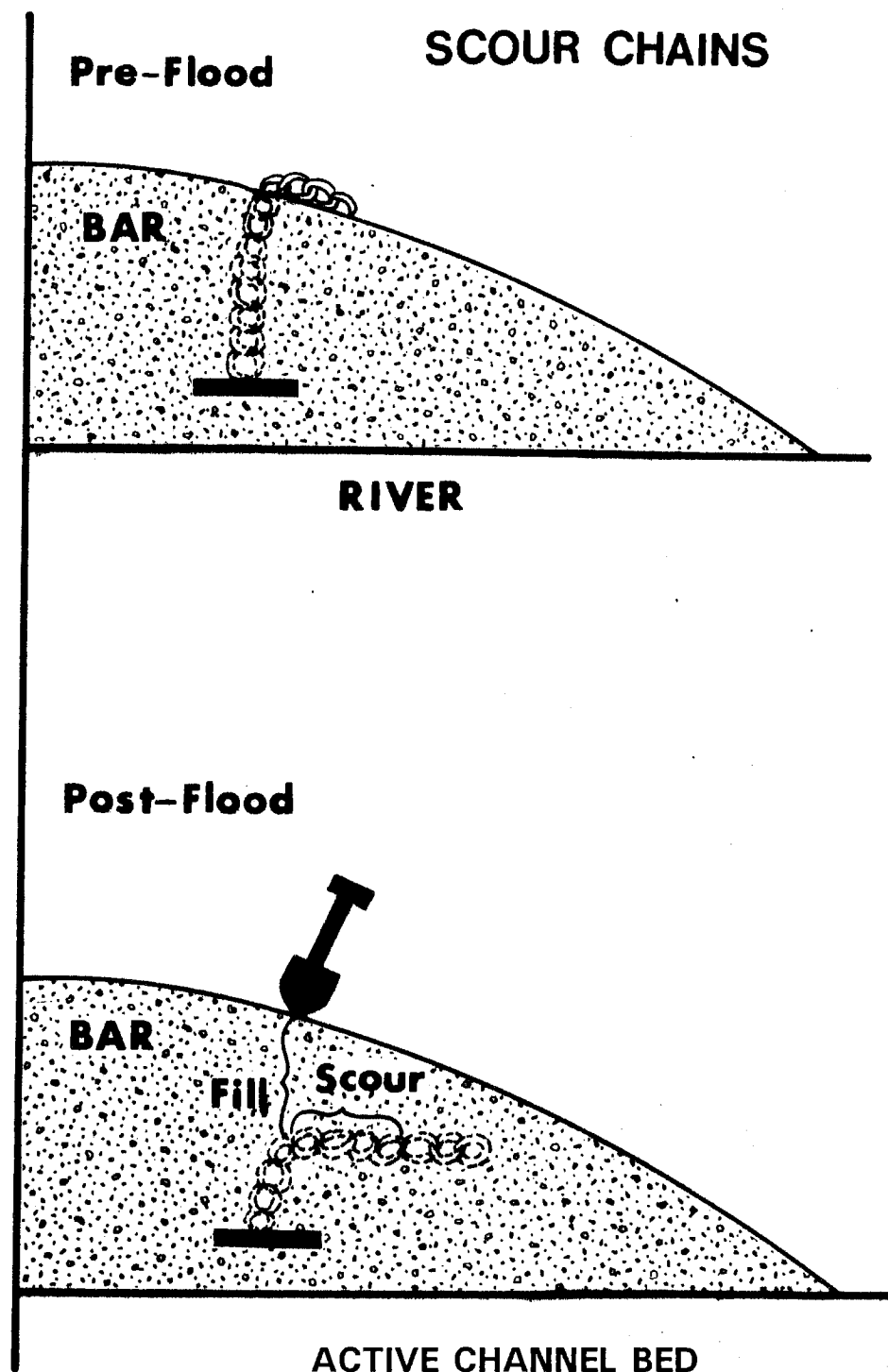


Figure 9. Scour chain in streambed, pre-flood and post-flood.

Table 9. Channel changes at cross sections on Prairie Creek, California, 1989-1990.

Location	Active Channel Width (m)	Change in Thalweg Elev (m)	Scour - (m ²)	Fill + (m ²)	Net Change (m ²)
Above Brown Ck	7.5	-0.042	0.10	0.03	-0.07
Below Brown Ck	11.0	0.007	0.01	0.20	0.18
Below Boyes Ck	14.0	0.044	0.18	0.23	0.06
Above Wolf Ck Bridge	12.5	0.034	0.16	0.28	0.11

Table 10. Depths of net scour or fill on Prairie Creek, California, 1989-90.

Location	Dist from Left Monument (m)	EXPOSED CHAIN LENGTH		Net scour (-) or fill (+) (cm)
		Jan 1990 (cm)	June 1990 (cm)	
Above Brown Ck	6.1	35.1	44.4	- 9.3
	7.6	42.7	38.0	+ 4.7
	9.1	50.6	40.0	+10.6
Below Brown Ck	6.5	37.5	39.5	- 2.0
	8.0	32.0	29.9	+ 2.1
	9.5	31.1	18.5	+12.6
Below Boyes Ck	11.0	29.9	31.4	- 1.5
	12.7	31.4	30.6	+ .8
	14.0	32.0	33.7	- 1.7
Above Wolf Ck Bridge	7.0	24.4	33.2	- 7.8
	9.5	25.9	24.7	+ 1.2
	11.0	24.4	26.7	- 2.3

E.4 Discussion

Channel changes at cross sections and scour chain data revealed insignificant amounts of scour and fill occurred within the streambed in Prairie and Brown Creeks. 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 (Lisle, personal communication). Results from the scour chain data supports conclusions of other elements of this study; that is, low winter flows of 1989-90 were not effective in flushing fine sediment from the Prairie Creek streambed. Based on this year's winter storm activity, infiltration of fine sediment below 15 cm depth in Brown Creek (see section II. F.3) coupled with low observed bed movement indicate long-term storage of fine sediment in subsurface gravel.

F. Subsurface Sediment Deposition and Storage in Streambeds

F.1 Study Objective

When gravels of streams affected by the bypass construction (Prairie Creek below Brown Creek confluence, Brown, Big Tree, Boyes, and May Creeks) were disturbed, light brown colored sediment plumes arose. Although not quantified, this color of subsurface fine sediment differed from the dark brown color of streams unaffected by the bypass (Godwood Creek, Prairie Creek above Ten Tapo Creek). This sharp contrast in color of subsurface fine sediment between affected and unaffected streams indicates that the affected streams received fresh inputs of subsurface as well as surface sediment from the October storm. Additionally, large sediment plumes arising from mechanical disturbance of the streambed surface were not observed prior to the October storm. The objective of this study was to: (1) quantify the fine sediment size fraction in subsurface gravels, (2) compare size composition of fine sediment deposited in pools with that of riffles, and (3) determine the depth that the fine sediment infiltrated the streambed.

F.2 Methods

Both freeze-core and McNeil sampling techniques were used to analyze particle size distribution of streambed gravels.

Lotspeich and Reid (1980) discuss in detail the tri-tube freeze-core construction and technique. A three-pronged probe was pounded into the streambed to a depth of 45 cm. Pressurized CO₂ was then injected into the hollow prongs, freezing the adjacent bed material around the prongs. The frozen core was winched from the streambed and placed on a multi-chambered collection tray (Fig. 10). The core was then broken apart into the trays, maintaining the stratigraphy in the tray compartments. The material was returned to the lab for analysis. All samples were dry-sieved and percent of fine sediment fraction by weight was calculated for the following size classes:

< 0.125 mm, 0.125-1 mm, 1-4 mm, 4-32 mm, 32-64 mm, and 64-128 mm.

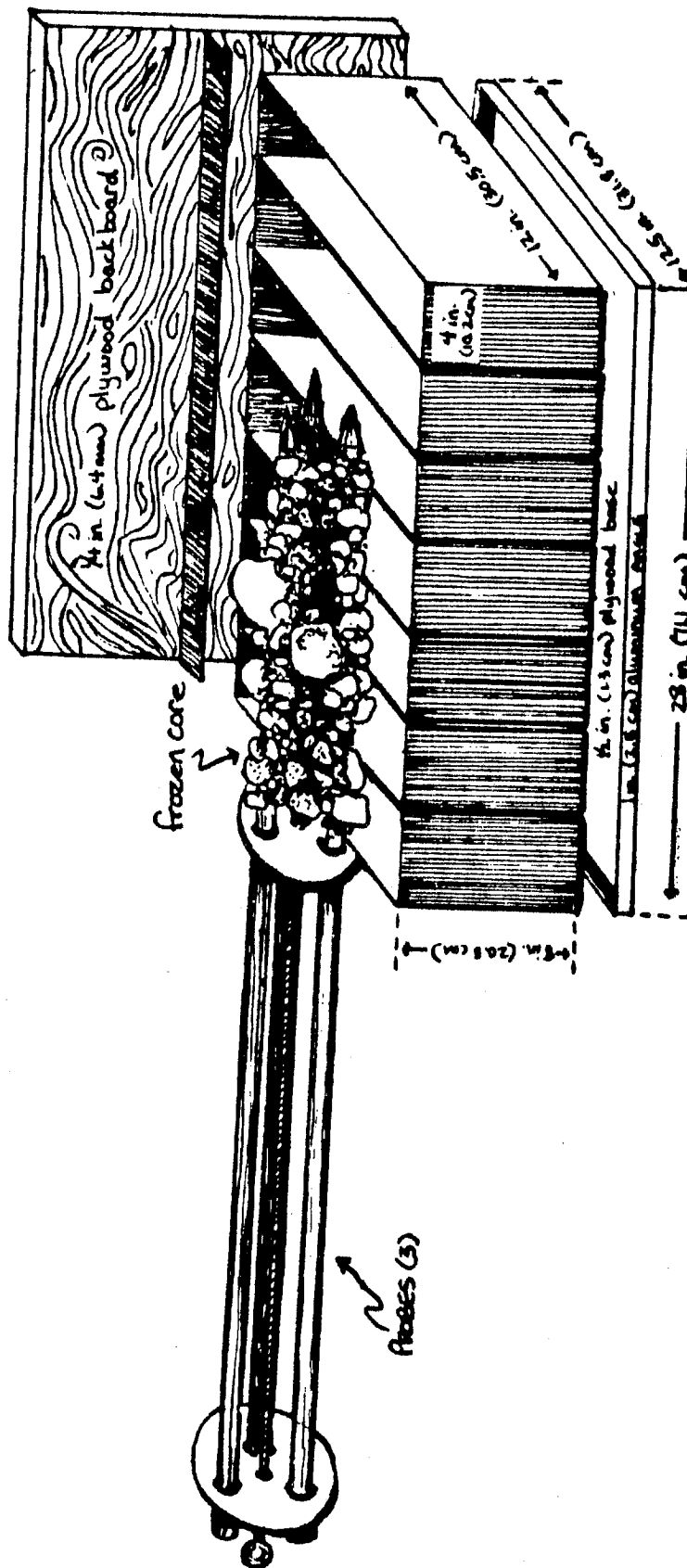


Figure 10. Illustration of a sediment core frozen onto a tri-tube freeze corer. The gravel is separated into separate trays to maintain stratigraphy.

The McNeil core sampler is an open-ended metal tube which samples a standard volume of stream gravel (McNeil and Ahnell 1960; Fig. 11). The sampler is driven into the streambed and the gravels encased within the tube are removed by hand and sent to the laboratory for analysis. Two different sized McNeil samplers were used in this study. Redwood National Park used a six-inch diameter McNeil sampler and PSW used a 12-inch diameter sampler. All samples are wet-sieved and percent of size fractions by volumes calculated. Sediment size classes were the same as the classes used for the freeze-core technique. The finest fraction (< 0.5 mm) was measured by plugging the bottom of the McNeil sampler and pouring the solution of water and suspended sediment into conical graduated Imhoff cones. Fine sediment was allowed to settle for 45 minutes and sediment in suspension beyond this period of time was discarded and not analyzed. The volume of settled fine sediment was read directly from the Imhoff cones.

As part of a separate, Caltrans-funded long-term bypass monitoring program, Redwood National Park has been annually sampling gravels at ten sites along Prairie Creek and its tributaries since 1985 (Redwood National Park, 1989). In 1989, gravel was freeze-core sampled at these sites in August. To detect the change in fine sediment caused by the October storm, four of these sites on Prairie Creek (Fig. 1) were freeze-core sampled again in November 1989. Six cores were taken from each site in August; three cores were taken from each site in November. Student's t tests ($P < 0.05$) were used to statistically detect differences in grain size classes by weight before and after the October storm.

To compare fine sediment composition in riffle sites versus pool sites, McNeil samples (12-inch diameter) were taken from Brown Creek pools and riffles. In the upper reach, LBR (Fig. 1), three pools and three riffles were randomly chosen as bed material sample sites. After the bed material was cored, it was wet-sieved in the field. The material greater than 2 mm was weighed and saved, to be used as experimental gravel, and material less than 2 mm was bagged and brought to the laboratory for analysis. Data from McNeil samples were also used to estimate the total amount of fine sediment stored within the streambed in the North Fork of Brown creek.

To determine depth of sediment infiltration, freeze-core samples were taken at a riffle and a pool site in both the upper and lower Brown Creek.

F.3 Results

Although mean percent fine sediment < 1 mm decreased at sites after the October storm, the change in Prairie Creek was not statistically significant (Table 11) except for the site above Boyes Creek confluence. No other significant differences were found between August and November for < 2 mm, < 4 mm, or any size classes except for a decrease in particles 0.125 - 1 mm in diameter at the site above Boyes Creek confluence.

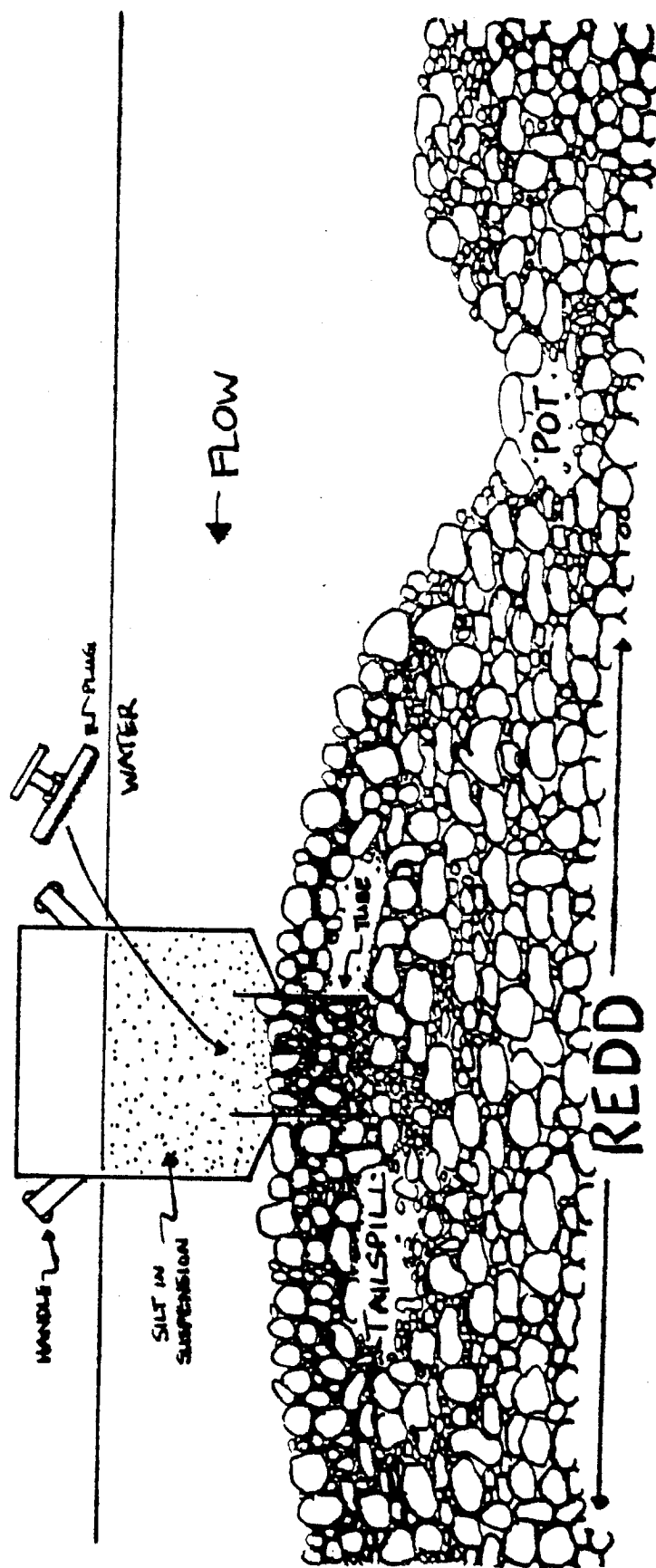


Figure 11. Illustration of coring a redd with a McNeil sampler. Once the gravels have been extracted from the core, the cylinder is plugged to capture the fine material in suspension.

Table 11. Mean percent (by weight) of fine sediment < 1 mm sampled with freeze-core apparatus before (n=6) and after (n=3) the October storm in riffles within reaches of Prairie Creek, California, 1989. Sampling locations were immediately above and below the mouths of tributaries listed.

Mean Percent of Fine Sediment < 1 mm by Weight		
Site	Before Storm	After Storm
Prairie Creek:		
Above Brown Ck	7.2	6.8
Above Boyes Ck*	8.5	6.3
Below Boyes Ck	7.1	7.1
Above May Ck	13.8	7.2
Mean	9.2	6.9

* Difference between before and after storm was significant at $P < 0.05$.

In upper Brown Creek, a breakdown of size class fractions of fine sediment determined from McNeil samples (Table 12) showed that generally percent of subsurface sediment finer than 2 mm in both riffles and pools was less with decreasing size class. The percent fine sediment < 1 mm was similar between pools and riffles; however, the percent fine sediment 1-2 mm in diameter was greater in pools.

To estimate the amount of sediment stored in the streambed of the North Fork of Brown Creek, we needed to determine the volume of gravels in Brown Creek, the volume of each McNeil sample and the average weight of fine sediment. The volume of gravels in Brown Creek can be estimated by considering the stream channel as a long rectangular box and multiplying the length of the creek by the width of the creek by the depth of sediment. The volume of gravels in Brown Creek from the streambed surface down to a depth where light-colored fine sediment was found (0.3 m) was estimated as:

$$2736 \text{ m (channel length)} \times 2 \text{ m (channel width)} \times 0.3 \text{ m (depth)} = 1641.6 \text{ m}^3$$

The average weight of fine sediment < 2 mm in the Brown Creek McNeil samples was 4.459 kg. The volume of each sample was 0.0212 m^3 (0.3 m in diam. and 0.3 m deep). Thus the average weight of fine sediment per cubic meter was $4.459 \text{ kg} / 0.0212 \text{ m}^3 = 210 \text{ kg/m}^3$. Then the weight of fine sediment in Brown Creek is $1641.6 \text{ m}^3 \times 210 \text{ kg/m}^3 = 345,289 \text{ kg}$, or 380 tons.

This estimate does not include surface fine sediment and is based only on the samples taken in the upper reach of Brown Creek. Results from the freeze-core data show that the lower reach of Brown Creek contains a similar amount of fine sediment as the upper reach, so this estimate is probably reasonable.

Freeze-core data from Brown Creek riffles and pools are summarized in Table 13. Subsurface gravels in both pools and riffles are relatively clean of fine sediment in the top five cm. An obvious bulge in percent fine sediment is

present at a depth of 6 to 40 cm. The amount of fine sediment stored in the gravel bed below 40 cm depth is not known. The fine sediment bulge is fairly constant for each freeze-core, although pools have a slightly higher percentage of fine sediment at 16 - 35 cm depth. This same pattern was found in freeze-core samples from Brown Creek riffles taken before the storm. The Brown Creek freeze-core samples taken after the October storm showed that from the streambed surface to 15 cm depth, an overall visual estimate of the interstices filled with fine sediment ranged from 45% at the upper reach to 30% at the lower reach. Below the 15 cm depth all the cores exhibited 90-100% of the interstices filled with fine sediment. No visual estimates were made on cores taken before the storm.

Table 12. Mean percent of subsurface fine sediment < 2 mm by total sample weight. Samples were taken with the McNeil sampler on upper Brown Creek, California, 1990.

Habitat	Mean Percent of Fine Sediment (< 2 mm) by Weight					
	1-2	.5-1	.25-.5	.125-.25	.063-.125	<.063 mm
Riffle #1	5.59	5.07	3.03	0.98	0.34	0.58
Riffle #2	2.23	1.70	1.09	0.69	0.26	0.40
Riffle #3	0.99	0.79	0.50	0.30	0.21	0.31
Pool #1	5.05	3.08	1.41	0.55	0.50	0.45
Pool #2	4.47	2.78	1.46	0.76	0.40	0.42
Pool #3	4.45	2.93	1.45	0.68	0.32	0.34
Mean of Riffles	2.94	2.52	1.54	0.66	0.27	0.43
Mean of Pools	4.66	2.93	1.44	0.66	0.41	0.40
Mean of All	3.80	2.73	1.49	0.66	0.34	0.42

Table 13. Brown Creek freeze-core data. Change in the percent of fine sediment fraction (< 2 mm) by weight with depth in the streambed

Site	Percent of Fine Sediment < 2 mm by Weight							
	Depth of Core (cm)							
	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
UBR - Riffle	10.1	14.3	12.8	14.2	15.7	19.8	16.5	18.4
LBR - Riffle	<u>1.4</u>	<u>5.9</u>	<u>15.8</u>	<u>12.1</u>	<u>12.2</u>	<u>13.5</u>	<u>18.1</u>	<u>24.5</u>
Riffle Means	5.8	10.1	14.3	13.2	14.0	16.7	17.3	21.5
UBR - Pool	2.1	10.7	14.8	17.1	19.2	19.5	21.6	16.4
LBR - Pool	<u>4.2</u>	<u>9.1</u>	<u>13.0</u>	<u>24.5</u>	<u>18.3</u>	<u>15.5</u>	<u>20.1</u>	<u>18.8</u>
Pool Means	3.2	9.9	13.9	20.8	18.8	17.5	20.9	17.6

F.4 Discussion

Recent surface deposition of sediment from the bypass in October was visible and quantified in affected streams (see previous Section E). We would expect sediment to infiltrate into the subsurface streambed, as well. This process seemed apparent when freeze-cores on Brown Creek showed light colored fine sediment accumulations increasing with depth. Yet no significant change was detected in Prairie Creek by freeze-cores of gravel after the storm except for a decrease at one site. This contradicts the observation of large fine sediment plumes arising from disturbed gravels after the storm that were not present before the storm. The sampling technique was limited and perhaps inadequate to represent actual conditions. Moreover, a possibility exists that freeze-core sampling is insensitive to the visibly obvious, yet very fine sediment fraction, deposited in the creek. The McNeil sampler detected at least as much fine material < 1 mm in riffles as in pools. Additionally, infiltration of water into the McNeil sampler was very slow, indicating fine sediment was blocking interstitial gravel pores. Unfortunately, McNeil samples were never taken from the gravels before the storm for comparison. The next section of this report (Section G) evaluates freeze-core vs. McNeil sample effectiveness in detecting fine sediment to assist in the interpretation of these results.

The finding of an increase in fine sediment with depth is in contrast to flume studies, where fine sediment infiltrating a gravel bed were constricted to the near surface gravels (Diplas and Parker, in press). We hypothesize that the very fine nature of bypass derived sediment might allow it to infiltrate deeper into the relatively open framework gravels of Brown Creek and thus, be responsible for the increase. Another possibility is that the pounding of probes into the gravel may redistribute fine sediment deeper into the streambed.

G. Comparisons Between Freeze-Core and McNeil Sampling Methods

G.1 Study Objective

Since all gravel sampling techniques have biases, selection of a sampling method can affect the results and interpretation of changes in the fine sediment fraction within the streambed. In our studies over the 1989-1990 winter period, we used both freeze-core and McNeil sampling techniques. Accuracy of freeze-core versus McNeil sampling techniques as reported in the literature is inconsistent. For example, Everest et al. (1982) found freeze-core sampling to be more accurate at estimating the percent of fine material than McNeil sampling. In contrast, Ringler (1970) reported the McNeil to be more accurate in determining the percent of fine sediment. The objective of this study was to compare these two methods and evaluate which provides more accurate results in our study streams.

G.2 Methods

The freeze-core and McNeil sampling method are described in detail in the previous methods section (see Section F.3).

In March, three pairs of freeze-core and McNeil samples were collected from potential spawning sites on lower Brown Creek. The sites selected had large silt/clay surface accumulations along the water's edge as a result of sediment input from the bypass.

Laboratory analyses of samples differed for the freeze-core and McNeil techniques used in other portions of this study. Freeze-core samples are dry-sieved and percent fine sediment analyzed by weight. In comparison, McNeil samples were wet-sieved and percent fine sediment analyzed by volume. In this test, all samples were sieved and analyzed to determine percent by weight and volume for each of the following size classes: < 0.5 mm, 0.5-1 mm, 1-2 mm, 2-4 mm, 4-32 mm, 32-128 mm, and > 128.0 mm. Differences in percent fine sediment in each size class between methods were statistically tested for significance using analysis of variance. Differences in percent fine sediment between gravimetric and volumetric analyses were also tested for significance using paired *t* tests ($P < 0.05$).

G.3 Results

The percent volume of fine sediment detected by freeze-core sampling was almost half the percent detected by McNeil sampling for the size class < 0.5 mm ($P < 0.05$; Table 14). Although not statistically significant, the same trend was apparent in the percent by weight comparison. However, for 0.5-1 mm, freeze-core samples detected slightly more percent volume of fine sediment than McNeil, although the difference was significant only at the ten percent level. Percent fine sediment did not significantly differ between methods for 1-2 mm or 2-4 mm size classes or for < 1 mm and < 2 mm ($P > 0.1$).

Table 14. Mean percent particle sizes detected by McNeil (n=3) and freeze-core (n=3) gravel samples from potential spawning sites on Brown Creek, northern California, spring 1990. Each sample was analyzed by volume and weight. Bracketed pairs were significantly different at $P < 0.05$.

Method	Mean Percent Fine Sediment					
	<0.5	< 1	< 2	0.5-1*	1-2	2-4 mm
Volume:						
McNeil	20.0	23.2	27.8	3.2	4.5	4.8
Freeze-Core	11.0	16.1	20.7	5.1	4.6	4.8
Weight:						
McNeil	5.9	8.1	11.6	2.2	3.5	4.8
Freeze-Core	4.2	7.2	10.8	3.1	3.5	3.8

* The difference between McNeil and freeze-core for this size class was significant at $P < 0.10$.

The amount of fine sediment measured by volumetric analysis (with wet sieving) was greater than gravimetric analysis (with dry sieving) for both methods and all size classes tested except freeze-core percent fine sediment 1-2 mm and McNeil percent fine sediment 2-4 mm (Table 14).

G.4 Discussion

In most fishery studies conducted on Prairie Creek, fine sediment was defined as less than 1 mm in diameter. Although the sample size was small, our results from a comparison of freeze-core to McNeil sampling methods indicate that freeze-cores can underestimate the smallest fine sediment (< 0.5 mm). Conversely, McNeil sampling can slightly underestimate the upper end of this fine sediment range (0.5 - 1 mm), making it difficult to detect a difference in fine sediment between methods when data are grouped into the < 1 mm range. The nearly identical values produced between 1 and 4 mm indicate either method is suitable in this range. Unfortunately, it is unclear which method represents the most accurate picture of gravel size composition. However, if changes in one size fraction is of interest, the method that detects greater amounts of that size fraction will be most sensitive to changes. Therefore, if changes in particles 0.5 - 1 mm are of interest, freeze-core may be the most appropriate method; conversely, McNeil should be selected if the focus is on changes in very fine material < 0.5 mm.

Of importance, the standard procedure of a 45-minute settling time in the Imhoff cone was insufficient for settling very fine silts and clays (the unsettled fine sediment was discarded). Graphs from Dingman (1984) and Guy (1969) show that after 45 minutes, particles > 0.156 mm will have settled in the cone, but very fine silt and clay may still be in suspension. Flocculation of clay particles further complicates the picture. Consequently, when using a McNeil sampler and these settling procedures, the size class < 0.5 mm actually approximates 0.15 to 0.5 mm. Saving a sample of the unsettled

materials for laboratory analysis would improve results from the McNeil sampling procedure.

As our results indicate, volumetric analysis (McNeil technique) is more sensitive to fine sediment than gravimetric analysis (freeze-core). The conversion factor from volume to weight was not constant between samples or techniques, ranging from one to four. As a consequence, conversion factors provided in the literature (Shirazi et al. 1979) should not be applied to our study results. Analysis of McNeil samples by volume after wet sieving gave percent fine values < 1 mm that were on average three times the value of freeze-core sample analysis by weight after dry sieving (ranging from two to five times greater). Data comparisons with future and past studies on Prairie Creek should be conducted cautiously with this in mind.

Field analysis of the surface sediment deposited on the banks of impacted streams such as Brown Creek after the storm showed a large fraction of silt and clay (particle size diameter < 0.062 mm). If this material was deposited within the gravels, freeze-core sampling was inappropriate for detecting changes in this very fine material. Furthermore, because of their light weight, fine sediment are not well represented as a percent by weight. Yet, the volume of intragravel pore space they occupy in a redd can be a critical component of egg mortality. For this reason, we switched to using the McNeil sampling procedure (volumetric analysis) as appropriate in the following studies to document changes in fine sediment in redds and potential spawning sites over the winter period.

H. Subsurface Storage of Fine Sediment in Potential Spawning Sites

H.1 Study Objective

Streams having large percentages of fine sediment within gravel provide poor spawning substrate for salmonids (McNeil and Ahnell 1964, Koski 1975, Philips et al. 1975, Cederholm et al. 1981). The objective of this study was to document change in percent fine sediment within potential spawning sites over the winter period, 1989-90.

H.2 Methods

In cooperation with the California Department of Fish and Game, we sampled twelve sites (Fig. 1) to evaluate distribution of sediment sizes in spawning habitat after the October storm. Seven of these sites were from Prairie Creek and one each was from lower Boyes Creek, lower Brown Creek, Lost Man Creek, Godwood Creek, and Big Tree Creek. The latter two creeks were sampled to compare two small tributaries, one affected (Big Tree Creek) and the other unaffected by the bypass (Godwood Creek). Lost Man Creek was evaluated as a control stream for Prairie Creek. At each site, three McNeil sample cores were taken from likely spawning sites on riffle crests. Samples were collected in the fall following the October storm (late October and November) and spring (May and June) at the end of the storm season. Samples were collected only in June on Godwood and Big Tree Creeks. Using the same procedure listed under the egg survival study (Section III. B.), we sieved the samples, volumetrically measured size class fractions, calculated percentages, and statistically tested for differences between the two sampling periods ($P < 0.05$).

H.3 Results

Percent volume of fine sediment < 1 mm in likely spawning sites on Prairie Creek following the October storm averaged 24.5%, ranging from 20.6 to 29.9% (Table 15). The lower section of the tributary Brown Creek had the highest fine sediment volume after the October storm (32.9%). Percent fine sediment did not significantly differ between Prairie Creek and the control stream, Lost Man Creek, during the fall sampling. In the spring, fine sediment in Prairie Creek was statistically significantly higher than Lost Man Creek by 6.9%. However, percent fine sediment in Prairie Creek did not significantly change over the winter period. Neither was percent fine sediment significantly associated with downstream direction on Prairie Creek. However, the percent fine sediment in Prairie Creek above tributaries decreased over time more than at locations below tributaries. At the sites on Boyes, Brown, and Lost Man Creeks, percent fine sediment decreased by 1.8%, 11.7%, and 5.6% respectively; the decrease was statistically significant only for Brown Creek.

Percent fine sediment < 1 mm did not significantly differ between Godwood and Big Tree Creeks. However, fine sediment in the size classes 0.5-1 mm, 1-2 mm and < 4 mm was significantly higher in Big Tree than Godwood Creek. No significant differences existed for other size classes (Table 16).

Table 15. Mean percent volume of fine sediment < 1 mm found in gravel sampled at riffle crests in potential spawning habitat of Prairie Creek and some of its tributaries, northern California, 1989-1990.* Fall sampling was after the October storm.

Mean Percent Volume of Fine Sediment < 1 mm			
	Fall	Spring	Difference
<u>Prairie Creek:</u>			
Above Ten Tapo Creek	28.4	25.4	-3.0
Below Ten Tapo Creek	26.2	26.6	+0.4
Above Brown Creek	25.7	25.3	-0.4
Below Brown Creek	20.6	20.4	-0.2
Above Boyes Creek	29.9	26.0	-3.9
Below Boyes Creek	22.0	22.7	+0.7
Above May Creek	18.6	29.7	+11.1
Mean	24.5	25.2	+0.7
<u>Prairie Creek Tributaries:</u>			
Lower Boyes Creek	26.8	25.0	-1.8
Lower Brown Creek	32.9	21.2	-11.7**
Lost Man Creek	23.9	18.3	-5.6

* Data were generated by the California Department of Fish and Game and Redwood National Park.

** Difference is significant at $P < 0.05$.

Table 16. Mean percent of fine sediment by volume (n=3 for each creek) found in gravel sampled at riffle crests in potential spawning habitat of Big Tree Creek (affected by bypass) and Godwood Creek (unaffected by bypass), northern California, June 1990.*

	Mean Percent Volume of Fine Sediment				
	< 1 mm	< 2 mm	< 4 mm	0.5-1 mm	1-2 mm
Big Tree Creek	20.9	25.6	32.9	3.7	4.7
Godwood Creek	17.1	19.0	23.6	2.1	1.9
Difference	3.8	6.6	9.3*	1.6*	2.8*

* Difference is significant at $P < 0.05$.

H.4 Discussion

The amount of subsurface fine sediment in potential spawning gravels did not change over the winter period in Prairie Creek, but it decreased at the sampled site in Brown Creek. One-third of the fine sediment within the gravel appears to have been removed from these few riffle crests in Brown Creek. This may not be representative of the rest of Brown Creek. Although data are limited, this would suggest subsurface sediment is flushing out of one of the most impacted creeks, Brown Creek, and is being transported to Prairie Creek. This contrasts with cross section data showing little transport of surface fine sediment in lower Brown Creek. More sampling is needed to determine if subsurface sediment is responding differently than surface sediment (variability is high in gravels of these streams - coefficient of variation within a sample site on Prairie Creek ranges from 19% to 29%). In agreement with bed mobility findings, Prairie Creek fine sediments do not appear to be changing.

In June, Big Tree Creek had larger amounts of fine sediment than the control creek, Godwood Creek, for medium to coarse sand fractions. We have no baseline data on these two creeks before the October storm, and it is unknown whether Godwood Creek is a suitable control stream. Godwood Creek is different morphologically than Big Tree Creek. If we assume Godwood Creek represents natural levels in Big Tree Creek, our result suggests the bypass caused additional sand to be deposited into Big Tree Creek.

Potential spawning habitat with fine sediment greater than 30%, as found in Brown Creek, has been reported to result in low egg survival to emergence values (Everest et al. 1987). Despite the mild winter, it is likely cutthroat trout and coho salmon that spawned in Brown Creek were adversely impacted this past winter. Sampling next winter is required to test whether the decrease in fine sediment noted over last winter in Brown Creek was an isolated instance occurring on a few riffle crests or indicative of a widespread trend which may

continue. An egg survival study is required to determine how mainstem spawners, such as chinook salmon, are being affected by the fine percentage range (20-30%) found in Prairie Creek.

Finally, we found that spawning gravel above Ten Tapo Creek confluence should not be used as a control for Prairie Creek below Brown Creek confluence. Above Ten Tapo Creek, Prairie Creek is the size of its small tributaries.

I. Total Sediment in Brown Creek

I.1 Study Objective

Combining our October storm sediment estimates, January-June sediment measurements, and estimates of surface and subsurface storage of sediment in the North Fork of Brown Creek, we can create a balance for the 1989-1990 storm season. The input of sediment into Brown Creek is equal to what was deposited in the stream plus what was flushed from the stream. The objective is to determine total amount of fine sediment in Brown Creek following the October storm.

I.2 Methods

Values for the tonnage of sediment in the North Fork of Brown Creek are taken from the results reported in previous sections of this study. Sediment load or transport for the season was determined from suspended sediment discharge measurements (see Section C.3). Surface and subsurface storage for the North Fork of Brown Creek was calculated by extrapolating the results from the two PSW study reaches to the rest of the channel (see Section D.3 and F.3 respectively).

I.3 Results

Tonnage of sediment in the north fork of Brown Creek is summarized as follows:

	<u>tons</u>	<u>Data Source</u>
October storm sediment transport	200	Section C.3, page 22
January-June sediment transport	87	Section C.3, page 22
Channel bed surface storage (<2 mm diam)	141	Section D.3, page 30
Channel bed subsurface storage in April	<u>380</u>	Section F.3, page 41
Total	808	

A total of 808 tons either left Brown Creek or is still in storage in the stream channel. This amount represents the amount of sediment entering the north fork of Brown Creek from the bypass in October, 1989. The above figures indicate that over 73% of the fine sediment remaining in Brown Creek is stored subsurface within the gravel interstices.

I.4 Discussion

If we assume the south fork of Brown Creek reacted similarly to the intensively studied north fork, and the amount of sediment deposited is proportionate to its drainage area, then the total sediment flushed from Brown Creek plus that still in storage is about 990 t. The Final Environmental

LB drainage area

$$\frac{808}{1.4 \text{ mi}^2} = \frac{152}{\text{mi}^2}$$

Lower Brown Creek
 95000 sq mi drainage area

$$* .315 \text{ mi}^2 \text{ south fork Brown Ck}$$

Impact Statement predicted a short-term sediment loss of 1138 t into Brown Creek, with no significant impact on fisheries. Although the sum of the amounts of sediment which were transported through and what still remains in the stream channel (808 t) is somewhat smaller than the amount predicted for Brown Creek, the percent of fine sediment in Brown Creek gravels is much greater than was anticipated when the predicted sediment tonnage was assumed to be distributed evenly over the streambed in the FEIS. The amount of fine sediment anticipated to infiltrate into the streambed was so low that no impact to fisheries was predicted. The very fine nature of the sediment can adversely affect gravel permeability, however, even though the net tonnage is below the amount predicted for Brown Creek by the FEIS. Because the greatest proportion of fine sediment remaining in Brown Creek is subsurface (73%), impacts from fine sediment are expected to be persistent. This sediment will not be flushed from the creek until the streambed is extensively mobilized, which will likely require a 5- to 10-year recurrence interval flow.

III. EFFECTS ON SALMONID FISH

We addressed the effect of October sedimentation on fish by studying several stages of the salmonid reproductive cycle. First, to determine whether sediment inhibited spawning, we conducted spawning surveys. Second, for those fish that spawned, we examined egg survival in relation to percent fine sediment in artificially constructed redds and in natural redds. Thirdly, we assessed gravel permeability and dissolved oxygen concentrations in artificially cleaned riffles. Finally, to understand effects of fine sediment on the food base, we surveyed benthic macroinvertebrates of affected streams.

A. Spawning Surveys

A.1 Study Objective

Salmonids may abandon spawning in an area if spawning gravels contain too much fine sediment. This year's additional sediment input into Prairie Creek could inhibit spawning by reducing the amount of suitable spawning habitat. The objective of this study was to determine: (1) whether fish spawned in Prairie Creek, (2) location of redds, and (3) which salmonid species spawned in Prairie Creek.

A.2 Methods

Spawning surveys were conducted on Prairie Creek from below the channelized portion (downstream of the May Creek confluence) upstream to approximately 1.5 miles north of Brown Creek confluence (Fig. 1). Three surveys were conducted between November 30, 1989 and March 16, 1990. All redds, live and dead salmon, and steelhead were recorded and locations mapped. Redds and carcasses were flagged to avoid counting them more than once. Tributaries were not surveyed.

A.3 Results

We counted 116 redds and 137 fish (dead and alive) in the surveyed section of Prairie Creek (Table 17). Chinook and coho salmon and steelhead trout were present. Seventy percent of the redds and 60% of the fish surveyed were found below a fish weir located downstream of Boyes Creek confluence next to Prairie Creek Redwoods State Park's campground. Examination of salmon carcasses indicated that 15 of 16 females had spawned. The ratio of redds to total fish observed was 0.8; the ratio of redds to carcasses was 2.3.

To compare these results to past spawning records, Prairie Creek fish trapping records from 1985 to 1990 are presented in Table 18. Spawning survey results from 1985 to 1990 on Prairie Creek are tabulated in Table 19.

Table 17. Number of redds and carcasses by species (number of live fish in parenthesis) recorded during three spawning surveys of stream reaches along Prairie Creek, northern California, winter 1989-1990.

Stream Reach	Redds	Chinook	Coho	Steelhead**	Unknown
Brown Ck to 1.5 mi above Brown Ck	11	0	1 (11)	0	0
Big Tree Ck to Brown Ck	6	0 (10)	0 (1)	0	0
Boyes Ck to Big Tree Ck	14	5 (3)	1 (6)	0 (2)	1 (2)
Fish weir* to Boyes Ck	4	2 (1)	1 (3)	0 (1)	1 (3)
May Ck to fish weir	68	20 (13)	13 (18)	0 (7)	4 (3)
Below channelized portion to May Ck	13	2	0	0 (1)	0 (1)
Total	116	29 (27)	16 (39)	0 (11)	6 (9)

* The fish weir was part of the trapping effort for a hatchbox-rearing program on Prairie Creek. It was located near Campground 57 in the Prairie Creek campground, Prairie Creek Redwoods State Park.

** Steelhead are repeat spawners and rarely are found as carcasses in stream surveys.

Table 18. Prairie Creek fish trapping records for 1985-1990 from Humboldt County Prairie Creek Fish Hatchery and Pacific Coast Federation of Fishermen Association (PCFFA) (1990).

	PCFFA*	Humboldt County**			
	1989-90	1988-89	1987-88	1986-87	1985-86
Fish removed for spawning	96	3	10	7	13
Fish counted and passed	125	122	281	114	241
Total fish counted	221	125	291	121	254

* Trap was located just downstream of Boyes Creek confluence and was in place every day.

** Trap was located just upstream of Lost Man Creek confluence and was in place on odd days.

Table 19. Number of fish and redds observed during spawning surveys conducted by Redwood National Park on Prairie Creek, northern California 1985-1990.

	1989-90	1988-89	1987-86	1986-87	1985-86
Redds observed below PCFFA trap*	81	23	61	19	14
Fish observed below PCFFA trap	82	31	82	22	22
Redds observed above PCFFA trap	35	27	113	44	37
Fish observed above PCFFA trap	55	44	144	32	111
Total redds	116	50	174	63	51
Total carcasses	51	54	218	20	56
Total fish (live & dead)	137	75	226	54	133
# Survey days	11	5	6	6	6
# Redds per survey day	10.6	10.0	29.0	10.5	8.5
# Fish per survey day	12.4	15.0	37.6	9.0	22.1
# Redds per fish	0.84	0.66	0.76	1.16	0.38
# Redds per carcass	2.27	0.92	0.79	3.15	0.91

* PCFFA trap was in place only in 1989-90.

A.4 Discussion

The finding that most redds and fish were located below Boyes Creek confluence is not surprising considering the Pacific Coast Federation of Fishermen Association (PCFFA) trapped and removed 96 fish (46 chinook salmon, 39 coho salmon, 3 steelhead and 8 cutthroat trout) at the weir just downstream of this point. In previous years' spawning surveys, fish were not trapped at this location (Table 18), and the majority of fish (58 to 83%) and redds (54 to 81%) were located upstream of the PCFFA trap (Table 19). Although this trapping effort obscures any sediment-caused shifts in spawning distribution, our results indicate that spawners did not completely avoid any bypass-affected stream reaches that were surveyed on Prairie Creek.

Using records from fish traps and spawning surveys, the 1989-90 strength of the spawning run falls within the range of previous years (Tables 18 and 19). Although more live fish, carcasses, and redds were counted this season than during most other years, this is likely the result of increased survey and trapping efforts rather than increased numbers (see ratios of redds and fish to survey days, Table 19). Accounting for this increased effort, the 1989-90 run was similar to the run in 1988-89, another year of dry weather.

The ratio of redds to fish observed can be used as an index to whether fish spawned. Unfortunately, it is a weak index to rely on because the fish numbers do not represent a population estimate. Nevertheless, the ratio of redds to fish (0.84) observed has remained fairly consistent year to year, being slightly higher this year than most other years. The ratio of redds to carcasses (2.27) is higher than most previous years. This might indicate fish were constructing redds at the same rate or greater than other years. In conjunction with the finding that most females had released their eggs, this suggests that spawning was not inhibited this year in Prairie Creek.

We must be cautious in the above interpretation, since we never verified whether any of the redds were "false" redds. When a spawning site is found unsuitable to a female, she could potentially abandon the redd without depositing eggs to start a new one elsewhere. Briggs (1953) found that over 1/3 of the redds he examined on Prairie Creek were false. Thus, false redds could have increased this year due to sedimentation. In support of this, results from a 1990 juvenile production study conducted by a HSU graduate student indicated salmonid juvenile production in bypass-affected streams was much lower than unaffected streams. This was particularly true in tributaries which were not surveyed for redds or carcasses.

B. Egg Survival

B.1 Study Objective

Infiltration of large amounts of fine sediment into salmonid redds can reduce the reproductive success of salmonids (Everest et al. 1987). Fine sediment generally reduces permeability of gravels (McNeil and Ahnell 1964), intragravel water flow (Cooper 1965) and thus availability of dissolved oxygen. Low dissolved oxygen can cause direct mortality (Alderice et al. 1958) or delay development of alevins (Shumway et al. 1964, Brannon 1965). Although many studies have addressed effects of sedimentation on salmonids, few studies have examined the effect of very fine sediment, which was deposited during the October storm, on salmonid spawning gravels.

The objective of this study was to determine whether egg survival was affected by recent sediment inputs from the bypass. Specifically, the study was designed to answer three questions: (1) Does the percent of eyed steelhead eggs that survive to hatching differ between streams impacted (Prairie Creek) and unimpacted (Lost Man Creek) by the Highway 101 Bypass? (2) Does the percent of fine sediment change within the redd during egg incubation, and if so, does it affect egg survival? (3) Does egg survival decrease in the downstream direction on Prairie Creek, due to the cumulative effect of sediment input from impacted tributaries?

B.2 Methods

Lost Man Creek, a stream unimpacted by the bypass, was selected as a control stream. Due to past logging, Lost Man Creek is not as pristine a stream as Prairie Creek was prior to Bypass construction, nor is it geologically identical. However, it was the best control stream available and is climatologically similar.

Procedures used to estimate egg survival were adapted from Burton et al. (1990). Between February 16, 1990 and March 7, 1990, we constructed eighteen artificial steelhead redds: ten in Prairie Creek and eight in Lost Man Creek. Artificial redds were located in areas where fish were observed spawning upstream and downstream of major tributary confluences (Fig. 1).

Redd construction involved digging a 25-cm deep hole and sifting gravel with shovels, using the downstream current to form the tailspill. We then placed recently eyed steelhead eggs, obtained from Prairie Creek Fish Hatchery, in enamel-coated colander baskets (0.31 cm mesh) filled with gravel. The basket gravel, dug from the redd, was cleaned of all fine-grained sediment (sand or finer). After sewing a fiberglass 0.16 cm mesh screen cover to the basket top using monofilament line, we placed one basket in the hole. Repeating the process, we dug another hole upstream for the next basket, allowing the sifted displaced gravel to bury the downstream basket. In all we constructed 4 holes, burying a total of 3 baskets (having rim diameters of 27.5, 22.5, and 17.5 cm) in each redd to mimic natural egg pockets (Fig. 12). The fourth and most upstream hole remained empty, representing the "pot". The large, medium, and small baskets contained 100, 75, and 25 eggs respectively, or 200 eggs per redd. After allowing the eggs to incubate the required number of days until hatching, baskets were removed and number of alevins (sac fry) were counted. Baskets were slid into a dishtub underwater to minimize loss of fine sediment during removal.

Unless otherwise specified, percent fine sediment < 1 mm was used to define fine sediment. This is the size believed to have the greatest effect on survival to hatching. In most cases the statistical significance of results for fine sediment < 1 mm were the same as for fine sediment < 0.5 mm or < 2 mm, so < 1 mm adequately represented the results.

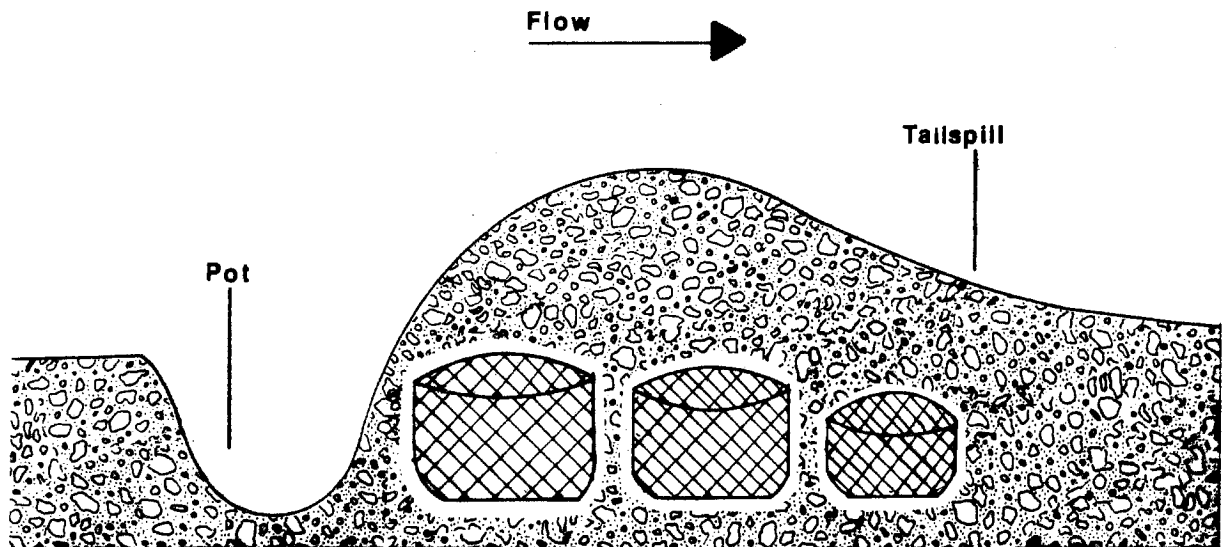


Figure 12. Longitudinal cross section of an artificial redd constructed to determine egg survival in Prairie Creek. Each basket, containing clean gravel and eggs, was buried in a ten-inch deep hole and a mound of sifted gravel results downstream of the pot or hole.

To interpret egg survival results, gravel was sampled from each tailspill at the time of its construction and during basket removal. Samples were cored using a McNeil sampler (refer to Figure 11). The finest fraction (< 0.5 mm) was measured by pouring the suspended sediment and water into Imhoff cones to settle for 45 minutes; sediment in suspension beyond this period of time was discarded. In addition, gravel within the baskets was saved for analysis.

In cooperation with Caltrans personnel, we wet-sieved gravel samples and volumetrically analyzed them using the following grain size sieves: < 0.5 mm, 0.5-1 mm, 1-2 mm, 2-4 mm, 4-32 mm, 32-128 mm, and > 128.0 mm.

Differences between streams (Prairie and Lost Man Creeks) and over time in percent egg survival and percent volume of several size classes were statistically tested for significance using analysis of variance and paired t tests respectively. To reduce non-normality, all percent estimates were converted by an arcsine transformation. When test assumptions of homogeneity of variance and normality between groups were severely violated, we used the nonparametric Kruskal-Wallis test. We also evaluated effect of basket size to exclude potential bias. Finally, Pearson product moment correlations between survival and percent fine sediment in baskets and the tailspill were statistically tested for significance. Spearman's rank correlation coefficient was used to test for increases in fine sediment or decreases in survival in a downstream direction on Prairie Creek. Differences and correlations were considered to be statistically significant when the probability of the observed difference or correlation occurring by chance was less than 5 times in 100 ($P < 0.05$).

Two additional redds containing "green" (spawned and fertilized within 24 hours) steelhead eggs were constructed in Prairie Creek just above Boyes Creek confluence. Handling of these eggs caused appreciable mortality; consequently, we discontinued using green eggs. Results for these two redds were not included in the statistical analysis.

B.3 Results

Eyed steelhead eggs were incubated in the two streams between February 16, 1990 and April 10, 1990. Mean percent survival to hatching was 71% in Prairie Creek and 85% in the control stream, Lost Man Creek. The difference between streams was not statistically significant. Survival ranged from 72 to 96% in all redds except two in the most downstream stretch of Prairie Creek (below May Creek confluence), which had a survival of 0% (Table 20 and Appendix A). These two redds and, to a lesser extent, the second redd below the picnic area in Lost Man Creek were infested with oligochaete worms. When worm-infested redds were excluded, mean percent survival was 88% in Prairie Creek and 86% in Lost Man Creek. The two redds planted with green eggs in Prairie Creek averaged 49% and 73% egg survival.

In all analyses, basket size had no effect on egg survival, but it significantly affected amount of fine sediment. Large baskets accumulated greater percent fine sediment than small baskets. Consequently, differences in fine sediment were evaluated separately for each basket size.

There were no significant differences between Prairie Creek and the control stream in percent fine sediment < 1 mm in the baskets or tailspill (Figure 13, Table 20 and Appendix B). However, percent fine sediment < 1 mm significantly

STEELHEAD EGG SURVIVAL HATCHED IN BASKETS IN ARTIFICIAL REDDS

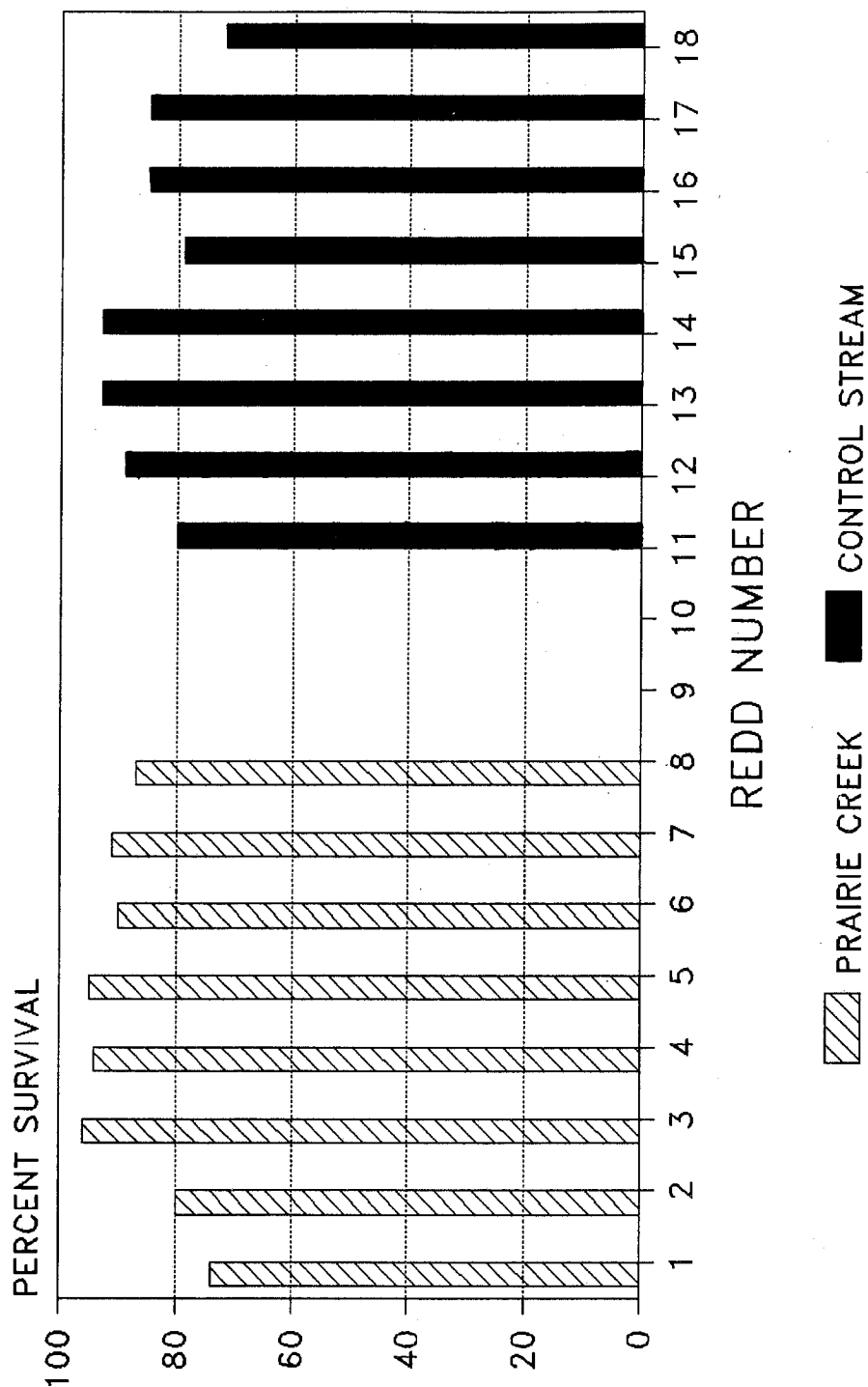


Figure 13. Percent of eyed steelhead eggs (200 eggs/redd) that survived to hatching when incubated in baskets in artificial redds on Prairie Creek (affected stream) and Lost Man Creek (control stream) in northern California, 1990.

Table 20. Percent of eyed steelhead eggs (200 eggs/redd) that survived to hatching when incubated in baskets in artificial redds on Prairie Creek (affected stream) and Lost Man Creek (control stream) in northern California, 1990. Associated percent volume fine sediment < 1 mm diameter in the baskets after hatching is also shown.*

Location	INDIVIDUAL REDD	
	% Survival	% Fine Sediment
<u>Prairie Creek:</u>		
Above Brown Ck - Redd #1	74	1.2
Above Brown Ck - Redd #2	80	1.5
Below Brown Ck - Redd #1	96	2.4
Below Brown Ck - Redd #2	94	0.8
Above Boyes Ck - Redd #1	95	1.2
Above Boyes Ck - Redd #2	90	2.7
Below Boyes Ck - Redd #1	91	2.8
Below Boyes Ck - Redd #2	87	6.0
Below May Ck - Redd #1**	0	1.5
Below May Ck - Redd #2**	0	5.7
Mean	71	2.6
<u>Lost Man Creek:</u>		
Above Tributary Redd #1	80	1.9
Above Tributary Redd #2	89	2.3
Above Double Bridge Redd #1	93	2.1
Above Double Bridge Redd #2	93	1.4
Below Double Bridge Redd #1	79	3.5
Below Double Bridge Redd #2**	85	4.0
Below Picnic Area Redd #1	85	6.6
Below Picnic Area Redd #2	72	8.1
Mean	85	3.7

* Eyed steelhead eggs were incubated in these streams for various periods of time between February 16, 1990 and April 10, 1990.

** Estimates were derived from two baskets and 175 eggs/redd, which differed from the others which were derived from three baskets and 200 eggs/redd.

increased during the incubation period in all sites. Mean percent fine sediment in baskets increased from 0 to 2.6% in Prairie Creek and from 0 to 3.7% in Lost Man Creek. Mean percent fine sediment within the tailspill correspondingly increased 7.0% (from 8.0 to 15.0%) in Prairie Creek and 8.6% (from 10.3 to 18.9%) in Lost Man Creek (Appendix B). There were no significant ($P < 0.5$) correlations between these levels of fine sediment and egg survival, although a slight trend of an inverse correlation between basket fine sediment and survival exists ($\rho = -0.24$; $P < 0.10$) (Figs. 13 and 14).

Egg survival was not associated with downstream direction on Prairie Creek unless the worm-infested baskets below May Creek confluence were included in the analysis (Spearman's $\rho = -0.44$ and $P < 0.05$ with worm-infested baskets, Spearman's $\rho = -0.11$ and $P > 0.05$ without worm-infested baskets). Moreover, basket fine sediment in the reach least affected by the bypass (above Brown Creek confluence) was not significantly lower than fine sediment in other reaches (Fig. 15). However, basket fine sediment was positively associated with a downstream direction in both Prairie Creek and Lost Man Creek (Spearman's $\rho = 0.57$ and 0.83 , respectively; $P < 0.05$). This relationship did not hold true for mean tailspill fine sediment in Prairie Creek (Fig. 16) or Lost Man Creek. Egg survival was slightly negatively associated with downstream direction on Lost Man Creek (Spearman's $\rho = -0.34$; $P < 0.05$).

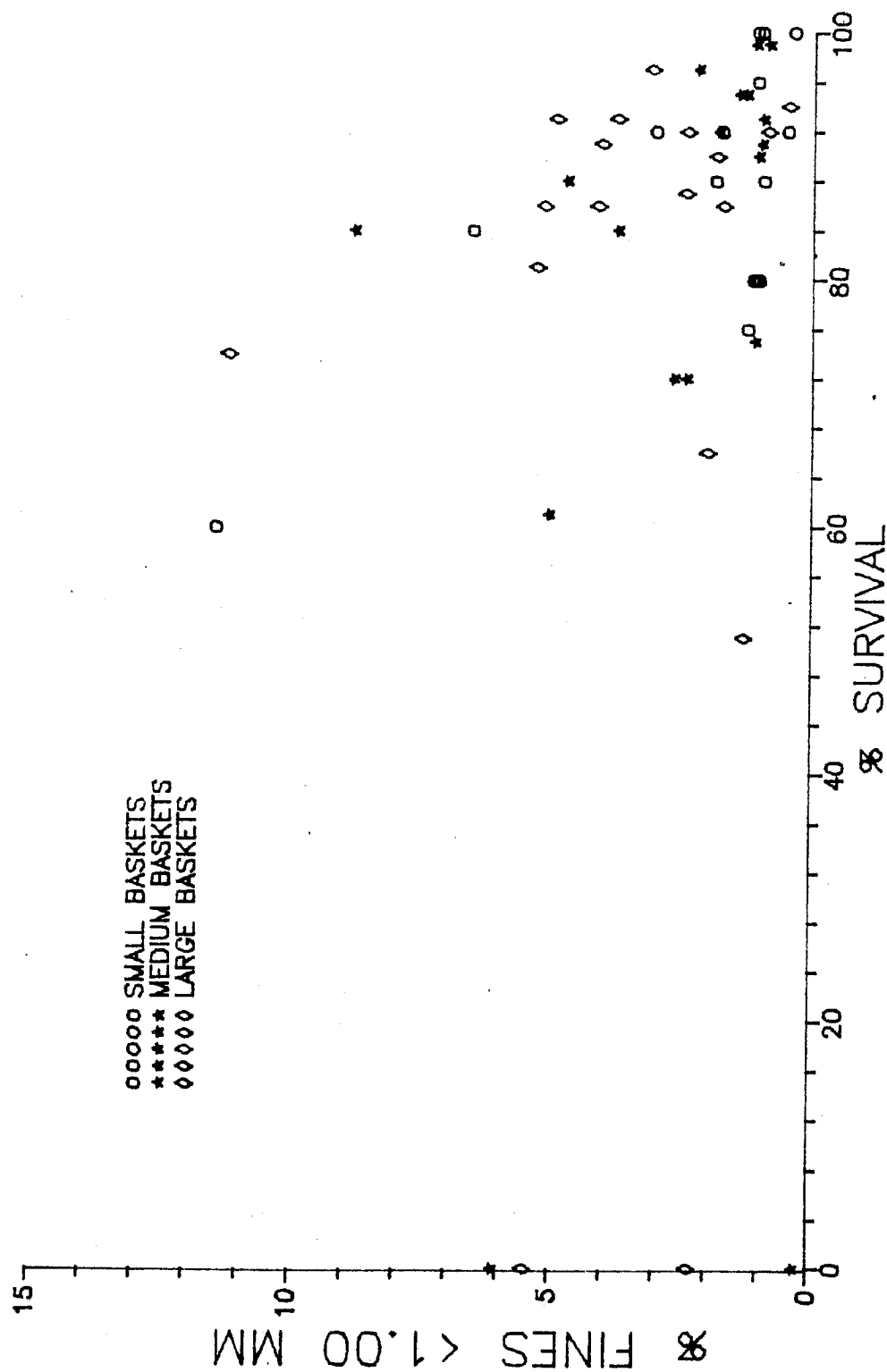


Figure 14. Correlation ($r = -0.24$) between percent fines and percent egg survival of baskets in artificial redds ($P = 0.89$).

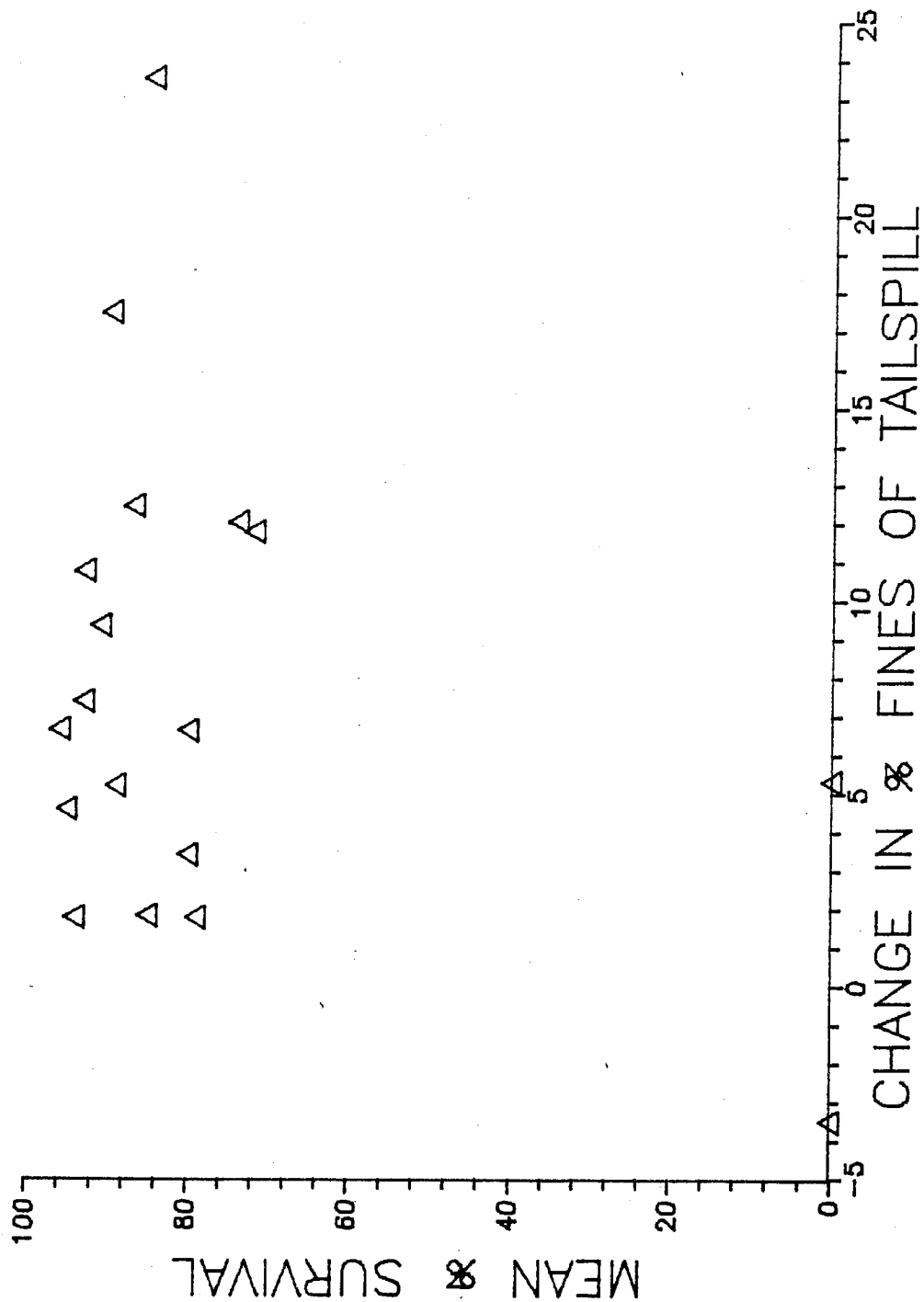


Figure 15. Relationship between percent egg survival in artificial redds on Prairie and Lost Man Creek and the change in percent fines in the tailspill during the incubation period. No significant correlation was detected.

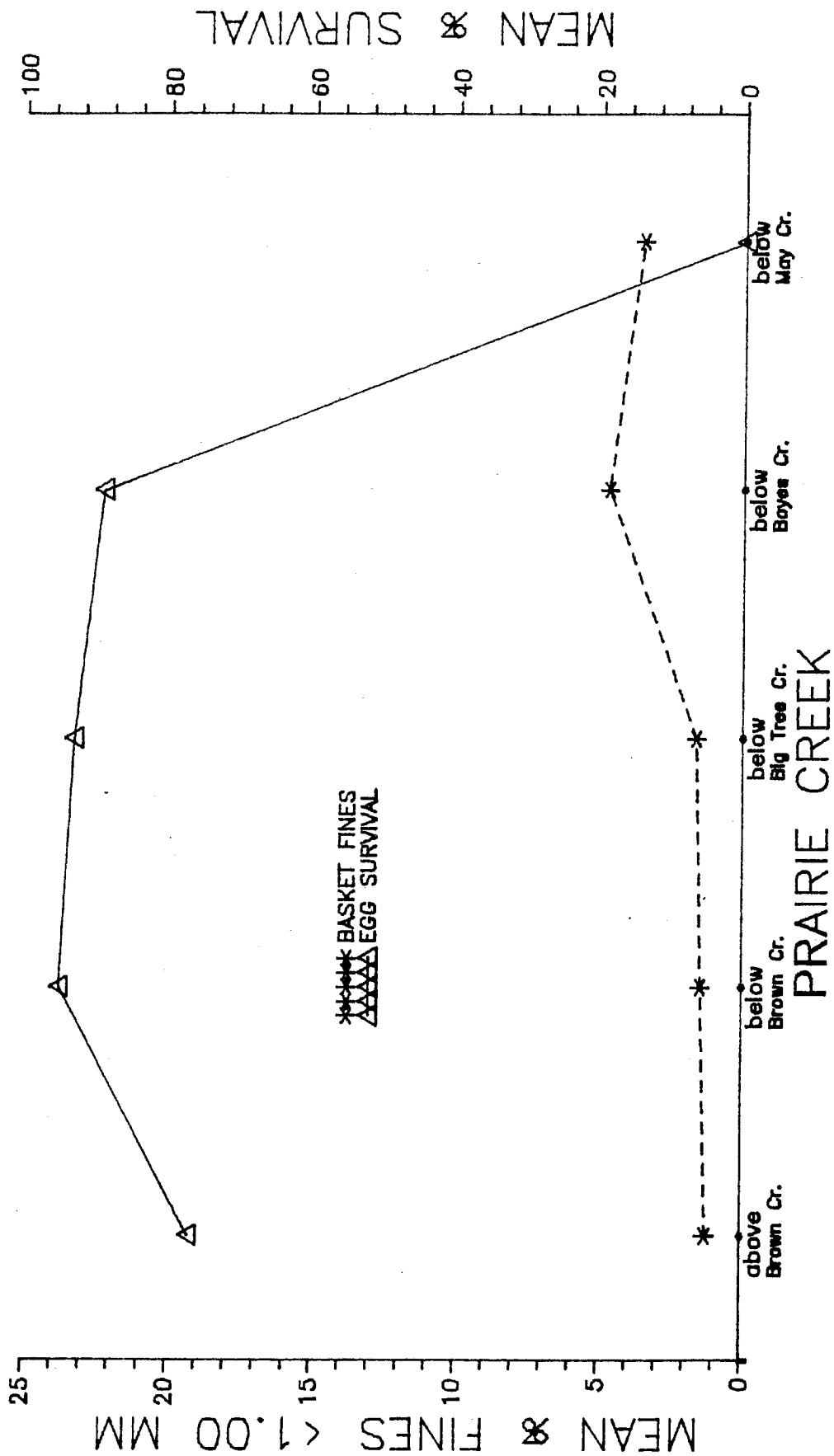


Figure 16. Downstream changes (left to right) in mean percent fines (<1.00 mm) and mean percent survival. Percent fines and percent survival were analyzed from egg baskets within artificial redds created above and below tributaries to Prairie Creek.

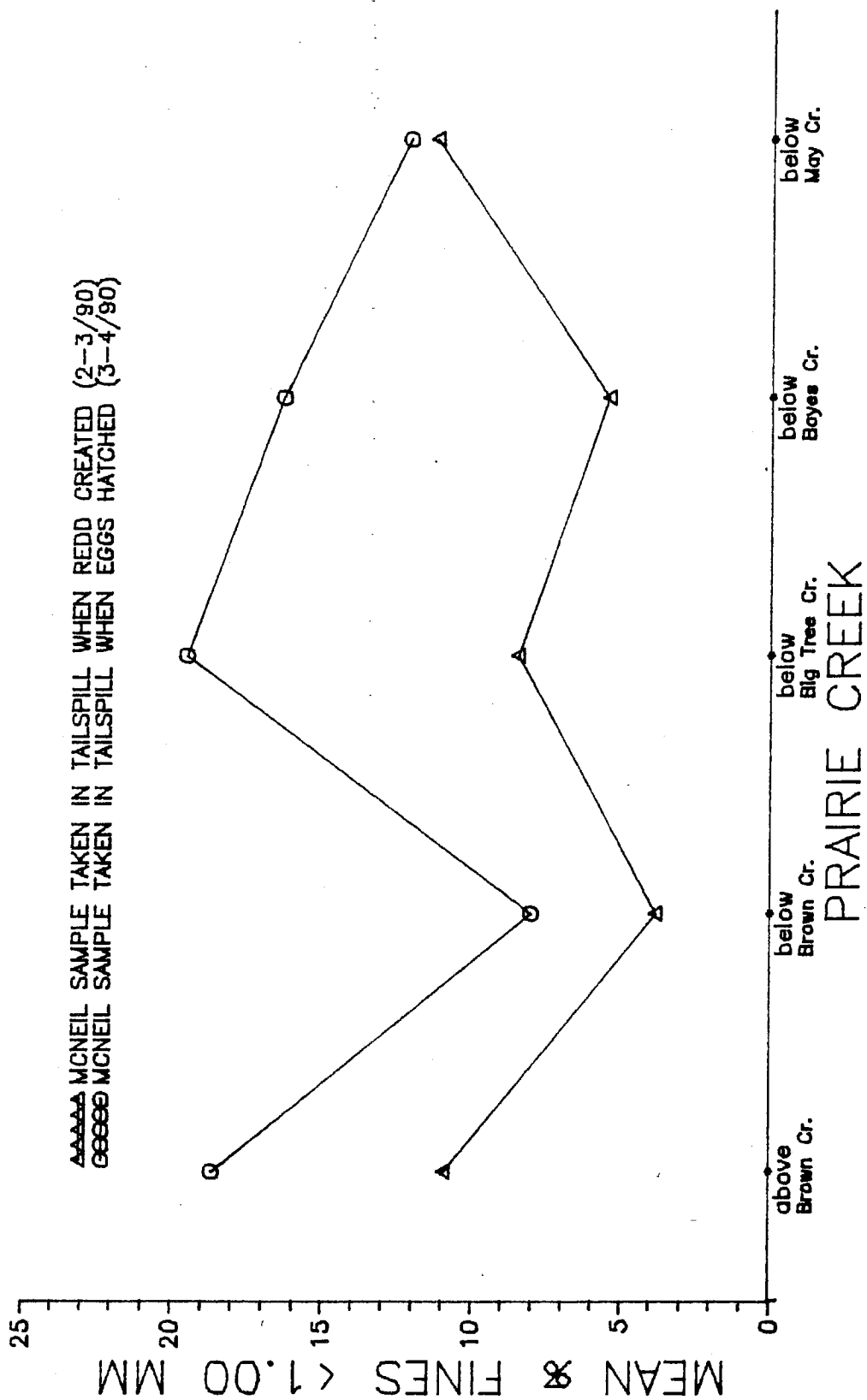


Figure 17. Downstream changes (left to right) in mean percent fines (<1.00 mm) on Prairie Creek. Percent fines analyzed from McNeil samples taken in tailspill within artificial redds created above and below tributaries to Prairie Creek.

B.4 Discussion

Egg survival to hatching was relatively high in this study for all but two redds. The complete failure of the two redds below the May Creek confluence to produce alevins was probably due to the worm masses, rather than sedimentation. Percent fine sediment in these redds was no worse than redds having survival rates up to 89%, and in the late 1940's Briggs (1953) found egg mortality positively correlated with degree of worm infestation in natural redds in Prairie Creek. The third of our infested redds had only a few worms, which could account for its better survival rate of 72%. Briggs found the worms were most abundant when steelhead were spawning. It seems that today (with 17% infestation rate) as well as 40 years ago (with 27% infestation rate), oligochaete worms are a natural and important source of steelhead egg mortality in Prairie Creek.

When worm-infested redds were excluded from his analysis, Briggs (1953) estimated egg survival to hatching in natural steelhead redds to be 85% in Prairie Creek. This is similar to our 88% survival when infested redds were excluded. Unlike our study which started with eyed eggs, Briggs' figure includes survival of eggs from green to the eyed stage. To be comparable, our figure would need to be adjusted downward for infertility and mortality incurred in early egg development. This information is not available (our 49% and 73% survival estimates derived from redds with green eggs are unreliable due to our handling procedures). Assuming our artificial redds functioned as natural redds, these study results appear to indicate steelhead trout could have successfully spawned and produced alevins during the months of February through April, 1990, in either Lost Man Creek or the impacted stream, Prairie Creek.

Egg survival was expected to generally decrease and percent fine sediment generally increase in a downstream direction on Prairie Creek as tributary sediment inputs accumulated. This relationship was weak at best, and the survival trend disappeared when redds biased by the presence of worms were removed. Furthermore, the control stream portrayed a similar relationship, indicating the downstream trend is not unique to bypass-affected streams.

These study results should be kept in context, as they apply only to steelhead eggs during a relatively dry period. Rainfall records show this period during which eggs incubated had precipitation 7.9 inches below average, or 67% of normal (gaged at Prairie Creek Fish Hatchery). Although sediment within the artificial redds increased, the amount does not appear to have been large enough to adversely affect hatching success. This is not surprising considering that sediment transport is low during low rainfall periods. During the heavier rains in December and January when the Chinook salmon were spawning, sediment accumulations in redds may have been much greater and could have adversely impacted egg survival.

In a study using methods similar to ours, Cederholm et al. (1981) found a 2% reduction in Coho salmon egg survival to emergence for each 1% increase in fine sediment < 0.85 mm over natural levels. Unlike Cederholm et al., however, we did not test whether alevins would have successfully emerged from the gravel. Thus, we can not conclude that egg survival to emergence was successful without data on whether entrapment within gravel was a problem.

Additional study is needed to address effects of sedimentation on egg survival to emergence for chinook salmon, coho salmon, and steelhead trout during a normal or high rainfall year.

Although basket size affected the amount of fine sediment accumulated, the level of accumulation was probably too low to bias survival. Future studies should use baskets of equal size to avoid potential bias. However, in this study, basket size was also correlated to position of the basket in the redd, with larger baskets located upstream of smaller baskets. The greater percent fine sediment in larger baskets may be due to the hydraulics created by the pot, depositing more fine sediment into the upstream portion of the redd. Another interpretation may be that small baskets lose more fine sediment when removed from the gravel due to their larger surface area to volume ratio.

Finally, increases in fine sediment were higher in the tailspill than in baskets. Chapman (1988) argued that the egg pocket may have greater protection from infiltration by fine sediment than overlying layers of a redd. Assuming our baskets represented egg pockets, our results corroborate his argument that fine sediment in the surface layer may form a protective seal. Although we did not collect egg pocket data for the natural redd study (see section C.3), future sampling of redds ought to include the egg pocket. Moreover, since fine sediment increased in our "egg pockets" in a downstream direction as tributary sediment inputs increased, but did not do so in the tailspills, egg pockets may be more indicative of subsurface sediment changes.

C. Infiltration of Fine Sediment into Cleaned Gravels

C.1 Study Objectives

This portion of the study was designed to quantify the amount of fine sediment infiltrating Prairie Creek and Brown Creek cleaned streambed gravels over most of the winter period and its potential impact on salmonid spawning habitat. Salmonid eggs require a free flow of oxygenated water in order to survive and remove metabolic wastes; excessive fine sediment in the redd may reduce hydraulic conductivity, thereby killing eggs (Coble 1961). Fine sediment may also form a physical barrier to emergence of fry from subsurface gravels to surface waters (Phillips 1975, Hausle and Coble 1976). The objective of the study was to directly measure the quantity of fine sediment infiltrating clean gravels over the course of the 1989-90 rainy season.

C.2 Methods

Early in the winter season waterproof bags were buried beneath columns of clean gravel in the streambed. The bags and columns of gravel above were removed at the end of the season (Fig. 17). Bags were placed at four riffle crests on Prairie Creek, at five sites on Brown Creek (three in riffles and two in pools), and at a control riffle crest on Lost Man Creek (Fig. 1). Lost Man Creek was chosen as a control because its drainage does not receive sediment from the bypass right-of-way. Two sites were located just up- and

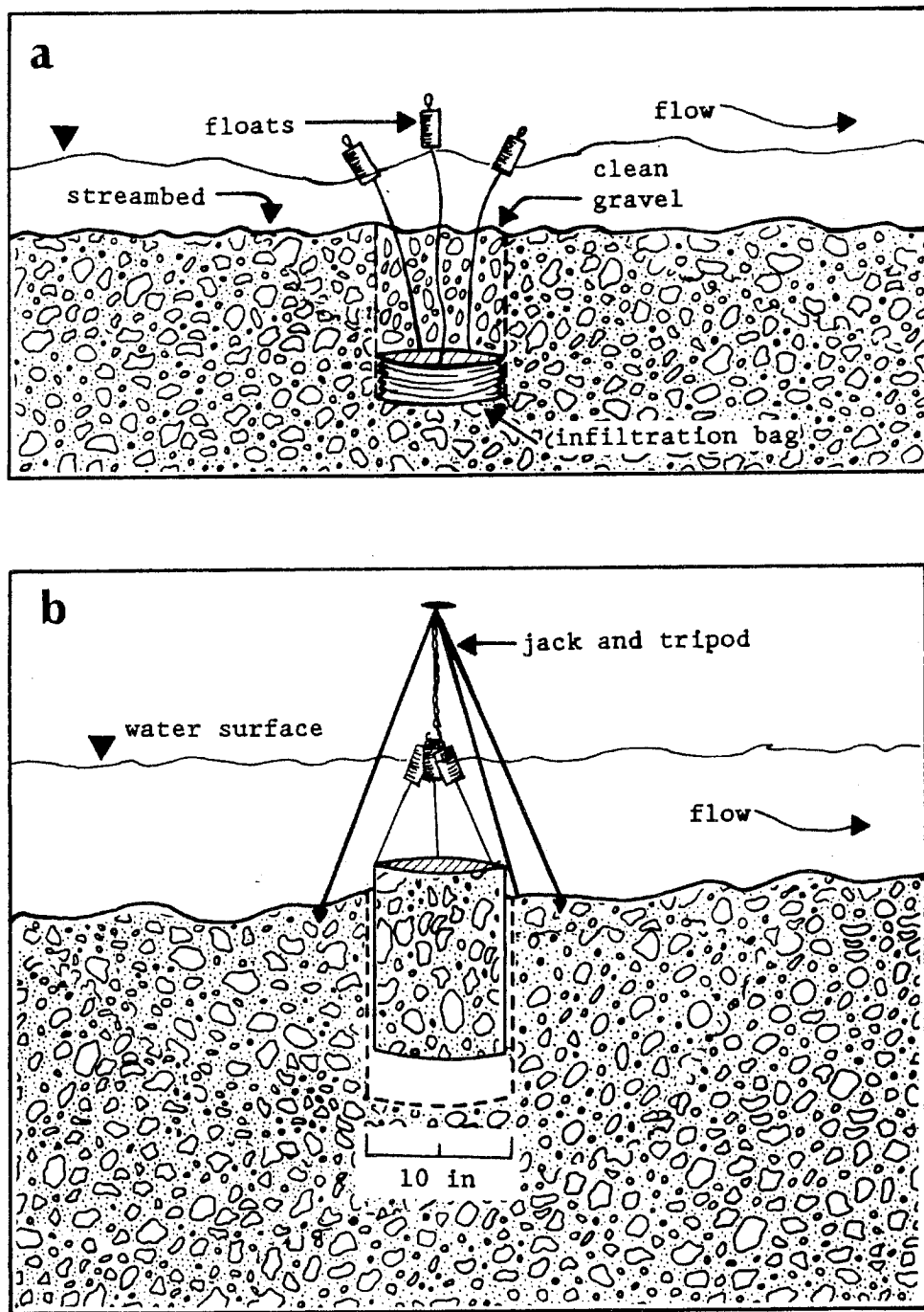


Figure 18. a) Infiltration bag installed at beginning of season.
b) Bag and gravel removed at end of storm season.

downstream of the mouths of Brown and Boyes Creeks on Prairie Creek. Additional criteria employed in choosing the Prairie Creek sites for the infiltration study were that they be straight, unobstructed reaches at heads of riffles, in areas likely to be used by salmonids for spawning.

During bag emplacement, an 18 inch (46 cm) deep hole was dug in the streambed. Gravel was removed and sieved in the field. Only the fractions greater than 5.6 mm in diameter were retained (except for Brown Creek, where only fractions greater than 2.0 mm were retained.) The bag, folded flat, accordion-style was placed in the bottom of the hole with three floats on cables attached to it, to allow later location and removal. Gravel was then replaced in the hole and contoured to the bed surface. Bags were installed in the field in December, 1990, prior to the highest seasonal discharges in January. Brown Creek bags were removed on April 14, 1990. In May and June 1990, bags were removed at all Prairie Creek sites except at PBBR. Sediment and water contained in the bags was retained and transported to the laboratory for particle size analysis.

Samples were dry-sieved to separate a number of different size fractions (< 0.5 mm, 0.5-1 mm, 1-2 mm, 2-4 mm, 4-32 mm, 32-64 mm, 64-128 mm, > 128 mm), and each fraction weighed. Brown Creek bag samples were sieved down to the < 0.063 mm class. One sample (from PBBY) was also wet-sieved and analyzed volumetrically for purposes of comparison with gravimetric data.

Weight percent of the entire sample was calculated for each size class for all samples. Student's *t* test was performed to determine the significance of any observed differences between the control site and impacted sites. Classes compared were cumulative weight percentages from the < 0.5 mm class through the < 4.0 mm class. These classes represent the net fine sediment in that class infiltrated into the sample during the study period. The sample from PBBY was also analyzed volumetrically to calculate a volume % to weight % ratio. The volume %-to-weight % ratios and apparent specific gravities calculated for the PBBY site were compared by inspection with similar ratios calculated from subsurface (freeze-core and McNeil) samples from a site near the gaging station on lower Brown Creek (see section II.G). This comparison was made in order to investigate the validity of the volume-to-weight relationship established in the Prairie Creek below Boyes Creek site.

C.3 Results

Results of particle size analyses are reported in Table 21, 22 and Appendix C. In all cases, infiltration bag samples showed a net addition of fine sediment < 4 mm in diameter over the season. Table 21 shows results of the comparison of Prairie and Lost Man Creeks. All three Prairie Creek samples received a significantly (two times greater, $P < 0.1$) greater proportion of fine sediment < 4 mm than did the Lost Man Creek (control) sample. The mean percent by weight of fine sediment < 2 mm which infiltrated into Brown Creek riffles was 3 times that in the single riffle sampled in the control stream (Lost Man Creek).

Table 21. Summary of particle size analyses by weight of Prairie Creek infiltration bag samples retrieved following the winter of 1989-1990. (Percentages expressed as percent of total sample weight; larger size fractions omitted.) All sites were at heads of riffles.

Location	Weight percent in size class (mm)			
	2 - 4	1 - 2	0.5 - 1	<0.5
Lost Man Creek (control)	0.37	0.36	0.28	1.58
Prairie Creek below Boyes Creek	1.42	0.76	0.23	2.06
Prairie Creek above Boyes Creek	0.25	0.28	0.51	2.68
Prairie Creek above Brown Creek	0.39	0.49	0.78	2.31
Means of Prairie Creek samples	0.6%	0.51	0.51	2.35

Location	Cumulative weight percent in size class (mm)			
	<4	<2	<1	<0.5
Lost Man Creek (control)	2.60	2.23	1.86	1.58
Prairie Creek below Boyes Creek	4.47	3.05	2.29	2.06
Prairie Creek above Boyes Creek	3.72	3.47	3.19	2.68
Prairie Creek above Brown Creek	3.96	3.57	3.09	2.31
Means of Prairie Creek samples	4.05	3.36	2.86	2.35

Table 22. Summary of particle size analyses by weight of Upper Brown Creek infiltration bag samples retrieved in April 1990. (Percentages expressed as percent of total sample weight; larger size fractions not listed.)

Sample	Weight percent in sieve (mm)					
	1 - 2	0.5 - 1	0.25- 0.5	0.125- 0.25	0.063- 0.125	<0.063
Riffle 1	1.59	1.23	1.02	0.90	1.33	3.97
Riffle 2	1.53	0.99	0.97	0.92	0.60	0.75
Riffle 3	2.31	0.58	0.29	0.23	0.23	0.58
Pool 1	8.68	2.35	1.26	1.13	1.36	2.75
Pool 2	2.81	2.56	1.36	0.73	0.49	0.77
Mean of riffles	1.81	0.93	0.76	0.69	0.72	1.77
Mean of pools	5.74	2.45	1.31	0.93	0.92	1.76
Mean of all	3.38	1.54	0.98	0.78	0.80	1.76

Sample	Cumulative weight percent in size class (mm)					
	<2	<1	<0.5	<0.25	<0.125	<0.063
Riffle 1	10.05	8.46	7.23	6.21	5.31	3.97
Riffle 2	5.75	4.22	3.23	2.26	1.34	0.75
Riffle 3	4.22	1.91	1.33	1.05	0.81	0.58
Pool 1	17.53	8.85	6.50	5.24	4.11	2.75
Pool 2	8.70	5.90	3.34	1.98	1.26	0.77
Mean of riffles	6.67	4.87	3.93	3.17	2.49	1.77
Mean of pools	13.12	7.37	4.92	3.61	2.68	1.76
Mean of all	9.25	5.87	4.33	3.35	2.57	1.76

Results show significant accumulation of the finest fractions analyzed. In Brown Creek, the < 0.063 mm fraction (silts and clays) represented the largest proportion of particles < 1 mm in diameter (Table 22). Prairie Creek samples had their highest proportion of fine sediment < 4 mm in the < 0.5 mm class (Table 21). Brown Creek samples had a relatively large proportion of particles in the 1-2 mm class (mean of 3.38% of the total sample). Prairie Creek samples displayed no such bulge in this size class. Brown Creek riffle samples in general accumulated more fine sediment (6.67% vs. 3.36% in the < 2 mm category) than did Prairie Creek samples. Brown Creek pool samples accumulated more total fine sediment than did riffle samples (13.12% vs. 6.67%), particularly in larger size classes.

In the Prairie Creek below Boyes Creek infiltration bag sample, volumetric analysis showed a much greater volume percentage than weight percentage for fine sediment size classes analyzed (4 mm and smaller). This difference is particularly pronounced in the finest size class analyzed (< 0.5 mm), where the volume percentage of fine sediment in this class (15.2%) is 7.38 times greater than weight percent (2.06%), resulting in an apparent specific gravity of 0.32 (Appendix C). For all particles < 4 mm in diameter, the volume percent to weight percent ratio was 4.05 and apparent S.G. was 0.59; for the sample as a whole the specific gravity was 2.38. In comparison, freeze-core and McNeil data from Brown Creek, (which were the only other subsurface data available with both gravimetric and volumetric particle size analyses), showed a similar trend but with considerably less exaggeration.

C.4 Discussion

Our results indicate that Brown Creek accumulated more fine sediment, despite the shorter monitoring period, than Prairie Creek and that Prairie Creek in turn accumulated more fine sediment than the control stream. Proportions of very fine sediments (fine sands, silts, and clays) dominated sample sets. The appearance of more coarse sands (1-2 mm) in Brown Creek, especially in pools, demonstrates local deposition of sediments and limited transport out of the tributary system. These indications are consistent with the overall conclusion that a reservoir of fine sediment remains in Brown Creek and other Prairie Creek tributaries and it will likely remain there until higher discharges occur than were experienced in 1990.

The statistical analysis of Prairie Creek infiltration bag data for fine sediment accumulation in comparison to Lost Man Creek data shows a significantly larger proportion of infiltrated fine material in Prairie Creek. Although these differences between Prairie Creek and the control stream were statistically significant, these results should be viewed with caution because only a single sample was taken in the control stream (the extent of variability of sediment accumulation over the winter period in the subsurface of Lost Man Creek cannot be assessed with present data). Also, infiltration of fine sediment into riffle crests in the main channel of Prairie Creek does not appear to have reached levels which would be considered damaging to successful spawning.

The calculated volume to weight ratios support the conclusions in section II.G that conversion factors between weight and volume are not widely applicable. This is probably due to factors which affect the water content of the material, such as particle size distribution (clays tend to retain more water than granular particles) and time in residence. The importance of this issue

is that the influence on intragravel flow of infiltrating fine sediment might be more a function of the volume of pore space they occupy than their weight.

D. Redd Gravel Permeability and Dissolved Oxygen

D.1 Study Objective

To complement various means used to quantify particle size distribution of streambed sediments, permeability of gravels in Prairie Creek was also tested. Permeability testing has been used in several studies to assess impacts to spawning gravels from fine sediments (Terhune 1957, Gangmark and Bakkala 1958, Coble 1961, Meehan and Swanston 1977, Barnard in press). One potential problem of this type of sediment input is excessive clogging of subsurface streambed gravels. This arises as fine bedload material sifts downward through interstitial pathways and as a portion of the suspended load settles out from intragravel flow of turbid water. Certainly, this process occurs to some degree in even the most undisturbed watersheds; however, increased watershed erosion may accelerate this process to damaging levels.

Increasing content of fine sediment has been shown to cause decreases in permeability of streambed gravels (Chapman 1988). As permeability diminishes, so would the rate of intragravel flow, all other factors being equal. Survival and health of aquatic organisms inhabiting the streambed (including salmonid eggs) are dependent upon an adequate supply of dissolved oxygen (DO) and hydraulic removal of waste metabolites. Numerous researchers have related DO to salmonid egg and embryo development (see Chapman 1988 for an exhaustive review of this topic). The objective of this facet of the monitoring effort was to track changes in permeability and dissolved oxygen in artificial redds through the winter runoff season (including the egg incubation and fry emergence period).

D.2 Methods

In late November, initial tests of gravel permeability in riffle crests were performed by Trinity Fisheries Consulting, a local firm specializing in fish habitat analyses. A modification of Terhune's method (1958) was employed, using a steel standpipe driven into the streambed. Three tests were performed at each of twelve uncleaned riffle crests (likely salmonid spawning sites). Test sites were located in the main channel of Prairie Creek above and below confluences of affected tributaries, in two affected tributaries, and in Lost Man Creek, which was unaffected and therefore served as a control site.

It was originally intended to repeat these tests several times between storms, during, and again following the end of the runoff season. Because of concerns regarding the reliability of tests using the driven standpipe (the process of driving the pipe into the streambed may cause disturbance of streambed sediment), a different method was adopted by December.

Several standpipes modelled after those described by Gangmark and Bakkala (1958) were acquired from the California Department of Fish and Game (CDFG) for use in this study. Others were fabricated (Fig. 18 a), using the same pattern and diameter of perforations as those from CDFG, so that there were enough to place four each (three which we fabricated and one from CDFG) at four locations in Prairie Creek. Four sets of pipes were installed in the main channel of Prairie Creek (Fig. 1): 1) above the confluence with Brown Creek (control site), 2) below the confluence with Brown Creek, 3) at a frequently used spawning riffle below the confluence with Boyes Creek, and 4) just upstream of the confluence with May Creek.

In an attempt to mimic a fish creating a redd, we dug a pit about 1.5 meters in diameter in the streambed at a riffle crest. Water flowed through the material as it was shovelled out. This process allowed much fine sediment to be washed downstream. Standpipes were then placed into the pit in an upright position with the top of the perforations at a depth of 30 cm below the surrounding streambed (the approximate depth of salmonid eggs in a typical redd in Prairie Creek). Cleansed gravel was then backfilled around the standpipes, leaving the top of pipes nearly flush with the streambed (except for CDFG pipes, which were taller).

Permeability testing procedures followed those of Terhune (1958), whereby the rate of water inflow was measured in the standpipe following development of a one inch head (water level in the pipe was lowered to one 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 one inch below the free water surface. The tubing was attached to a vacuum pump via a graduated catchment chamber (Fig. 18 b). Following development of a one inch head (as indicated by air bubbles entrained in the water being suctioned into the chamber), the volume of inflow into the chamber was measured over a measured length of time. This yielded rates of water inflow, which are directly correlated with permeability and will be converted to values of permeability upon calibration of pipes at a later date.

Initial permeabilities in cleaned gravels were measured following standpipe installation in mid-January. A second series of tests was performed in late February, and a third in early May. Final tests were performed in July, representing ending permeabilities for the 1990 water year. Timing of tests was designed to bracket significant storms of the runoff season. Unfortunately, no tests were conducted prior to the January 8 storm, which was the largest of the season.

Dissolved oxygen was measured several times during the winter between storm periods. A DO meter probe was lowered into permeability standpipes to obtain the oxygen concentration of intragravel water in the streambed. DO was also measured in surface water adjacent to the standpipes for comparison.

D.3 Results

Results from the Trinity Fisheries Consulting permeability tests are shown in Appendix D. Their pipes were calibrated in a flume to get permeability rates

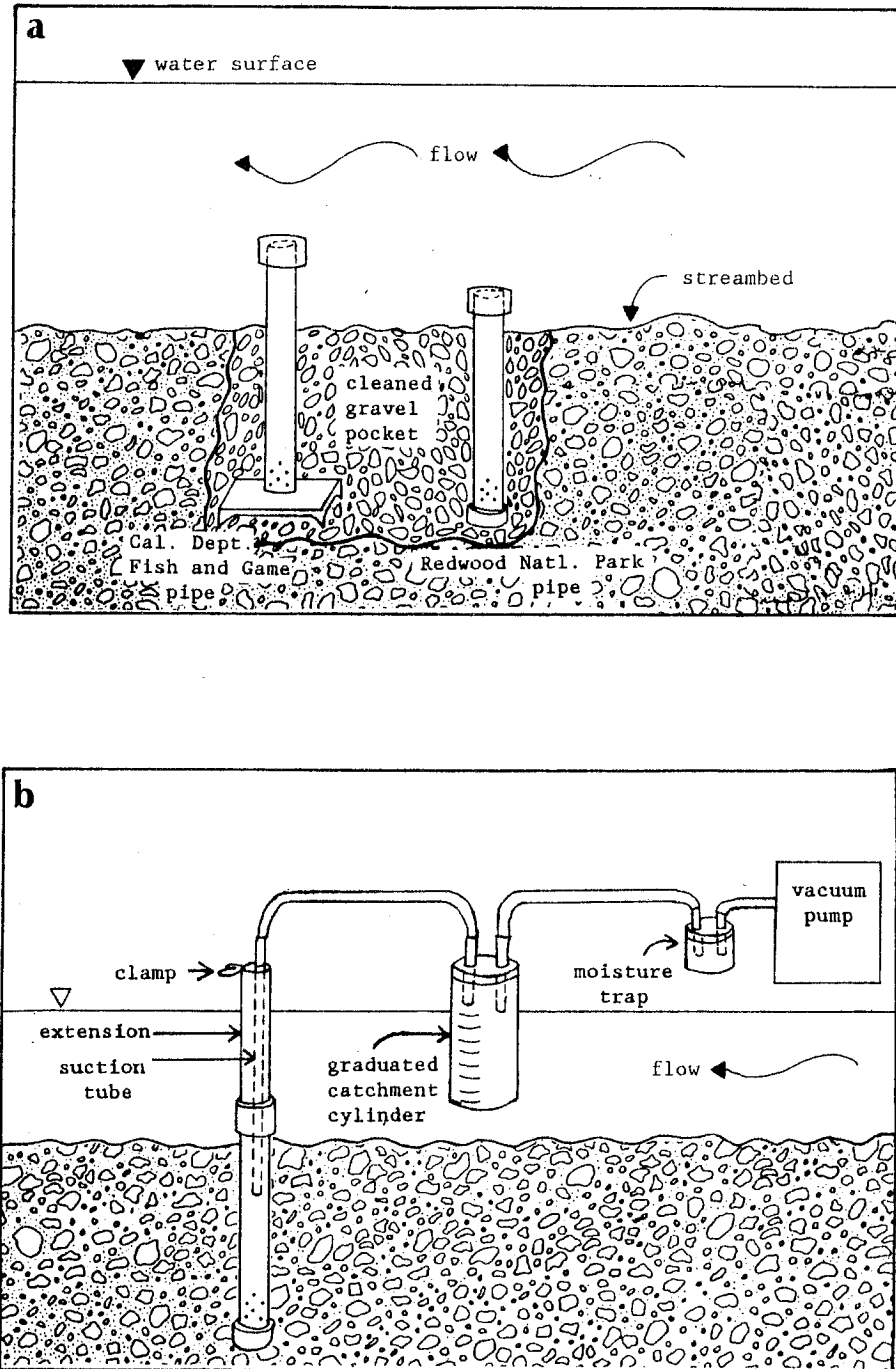


Figure 19. Permeability pipes:
 a) Installed in streambed.
 b) Additional pipe and equipment attached during actual testing.

in cm/hr. Because both hole patterns in pipes and the standpipe installation were different from later tests by Redwood National Park, the two sets of data should not be compared to each other.

Percent changes in inflow rate for each of the Redwood National Park in-place pipes, along with mean percent changes at each site are shown in Table 23 (Figure 21). Results show marked decreases in standpipe inflow rates (and thus permeabilities) for all but three of the sixteen pipes. Net decreases in inflow rates were as high as 51 percent (just below Brown Creek) with most of the others falling in range of 25-40% decrease in inflow rate. Three of the standpipes actually experienced slight increases in inflow rates during the winter.

Table 23. Inflow rates¹ for Prairie Creek permeability pipes for the 1989 water year at sites near the tributaries listed.

Site	Pipe ²	Inflow Rates on Testing Dates (cm ³ /sec)				Net Change (%)
		01/18/90	02/22/90	05/01/90	07/31/90	
Above Brown Ck	A	88.27	98.98	100.09	61.30	-30
	B	117.43	95.15	107.19	101.50	-14
	C	115.48	107.17	97.97	105.90	-8
	D	112.32	82.56	81.84	80.60	-28
					mean =	-20
Below Brown Ck	A	67.07	51.62	33.88	33.00	-51
	B	74.02	58.55	52.46	44.44	-40
	C	52.41	39.63	37.06	30.30	-42
	D	32.86	25.11	31.71	33.70	+3
					mean =	-33
Below Boyes Ck	A	49.94	45.20	35.95	27.90	-44
	B	59.40	47.93	46.53	44.30	-25
	C	32.58	34.04	34.07	33.20	+2
	D ³	---	---	---	---	--
					mean =	-22
Above May Ck	A	53.43	47.44	48.98	60.00	+12
	B	73.31	64.53	49.75	58.40	-28
	C	70.37	60.59	53.58	47.30	-33
	D	70.06	69.12	59.29	51.20	-27
					mean =	-19

¹ data shown are averages of 4-5 runs for each test.

² A is upstream pipe, B is right pipe, C is left pipe, and D is downstream pipe.

³ pipe damaged prior to any testing - no data.

PERMEABILITY

PRAIRIE CREEK

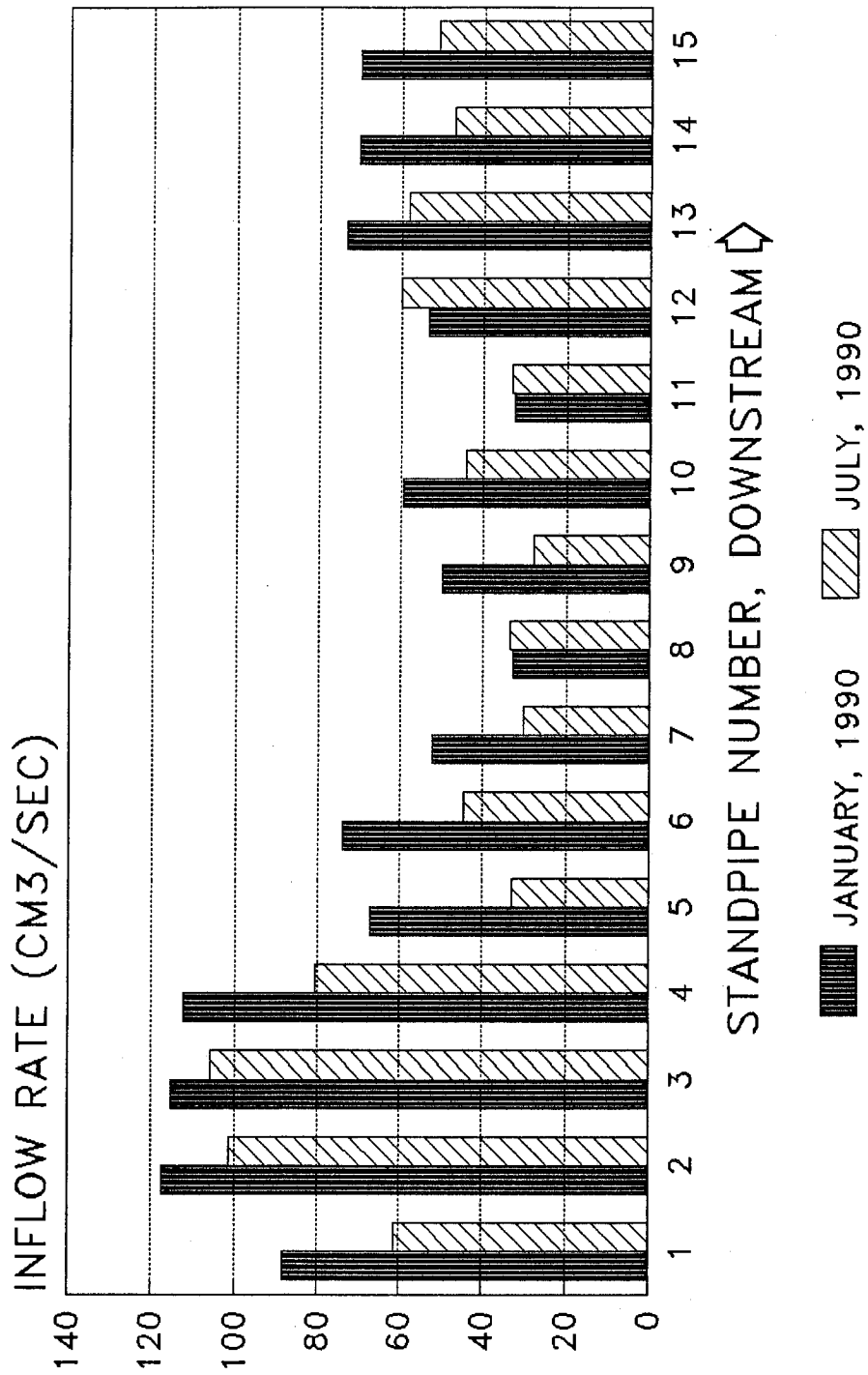


Figure 20. Comparison of inflow rates for Prairie Creek standpipes in January and July, 1990.

As shown in Table 24 (Figure 21), differences in DO concentrations between intragravel water and surface water were not large in either February, May or July. The largest differences during the egg incubation period (February), averaged 2.0 ppm for four pipes below the mouth of Brown Creek. This difference is more than twice that found at other sites.

Table 24. Dissolved oxygen (DO) concentrations at permeability test sites in Prairie Creek near tributaries listed during 1990.

Site	Pipe	DO Concentrations on Testing Dates (ppm)			Percent Change Feb-July
		02/22/90 IGW / SW ¹	05/01/90 IGW / SW	07/31/90 IGW / SW	
Above Brown Ck	A	9.5/11.0	9.9/12.1	8.0/8.6	-15.8%
	B	10.4/11.0	10.2/12.1	8.7/8.7	-16.0%
	C	11.0/11.1	9.0/12.1	8.7/8.7	-20.9%
	D	10.8/11.1	11.7/12.1	7.7/8.7	-28.7%
Mean Difference between IGW and SW:		0.6 ppm	1.9 ppm	0.4 ppm	
Below Brown Ck	A	7.8/10.8	9.8/12.4	8.9/9.8	+14.1%
	B	9.3/10.8	9.7/12.4	8.8/9.6	-5.4%
	C	8.7/10.8	11.0/12.4	9.4/9.8	+8.0%
	D	9.6/10.8	9.6/12.4	9.1/9.7	-5.2%
Mean Difference between IGW and SW:		2.0 ppm	2.4 ppm	0.7 ppm	
Below Boyes Ck	A	11.2/11.3	8.1/12.1	9.1/9.8	-18.8%
	B	10.4/11.3	8.3/12.0	9.1/9.9	-12.5%
	C	10.5/11.3	8.1/ --	8.9/9.9	-15.2%
	D ²	----	----	----	----
Mean Difference between IGW and SW:		0.6 ppm	4.3 ppm	0.8 ppm	
Above May Ck	A	10.2/10.9	9.4/12.0	8.9/9.2	-12.7%
	B	10.6/10.9	8.1/12.0	8.5/9.1	-19.8%
	C	10.4/10.9	8.0/12.0	8.6/9.1	-17.3%
	D	10.7/10.9	7.5/12.0	8.6/9.1	-19.6%
Mean Difference between IGW and SW:		0.4 ppm	3.8 ppm	0.5 ppm	

¹ IGW = intragravel water; SW = surface water.

² pipe damaged prior to any testing - thus no data available.

DISSOLVED OXYGEN PRAIRIE CREEK

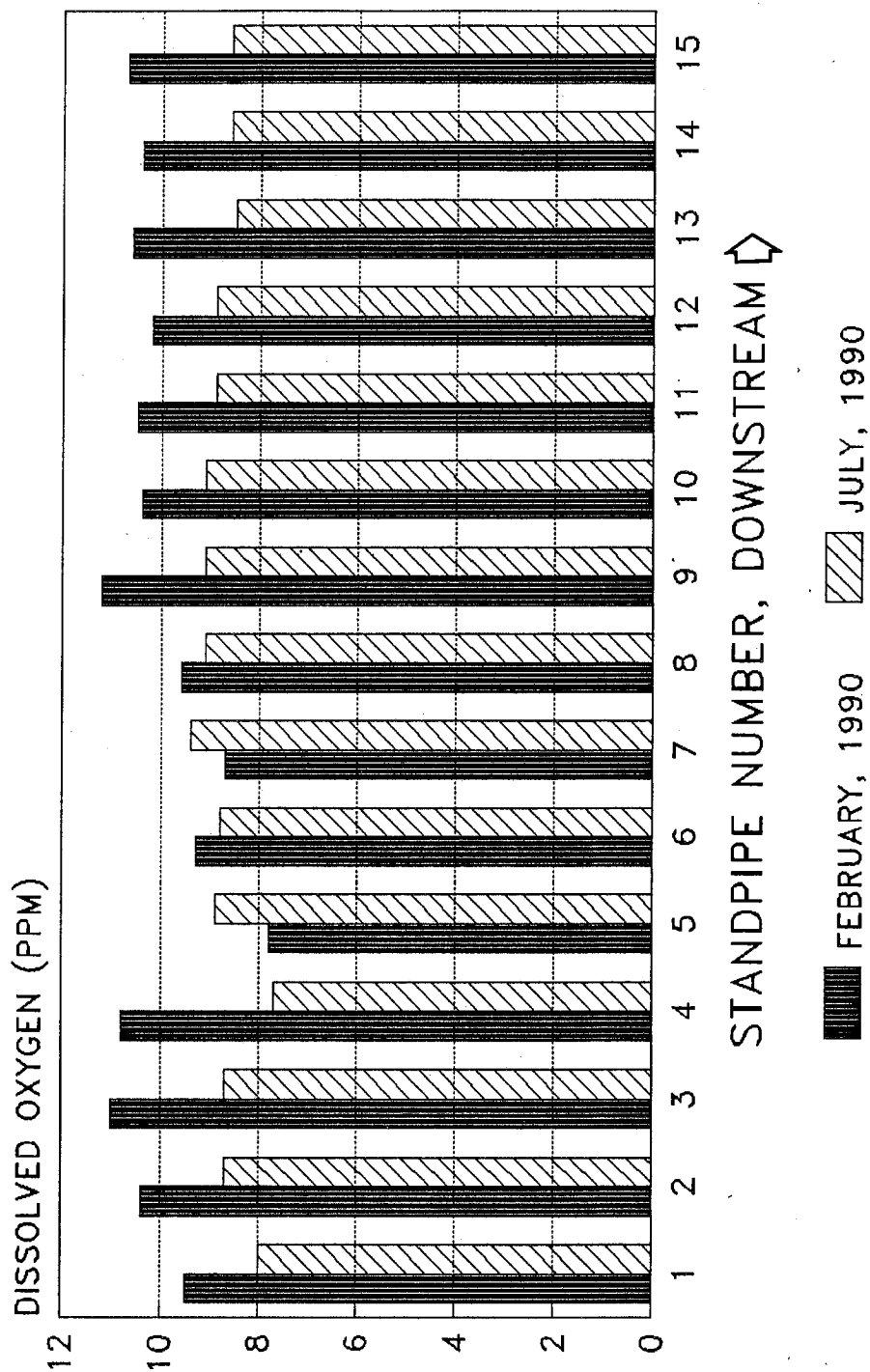


Figure 21. Comparison of dissolved oxygen in Prairie Creek standpipes in February and July, 1990.

D.4 Discussion

Several difficulties exist in interpreting the results of permeability tests. First, there is some uncertainty as to whether the control site (above Brown Creek) was truly unaffected by sedimentation from highway bypass construction. Although erosion from the bypass did enter Ten Tapo Creek during the October storm, it is unknown whether effects from this event were significant at the control site, which is about three miles downstream from the mouth of Ten Tapo Creek.

Second, decreases in permeability were probably affected by the initial permeability of the cleansed gravel. In locations where initial permeabilities are relatively low, infiltration of fine sediment into the streambed is likely to be impeded because the rate of movement of sediment laden water through the gravels is lower. This factor may explain the results for Pipe D at the site below Brown Creek and for Pipe C at the site below Boyes Creek. These two pipes had the lowest initial inflow rates (about 33 cm/sec), which were measured two to four weeks after installation, and exhibited the smallest change in inflow rates of all (+3% and +2%, respectively). These changes in inflow rate are not considered significant because they are within the range of measurement error of the pump testing equipment.

As shown in Table 23, the greatest percent decreases in inflow rates for individual standpipes occurred downstream of Brown Creek. Further, there is a distinct trend of smaller decreases in inflow rates with increasing downstream distance from the mouth of Brown Creek, both in terms of the maximum decrease for an individual pipe within a site and for the mean inflow rate for all pipes at a site. This trend is interpreted to reflect the relatively large contributions of fine sediment from Brown Creek to the main channel of Prairie Creek, which are attenuated with increasing downstream distance.

The anomalous results for Pipe D at the site below Brown Creek and Pipe C at the site below Boyes Creek may warrant a cautious examination of results with these data removed. Recalculation of mean inflow rate decreases without these two pipes in the data set yields the following:

<u>Site</u>	<u>Mean inflow rate decrease (percent)</u>
Above Brown Ck	-20
Below Brown Ck	-44
Below Boyes Ck	-35
Above May Ck	-19

Viewing the data in this way indicates larger decreases in inflow rates for sites below Brown and Boyes Creeks (and thus, greater impacts to Prairie Creek) and a stronger trend of attenuation of effects downstream of Brown Creek.

It should be mentioned that several other tributaries enter Prairie Creek within the reach encompassed by permeability test sites. Big Tree Creek and Boyes Creek, both affected by erosion from the bypass, contribute sediment to Prairie Creek upstream of the lower two sites. Godwood Creek, which enters Prairie Creek between the two lowest sites and is unaffected by the bypass,

probably dilutes suspended sediment concentrations to some degree above May Creek. The spatial distribution of these probable effects of tributary contributions is consistent with permeability test results (the site below the mouth of Boyes Creek exhibited greater decreases in permeability rates than would be expected from Brown Creek inputs alone, and the site above May Creek exhibited lower decreases in permeability, both because of its great distance downstream of both Brown and Boyes Creeks and because of probable sediment dilution by Godwood Creek water).

Although test results indicate marked decreases in inflow rates of standpipes placed in streambed gravels of Prairie Creek, especially below Brown and Boyes Creeks, comparison with results from other studies of redd permeability cannot be done until these results are converted to values of permeability (following standpipe calibration). Several studies have shown a positive correlation between decreases in permeability of streambed gravels and salmonid egg mortality; however, no "threshold" values of critical permeability levels have been established.

Dissolved oxygen concentrations at all the sites sampled were above those reported in the literature to result in widespread salmonid egg mortality (approximately ≤ 2 ppm) (Chapman, 1988). However, even small decreases in dissolved oxygen concentration may result in both increases in percent mortality as well as restricted embryo growth, which may diminish survivability after fry emergence. Dissolved oxygen concentrations found in intragravel water in this study were lower than those reported in several studies to cause increased percent mortality and restricted embryo growth. Further study relating DO to egg survival is needed to assess if these levels of DO are detrimental.

While permeability and DO concentration have been widely used as indicators to quantify the effects of fine sediment in salmonid redds (Chapman 1988), neither of these variables can stand alone to assess impacts of fine sediment on salmonid redds. If intragravel water is moving relatively fast (as it would if permeability is high) but is low in dissolved oxygen concentration, conditions for salmonid egg and fry survival would be poor. Conversely, if intragravel water is moving relatively slow, conditions may still be poor even if DO concentration is high (Shumway et al. 1964). It is the rate of dissolved oxygen transport to the egg pocket within the redd that is of critical importance, a variable which is a function of both the rate of water movement and the DO concentration. For this reason, future monitoring should focus on measurements of both apparent velocity and DO. These values can be combined to give DO transport rate of the intragravel water, which is likely to be better correlated with survival than either permeability or DO individually.

E. Fine Sediment in Natural Redds

E.1 Study Objective

When salmonids construct redds, they clean the gravel so the redds often contain less than 9% fine sediment (< 1 mm) by weight (Everest et al. 1987). However, the fine sediment in storage in Prairie Creek after the October storm could have slowly infiltrated back into newly constructed redds and adversely affected incubating eggs. The objective of this portion of the study was to determine the degree of infiltration of fine sediment into natural redds, specifically, the change in percent fine sediment within natural redds in Prairie Creek over the winter period, 1989-1990.

E.2 Methods

Four natural salmon redds in Prairie Creek and one in Lost Man Creek (a control site unaffected by the bypass) were selected for gravel sampling (Fig. 1). We chose the redd located below the Big Tree Creek confluence for repeated sampling following rainstorms throughout the winter. Other redds were sampled once early in the winter and again in the spring. During each sampling period, we cored three gravel samples within each redd using a McNeil sampler. Samples were wet-sieved and volumetrically analyzed for the same size classes listed under methods for the egg survival study (section III.B). Statistical procedures followed those outlined under the egg survival study, with significance tested at $P < 0.05$.

E.3 Results

Over the winter period, mean percent volume of fine sediment < 1.0 mm within natural redds in Prairie Creek increased to 20.3% (Table 25). Percent fine sediment at end of the winter in the Lost Man Creek redd, 18.8%, did not differ significantly from this. Percent of redd fine sediment was positively associated with downstream direction on Prairie Creek in the early winter and spring (Spearman Correlation Coefficient = 0.7 in both cases, $P < 0.05$). Above Brown Creek confluence, where bypass effects were less, fine sediment that had accumulated in the Prairie Creek redd averaged 10.5%. Downstream of this point, redd fine sediment was significantly higher, averaging 23.6%.

Mean fine sediment in the most intensively sampled redd, the one below Big Tree Creek confluence, was 12.7% in December, a level significantly lower than mean fines sampled adjacent to the redd at 30.8%. Intermittent sampling of this redd between December and May demonstrated percentages fluctuated to a maximum of 27.8%. Eggs in this redd likely experienced fine sediment as high as 27.8% before hatching. A comparison of the Prairie Creek hydrograph (Fig. 4) to the timing of these sediment fluctuations reveals that percent fine sediment significantly increased by 17.5% to 28.0% following the largest storm of the winter on January 7th and 8th.

Table 25. Mean percent volume of < 1.0 mm fine sediment found in McNeil gravel samples obtained from natural redds (n=3 each) in Prairie and Lost Man Creeks, northern California, winter 1989-1990.

Stream Reach	Date Sampled	Mean Percent Fines	Difference
<u>Prairie Creek:</u>			
Above Brown Creek	2-18-90	4.6	
	5-25-90	10.5	+ 6.9
Below Brown Creek	2-11-90	5.6	
	5-25-90	14.5	+ 8.9*
Below Big Tree Creek	12-07-89	12.7	
	1-04-90	10.1	- 2.6
	1-18-90	27.8	+17.7*
	2-07-90	20.0	- 7.8**
	5-08-90	31.3	+11.3*
Below Boyes Creek	2-20-90	19.4	
	6-04-90	25.0	+ 5.6
Mean	02-90	12.4	
	5/90 & 6-90	20.3	+ 7.9*
<u>Lost Man Creek:</u>			
Below Picnic Area	2-06-90	11.6	
	6-05-90	18.8	+ 7.2

* Difference over time is significant at $P < 0.05$

** Difference over time is significant at $P < 0.10$

From February to June, mean percent fines in Prairie Creek redds increased an average of 7.9% (significant when all redds were combined), ranging from 5.6 to 11.3%. Fine sediment increased 7.2% in the Lost Man Creek redd during this same period, although this was not statistically significant. Mean increases for reaches on Prairie Creek are shown in Figure 19.

E.4 Discussion

Redds constructed farthest upstream on Prairie Creek contained less fine sediment. Upstream reaches were the least affected by the bypass. As expected, this suggests sediment derived from the bypass caused the increase of fine sediment within the downstream redds.

% FINES <1.00MM

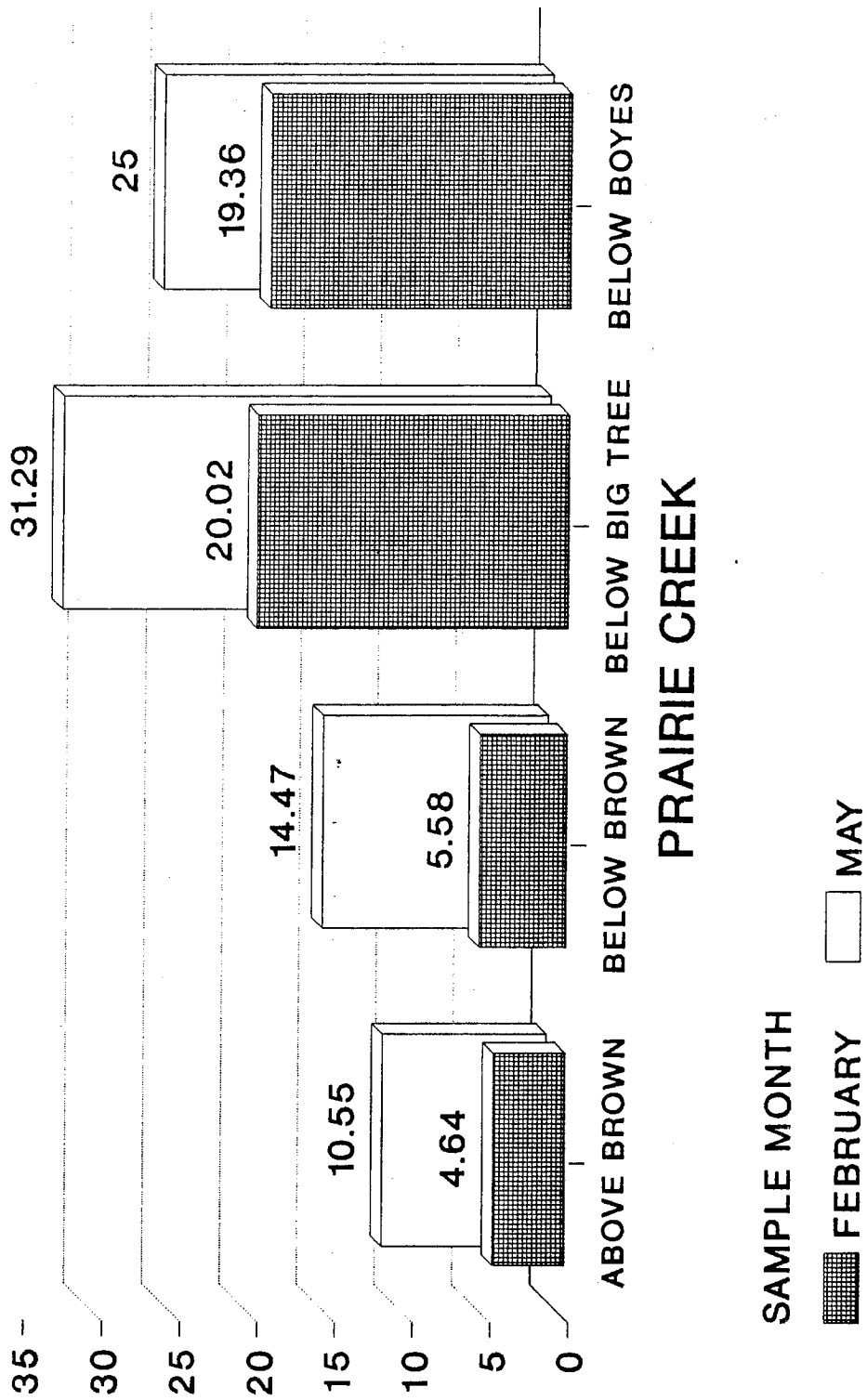


Figure 22. Percent fines (<1.00 mm) in natural redds in February and May, 1990, on Prairie Creek. Downstream direction is from left to right.

Both Tagart (1976) and Cederholm et al. (1981) reported a 14% drop (down to 18 and 3%, respectively) in Coho salmon egg survival to emergence when fine sediment within natural redds exceeded 20%. Other studies indicate increases of fine sediment in redds by 5 to 10% or more is deleterious to egg survival (Hall and Lantz 1969 and McCuddin 1977, Burton et al. 1990). Unfortunately the diameter of the fine sediment and the methods used vary from study to study, and whether the value was determined as a percentage by weight or volume is not always clear. As shown by our freeze-core vs. McNeil comparison study, percentages can differ based on the technique and particle diameter used. Therefore, it is difficult to directly compare our percent fine sediment to other studies to determine potential effects on egg survival to emergence.

An egg survival study, similar to the one reported in the section III.B, could provide information on the effect of these levels of fine sediment on egg survival to emergence. Unfortunately, the egg survival study conducted in the winter of 1990 was begun after the major storm activity of the season had passed. Additional study under more typical (higher) winter storm conditions is required to more accurately estimate how egg survival rates would be affected by increased fine sediment loads in a normal winter.

The large difference in fine sediment between the redd below Big Tree Creek confluence and adjacent gravels verifies how effective fish are at cleaning the gravels in the redd and reveals a large fine sediment source available for reinfiltration into the redd. Had there been greater sediment transport during the winter season, even larger amounts of sediment may have infiltrated into the redds.

The fluctuation in percent fine sediment over the winter period in the repeatedly sampled redd may show that sediment moves in and out of the streambed during the winter. The largest storm of the winter appeared to be responsible for depositing the largest amounts of fine sediment in the redd. Thus, fine sediment can attain high levels in Prairie Creek redds during the winter season. Such increases would be masked if only one or two gravel samples are taken during the season. Repeated sampling during the egg incubation and alevin stages is required to gain a true picture of the conditions to which the eggs/alevins are subjected (although the effects of repeated disturbance causing artificial cleaning should be considered). Thus, percent fine estimates based on our limited sampling should be considered conservative.

Although Lost Man Creek has been used as a control stream, its sedimentation levels are high, perhaps due to past logging disturbances. In future studies, Lost Man Creek should not be used as a control since it does not represent the more pristine condition of pre-bypass Prairie Creek and its bedrock geology is different. Although somewhat impacted by Ten Tapo Creek's bypass-derived sediments, the section above Brown Creek might serve as a superior control.

F. Benthic Macroinvertebrate Surveys

F.1 Study Objective

Extensive sedimentation in a stream can adversely affect the benthic macroinvertebrate community (Williams and Mundie 1978). Sediment can affect habitat suitability and/or food availability for invertebrates. Many vertebrate species, particularly salmonids, depend on invertebrates as a food source. The objectives of this study were to determine (1) whether sedimentation affected the overall abundance of benthic macroinvertebrates, and (2) would the supply of invertebrates be desirable as a food source for salmonids be sufficient to support salmonids, particularly the thousands of juvenile salmonids released into the system from the hatch box program in the spring and summer, 1990.

F.2 Methods

Using a Surber sampler (area = 1 sq ft, mesh size = 0.32 mm), three samples of benthic macroinvertebrates were collected at each of nine sites, seven along Prairie Creek and two on Prairie Creek tributaries: Prairie Creek above and below Ten Tapo Creek (PATT, PBTT), Prairie Creek above and below Brown Creek (PABR, PBBR), Prairie Creek above and below Boyes Creek (PABY, PBBY), Prairie Creek above May Creek (PAM), Lower Brown Creek (LOBR) and Lower Boyes Creek (LOBY) (Fig. 1).

PABR was selected as the control stream. Although PATT was unaffected by the bypass due to its location far upstream in the watershed, streamflow at the site was low and unrepresentative of affected stream sites. Canopy cover, substrate, particle size and streamflow of that reach also differed considerably from sites further downstream. PATT is best used as an indicator of future basinwide changes unrelated to the bypass. Both PBTT and PABR were potential control sites because they were only slightly affected by bypass inputs from Ten Tapo Creek. PABR was selected because its larger discharge was comparable to the more impacted downstream sites.

Three samples were collected at most of the sites immediately following the October storm event (November 8, 14) and again the following spring (April 26, May 5). No samples were collected for PBBR during fall 1989, and only one sample was collected for PAM during fall 1989. Samples were collected from riffles and stored in jars containing 70% ethyl alcohol. Macroinvertebrates were separated from organic debris in the laboratory under a Nikon dissecting microscope, identified to taxonomic order and enumerated. Numbers of individuals, number of orders and order diversity indices (Wilhm and Doris 1968) were calculated for each sample.

Data collected in 1985 and 1987 for four Prairie Creek sites (Redwood National Park, unpublished data) were compared to the 1990 data to determine effects of the October storm. Unfortunately, the seasons did not overlap perfectly, so the comparison is rough. Spring 1990 samples were collected during the last week of April and the first week of May. Samples from 1985 and 1987 were collected during the first week of June and July. Differences in the number of individuals, number of orders, order diversity, and relative abundance of

orders between streams (control stream vs. affected streams) and years (same seasons were compared) were statistically tested for significance using two-way analysis of variance (ANOVA). One-way ANOVA was used to compare the same variables for (1) post-October storm means between the control and the affected streams, (2) means between post-storm fall 1989 and spring 1990 and (3) means between pre-storm fall and spring 1985 and post-storm fall 1989 and spring 1990. Differences were considered to be statistically significant when $P < 0.10$.

F.3 Results

Mean number of individual macroinvertebrates in spring 1990 increased for all sampling sites when compared to the previous fall. Increases at PATT, PBTT, PBBY, PAM, LOBR and LOBY were statistically significant ($P < 0.10$) (Fig. 23). Mean number of orders also increased at all sites in spring 1990; PATT, PBTT, PAM and LOBY were statistically significant ($P < 0.10$) (Fig. 24). Order diversity values increased in spring 1990 for all sites except PABR. Increases at PATT, PBTT, PABY, PAM and LOBR were statistically significant ($P < 0.10$) (Fig. 25).

In almost all cases during fall 1989, mean number of individuals, orders and order diversity were greatest in the control site; however, the difference in number of individuals at this site was only significant when compared to the impacted tributaries and to sites relatively unimpacted above and below Ten Tapo Creek. The difference in diversity was only significant when compared to the sites above and below Boyes Creek. No differences between mean number of orders were significant (Table 26). In general, streams having low flow, such as PATT, PBTT and the tributaries LOBR and LOBY, had fewer individuals immediately after the storm than the higher flow streams. All of these trends and differences were not apparent in spring (Table 26).

When comparing seasons from 1985 to 1990 at four Prairie Creek sites (Figs. 26, 27, 28), mean number of individuals, orders and diversity indices were all highest in fall 1987. Post-October storm results in fall 1989 and spring 1990 were not significantly lower than fall and spring 1985, respectively, when bypass construction was in the initial phases. In both fall 1985 and fall 1989, diversity was higher at the control stream than many of the affected sites. Diversity in fall 1985 was significantly greater at the control site than PBBY and PAM ($P < 0.05$). Thus, lower diversity at the affected sites is not necessarily due to the October 1989 storm.

Two-way ANOVA tests indicated some significant interactions between site (control vs. affected) and year. In fall following the October storm, in comparison with the control site, the number of individuals at PABY and PBBY significantly declined from 1985 fall levels. However, by spring 1990, invertebrate levels had risen at these sites, and levels were similar between most of the affected and unaffected stream sites. Other significant interactions at PABY and PAM showed invertebrate diversity increasing more in the affected sites, suggesting no adverse affect on diversity due to the storm. No other two-way ANOVA tests showed significant interactions in the

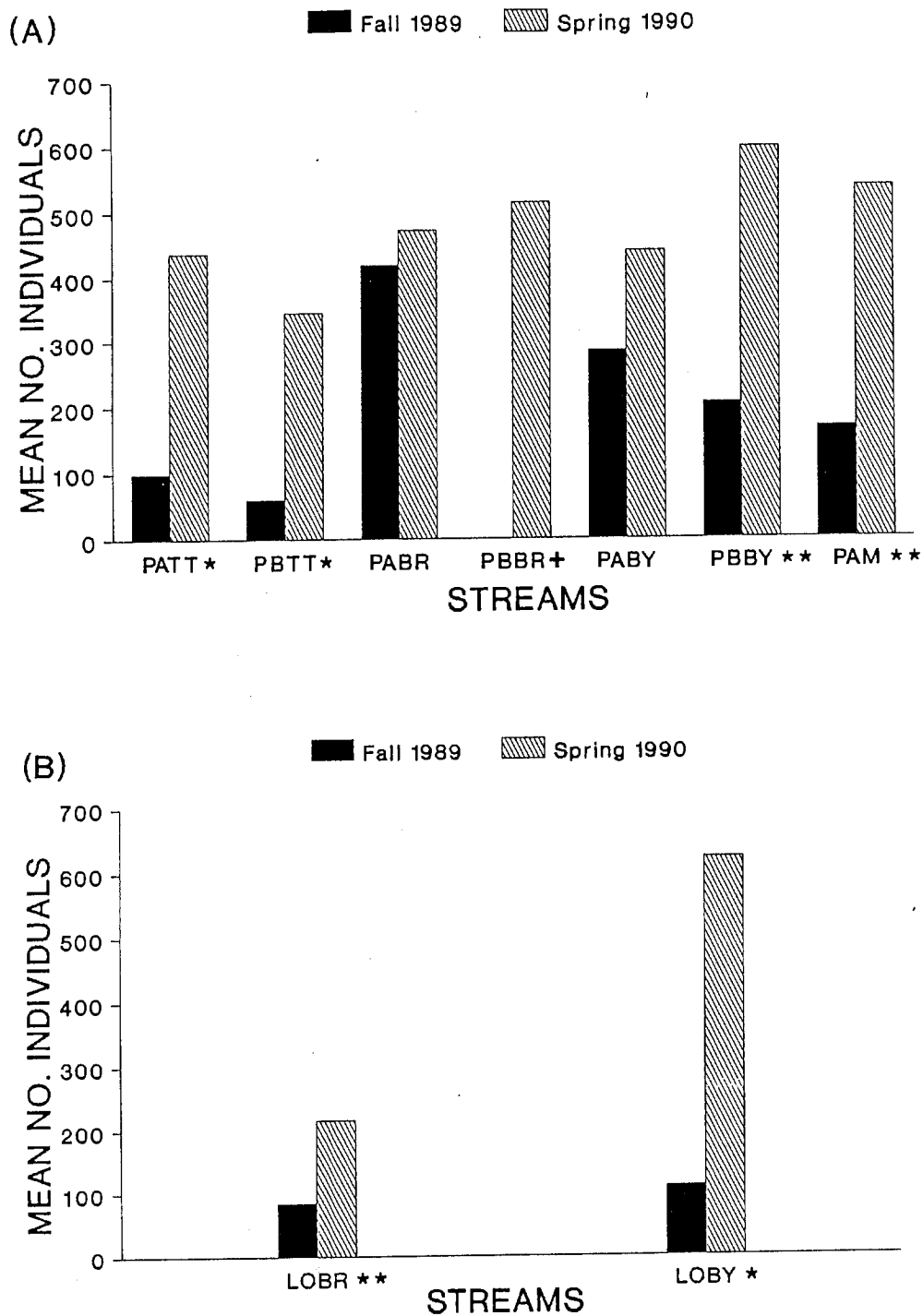


Figure 23. Mean number of macroinvertebrate individuals ($n = 3$) for fall 1989 and spring 1990 for Prairie Creek and two tributaries. Downstream direction is from left to right. * = Significant between seasons at $p < 0.05$. ** = Significant between seasons at $p < 0.10$. + = No samples collected for fall 1989. (A) = Prairie Creek sites: Prairie above Ten Tapo (PATT), Prairie below Ten Tapo (PBTT), Prairie above Brown (control) (PABR), Prairie below Brown (PBBR), Prairie above Boyes (PABY), Prairie below Boyes (PBBY) and Prairie above May (PAM). (B) = Prairie Creek tributaries: Lower Brown (LOBR) and Lower Boyes (LOBY).

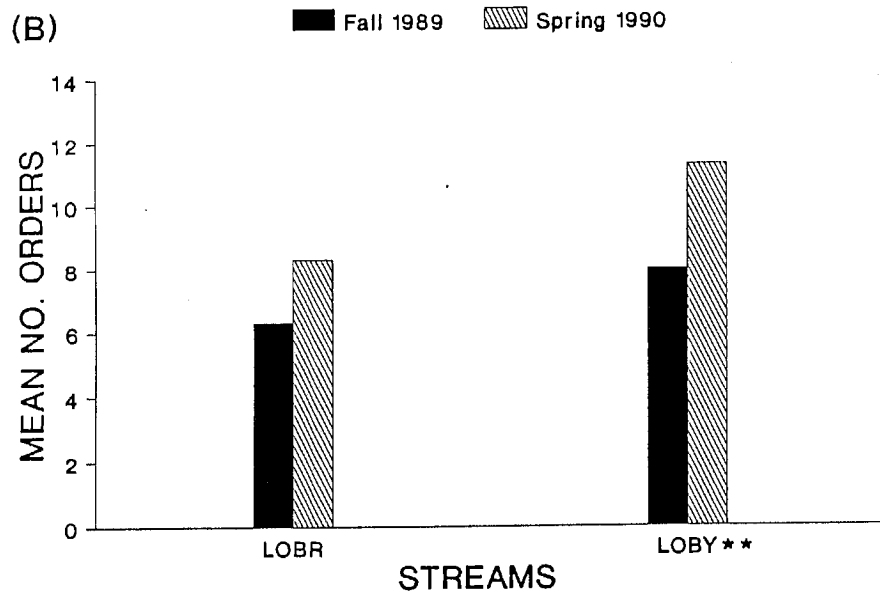
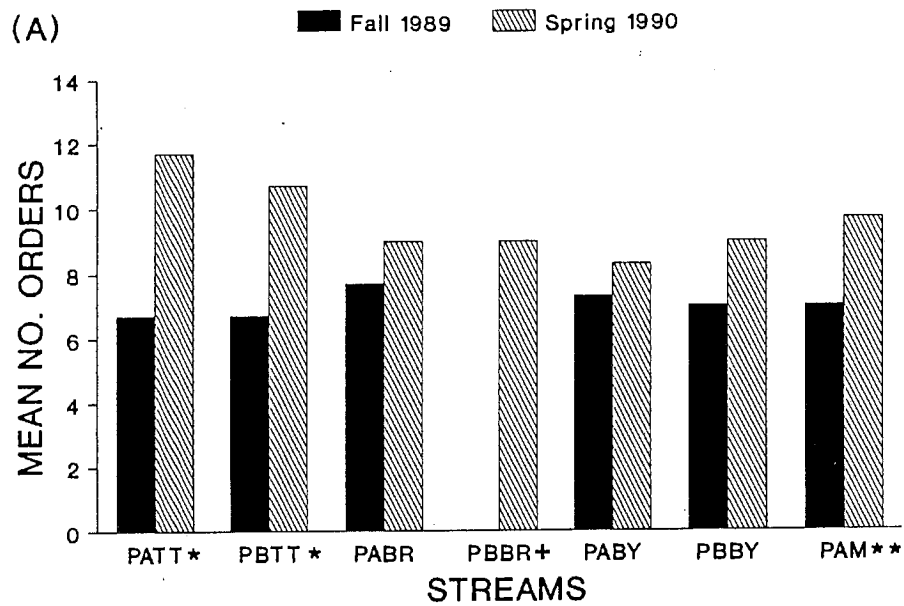


Figure 24. Mean number of macroinvertebrate orders ($n = 3$) for fall 1989 and spring 1990 for Prairie Creek and two tributaries. Downstream direction is from left to right. * = Significant between seasons at $p < 0.05$. ** = Significant between seasons at $p < 0.10$. + = No samples collected for fall 1989. (A) = Prairie Creek sites: Prairie above Ten Tapo (PATT), Prairie below Ten Tapo (PBTT), Prairie above Brown (control) (PABR), Prairie below Brown (PBBR), Prairie above Boyes (PABY), Prairie below Boyes (PBBY) and Prairie above May (PAM). (B) = Prairie Creek tributaries: Lower Brown (LOBR) and Lower Boyes (LOBY).

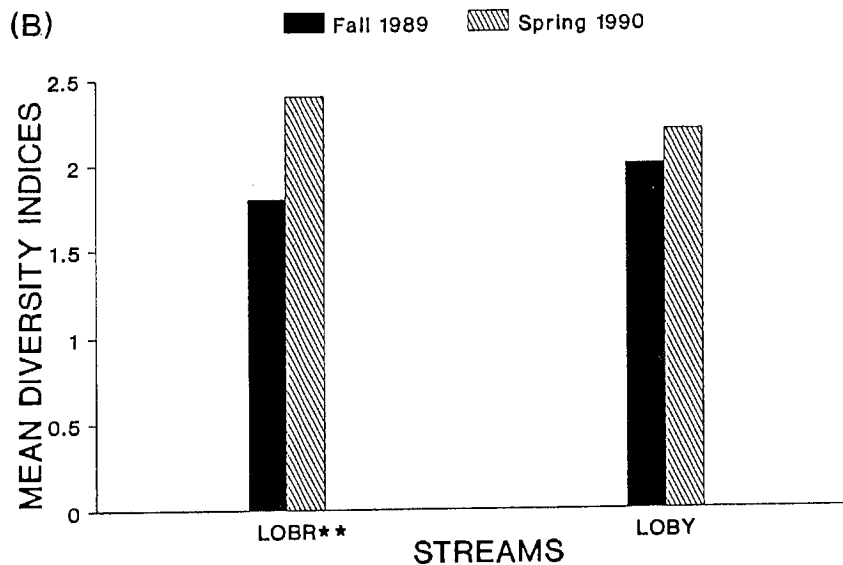
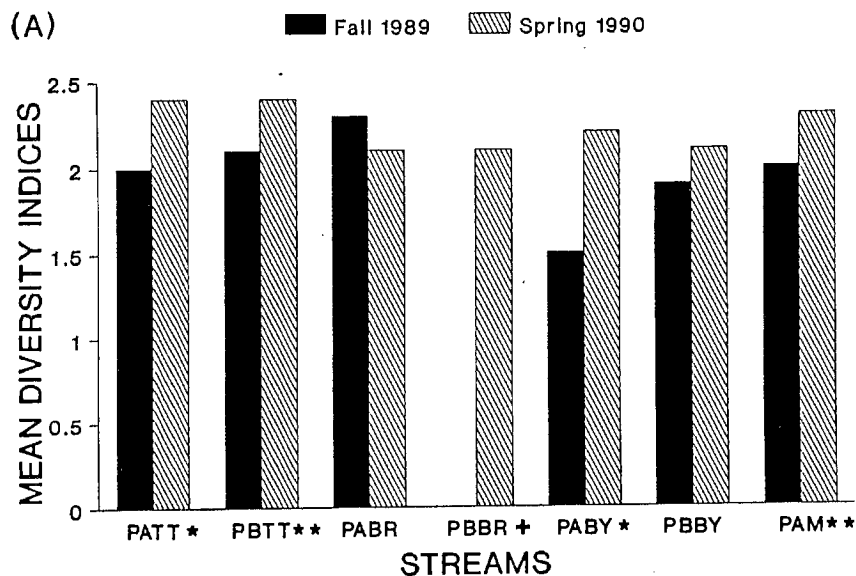


Figure 25. Mean order diversity indices ($n = 3$) for macroinvertebrates during fall 1989 and spring 1990 for Prairie Creek and two tributaries. Downstream direction is from left to right. * = Significant between seasons at $p < 0.05$. ** = Significant between seasons at $p < 0.10$. + = No samples collected for fall 1989. (A) = Prairie Creek sites: Prairie above Ten Tapo (PATT), Prairie below Ten Tapo (PBTT), Prairie above Brown (control) (PABR), Prairie below Brown (PBBR), Prairie above Boyes (PABY), Prairie below Boyes (PBBY) and Prairie above May (PAM). (B) = Prairie Creek tributaries: Lower Brown (LOBR) and Lower Boyes (LOBY).

Table 26. Mean number of macroinvertebrate individuals, orders and diversity indices for aquatic macroinvertebrates at monitoring sites on Prairie Creek and its tributaries, northern California, during fall 1989 and spring 1990.

Monitoring Site	Mean No. Individuals	Mean No. Orders	Mean Diversity
FALL 1989			
<u>Prairie Creek</u>			
Above Ten Tapo Creek	98.7*	6.7	2.0
Below Ten Tapo Creek	59.7*	6.7	2.1
Above Brown Creek (control stream)	420.3	7.7	2.3
Above Boyes Creek	285.7	7.3	1.5*
Below Boyes Creek	206.0	7.0	1.9*
Above May Creek	168.0	7.0	2.0**
<u>Prairie Creek Tributaries</u>			
Lower Brown Creek	84.3*	6.3	1.8
Lower Boyes Creek	109.3*	8.0	2.0
SPRING 1990			
<u>Prairie Creek</u>			
Above Ten Tapo Creek	438.0	11.7	2.4
Below Ten Tapo Creek	345.3	10.7	2.4
Above Brown Creek (control stream)	474.3	9.0	2.1
Below Brown Creek	516.7	9.0	2.1
Above Boyes Creek	442.0	8.3	2.2
Below Boyes Creek	600.6	9.0	2.1
Above May Creek	540.0	9.7	2.3
<u>Prairie Creek Tributaries</u>			
Lower Brown Creek	216.0	8.3	2.4
Lower Boyes Creek	623.0	11.3	2.2

* Significantly different from control stream at $P < 0.05$

** Significantly different from control stream at $P < 0.10$

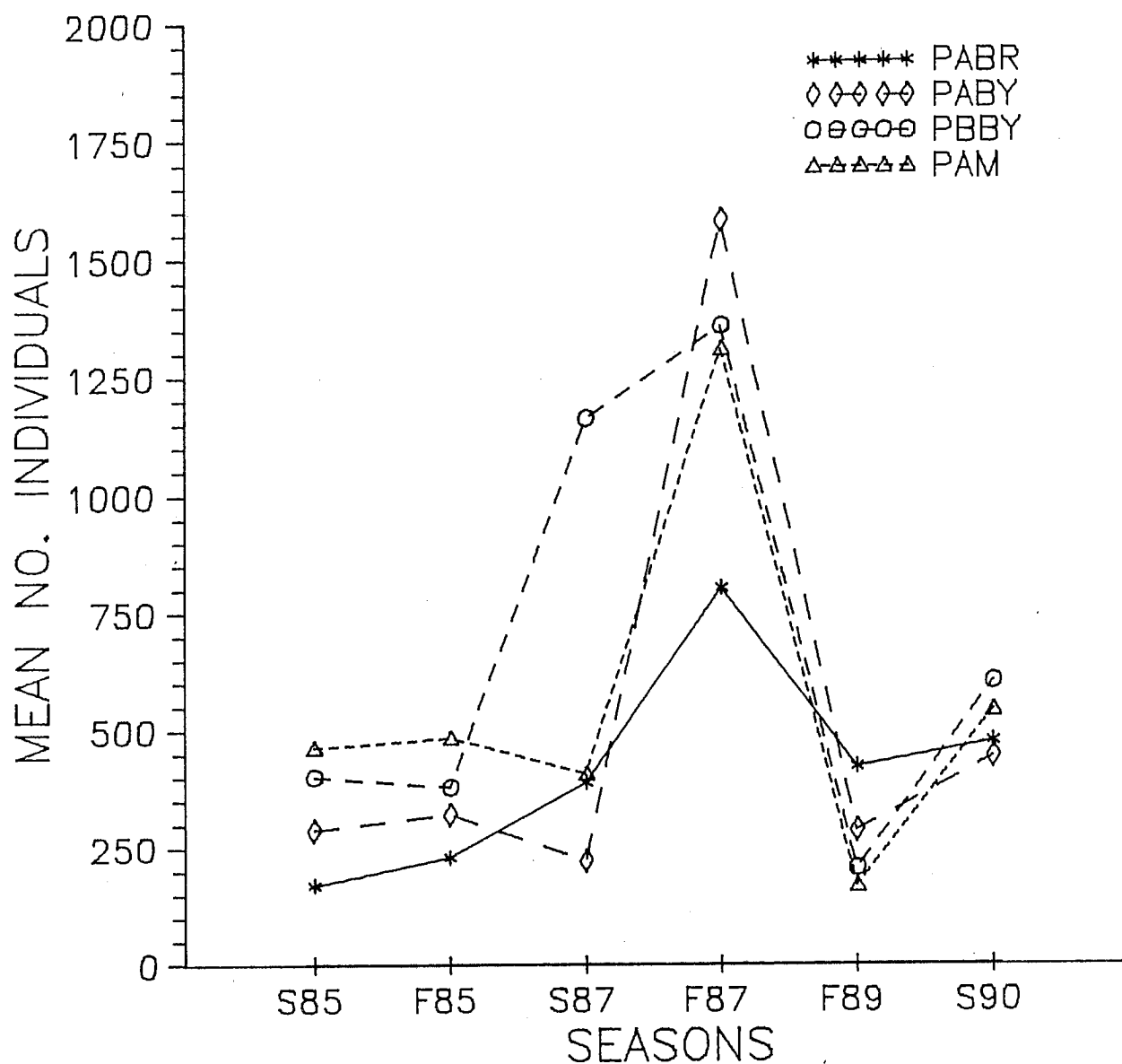


Figure 26. Mean number of macroinvertebrate individuals for Prairie Creek above Brown Creek (PABR), Prairie Creek above Boyes Creek (PABY), Prairie Creek below Boyes Creek (PBBY) and Prairie Creek above May Creek (PAM) for S85 (summer 1985 - July 2-3), F85 (fall 1985 - October 30 - November 2), S87 (summer 1987 - June 8-9,11), F87 (fall 1987 - September 30, October 2-3), F89 (fall 1989 - November 8,14) and S90 (spring 1990 - April 26, May 1). n = 5 for 1985 and 1987; n = 3 for 1989 and 1990.

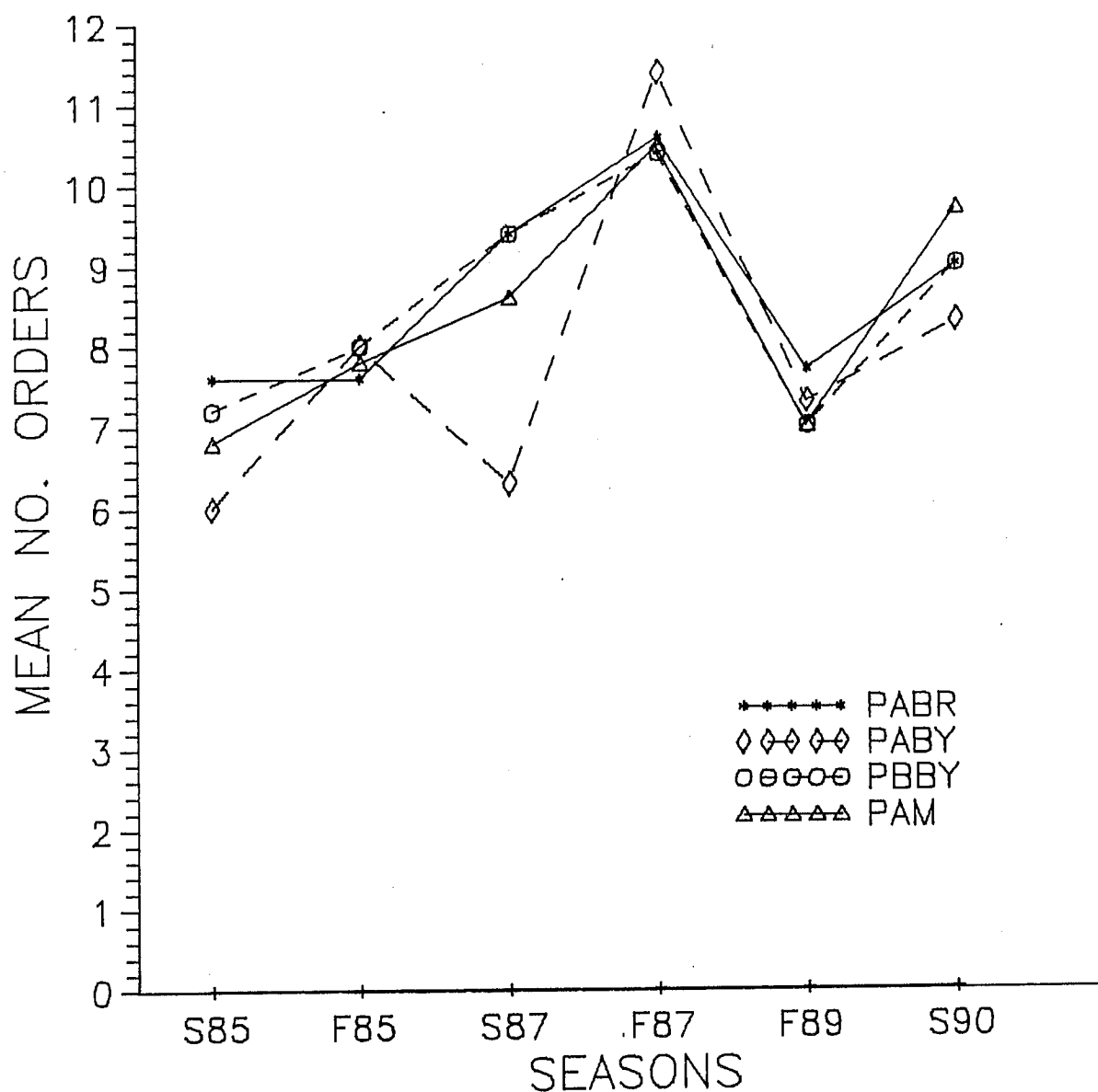


Figure 27. Mean number of macroinvertebrate orders for Prairie Creek above Brown Creek (PABR), Prairie Creek above Boyes Creek (PABY), Prairie Creek below Boyes Creek (PBBY) and Prairie Creek above May Creek (PAM) for S85 (summer 1985 - July 2-3), F85 (fall 1985 - October 30 - November 2), S87 (summer 1987 - June 8-9,11), F87 (fall 1987 - September 30, October 2-3), F89 (fall 1989 - November 8,14) and S90 (spring 1990 - April 26, May 1). $n = 5$ for 1985 and 1987; $n = 3$ for 1989 and 1990.

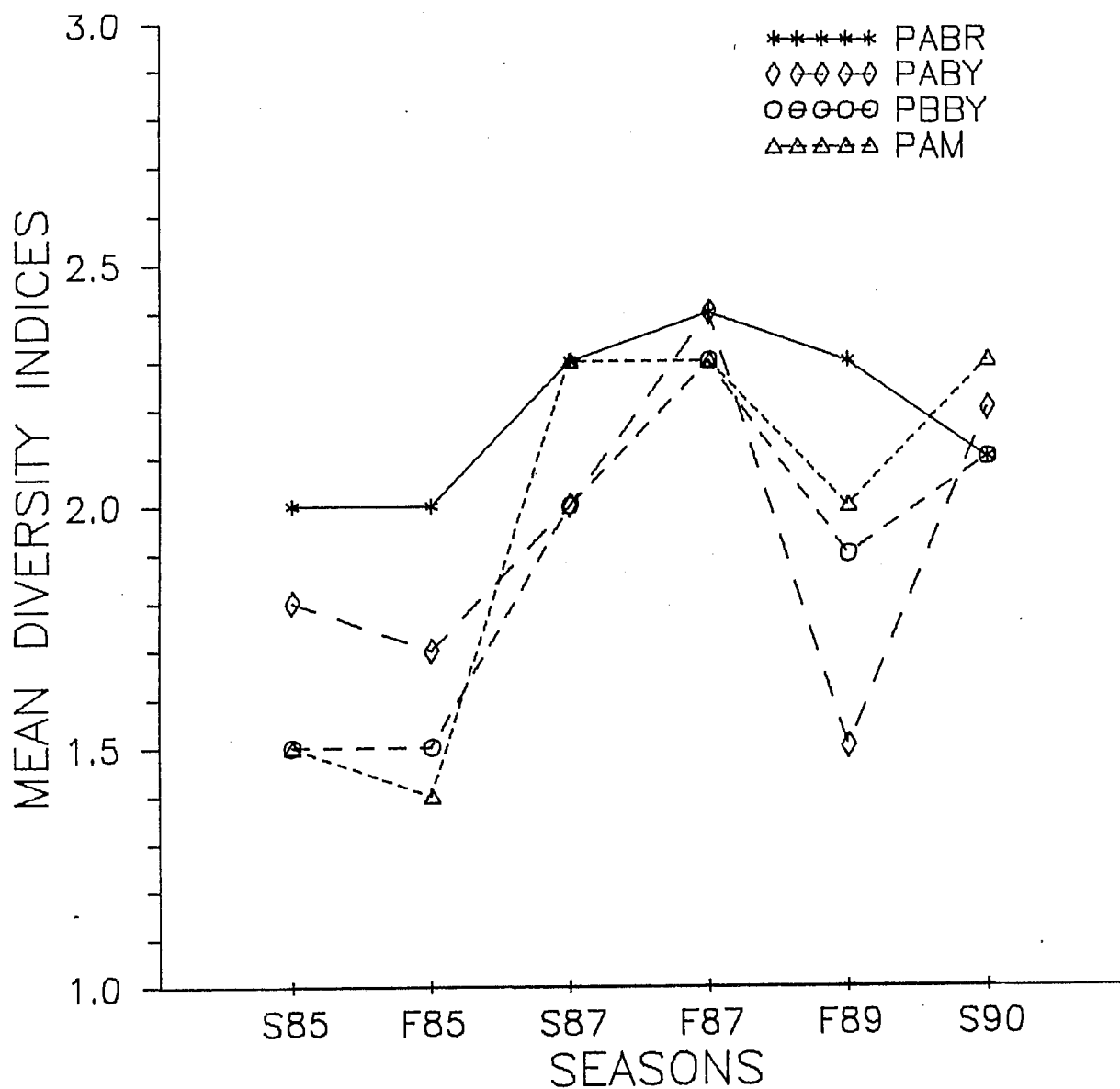


Figure 28. Mean order diversity indices for macroinvertebrates for Prairie Creek above Brown Creek (PABR), Prairie Creek above Boyes Creek (PABY), Prairie Creek below Boyes Creek (PBBY) and Prairie Creek above May Creek (PAM) for S85 (summer 1985 - July 2-3), F85 (fall 1985 - October 30 - November 2), S87 (summer 1987 - June 8-9,11), F87 (fall 1987 - September 30, October 2-3), F89 (fall 1989 - November 8,14) and S90 (spring 1990 - April 26, May 1). $n = 5$ for 1985 and 1987; $n = 3$ for 1989 and 1990.

fall data, indicating other trends over time in the control and the affected sites were similar before and after the storm. Spring results did not reveal any adverse effects from the storm.

Appendix E gives a cumulative listing of taxa by order for fall 1989 and spring 1990 for Prairie Creek and its tributaries. Although Appendix E demonstrates that total abundance of individual invertebrates increased from fall 1989 to spring 1990, the relative abundance of some invertebrate orders decreased. When comparing between fall 1989 and spring 1990 at the sites relatively unaffected by the bypass (PABR, PATT, PBTT), percentages of Trichoptera and Coleoptera decreased significantly in spring ($P < 0.10$); percentages of Diptera increased ($P < 0.05$). When a similar comparison was made for the affected sites, Ephemeroptera decreased significantly in the spring ($P < 0.05$), but Diptera increased ($P < 0.05$). Regardless of season or year, Ephemeroptera was usually the most abundant order at all sampling sites (Fig. 29).

When the relatively unaffected sites above Brown Creek were compared to the affected sites in fall 1989, relative abundance of Diptera and Plecoptera were significantly lower in the affected sites ($P < 0.05$). In contrast, Coleoptera and Ephemeroptera were significantly higher in the affected sites ($P < 0.05$). In spring 1990, relative levels of Plecoptera were still depressed ($P < 0.05$). In addition, relative relative levels of Coleoptera remained higher in the affected sites ($P < 0.05$) (Fig. 29).

Results of two-way ANOVA tests for relative abundance of macroinvertebrate orders showed some significant interactions between site and year. After the October 1989 storm, relative levels of Diptera at PABY and PBBY decreased significantly more than the control site ($P < 0.05$). However, other orders showed no effect immediately following the storm. From spring 1985 to spring 1990, Ephemeroptera declined significantly more in affected sites than in control sites, but Coleoptera, Trichoptera, and Diptera increased a greater amount at one or more of the affected sites.

F.4 Discussion

The abundance of benthic macroinvertebrates in spring 1990 tended to be greater at all sites than the previous fall period. If sample sizes had been larger, all of the differences may have been statistically significant. This overall increase may reflect an expected seasonal peak, generally occurring in late spring (Hynes 1970). The increase might also be an indication of the ability of benthic invertebrates to rebound or recolonize following a major sediment-laden storm event (Iwatsubo 1981, Giberson and Hall 1988). The latter reason may explain fall results at PABY and PBBY. The abundance of macroinvertebrates could have initially decreased because of the increase in fine sediment (Boon 1988). This trend would only represent a possible short-term effect of the bypass, however, since the difference between the control and all affected sites disappeared by spring.

Although many factors including current, water temperature, detritus particle size and abundance, and substrate type and size, can influence invertebrate abundance (Rabeni and Minshall 1977, Anderson 1979, Burgess and Bider 1980),

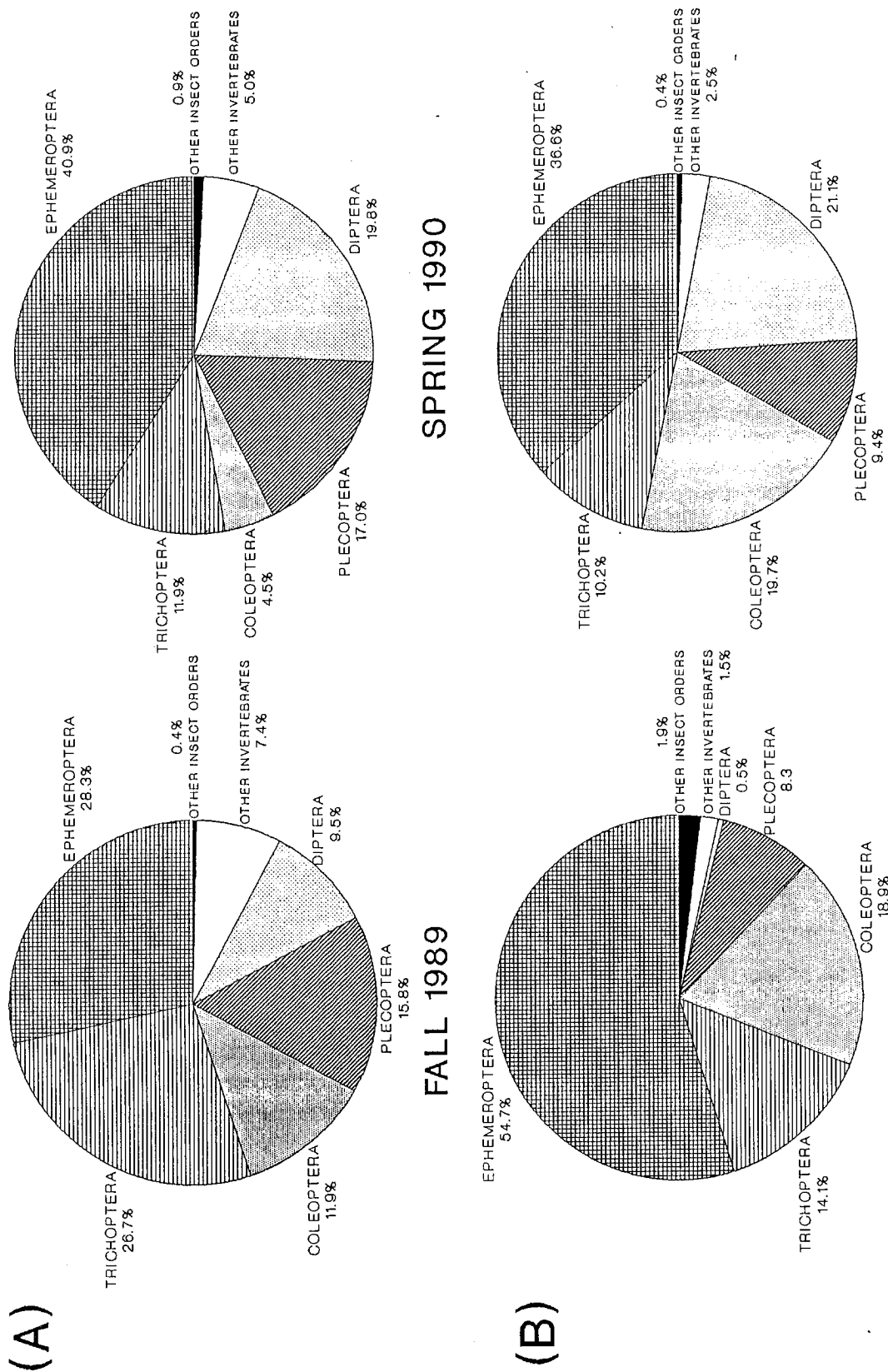


Figure 29. Comparison of relative abundance of macroinvertebrate individuals (by order) between combined control sites and combined affected Prairie Creek sites. (A) = control sites (PABR, PATT, PBTT); n = 3. (B) = combined affected Prairie Creek sites (PBBR, PABY, PBBY, PAM, LOBR, LOBY); n = 15 for fall 1989 and 18 for spring 1990.

fall 1989 invertebrate abundance and number of orders were similar to fall 1985 for four Prairie Creek sites. However, fall 1987 had considerably higher abundance. The amplitude of the fall 1987 peak may be explained by a bias due to the difference in sampling dates. Samples for fall 1985 and 1989 were collected in late October and early November. At this time, the invertebrate community abundance usually begins to decline from a seasonal peak in late summer-early fall (Hynes 1970). In contrast, the 1987 samples were collected in late September, coinciding with the expected seasonal peak. This seasonal peak occurs when young invertebrates emerge from eggs; the decline from the peak is a response to higher streamflows which wash invertebrates and detritus downstream (Iwatsubo 1981, Eggers 1987). Therefore, the increase in fall 1987 is probably an artifact of sampling time. Strange (1989) showed the same seasonal peaks and declines in his 1986 study on Prairie Creek.

Results of this study are difficult to interpret because community composition was only analyzed by order; most studies classify macroinvertebrate genera into functional groups based on feeding behavior (Merritt and Cummins 1984). Sediment probably affects individuals belonging to the same functional groups similarly, but orders can encompass many functional groups. Further analysis of summer data in 1985, 1987 and 1990 by functional group will be completed in fall 1992.

In this study of Prairie Creek sites, relative abundance of some orders decreased, whereas others increased following the October storm. Boon (1988) stated that Ephemeroptera and Coleoptera populations were reduced by an accumulation of fine sediment; he also found some families of Plecoptera and Diptera decreased, and Trichopteran populations either increased or decreased. Cline and Ward (1984) similarly found relative abundance of Ephemeroptera as well as Plecoptera decreased with increasing sediment, but Diptera increased. This study's one-way ANOVA results show some similar findings, except Coleoptera and Ephemeroptera were higher in affected sites. Two-way ANOVA results remove the effect of the natural differences between control and affected sites and yearly variation, and hence are more reliable. Our two-way ANOVA results for fall 1989 support some of Boon's findings (decreased Diptera), but not all (no change in other orders). For spring 1990, our results were more similar to those of Cline and Ward. At most sites, Ephemeroptera declined while the control site levels remained relatively constant, and Diptera increased more in the affected sites. However, at some affected sites in spring, Trichoptera and Coleoptera actually increased more than the control sites. Furthermore, Strange's (1989) study showed relative abundance of Ephemeroptera on Prairie Creek in 1986 was similar to this study's findings in 1989 and 1990.

Although there is seasonal and yearly variation in the relative abundance of invertebrate orders, the recolonization of macroinvertebrates by the spring of 1990 appears to have been successful. Salamunovich (1987) suggested that most salmonids are benthic foragers and are generally opportunistic, feeding on the most abundant prey available. Our results, which are based on a limited number of samples, indicate macroinvertebrate levels available to salmonid fry emerging in the spring have not been significantly diminished by the October storm.

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V. APPENDICES

APPENDIX A

Percent of eyed steelhead eggs that survived to hatching in artificial redds in Prairie and Lost Man Creeks, northern California, 1990.*

Stream Reach	Percent Survival to Hatching by Basket Size		
	Small	Medium	Large
Prairie Creek			
Above Brown Creek Redd #1	88	99	51
Above Brown Creek Redd #2	80	99	66
Below Brown Creek Redd #1	100	92	97
Below Brown Creek Redd #2	92	95	94
Above Boyes Creek Redd #1	100	97	92
Above Boyes Creek Redd #2	76	90	93
Below Boyes Creek Redd #1	88	91	91
Below Boyes Creek Redd #2	60	88	93
Below May Creek Redd #1	-**	0	0
Below May Creek Redd #2	-	0	0
Lost Man Creek			
Above Tributary Redd #1	80	72	86
Above Tributary Redd #2	96	88	87
Above Double Bridges Redd #1	92	95	92
Above Double Bridges Redd #2	100	93	90
Below Double Bridges Redd #1	80	75	81
Below Double Bridges Redd #2	-	84	86
Below Picnic Area Redd #1	84	84	86
Below Picnic Area Redd #2	92	61	74

*Eyed steelhead eggs were incubated in these streams for various periods of time between February 16, 1990 and April 10, 1990.

**Dashes indicate a basket of this size was not placed in the redd.

APPENDIX B

Percent of fine sediment (< 1.0 mm and 2.0 mm) found in gravel sampled from the tailspill of artificial redds in Prairie and Lost Man Creeks, northern California, 1990.

Stream Reach	DIAMETER < 1.0 mm Sampled during		DIAMETER < 2.0 mm Sampled during	
	Egg Placement	Egg Removal	Egg Placement	Egg Removal
Prairie Creek				
Above Brown Creek Redd #1	9.39	21.43	16.75	29.31
Above Brown Creek Redd #2	12.47	15.88	17.93	18.98
Below Brown Creek Redd #1	4.92	11.59	9.90	16.40
Below Brown Creek Redd #2	2.71	4.49	5.41	5.37
Above Boyes Creek Redd #1	12.95	17.55	15.49	21.97
Above Boyes Creek Redd #2	4.02	21.51	6.99	29.73
Below Boyes Creek Redd #1	7.63	16.99	12.24	24.28
Below Boyes Creek Redd #2	3.33	15.78	6.23	22.83
Below May Creek Redd #1	6.95	12.25	13.27	17.94
Below May Creek Redd #2	15.62	12.11	23.76	17.32
Lost Man Creek				
Above Tributary Redd #1	6.79	13.42	16.99	20.54
Above Tributary Redd #2	11.75	16.95	14.78	23.65
Above Double Bridges Redd #1	6.99	17.77	13.31	18.38
Above Double Bridges Redd #2	14.12	21.51	24.07	31.68
Below Double Bridges Redd #1	11.78	13.51	26.08	20.87
Below Double Bridges Redd #2	1.48	25.04	1.59	31.81
Below Picnic Area Redd #1	14.70	16.52	21.46	23.71
Below Picnic Area Redd #2	14.92	26.70	23.55	37.15

APPENDIX C

Weight-Volume Comparisons for Prairie Creek Infiltration Bags and Brown Creek Freeze-cores and McNeil Samples

Volumes and volume percentages of size fractions
Wet sieving of McNeil (McN) & freeze-core (FC) samples of lower Brown Cr.
& infiltration bag sample, Prairie Cr. below Boyes Cr. (PBBY)

Sample	Volume (ml) of size fraction (mm)					total		
	<0.5	0.5	1	2	4	32	64	
FC#1	981.6	513.5	388.0	414.5	1724.0	981.0	3956.0	8958.6
FC#2	426.8	242.0	248.0	298.0	1548.0	1153.0	2215.0	6130.8
FC#3	822.4	303.0	306.0	266.0	1042.0	1255.0	1460.0	5454.4
McN#1	709.5	134.0	200.0	240.0	1015.0	630.0	0.0	2928.5
McN#2	479.5	82.0	118.0	110.0	710.0	620.0	830.0	2949.5
McN#3	402.5	47.0	57.0	52.0	548.0	290.0	662.0	2058.5
PBBY	1644.0	40.0	110.0	165.0	3360.0	2610.0	2890.0	10819.0

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Sample	Volume % of size fraction (mm)					total		
	<0.5	0.5	1	2	4	32	64	
FC#1	10.96%	5.73%	4.33%	4.63%	19.24%	10.95%	44.16%	100.00%
FC#2	6.96%	3.95%	4.05%	4.86%	25.25%	18.81%	36.13%	100.00%
FC#3	15.08%	5.56%	5.61%	4.88%	19.10%	23.01%	26.77%	100.00%
McN#1	24.23%	4.58%	6.83%	8.20%	34.66%	21.51%	0.00%	100.00%
McN#2	16.26%	2.78%	4.00%	3.73%	24.07%	21.02%	28.14%	100.00%
McN#3	19.55%	2.28%	2.77%	2.53%	26.62%	14.09%	32.16%	100.00%
PBBY	15.20%	0.37%	1.02%	1.53%	31.06%	24.12%	26.71%	100.00%

Weights and Weight Percentages of Size Fractions.

Dry sieving of McNeil (McN) and freeze-core (FC) samples of Lower Brown Creek and infiltration bag sample, Prairie Creek below Boyes Creek (PBBY).

Sample	Weight (gm) of size fraction (mm)					total		
	<0.5	0.5	1	2	4	32	64	
FC#1	894.7	685.9	715.9	839.9	4338.3	4839.1	9168.3	21482.1
FC#2	418.7	397.9	519.3	564.1	3209.6	3237.5	6045.5	14392.6
FC#3	764.0	472.3	491.2	516.9	2993.9	4388.8	4382.0	14009.1
McN#1	484.9	212.4	333.3	521.8	2624.8	1825.3	0.0	6002.5
McN#2	341.0	113.4	200.0	237.0	1847.0	1769.8	2268.8	6777.0
McN#3	208.4	64.4	87.9	107.4	1305.5	884.0	1940.2	4597.8
PBBY	530.0	59.3	195.1	366.4	8938.3	7136.2	8500.9	25726.2

Sample	Weight % of size fraction (mm)					total		
	<0.5	0.5	1	2	4	32	64	
FC#1	4.16%	3.19%	3.33%	3.91%	20.19%	22.53%	42.68%	100.00%
FC#2	2.91%	2.76%	3.61%	3.92%	22.30%	22.49%	42.00%	100.00%
FC#3	5.45%	3.37%	3.51%	3.69%	21.37%	31.33%	31.28%	100.00%
McN#1	8.08%	3.54%	5.55%	8.69%	43.73%	30.41%	0.00%	100.00%
McN#2	5.03%	1.67%	2.95%	3.50%	27.25%	26.11%	33.48%	100.00%
McN#3	4.53%	1.40%	1.91%	2.34%	28.39%	19.23%	42.20%	100.00%
PBBY	2.06%	0.23%	0.76%	1.42%	34.74%	27.74%	33.04%	100.00%

Cumulative Volumes and Volume Percentages of Size Fractions.

Wet sieving of McNeil (McN) and freeze-core (FC) samples of lower Brown Creek and infiltration bag sample, Prairie Creek below Boyes Creek (PBBY).

Sample	Cumulative volume (ml) of size fractions (mm)				total
	<0.5	<1	<2	<4	>4
FC#1	981.6	1495.1	1883.1	2297.6	6661.0
FC#2	426.8	668.8	916.8	1214.8	4916.0
FC#3	822.4	1125.4	1431.4	1697.4	3757.0
McN#1	709.5	843.5	1043.5	1283.5	1645.0
McN#2	479.5	561.5	679.5	789.5	2160.0
McN#3	402.5	449.5	506.5	558.5	1500.0
PBBY	1644.0	1684.0	1794.0	1959.0	8860.0
					10819.0

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Sample	Cumulative volume % of size fraction (mm)				total
	<0.5	<1	<2	<4	>4
FC#1	10.96%	16.69%	21.02%	25.65%	74.35%
FC#2	6.96%	10.91%	14.95%	19.81%	80.19%
FC#3	15.08%	20.63%	26.24%	31.12%	68.88%
McN#1	24.23%	28.80%	35.63%	43.83%	56.17%
McN#2	16.26%	19.04%	23.04%	26.77%	73.23%
McN#3	19.55%	21.84%	24.61%	27.13%	72.87%
PBBY	15.20%	15.57%	16.58%	18.11%	81.89%
					100.00%

Cumulative Weights and Weight Percentages of Size Fractions.

Dry sieving of McNeil (McN) and freeze-core (FC) samples of lower Brown Creek and infiltration bag sample, Prairie Creek below Boyes Creek (PBBY).

Sample	Cumulative weight (gm) of size fractions (mm)				
	<0.5	<1	<2	<4	>4 total
FC#1	894.7	1580.6	2296.5	3136.4	18345.7
FC#2	418.7	816.6	1335.9	1900.0	12492.6
FC#3	764.0	1236.3	1727.5	2244.4	11764.7
McN#1	484.9	697.3	1030.6	1552.4	4450.1
McN#2	341.0	454.4	654.4	891.4	5885.6
McN#3	208.4	272.8	360.7	468.1	4129.7
PBBY	530.0	589.3	784.4	1150.8	24575.4
					25726.2

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Sample	Cumulative weight % of size fractions (mm)				
	<0.5	<1	<2	<4	>4 total
FC#1	4.16%	7.36%	10.69%	14.60%	85.40%
FC#2	2.91%	5.67%	9.28%	13.20%	86.80%
FC#3	5.45%	8.82%	12.33%	16.02%	83.98%
McN#1	8.08%	11.62%	17.17%	25.86%	74.14%
McN#2	5.03%	6.70%	9.66%	13.15%	86.85%
McN#3	4.53%	5.93%	7.84%	10.18%	89.82%
PBBY	2.06%	2.29%	3.05%	4.47%	95.53%
					100.00%

Ratios of Volume Percent to Weight Percent in Each Size Class.

Sample	Volume % / weight % of size fraction (mm)	1	2	4	32	64	total
	<0.5	0.5					
FC#1	2.63	1.80	1.30	1.18	0.95	1.03	1.00
FC#2	2.39	1.43	1.12	1.24	1.13	0.86	1.00
FC#3	2.76	1.65	1.60	1.32	0.89	0.86	1.00
McN#1	3.00	1.29	1.23	0.94	0.79	--	1.00
McN#2	3.23	1.66	1.36	1.07	0.88	0.84	1.00
McN#3	4.31	1.63	1.45	1.08	0.94	0.76	1.00
PBBY	7.38	1.60	1.34	1.07	0.89	0.81	1.00

Sample	Cumulative volume % / weight % of size fractions (mm)	<1	<2	<4	>4	total
	<0.5					
FC#1	2.63	2.27	1.97	1.76	0.87	1.00
FC#2	2.39	1.92	1.61	1.50	0.92	1.00
FC#3	2.76	2.34	2.13	1.94	0.82	1.00
McN#1	3.00	2.48	2.08	1.69	0.76	1.00
McN#2	3.23	2.84	2.39	2.04	0.84	1.00
McN#3	4.31	3.68	3.14	2.67	0.81	1.00
PBBY	7.38	6.80	5.44	4.05	0.86	1.00

Apparent Specific Gravities in Each Size Class (g/cm³).

Sample	Apparent S.G. (wt./vol.) of size fraction (mm)	2	4	32	64	total
	<0.5	0.5	1			
FC#1	0.91	1.34	1.85	2.03	2.52	4.93
FC#2	0.98	1.64	2.09	1.89	2.07	2.81
FC#3	0.93	1.56	1.61	1.94	2.87	3.50
MCN#1	0.68	1.59	1.67	2.17	2.59	2.90
MCN#2	0.71	1.38	1.69	2.15	2.60	2.85
MCN#3	0.52	1.37	1.54	2.07	2.38	3.05
PBBY	0.32	1.48	1.77	2.22	2.66	2.73
						2.32
						2.73
						3.00
						--
						2.73
						2.93
						2.94
						2.40
						2.35
						2.57
						2.05
						2.30
						2.23
						2.38

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Sample	Apparent S.G. (wt./vol.) of cumulative size fraction (mm)	<1	<2	<4	>4	total
	<0.5					
FC#1	0.91	1.06	1.22	1.37	2.75	2.40
FC#2	0.98	1.22	1.46	1.56	2.54	2.35
FC#3	0.93	1.10	1.21	1.32	3.13	2.57
MCN#1	0.68	0.83	0.99	1.21	2.71	2.05
MCN#2	0.71	0.81	0.96	1.13	2.72	2.30
MCN#3	0.52	0.61	0.71	0.84	2.75	2.23
PBBY	0.32	0.35	0.44	0.59	2.77	2.38

APPENDIX D

Results of permeability and dissolved oxygen tests conducted by Trinity Fisheries Consulting, November 21, 1989.

Location	Sample	Permeability (cm/hour)	Dissolved Oxygen (ppm) surface	Dissolved Oxygen (ppm) subsurface
Prairie Creek above	1	860	9.6	9.9
Brown Creek	2	1800	9.6	9.4
	3	700	9.6	9.6
Prairie Creek below	1	720	9.6	10.4
Brown Creek	2	2700	9.5	9.5
	3	1100	9.4	9.5
Prairie Creek above	1	310	10.4	10.4
Big Tree Creek	2	300	10.3	10.3
	3	780	10.4	10.3
Prairie Creek below	1	270	10.5	10.4
Big Tree Creek	2	580	10.5	10.4
	3	1900	10.6	10.5
Prairie Creek above	1	10600	10.2	9.5
Boyces Creek	2	65000	10.2	10.3
	3	50000	10.1	10.3
Prairie Creek below	1	1700	10.8	10.0
Boyces Creek	2	3800	10.6	10.2
	3	2900	10.6	10.2
Prairie Creek at Elk	1	1100	10.4	10.3
Prairie Campsite	2	460	10.5	10.4
No. 55	3	500	10.5	10.4
Prairie Creek above	1	1000	9.8	4.8
May Creek	2	1900	9.5	9.2
	3	34000	9.8	8.8
Prairie Creek below	1	2000	10.6	10.5
May Creek	2	4900	10.2	10.0
	3	5000	10.2	10.2
Brown Creek	1	320	10.1	9.0
	2	200	10.1	8.7
	3	<200	10.1	5.6
Boyces Creek	1	<200	10.2	9.8
	2	<200	10.2	10.0
	3	N/M ¹	----	----
Lost Man Creek	1	500	10.2	10.0
	2	880	10.2	10.0
	3	500	10.2	10.0

¹ not measurable; permeability too low.

APPENDIX E

Cumulative list of taxa (by order) for benthic macroinvertebrate samples collected fall 1989 and spring 1990 at Prairie Creek and two tributaries, northern California.

STREAM: PRAIRIE CREEK ABOVE TEN TAPO CREEK

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Coleoptera	15	40
Diptera	8	253
Ephemeroptera	149	480
Phalangida	0	1
Plecoptera	50	276
Thysanoptera	0	4
Trichoptera	49	178
Unknown	0	8
Arachnida		
Acari	1	13
Araneae	0	3
Crustacea		
Amphipoda	53	27
Gastropoda		
Mesogastropoda	2	19
Oligochaeta		
Unknown	9	12
Pelecypoda		
Unknown	0	7
NUMBER OF SAMPLES	3	3
MEAN NUMBER OF TAXA	6.7	11.7
Standard Deviation	0.6	0.6
MEAN NUMBER OF INDIVIDUALS	98.7	438.0
Standard Deviation	31.2	108.7
MEAN DIVERSITY INDEX	2.0	2.4
Standard Deviation	0.1	0.1

STREAM: PRAIRIE CREEK BELOW TEN TAPO CREEK

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Coleoptera	18	88
Diptera	0	168
Ephemeroptera	80	432
Hemiptera	2	0
Megaloptera	5	0
Plecoptera	36	185
Thysanoptera	0	2
Trichoptera	19	82
Unknown	0	10
Arachnida		
Acari	0	15
Araneae	0	16
Crustacea		
Amphipoda	13	23
Gastropoda		
Mesogastropoda	3	33
Oligochaeta		
Unknown	3	2
NUMBER OF SAMPLES	3	3
MEAN NUMBER OF TAXA	6.7	10.7
Standard Deviation	1.2	1.2
MEAN NUMBER OF INDIVIDUALS	59.7	345.3
Standard Deviation	35.5	110.6
MEAN DIVERSITY INDEX	2.1	2.4
Standard Deviation	0.2	0.1

STREAM: PRAIRIE CREEK ABOVE BROWN CREEK (control stream)

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Coleoptera	181	42
Diptera	160	331
Ephemeroptera	272	638
Plecoptera	194	183
Psocoptera	0	1
Thysanoptera	0	3
Trichoptera	406	191
Unknown	0	7
Arachnida		
Acari	2	15
Araneae	1	1
Crustacea		
Amphipoda	2	0
Gastropoda		
Mesogastropoda	28	10
Oligochaeta		
Unknown	15	1
NUMBER OF SAMPLES	3	3
MEAN NUMBER OF TAXA	7.7	9.0
Standard Deviation	0.6	1.0
MEAN NUMBER OF INDIVIDUALS	420.3	474.3
Standard Deviation	164.9	122.7
MEAN DIVERSITY INDEX	2.3	2.1
Standard Deviation	0.2	0.1

STREAM: PRAIRIE CREEK BELOW BROWN CREEK

HABITAT: RIFFLE

Class Order	Fall 1989 *	Spring 1990
Insecta		
Coleoptera		82
Diptera		360
Ephemeroptera		689
Plecoptera		208
Thysanoptera		1
Trichoptera		176
Unknown		6
Arachnida		
Acari		11
Araneae		3
Gastropoda		
Mesogastropoda		5
Oligochaeta		
Unknown		9
NUMBER OF SAMPLES	0	3
*(no samples collected Fall 89)		
MEAN NUMBER OF TAXA		9.0
Standard Deviation		1.0
MEAN NUMBER OF INDIVIDUALS		516.7
Standard Deviation		147.6
MEAN DIVERSITY INDEX		2.1
Standard Deviation		0.1

STREAM: PRAIRIE CREEK ABOVE BOYES CREEK

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Coleoptera	69	124
Collembola	0	1
Diptera	0	265
Ephemeroptera	561	583
Lepidoptera	4	0
Megaloptera	10	0
Plecoptera	59	168
Thysanoptera	0	1
Trichoptera	143	152
Arachnida		
Acari	0	8
Araneae	0	3
Gastropoda		
Mesogastropoda	6	20
Oligochaeta		
Unknown	5	1
NUMBER OF SAMPLES	3	3
MEAN NUMBER OF TAXA	7.3	8.3
Standard Deviation	0.6	0.6
MEAN NUMBER OF INDIVIDUALS	285.7	442.0
Standard Deviation	56.0	223.7
MEAN DIVERSITY INDEX	1.5	2.2
Standard Deviation	0.2	0.2

STREAM: PRAIRIE CREEK BELOW BOYES CREEK

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Coleoptera	157	309
Diptera	3	224
Ephemeroptera	561	874
Hemiptera	1	0
Isoptera	0	2
Megaloptera	12	0
Plecoptera	34	174
Thysanoptera	0	3
Trichoptera	88	165
Unknown	0	2
Arachnida		
Acari	0	1
Araneae	1	0
Crustacea		
Amphipoda	0	3
Gastropoda		
Mesogastropoda	16	38
Oligochaeta		
Unknown	1	0
NUMBER OF SAMPLES	3	3
MEAN NUMBER OF TAXA	7.0	9.0
Standard Deviation	1.0	2.0
MEAN NUMBER OF INDIVIDUALS	206.0	600.7
Standard Deviation	86.2	285.3
MEAN DIVERSITY INDEX	1.9	2.1
Standard Deviation	0.1	0.2

STREAM: PRAIRIE CREEK ABOVE MAY CREEK

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Coleoptera	33	339
Diptera	2	402
Ephemeroptera	82	579
Hymenoptera	0	3
Megaloptera	3	0
Plecoptera	19	118
Trichoptera	27	150
Unknown	0	5
Arachnida		
Acari	0	3
Araneae	0	1
Crustacea		
Amphipoda	0	1
Gastropoda		
Mesogastropoda	0	17
Oligochaeta		
Unknown	2	2
NUMBER OF SAMPLES	1	3
MEAN NUMBER OF TAXA	7.0	9.7
Standard Deviation	0.0	0.6
MEAN NUMBER OF INDIVIDUALS	168.0	540.0
Standard Deviation	0.0	106.0
MEAN DIVERSITY INDEX	2.0	2.3
Standard Deviation	0.0	0.1

STREAM: LOWER BROWN CREEK

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Coleoptera	59	73
Collembola	1	0
Diptera	1	732
Ephemeroptera	128	176
Lepidoptera	2	0
Megaloptera	0	1
Plecoptera	33	167
Psocoptera	0	4
Thysanoptera	0	4
Trichoptera	26	118
Unknown	0	3
Arachnida		
Acari	0	23
Araneae	0	0
Gastropoda		
Mesogastropoda	1	5
Oligochaeta		
Unknown	2	0
NUMBER OF SAMPLES	3	3
MEAN NUMBER OF TAXA	6.3	8.3
Standard Deviation	1.2	1.5
MEAN NUMBER OF INDIVIDUALS	84.3	216.0
Standard Deviation	20.7	81.2
MEAN DIVERSITY INDEX	1.8	2.4
Standard Deviation	0.4	0.3

STREAM: LOWER BOYES CREEK

HABITAT: RIFFLE

Class Order	Fall 1989	Spring 1990
Insecta		
Anoplura	0	1
Coleoptera	101	761
Collembola	1	0
Diptera	4	436
Ephemeroptera	136	314
Hemiptera	0	1
Homoptera	0	3
Lepidoptera	2	0
Megaloptera	5	0
Plecoptera	38	89
Thysanoptera	0	6
Trichoptera	29	185
Unknown	0	6
Arachnida		
Acari	0	3
Araneae	0	0
Crustacea		
Amphipoda	6	9
Gastropoda		
Mesogastropoda	2	12
Oligochaeta		
Unknown	3	42
NUMBER OF SAMPLES	3	3
MEAN NUMBER OF TAXA	8.0	11.3
Standard Deviation	2.0	0.6
MEAN NUMBER OF INDIVIDUALS	109.3	623.0
Standard Deviation	33.8	220.5
MEAN DIVERSITY INDEX	2.0	2.2
Standard Deviation	0.1	0.1