INTRAGRAVEL AND SURFACE WATER CONDITIONS IN THREE TRIBUTARIES OF REDWOOD CREEK

by

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INTRODUCTION

Redwood National Park, in northwestern California, was established by Congress on October 2, 1968 to preserve a portion of the coast redwood (Sequoia sempervirens) ecosystem. In October of 1973 the National Park Service awarded a contract to the U. S. Geological Survey for the performance of an environmental study of Redwood National Park, with emphasis on the Redwood Creek Drainage Basin. The study objectives are to survey the terrestrial and aquatic ecosystems in the park, identify the more serious threats to those ecosystems, and measure the effects of logging and associated road construction on Redwood National Park and its environs. Under cooperative agreement with the Geological Survey this project, "Intragravel and surface water conditions in three tributaries of Redwood Creek", was designed to provide data on intragravel conditions in some streams within the Redwood Creek Drainage Basin.

My study objectives included the monitoring of dissolved oxygen concentration and temperature of surface and intragravel water, and determination of the percentage composition of stream bottom materials in three tributaries of Redwood Creek. The research was conducted from June through November, 1974. The study areas were chosen so as to represent stream conditions in three different types of watersheds; virgin redwood forest, redwood forest recovering from logging, and recently logged redwood forest. As no pre-logging data were available, an assessment of the effects of logging on each tributary was not possible, but comparisons are made of the differences in surface and intragravel conditions among the streams in the three types of watersheds.

Redwood Creek, one of the major streams within Redwood National Park, arises in mid-Humboldt County near the eastern county line and flows in a northwesterly direction about 50 miles to the Pacific Ocean near Orick, in the northwest corner of the county. The drainage area is about 280 square miles and is typified as a long, narrow valley with steep sideslopes. The moderate gradient of Redwood Creek allows salmonids to ascend to the headwaters, but low summer flows throughout the basin limit the extent of nursery areas (California Department of Water Resources, 1965). The U. S. Fish and Wildlife Service (1960) estimated that the average size of runs of salmonids into the river system amounted to 5000 king salmon (*Oncorhynchus tshawytscha*), 2000 coho salmon (*O. kisutch*), and 10,000 steelhead trout (*Salmo gairdneri*).

The economy of the North Coast region of California depends heavily upon its forest products and fishery industries. A major portion of the fishery is dependent on three species of anadromous salmonids, king salmon, coho salmon, and steelhead trout which use the region's rivers and tributaries for spawning and nursery grounds. These waters can be seriously affected during and after logging operations. Removal of vegetation and disturbance of the watershed's soil mantle by logging may influence streams physically, chemically, and biologically. Alterations in stream water quality, runoff, temperature regimes, and energy flow patterns may occur. Logging debris deposited in the stream may block migration of fish and act as sediment traps. Increased sediment yields from surface erosion and mass soil movement can increase stream sedimentation. The presence of large-scale logging operations has accelerated an already high rate of natural soil erosion attributed to the region's abundant precipitation, unstable geologic formations, and steep, erosive soils (California State Water Resources Control Board, 1973).

Stream sedimentation is generally one of the major consequences of logging operations and exerts its effects primarily upon the stream bottom, although increased turbidity may reduce photosynthetic processes and hamper aquatic organisms. The deposition of sediment in the stream channel can reduce cover and habitat for fish, aquatic insects, and other organisms. The intragravel development of salmonid fishes from the egg stage through the alevin stage can be adversely influenced by sedimentation that inhibits the interchange of surface and intragravel water.

The processes by which surface and intragravel water are interchanged were studied by Vaux (1962, 1968). He found interchange to be affected by three streambed characteristics: permeability (the inherent ability of a porous medium to transmit fluids), depth of permeable materials, and configuration of the streambed. An increase in depth of permeable materials or permeability in the direction of flow created a downwelling of water into the streambed, decreases in the two factors created an upwelling out of the streambed. Upwelling occurred in areas of the streambed with concave profiles, whereas downwelling occurred in convex profiles. A change in any of the three controlling factors, such as decreased permeability due to sedimentation, could influence the interchange process.

A number of authors have reported on the influence of intragravel conditions on the survival and development of salmonid eggs and alevins. Koski (1966), as cited by Ringler (1970), found that fine sediments could block interstices among larger streambed materials and physically block the emergence of alevins. This blockage also can inhibit the interchange of surface and intragravel water which delivers dissolved oxygen and removes metabolic wastes from developing eggs and alevins within the streambed. Coble (1961), among others, found that reduced interchange can reduce the rate of survival of eggs and alevins. Wickett (1958) reported that the highest survival rates of pink salmon (O. gorbuscha) and chum salmon (O. keta) fry in four British Columbia streams were in those streams with high permeabilities. Under laboratory conditions, Shumway, et al. (1964) determined that reduced intragravel dissolved oxygen and apparent velocity of flow (the rate of seepage through a porous medium) resulted in delayed egg hatching, additional egg and alevin mortality, and reduced size of alevins of steelhead trout and coho salmon.

STUDY AREAS

The study areas were three small streams in the Redwood Creek Drainage Basin in northwestern Humboldt County (Figure 1). The northernmost stream is a tributary to Lost Man Creek, which enters Prairie Creek, a tributary to Redwood Creek. The watershed of this tributary to Lost Man Creek is recovering from logging (Figure 2). The Little Lost Man Creek study area is in a virgin watershed (Figure 3). Portions of the Panther Creek drainage were recently logged, this was the southernmost study area (Figure 4). Physical features of the watershed areas influencing the sampling sites are presented in Table 1.

Geologically, both the tributary to Lost Man Creek and Little Lost Man Creek are located on the Franciscan Formation which is characterized by Upper Jurassic to Upper Cretaceous rocks such as graywacke, shale, chert, and minor amounts of metasedimentary rocks. Panther Creek is located in an area of Pre-Cretaceous metasedimentary rocks, chiefly phyllite, slate, and schist (U. S. Department of Agriculture, 1970).

The U. S. Department of Agriculture (1970) indicated that the soils in the area of the three watersheds are deep to moderately deep loam type soils with good drainage and moderate subsoil permeability. The generalized soil type is the Hugo-Josephine association on 30 to 50 percent slopes, it is suited primarily for forestry and grazing. After removal

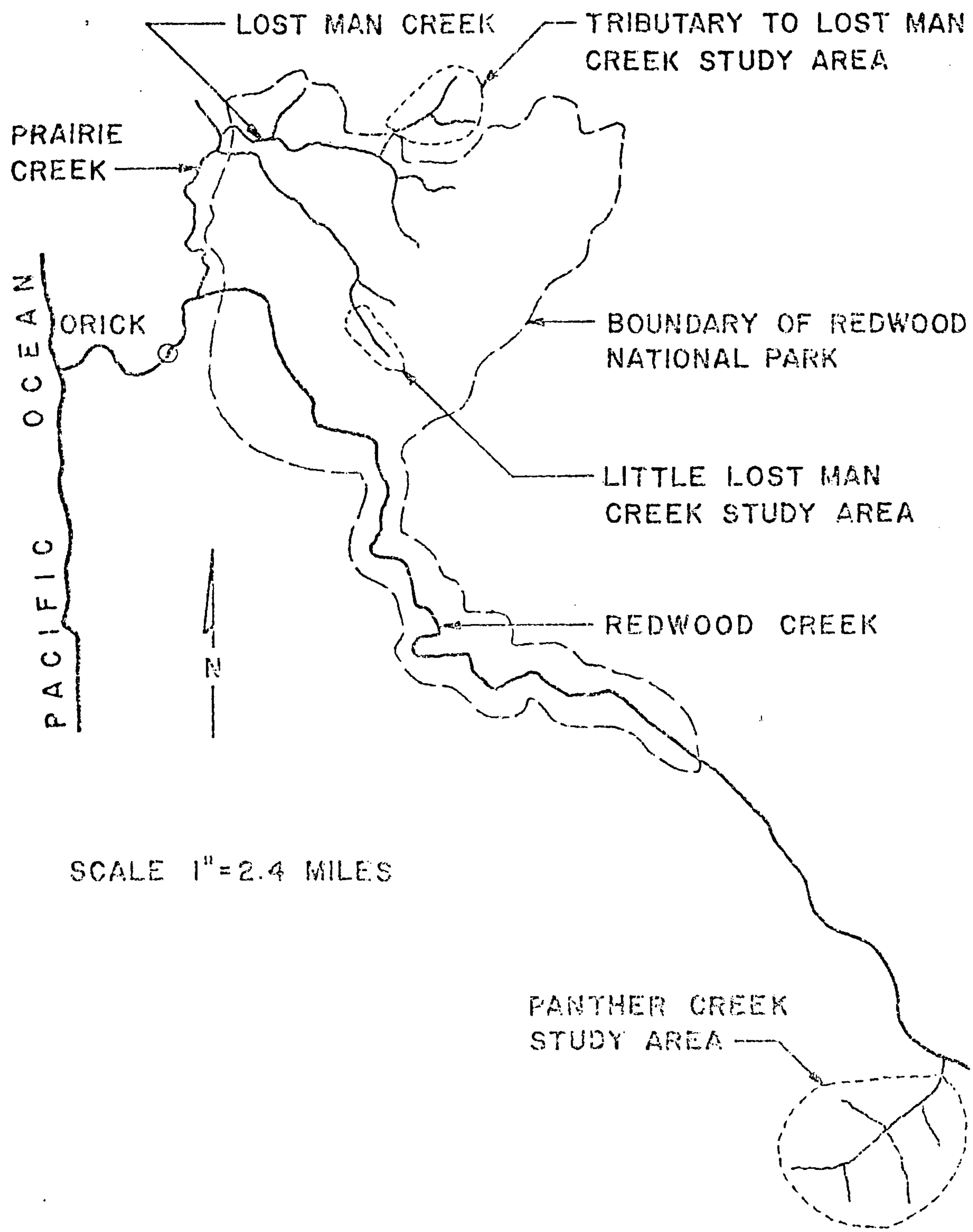

Figure 1. Location of the three study areas in relation to Redwood National Park, Humboldt County, California

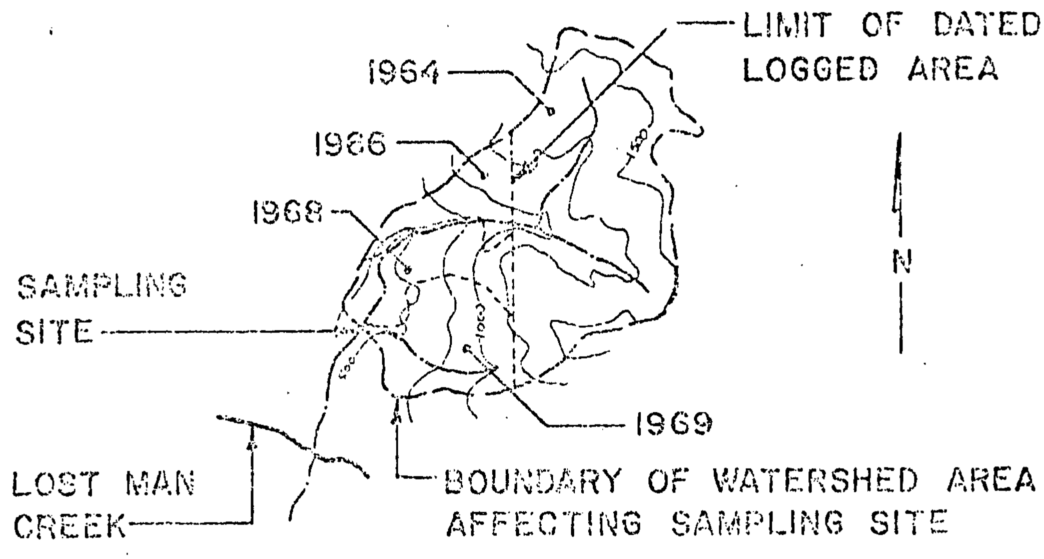

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Figure 2. Watershed area influencing the sampling site at tributary to Lost Man Creek, Humboldt County, California

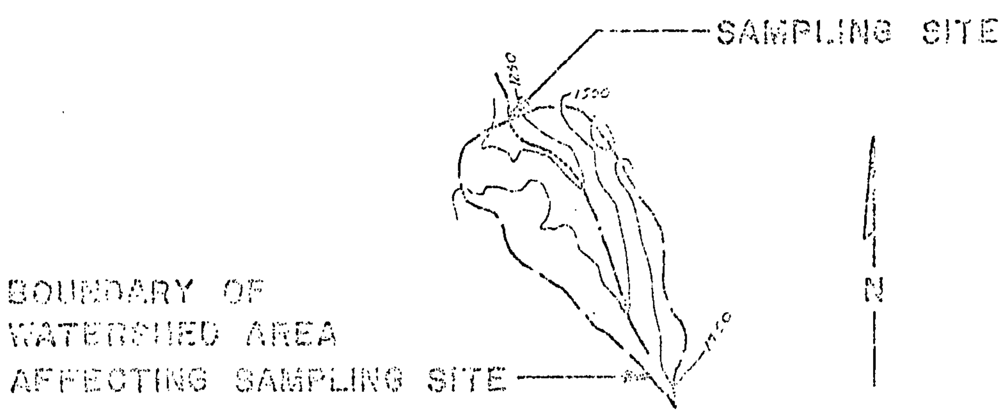

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Figure 3. Watershed area influencing the sampling site at Little Lost Man Creek, Humboldt County, California

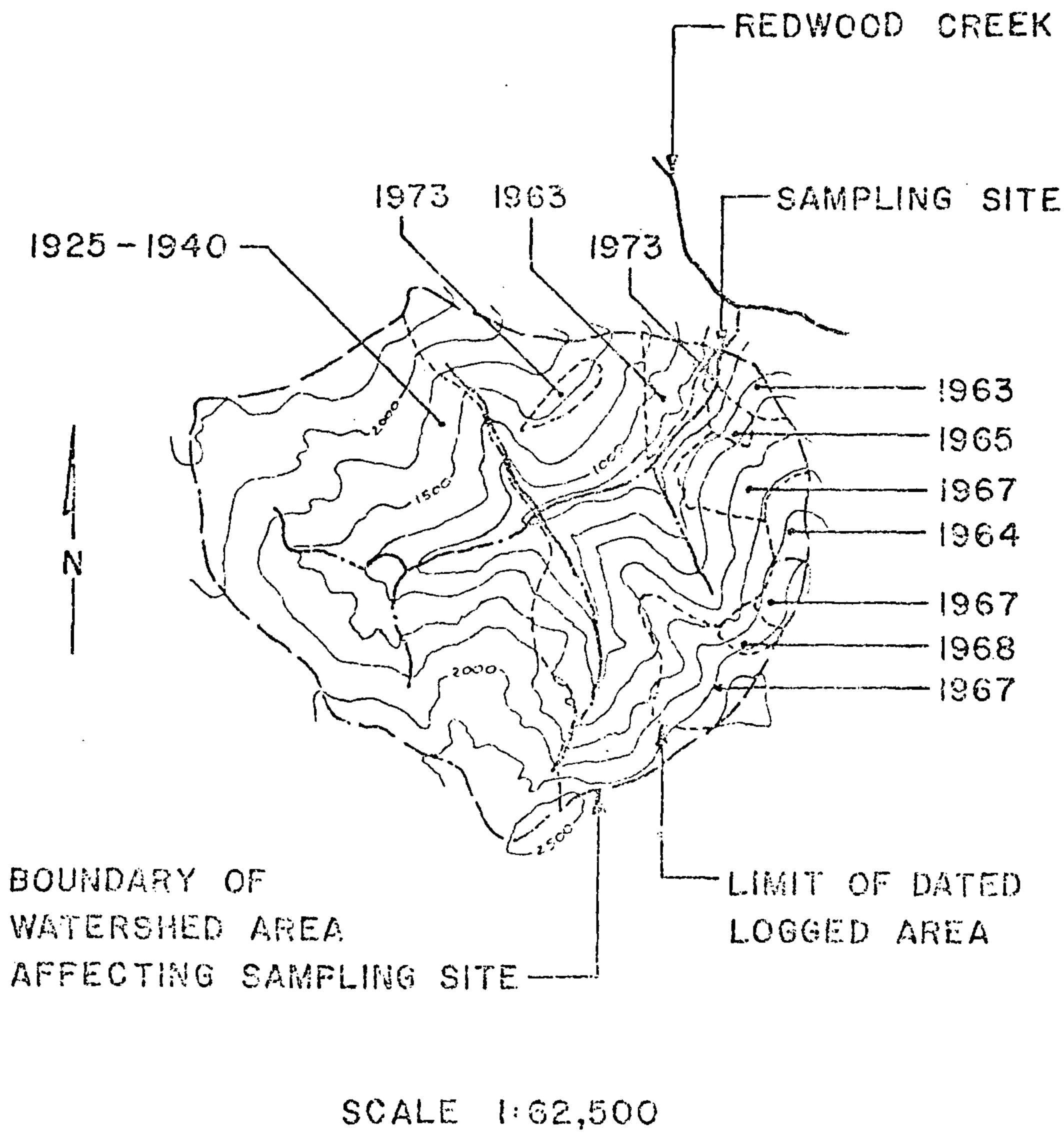

Figure 4. Watershed area influencing the sampling site at Panther Creek, Humboldt County, California

Table 1. Physical features of the watershed areas influencing the sampling sites of the three tributaries

Watershed characteristic	Little Lost Man Creek	Tributary to Lost Man Creek	Panther Creek
Area (acres)	535	1255	3860
Area (sq. mi.)	0.83	1.96	6.02
Orientation	NW	SW	NE
Mean slope (%)	30	27	36
Main channel			
Length (ft)	7300	11,100	14,750
Slope (%)	8.7	10.6	10.5
Elevation (ft)			
Maximum	1950	1500	2000
At site	1320	325	450

of vegetation these soils are characterized by a high erosion hazard.

The area's climate is characterized by dry summers and wet winters moderated by the nearby Pacific Ocean. Elford and McDonough (1964) found peak temperatures to occur in September, while 90 percent of the precipitation falls from October to April. Three weather report stations near the study areas provided temperature and precipitation data (Table 2).

Before logging, the three watersheds were vegetated primarily with coast redwood. The watershed upstream of the Little Lost Man Creek sampling site remains in the virgin condition. Logging of virgin redwood forests in the area of my study has been done almost exclusively with tractors. Felled logs were dragged to log landings serviced by haul roads. A major portion of the tributary to Lost Man Creek drainage was logged between 1964 and 1969 (Figure 5). In 1973 an area of approximately 10 acres adjacent to Panther Creek

Table 2. Climatological data from three weather report stations near the study areas, Orick, Prairie Creek Park (I), Redwood Creek near Blue Lake (II), and Hoopa (III)[a]

	I[b]	II[c]	III[d]
Elevation (ft)	161	975	350
Mean temperature (°F)			
Annual	52	-	56.9
Maximum	61.1	-	70
Minimum	42.8	-	43
Mean rainfall (in)			
Annual	70.9	60.4	57.3
Monthly			
January	11.9	11.8	11.6
February	10.7	9.5	9.2
March	9.5	7.9	7.5
April	4.7	4.4	3.2
May	4.0	3.1	2.4
June	1.5	1.1	0.9
July	0.3	0.2	0.1
August	0.5	0.4	0.4
September	1.2	1.5	1.0
October	6.2	3.7	4.5
November	8.8	7.0	6.8
December	11.7	9.9	9.8

[a]From Elford and McDonough (1964)

[b]Located 2.5 miles NW of tributary to Lost Man Creek site and 5 miles N of Little Lost Man Creek site

[c]Located 12 miles S of Panther Creek site

[d]Located 12 miles E of Panther Creek site

was logged (Figure 6). Other portions of the watershed had been logged in previous years (Figure 4).

Figure 5. A portion of the logged watershed at the tributary to Lost Man Creek study area

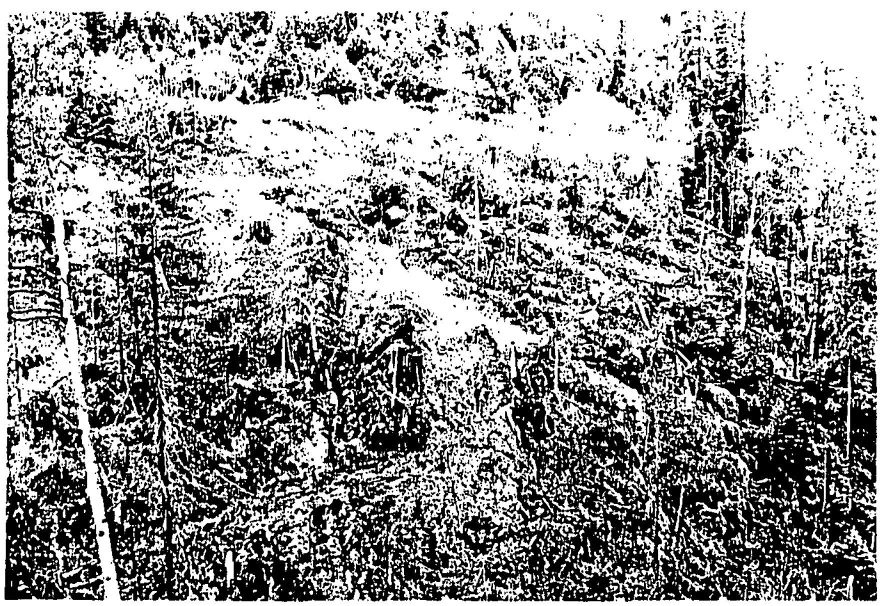

Figure 6. A portion of the area logged adjacent to Panther Creek's sampling site

METHODS

Sampling Site Stratification

McNeil (1962) found intragravel dissolved oxygen in Alaskan salmon streams varied widely. It varied both spatially and temporally, especially during periods of low streamflow. I expected such variation in my study streams and, so, I stratified the three sampling sites to reduce spatial variation and the number of samples required to achieve statistically useful results. From the discussions of Vaux (1962, 1968) I determined stream conditions whose stratification could be expected to reduce spatial variation of intragravel dissolved oxygen. I then used those criteria in the selection of my sampling sites. I selected sampling sites in riffle sections with a linear channel and relatively smooth water surface. I photographed each sampling site during summer low flow conditions to illustrate stream channel morphology, surface water profile, and streamside vegetation (Figures 7, 8, and 9). Gradients of the stream channels in the immediate vicinity of the sampling sites were similar: Little Lost Man Creek, 1.8 percent, tributary to Lost Man Creek, 1.5 percent, and Panther Creek, 1.9 percent. I did not determine permeability or depth of streambed materials, but I selected my sampling sites so that they were free of bedrock outcroppings and had no visible blankets of fine sediments.

Figure 7. Channel morphology, surface water profile, and streamside vegetation at the Little Lost Man Creek sampling site

Figure 8. Channel morphology, surface water profile, and streamside vegetation at the tributary to Lost Man Creek sampling site

Figure 9. Channel morphology and surface water profile at the Panther Creek sampling site

Stream Bottom Composition

Within each tributary's sampling site, I determined stream bottom composition at the beginning and end of the study. I used equipment and procedures similar to those described by McNeil and Ahnell (1964). After obtaining a core of the streambed with a McNeil stream bottom sampler I washed the sample through a set of standard sieves to separate the streambed materials into size classes. The sieves had the following mesh openings in mm: 26.67, 13.5, 6.73, 3.327, 1.7, 0.833, and 0.104. I used volumetric displacement to determine the contribution by each size class to the total stream bottom sample. Particles that passed through the finest mesh sieve were settled for 10 minutes in a settling cone, this allowed about 90 percent of the particles to settle (McNeil and Ahnell, 1964). I then read the volume, in ml, of the settled particles. Large volumes of water were taken by the stream bottom sampler and were used to wash samples through the sieves. The large amount of water used forced the following modification of the settling method. Water and sediment that had passed the finest mesh sieve were thoroughly mixed. I then extracted a 1.0 liter subsample of the mixture for settling as previously described. In the laboratory I determined that this modification of the settling method consistently underestimated the actual settled volume by 10 percent. To arrive at the actual volume of particles <0.104 mm in size that would have settled given sufficient time, I multiplied the settled volume twice by a factor of 1.1, once for the 10 minute settling period underestimation and once for the subsampling underestimation. Results of stream bottom sampling were biased because the 6 inch diameter opening of the stream bottom sampler excluded materials larger than that size.

Dissolved Oxygen

Intragravel dissolved oxygen concentration and water temperature were measured weekly through PVC plastic standpipes placed in the streambed to depths that ranged from 15 to 20 cm. The standpipes (Figure 10) were developed from those described by Terhune (1958), Gangmark and Bakkala (1958), and Coble (1961). Within each stream's sampling site I randomly placed five standpipes (Figure 11). I used the McNeil stream bottom sampler as a cofferdam to help prevent loss of suspendable sediments while I excavated enough stream bottom materials to place a standpipe. I placed a wooden plate with a rubber seal around the standpipe below the streambed surface to prevent surface water from traveling down the standpipe to the perforated section. In order to ensure resettlement of excavated streambed materials I allowed a week to elapse after standpipe installation before I sampled from the standpipes.

I determined the dissolved oxygen concentration of surface and intragravel water with a dissolved oxygen meter manufactured by the Yellow Springs Instrument Company. It was standardised before and after each sampling trip with the Alsterburg-Azide modification of the Winkler dissolved oxygen test (American Public Health Association, 1965).

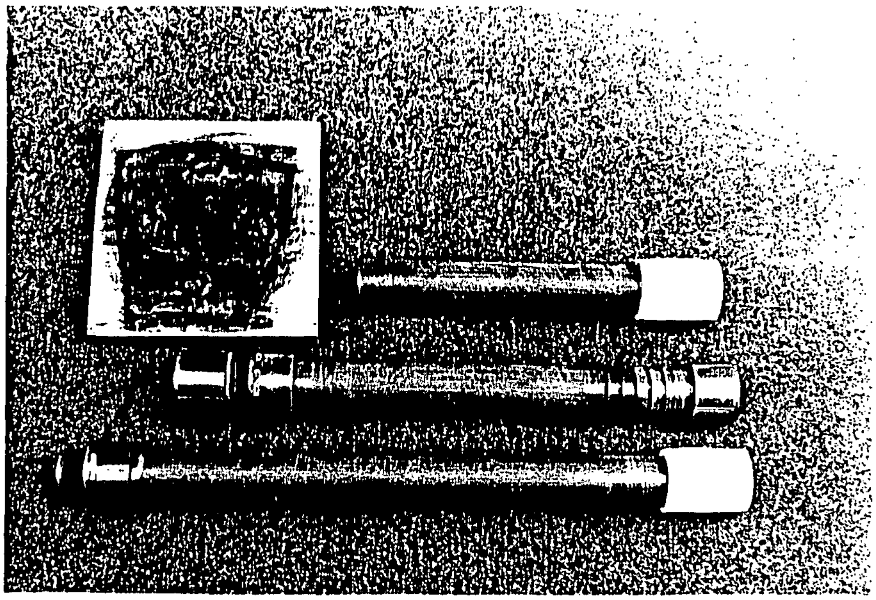

Figure 10. PVC plastic standpipe, extensions, and sealing plate used for the determination of intragravel dissolved oxygen concentration and temperature

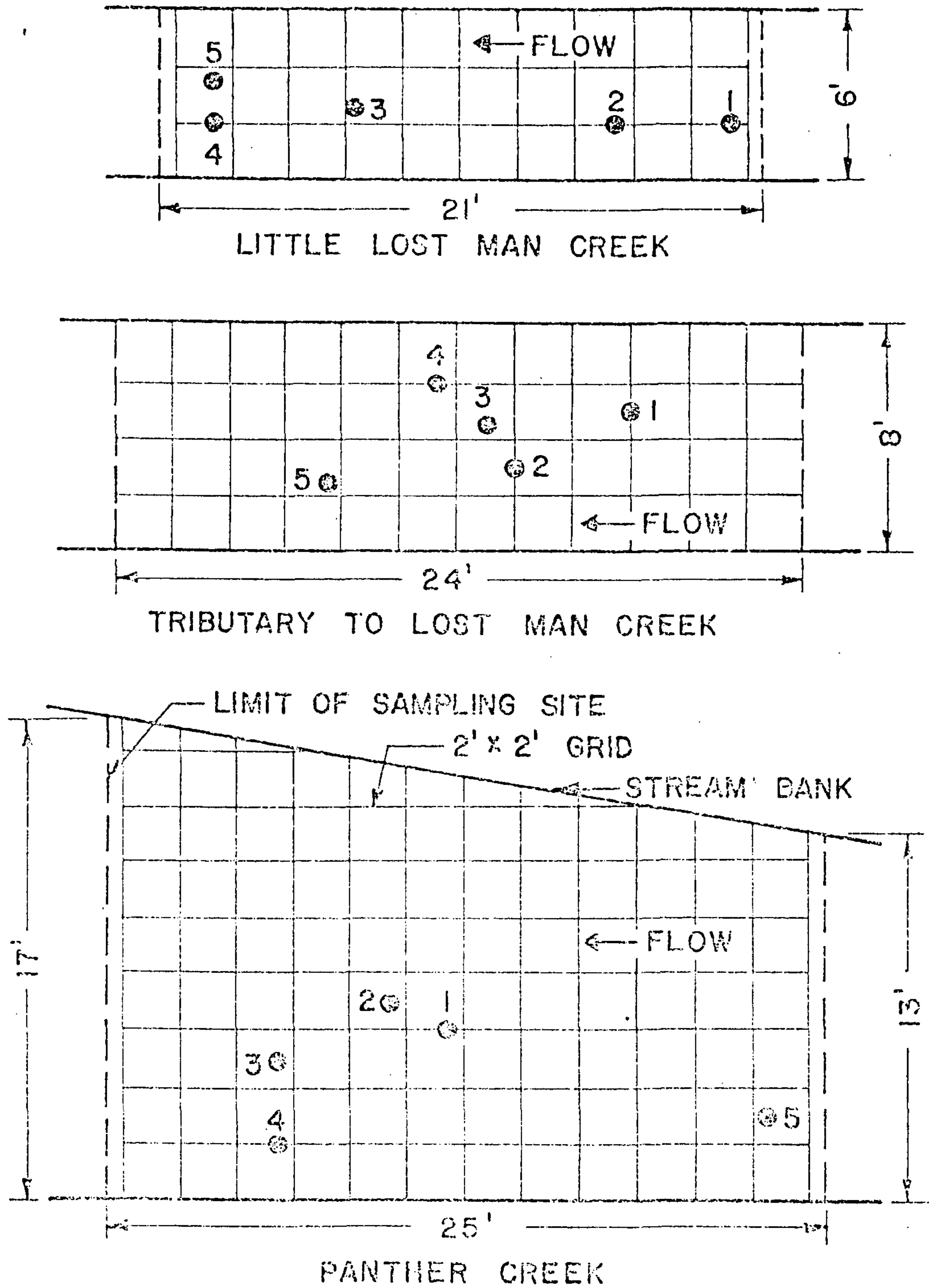

Figure 11. Location of the five standpipes of each tributary's sampling site

To sample intragravel water for dissolved oxygen concentration I installed a standpipe extension and withdrew standpipe water with a manual suction pump. This ensured a fresh sample for analysis. If the standpipe cap had stood above the surface water level I withdrew the volume of one standpipe, but if in placing the extension surface water entered the standpipe, I withdrew three standpipe volumes. I then determined the dissolved oxygen concentration with the meter adjusted for temperature and altitude.

I compensated for the effect of diel temperature changes on the solubility of oxygen in water by alternating the time of sampling at each of the three tributaries. I divided a sample day into three time blocks, 8 to 11 AM, 11 AM to 2 PM, and 2 to 5 PM, and then sampled each tributary an equal number of times in each block.

I analysed dissolved oxygen data in a number of ways in order to better illustrate regimes and interactions of surface and intragravel water dissolved oxygen conditions. For both surface and intragravel water I derived percentage saturation from the measured dissolved oxygen concentration. This procedure reduced the effects of altitude and temperature and made among site comparisons more nearly valid. I also developed an interchange percentage, the percentage that intragravel water dissolved oxygen concentration was of surface water dissolved oxygen concentration.

Temperature

I used a thermister to measure surface and intragravel water temperatures to within 0.1 °C. I recorded air temperature to within 0.5 °C with a mercury thermometer placed in a shaded location. To obtain records of fluctuations and interaction of surface and intragravel water temperatures I alternated two Belfort Instrument Company dual probe thermographs among the three tributaries. The intragravel probe was buried 20 cm deep and the surface probe was placed directly above on the streambed. A laboratory mercury thermometer, calibrated by the Geological Survey, was used to standardize my temperature measurement devices.

Streamflow

I measured streamflow with a pygmy type current meter attached to a graduated wading rod. I used stream gaging methods of the U. S. Geological Survey (1969). I also measured surface water velocity and depth upstream of each standpipe. These measurements were made on a weekly basis, except at Little Lost Man Creek from mid-September to mid-November when surface water flow ceased or was too low to measure.

RESULTS

Stream Bottom Composition

Dissimilar underlying geology and land use among the three study areas were reflected in different size ranges of stream bottom materials. Sampling sites at Little Lost Man Creek (Figure 12) and Panther Creek (Figure 13) had a wide range of particle size classes, but the tributary to Lost Man Creek sampling site (Figure 14) had mainly smaller stream bottom materials.

The summer and winter mean percentage composition of streambed materials <3.327 and <0.833 mm in size are listed in Table 3. These two size classes were most frequently encountered in the literature as having had adverse effects on intragravel conditions.

In Panther Creek, wintertime composition of streambed materials <3.327 mm in size was highly significantly greater ($U=85.0$, $p<0.01$, $df=10, 10$) than during the summer. Materials <0.833 mm in size also had a highly significantly greater ($U=85.5$, $p<0.01$, $df=10, 10$) wintertime composition. Winter streamflow eroded an unconsolidated upstream bank which resulted in deposition of a sediment layer throughout the sampling site. No significant differences existed between summer and winter streambed composition (<3.327 and <0.833 mm size classes) in the Little Lost Man Creek or tributary to Lost Man Creek sampling sites. In the winter I noted movement

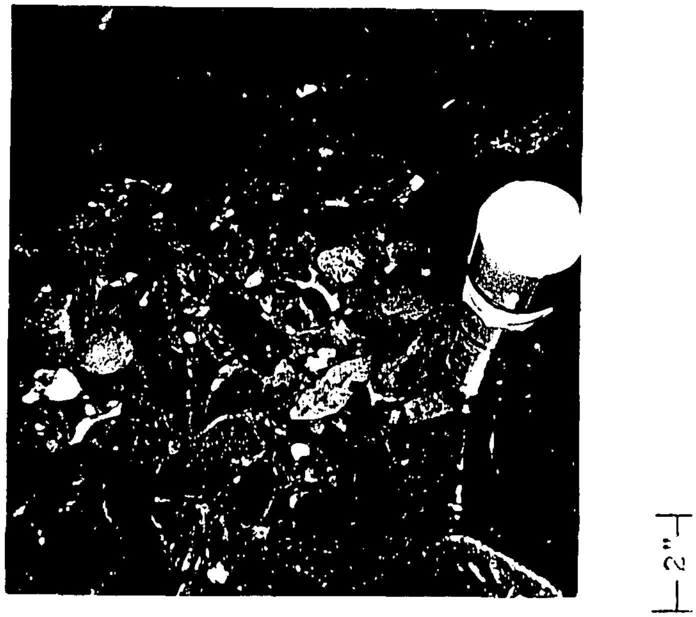

Figure 12. Wide range of streambed particle size classes in the Little Lost Man Creek sampling site

Figure 13. Wide range of streambed particle size classes in the Panther Creek sampling site

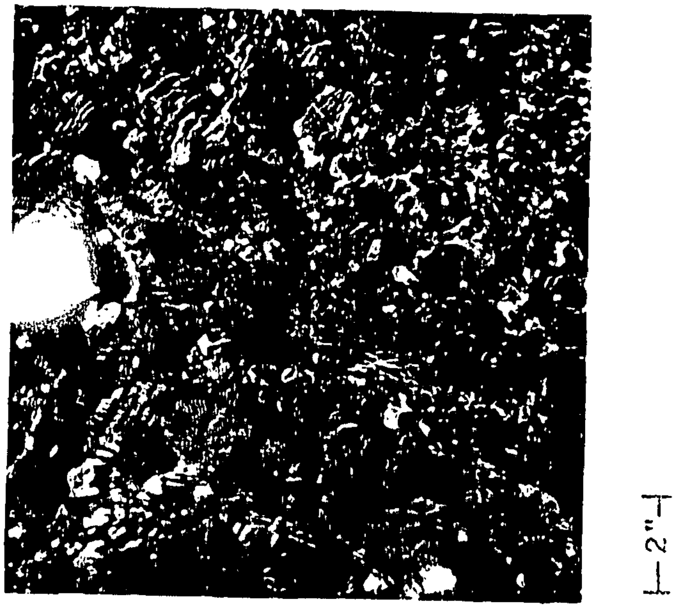

Figure 14. Restricted range of streambed particle size classes in the tributary to Lost Man Creek sampling site

Table 3. Mean percentage composition of particle size classes <3.327 and <0.833 mm in size for summer and winter stream bottom samples from the three sampling sites

Sampling site	Particle size class (mm)	Percent composition					
		Summer			Winter		
		Mean	SE	n	Mean	SE	n
Little Lost Man Creek	<3.327	27.9	2.9	10	30.1	2.6	10
	<0.833	15.1	2.0	10	17.5	2.0	10
Tributary to Lost Man Creek	<3.327	45.5	1.1	5	48.1	4.0	5
	<0.833	24.7	0.5	5	26.2	2.6	5
Panther Creek	<3.327	44.3	2.0	10	54.7	2.8	10
	<0.833	23.6	1.4	10	29.8	1.2	10

of sediment bars through the sampling site at tributary to Lost Man Creek, but stream bottom samples did not indicate any effects of such movements.

In the summer, the percentage composition of streambed materials <3.327 mm in size in Little Lost Man Creek was highly significantly less than in Panther Creek ($z=9.65$, $|diff.|=10.7$, $p<0.01$) and in tributary to Lost Man Creek ($z=11.83$, $|diff.|=12.1$, $p<0.01$); there were no significant differences between Panther Creek and tributary to Lost Man Creek. The test statistic z was derived from a non-parametric multiple comparison test for unequal sample sizes (Dunn, 1964, as cited by Hollander and Wolfe, 1973). In the winter, the percentage composition of streambed materials <3.327 mm in size in Little Lost Man Creek was highly significantly less than in Panther Creek ($z=9.65$, $|diff.|=12.6$, $p<0.01$); no significant differences existed between Little Lost Man Creek and tributary to Lost Man Creek or between Panther Creek and tributary to Lost Man

Creek.

The summertime percentage composition of streambed materials <0.833 mm in size in Little Lost Man Creek was highly significantly less than in tributary to Lost Man Creek ($z=11.83$, $|diff.|=12.1$, $p<0.01$) and significantly less than in Panther Creek ($z=7.89$, $|diff.|=8.2$, $p<0.05$); no significant differences existed between tributary to Lost Man Creek and Panther Creek. In the winter, the percentage composition of streambed materials <0.833 mm in size in Little Lost Man Creek was highly significantly less than in Panther Creek ($z=9.65$, $|diff.|=11.2$, $p<0.01$); no significant differences existed between Little Lost Man Creek and tributary to Lost Man Creek or between Panther Creek and tributary to Lost Man Creek.

Dissolved Oxygen

For each tributary I determined mean values of five dissolved oxygen categories sampled over the study period, June 26 to November 22, 1974. These are listed in Table 4 and include surface water dissolved oxygen concentration and percentage saturation, intragravel water dissolved oxygen concentration and percentage saturation, and the interchange percentage.

For samples taken throughout the study period, the mean surface water dissolved oxygen concentration in Panther Creek was highly significantly greater than that of Little Lost Man Creek ($q=6.16$, $p<0.01$, $df=57$) and significantly greater than that of tributary to Lost Man Creek ($q=3.31$,

Table 4. Mean values of five dissolved oxygen conditions sampled in the three sampling sites throughout the study period, June 26 to November 22, 1974

Dissolved oxygen condition	Little Lost Man Creek			Tributary to Lost Man Creek			Panther Creek		
	Mean	SE	n	Mean	SE	n	Mean	SE	n
Surface water									
Concentration(ppm)	9.88	0.13	20	10.31	0.13	20	10.81	0.19	20
Saturation(%)	93.8	0.75	20	99.5	0.42	20	104.1	0.96	20
Intragravel water									
Concentration(ppm)	9.64	0.06	96	6.56	0.27	100	8.39	0.29	100
Saturation(%)	91.7	0.36	96	62.5	2.56	100	80.0	2.64	100
Interchange percent	97.5	0.5	20	64.1	2.0	20	77.4	1.0	20

$p < 0.05$, df=57). Dissolved oxygen concentration of surface water in tributary to Lost Man Creek was significantly greater than in Little Lost Man Creek ($q=2.84$, $p < 0.05$, df=57).

In Panther Creek, the percentage saturation of surface water over the study period was highly significantly greater than that in tributary to Lost Man Creek ($q=5.45$, $p < 0.01$, df=∞) and Little Lost Man Creek ($q=9.24$, $p < 0.01$, df=∞). Percentage saturation of surface water in tributary to Lost Man Creek was highly significantly greater than in Little Lost Man Creek ($q=8.32$, $p < 0.01$, df=∞).

During the study period, weekly values of surface water dissolved oxygen concentration ranged thusly: Little Lost Man Creek, 9.10 to 11.35 ppm, tributary to Lost Man Creek, 9.40 to 11.40 ppm, and Panther Creek, 9.28 to 12.30 ppm (Figure 15). Ranges of weekly surface water percentage saturation were as follows: Little Lost Man Creek, 87.5 to 100.0 percent, tributary to Lost Man Creek, 95.0 to 103.0 percent, and Panther Creek, 99.0 to 112.0 percent (Figure 16). Little Lost Man Creek showed declines in both parameters during October, coinciding with cessation of surface water flow in the sampling site. The only surface water remaining was in pools that contained leaf litter. Following the initial winter storm on October 27, surface water flow resumed and dissolved oxygen concentration and percentage saturation of surface water increased. Both Panther Creek and tributary to Lost Man Creek exhibited periods of oxygen supersaturation in their surface waters. Panther Creek showed this throughout most of

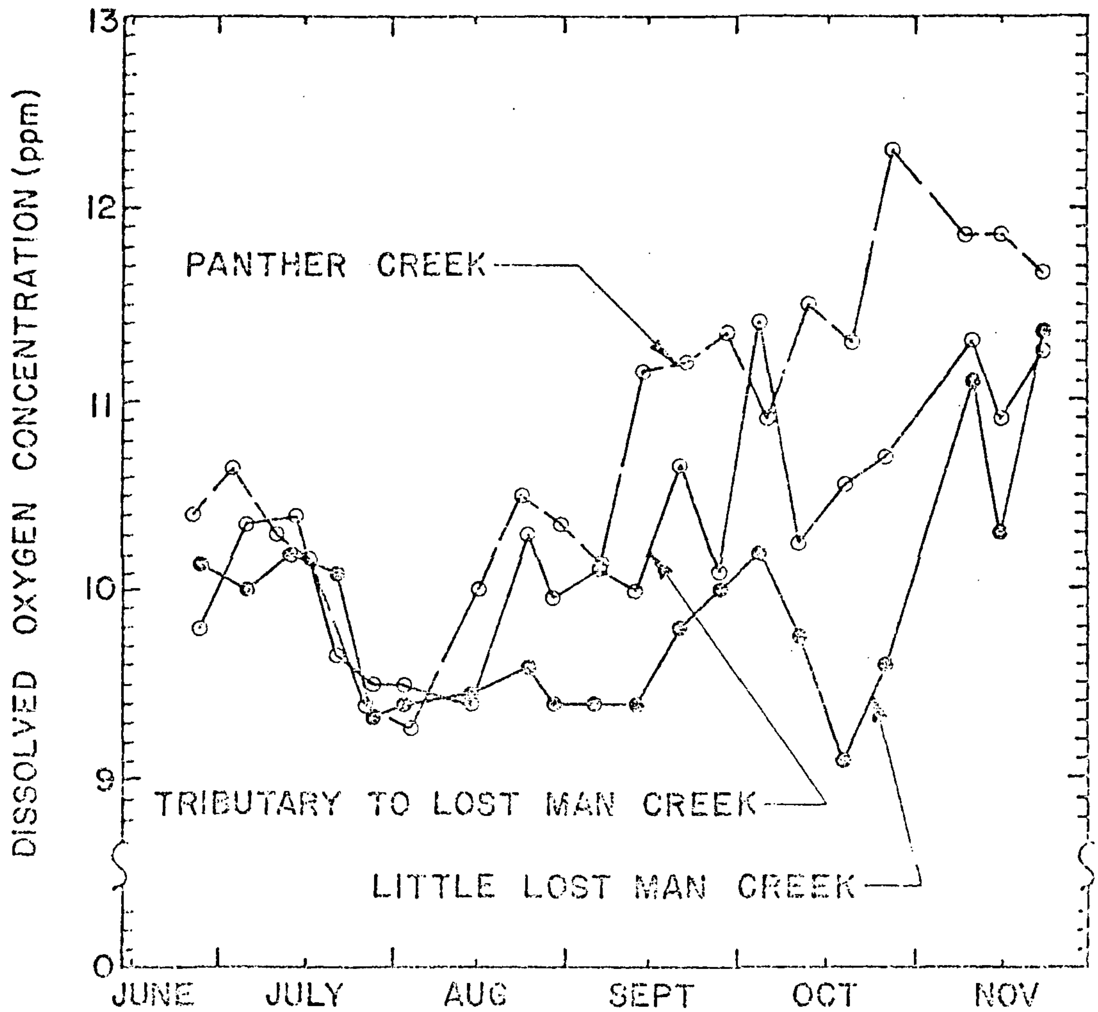

Figure 15. Weekly values of surface water dissolved oxygen concentration in the three sampling sites during the study period of June 26 to November 22, 1974

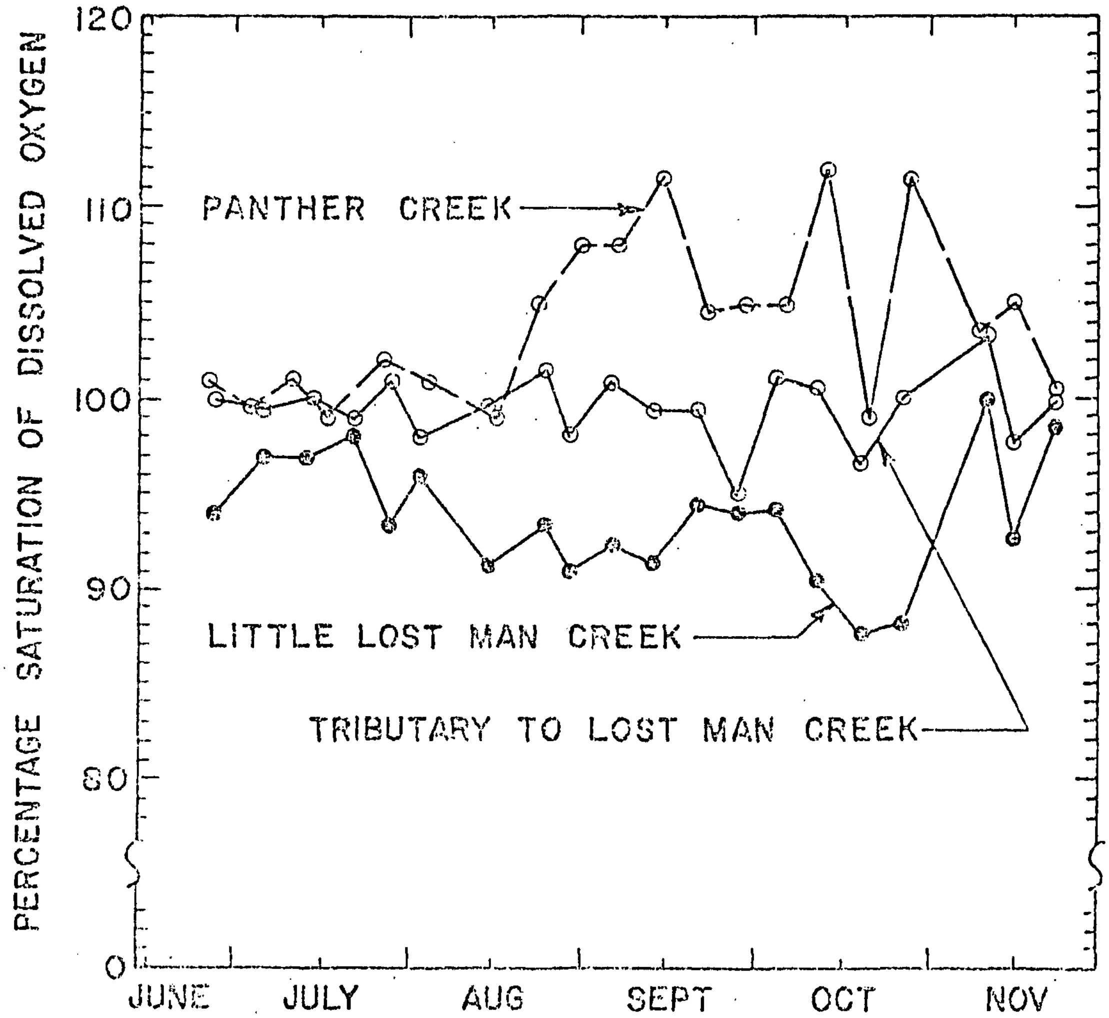

Figure 16. Weekly values of the percentage saturation of surface water dissolved oxygen concentration in the three sampling sites during the study period of June 26 to November 22, 1974

the study. I noted abundant growths of algae, Zygnema spp., in Panther Creek from June to late November. Unidentified algae growths also occurred in tributary to Lost Man Creek, but to a lesser degree than in Panther Creek. During October, in response to declining water temperatures, the sampling sites showed a tendency toward increased surface water dissolved oxygen concentration, except in Little Lost Man Creek during the October period of negligible surface water flow.

For samples taken throughout the study period, dissolved oxygen concentration of intragravel water in Little Lost Man Creek was highly significantly greater than in tributary to Lost Man Creek ($z=35.5$, $|diff.|=108.7$, $p<0.01$) and significantly greater than in Panther Creek ($z=29.0$, $|diff.|=34.5$, $p<0.05$). Intragravel dissolved oxygen concentration in Panther Creek was highly significantly greater than in tributary to Lost Man Creek ($z=35.5$, $|diff.|=78.2$, $p<0.01$).

In Little Lost Man Creek, percentage saturation of intragravel water sampled over the study period was highly significantly greater than in tributary to Lost Man Creek ($z=35.5$, $|diff.|=115.6$, $p<0.01$), but not significantly different from that in Panther Creek. Panther Creek had highly significantly greater values of intragravel water percentage saturation than did tributary to Lost Man Creek ($z=35.5$, $|diff.|=89.3$, $p<0.01$).

In Little Lost Man Creek, interchange percentage measured over the study period was highly significantly greater than in Panther Creek ($q=7.96$, $p<0.01$, $df=\infty$) and in tributary to Lost Man Creek ($q=9.65$, $p<0.01$, $df=\infty$). Panther Creek had a highly significantly greater interchange percentage than did tributary to Lost Man Creek ($q=6.46$, $p<0.01$, $df=\infty$).

Weekly mean values of dissolved oxygen concentration in the intragravel water in Little Lost Man Creek ranged from 9.00 to 11.17 ppm (Figure 17), while weekly mean percentage saturation ranged from 87.4 to 97.8 percent (Figure 18). During October, when there was no surface water flow, both parameters reached their lowest values. Surface water flow, replenished by the initial winter storm, and lowered water temperatures caused an increase in both parameters in November.

In Panther Creek, weekly mean values of dissolved oxygen concentration and percentage saturation of intragravel water ranged from 6.74 to 10.24 ppm (Figure 17) and 71.1 to 93.2 percent (Figure 18), respectively. During the period of lowest streamflow and elevated water temperatures, when intragravel conditions could be expected to decrease, supersaturated surface water increased rather than decreased intragravel water dissolved oxygen concentration and percentage saturation. Following the initial winter storms, both values declined, possibly in response to scouring away of a major portion of algae growth.

Weekly mean values of intragravel water dissolved oxygen concentration and percentage saturation in tributary to Lost Man Creek ranged from 3.24 to 7.94 ppm (Figure 17) and 28.7 to 76.3 percent (Figure 18), respectively. As at

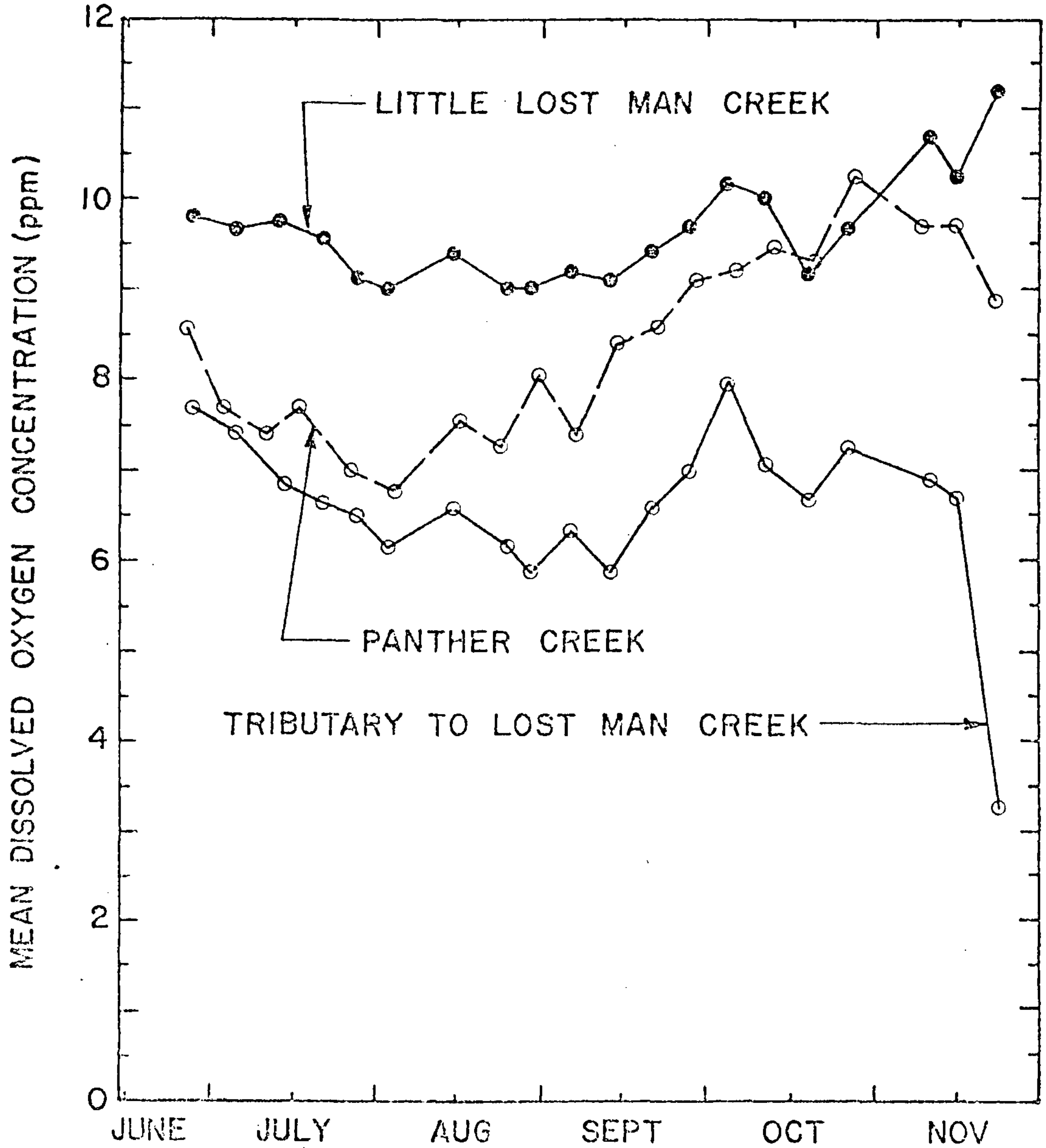

Figure 17. Weekly values of intragravel water dissolved oxygen concentration in the three sampling sites during the study period of June 26 to November 22, 1974

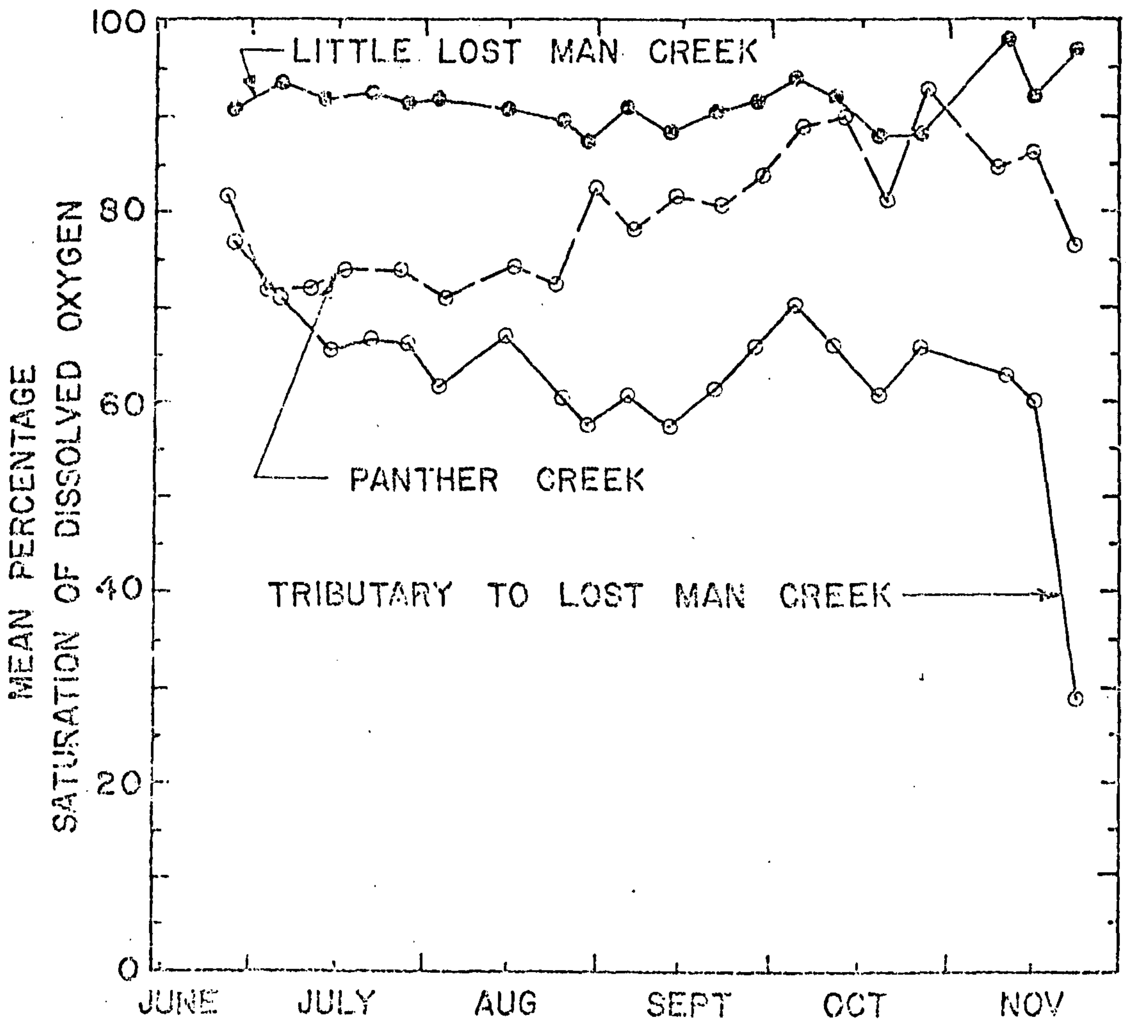

Figure 18. Weekly values of the percentage saturation of intragravel water dissolved oxygen concentration in the three sampling sites during the study period of June 26 to November 22, 1974

Panther Creek, supersaturated surface water elevated both parameters during September and October. Until the last sampling trip, intragravel conditions had not deviated markedly in tributary to Lost Man Creek, but following a number of storms that increased streamflow, mean intragravel water dissolved oxygen concentration fell to 3.24 ppm and percentage saturation to 28.7 percent. I noted a movement of fine bed-load sediments and increased turbidity during this period which may have been responsible for a reduction in interchange between surface and intragravel water.

The sampling sites were stratified with respect to stream conditions that influence interchange of surface and intragravel water. This was done to reduce spatial variation, but I found a wide range of intragravel water dissolved oxygen concentrations during sampling trips to two of the sites. In both tributary to Lost Man Creek and Panther Creek one or more standpipes delivered water with a much lower dissolved oxygen concentration than did the other standpipes. In contrast, the five standpipes in Little Lost Man Creek delivered about the same dissolved oxygen concentration (Table 5).

Temperature

For each sampling site I determined the mean values of surface and intragravel water temperatures taken over the study period (Table 6). Only in tributary to Lost Man Creek was mean surface water temperature significantly greater than that of intragravel water ($t=1.79$, $p<0.05$, $df=118$).

Table 5. Mean values of dissolved oxygen concentrations in individual standpipes of each of the three sampling sites, sampled during the study period of June 26 to November 22, 1974

Sampling site	Standpipe number	Dissolved oxygen conc. (ppm)				
		Mean	SE	Max	Min	n
Little Lost Man Creek	1	9.57	0.1	11.15	8.94	20
	2	9.49	0.1	11.15	8.78	20
	3	9.48	0.2	11.15	8.35	20
	4	9.81	0.1	11.25	8.98	18
	5	9.92	0.1	11.15	9.27	18
Tributary to Lost Man Creek	1	2.70	0.1	4.19	1.70	20
	2	4.76	0.3	7.79	1.85	20
	3	8.05	0.3	10.00	4.10	20
	4	8.55	0.3	10.30	3.95	20
	5	8.74	0.3	10.70	3.65	20
Panther Creek	1	9.29	0.3	11.50	7.00	20
	2	8.83	0.4	11.35	6.10	20
	3	10.50	0.2	11.85	9.00	20
	4	10.01	0.2	11.50	8.50	20
	5	3.31	0.3	5.00	1.05	20

Table 6. Mean values of surface and intragravel water temperatures sampled in the three sampling sites throughout the study period, June 26 to November 22, 1974

Sampling site	Temperature, °C Surface			Intragravel		
	Mean	SE	n	Mean	SE	n
Little Lost Man Creek	11.02	0.4	20	11.10	0.2	96
Tributary to Lost Man Creek	13.68	0.6	20	12.73	0.2	100
Panther Creek	13.35	0.7	20	12.96	0.3	100

Weekly surface water temperatures in Little Lost Man Creek ranged from 7.2 to 14.1 °C, those in tributary to Lost Man Creek from 9.8 to 18.0 °C, and those in Panther Creek from 7.9 to 19.1 °C (Figure 19). Weekly mean intragravel water temperatures had the following ranges; Little Lost Man Creek,

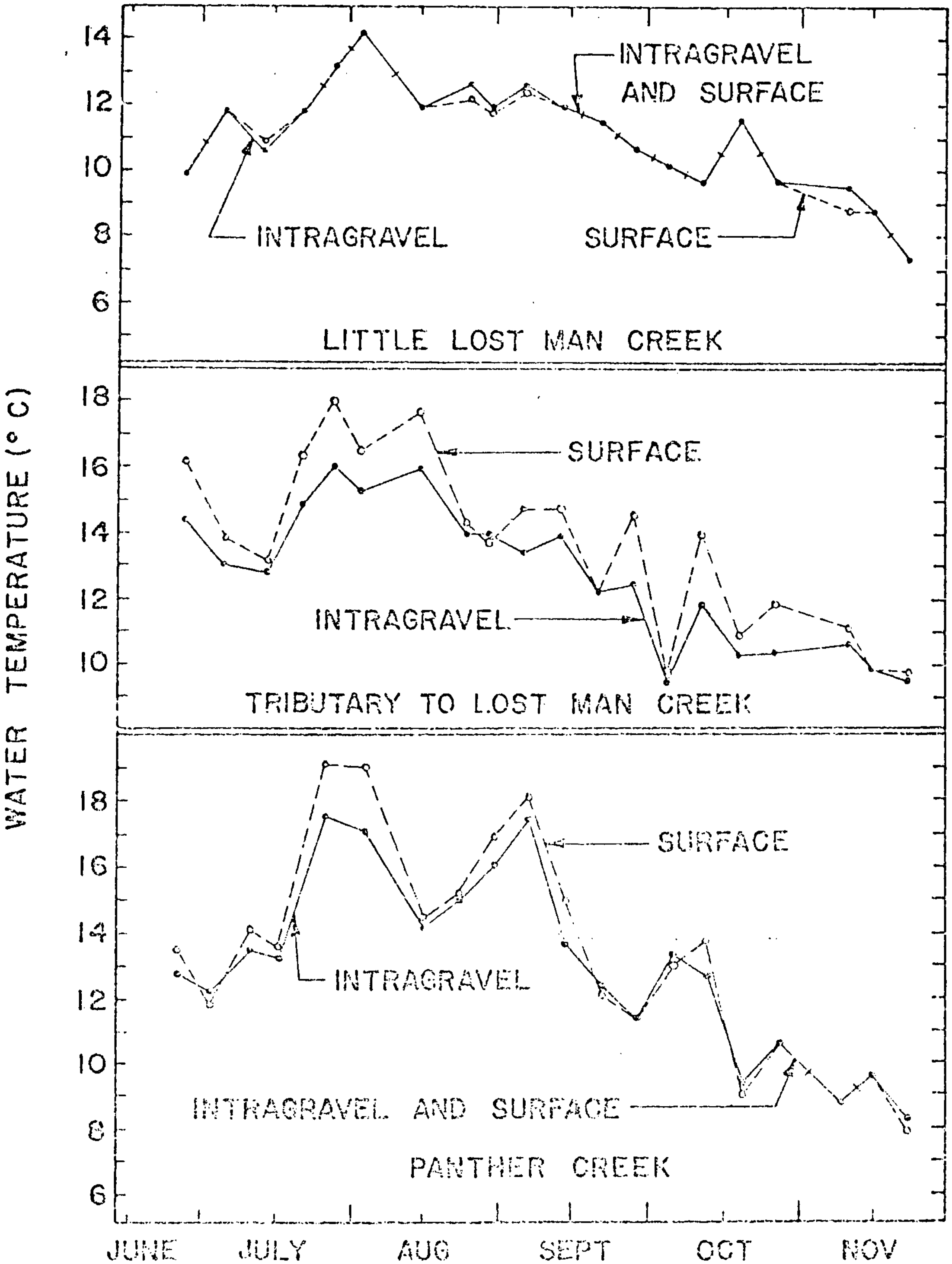

Figure 19. Weekly values of surface and intragravel water temperatures in the three sampling sites during the study period, June 26 to November 22, 1974

7.2 to 14.1 °C, tributary to Lost Man Creek, 9.5 to 16.0 °C, and Panther Creek, 8.8 to 17.6 °C (Figure 19). For each week, surface and intragravel water temperatures in Little Lost Man Creek were usually equal,,but in tributary to Lost Man Creek and Panther Creek surface water was normally warmer than intragravel water. In Little Lost Man Creek, peak water temperatures were reached in early August. In tributary to Lost Man Creek, peaks occurred in July and August and in Panther Creek peaks occurred in August and September. By late September a general decline in water temperature was apparent at the three sampling sites.

In Little Lost Man Creek, the surface water temperatures sampled over the study period were highly significantly less than those in Panther Creek ($q=5.32$, $p<0.01$, $df=\infty$) and in tributary to Lost Man Creek ($q=4.34$, $p<0.01$, $df=\infty$), no significant differences existed between Panther Creek and tributary to Lost Man Creek.

In Little Lost Man Creek, intragravel water temperatures sampled over the study period were highly significantly less than in tributary to Lost Man Creek ($z=35.5$, $|diff.|=65$, $p<0.01$) and in Panther Creek ($z=35.5$, $|diff.|=68.1$, $p<0.01$), no significant differences existed between tributary to Lost Man Creek and Panther Creek.

Thermograph records of Little lost Man Creek showed that surface and intragravel water had the same maximum (12.2 °C) and minimum (8.3 °C) temperatures over the period of record, July 6 to July 20, 1974. During the period of record at tributary to Lost Man Creek, July 26 to September 27, 1974, surface and intragravel water temperatures reached the same maximum (21.7 ° C) and minimum (8.3 ° C) values. The period of record at Panther Creek was the same as at tributary to Lost Man Creek, but revealed differences between minimum and maximum water temperatures of surface and intragravel water. Surface water temperatures ranged from 9.4 to 19.4 ° C, while intragravel temperatures ranged from 12.2 to 15.0 ° C. As the periods of record did not coincide among the three sampling sites nor were they representative of the entire study period I did not statistically analyse the thermograph data.

Differences in interchange were indicated by the thermograph patterns from the three sampling sites (Figure 20). At Little Lost Man Creek and tributary to Lost Man Creek surface and intragravel water coincided in magnitude and timing of temperature change. At Panther Creek, intragravel temperature changed less in magnitude than did surface water, and changes in temperature lagged about 3 hours behind similar changes in surface water temperature.

Streamflow

Streamflow at the three sampling sites ranged as follows: Little Lost Man Creek, <0.02 to 0.37 cfs, tributary to Lost Man Creek, 1.25 to 3.26 cfs, and Panther Creek, 0.24 to 3.15 cfs (Table 7). The decline of streamflow during the summer and fall months was reversed following the initial winter

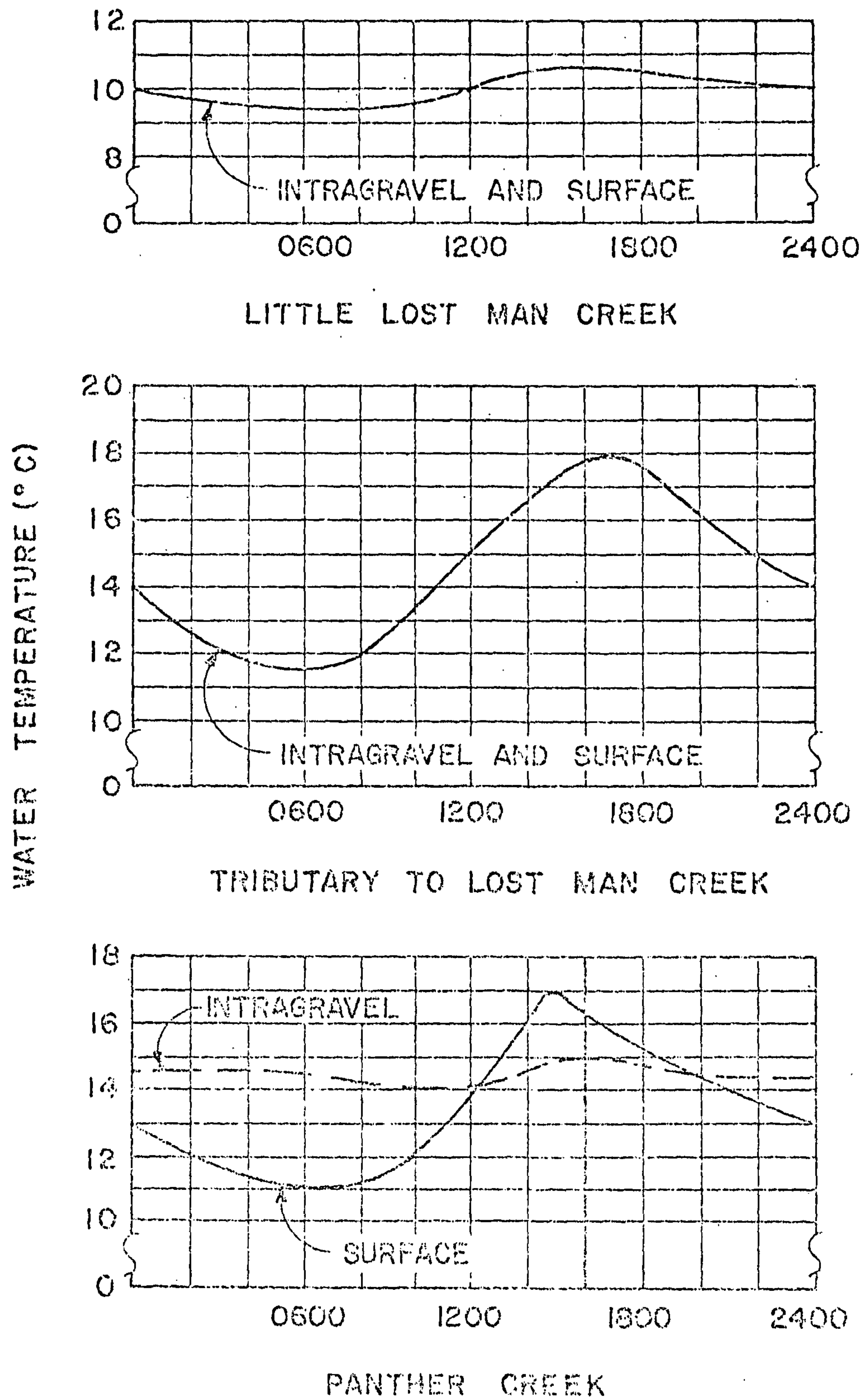

Figure 20. Representative summertime thermograph patterns of surface and intragravel water temperatures at the three sampling sites

Table 7. Streamflow in the three sampling sites during the study period, June 26 to November 22, 1974

Sampling period	Little Lost Man Creek	Tributary to Lost Man Creek	Panther Creek
June			
26 - 27	0.12	2.24	3.15
July			
3 - 5	0.13	2.32	2.58
11 - 14	0.14	1.93	2.33
17 - 21	-	2.21	2.09
26 - 27	0.08	2.14	1.41
August			
3 - 4	0.06	1.96	0.90
15 - 16	0.04	1.86	0.65
23 - 24	0.03	2.03	0.68
29 - 31	0.03	1.93	0.67
September			
6 - 7	0.03	1.73	0.44
13 - 14	0.02	1.62	0.40
21 - 22	<0.02	1.49	0.36
27 - 28	<0.02	1.38	0.28
October			
4 - 5	<0.02	1.49	0.25
11 - 12	<0.02	1.35	0.24
18 - 19	<0.02	1.25	0.25
25 - 26	<0.02	1.44	0.36
November			
8 - 9	0.05	2.00	1.58
15	0.04	1.53	0.81
22	0.37	3.26	2.68

storm on October 27.

I noted that the relative change in streamflow in tributary to Lost Man Creek was not as pronounced as in the other two sampling sites. I compared the initial to the lowest recorded streamflow and found that tributary to Lost Man Creek declined 44 percent, while Little Lost Man Creek and Panther Creek declined 100 percent and 92 percent, respectively.

I measured surface water velocity and depth upstream of each standpipe to determine if a correlation existed between those two measurements and standpipe dissolved oxygen concentration. No such correlation was evident because surface water velocity at each standpipe was variable throughout the study. In response to changing stream levels, stream bottom materials deflected surface water flow and accounted for the variability in velocity.

DISCUSSION

Stream Bottom Composition

The two streams in the logged areas, tributary to Lost Man Creek and Panther Creek, had percentages of fine sediments (<3.327 and <0.833 mm in size) in their streambeds from one and a half to two times greater than did Little Lost Man Creek, the stream in the unlogged area. A geologist pointed out that the observed differences in stream bottom composition among the three sampling sites could be reflective of differences in bedrock geology and land use, however, the relative contribution of each would not be possible to determine (personal communication, R. Janda, U. S. Geological Survey).

No comparisons with pre-logged streambed composition were possible as there were no such data for the three study streams. Studies on two Northern California coastal streams provided data for comparison. Burns (1970) reported the percentage composition of streambed materials in Godwood Creek, in an unlogged redwood watershed near Redwood National Park. He found that materials <3.327 and <0.833 mm in size constituted 30.9 and 17.7 percent of the streambed composition, respectively. The percentages did not fluctuate markedly during Burns' three year sampling program. His results compare well with the conditions I observed in Little Lost Man Creek, namely, materials <3.327 and <0.833 mm in size represented, on the average, about 29 and 16 percent of the streambed composition, respectively. Burns (1972) determined the effects of logging and road building on the streambed composition in the South Fork of Casper Creek, a coastal redwood stream. Following road construction, the percentage of materials $<$0.833 mm in size increased from 20.6 to 34.2. The following summer the percentage had returned to pre-logging levels, but 22 months afterwards the percentage was back to 28.5. Burns' results compare favorably with the composition of streambed materials $<$0.833 mm in size I observed in both tributary to Lost Man Creek and Panther Creek, namely, averages of about 25 and 27 percent, respectively.

The movement of bedload sediment in response to increased streamflow I observed in tributary to Lost Man Creek and Panther Creek exemplified a problem involved in the determination of streambed composition. The amount of fine bedload sediments in a particular area can be strongly influenced by a stream's transportive abilities which vary in response to changes in streamflow. Shapley and Bishop (1965) added sediment of some Alaskan streams and found it was removed by freshets and floods. Ringler (1970) felt that layers of fine sediments that he observed following logging operations were either flushed downstream and/or incorporated into the streambed. McNeil and Ahnell (1964) reported that spawning fish in the process of redd construction reduced fine sediment content of the redd area.

Several studies have shown that streams tended to return to their pre-logged streambed composition soon after logging operations ceased and revegetation was allowed. Sheridan and McNeil (1968) found that after two Alaskan streams had been allowed to recover from logging for five years there were no significant differences between pre and post-logging streambed composition. Platts (1972), referring to the South Fork of Idaho's Salmon River, said that streambed composition will have returned to pre-logged condition within a decade of the cessation of logging operations. Panther Creek can be expected to remain at its present condition of streambed composition or increase in levels of fine sediments because logging operations within the watershed are planned to continue. Tributary to Lost Man Creek, for six years recovering from logging, may be in the process of returning to its pre-logged streambed composition.

Dissolved Oxygen

For the overall study period, surface water in tributary to Lost Man Creek and Panther Creek had significantly higher dissolved oxygen concentrations and percentage saturations than did Little Lost Man Creek. I felt that the chief reasons for the greater amounts of dissolved oxygen in the two logged streams were their continued turbulent streamflow and, especially, the production of oxygen by periphyton that existed in both streams nearly throughout the study. I saw no periphyton in Little Lost Man Creek's sampling site. On both logged watersheds the overstory vegetation along the stream had been removed. This allowed abundant insolation to reach the stream channels. Periphyton have been known to respond to such conditions by producing supersaturated dissolved oxygen conditions in streams during daylight hours (Reid, 1961). Other factors also influence the dissolved oxygen concentration of water and need to be discussed to better explain the differences observed in this study.

Increases in altitude reduce the dissolved oxygen holding ability of water because of the reduction in atmospheric pressure associated with increased altitude (Reid, 1961). The sampling site at Little Lost Man Creek was about 1000 feet higher in altitude than the other two sampling sites, therefore Little Lost Man Creek had a lower oxygen holding capacity than did the other two sites, in regard to altitude.

Increased water temperature also reduces the dissolved oxygen holding ability of water (Reid, 1961). For the overall study, surface water temperatures at tributary to Lost Man Creek and Panther Creek were significantly higher than those in Little Lost Man Creek. Therefore, Little Lost Man Creek had a greater oxygen holding capacity than the other two sites, in regard to temperature.

Turbulent streamflow adds oxygen to streams by reaeration with atmospheric oxygen (Reid, 1961). The cessation of surface water flow that I noted in Little Lost Man Creek's sampling site resulted in a temporary decline in surface water dissolved oxygen concentration; the other two sampling sites maintained turbulent streamflow throughout the study.

For the overall study period, Little Lost Man Creek had higher levels of intragravel water dissolved oxygen concentration and percentage saturation. Tributary to Lost Man Creek, in a clear-cut watershed, had the lowest values of the two parameters. I felt that differences in interchange among the three sampling sites were primarily responsible for the observed differences in intragravel dissolved oxygen concentration and percentage saturation. From my stream bottom sampling program I found that the two logged sampling sites had greater amounts of streambed materials <0.833 mm in size. It has been demonstrated that this particle size class can impede interchange and thus reduce intragravel dissolved oxygen concentration (Vaux, 1962, 1968). The interchange percentage that I derived supported my hypothesis that interchange had been impeded at the two logged sampling sites. Little Lost Man Creek's sampling site had a highly significantly greater interchange percentage than either logged sampling site.

Intragravel water dissolved oxygen concentration has been shown to be largely dependent on interchange with surface water (Vaux, 1962, 1968). The effects of altitude, water temperature, and oxygen production by periphyton as they affect surface water dissolved oxygen concentration apply as well to intragravel water. Of interest in the two logged sampling sites was the effect that supersaturated surface water had on intragravel water dissolved oxygen concentration. Both higher water temperatures and reduced summer streamflow should have resulted in a decline in intragravel dissolved oxygen concentration, but an increase occurred due to interchange with supersaturated surface water. This was the only time where intragravel water in a logged sampling site, Panther Creek, exceeded the mean dissolved oxygen concentration of intragravel water in the Little Lost Man Creek sampling site. At this time Little Lost Man Creek had reached its lowest intragravel dissolved oxygen concentration because of the cessation of surface water flow.

The results of Oregon's Alsea Watershed Study were similar to mine with respect to intragravel dissolved oxygen concentrations. Ringler (1970) found the mean intragravel dissolved oxygen concentration in a stream in a clear-cut watershed was highly significantly less than that of one in a patch-cut watershed where 30 percent of the timber had been removed and buffer strips were retained along the perennial stream channels. He also reported that the mean percentage saturation of intragravel water dissolved oxygen was 61.8 percent in the clear-cut watershed's stream and 76.7 percent in the patch-cut watershed's stream. In the stream in the watershed that was clear-cut he found that the pre-logging intragravel dissolved oxygen concentration of streambed areas formerly occupied by redds fell 43 percent after logging of the watershed. Hall and Lantz (1969) found that during logging of the clear-cut watershed the intragravel dissolved oxygen concentration of its stream averaged 4.2 ppm, while during the same period, a stream in an unlogged control watershed averaged 9.0 ppm.

Spatial variation of intragravel dissolved oxygen concentration such as I found in both logged sampling sites has been previously reported (McNeil, 1962 and Ringler, 1970). My sampling sites were stratified to reduce spatial variation, but results at the two logged sampling sites showed that the stratification selected did not reduce spatial variation. A visual inspection of each of the sites revealed no apparent reason for a low dissolved oxygen concentration in a particular standpipe.

Temperature

For the overall study period, surface water temperatures in Little Lost Man Creek were highly significantly less than those in tributary to Lost Man Creek or Panther Creek. The differences among the mean surface water temperatures were small, 2.7°C was the greatest difference. Differences in maximum recorded surface water temperatures were larger, Little Lost Man Creek was 4.1 and 5.0°C cooler than tributary to Lost Man Creek or Panther Creek, respectively.

The differences in mean and maximum surface water temperatures were reflective of the differences in overstory and streamside vegetation among the three watersheds. Brown and Krygier (1967) determined that the amount of solar radiation reaching a stream's surface largely determined the stream temperature, not convective or conductive heat transfer. The virgin watershed of Little Lost Man Creek shaded the stream throughout the day and kept daily water temperature changes to within 1.0°C. Although a majority of Panther Creek's watershed is forested, the sampling site was located in logged areas with sparse overstory and streamside vegetation. The stream channel is oriented in a northeast direction and was thus exposed to direct solar radiation for a major part of the day during the summer months. In both Panther Creek and tributary to Lost Man Creek, typical differences between daily maximum and minimum surface water temperatures were 6.0°C. Tributary to Lost Man Creek had little overstory vegetation on its clear-cut watershed, but streamside vegetation was abundant. A low understory of streamside vegetation has been found to be able to protect a small stream from large changes in water temperature (California State Water Resources Control Board, 1973).

No prior water temperature data were available for the three study streams so I could not determine the effects of logging on stream temperature. However, several studies have been conducted on the effects of logging on stream temperature. Meehan, et al. (1969) compared stream temperatures in two Alaskan streams, an unlogged control stream and one with 25 percent of its area clear-cut. They found that temperatures in the logged stream had increased significantly during August and September. In a stream in a clear-cut watershed of Oregon's Alsea Study, the maximum pre-logging stream temperature increased from 16°C to 30°C following removal of logging debris from the stream channel and burning of the watershed (Hall and Lantz, 1969). In the same stream, Brown (1970) found that surface water temperatures had declined in response to shade provided by the regrowth of streamside vegetation. Referring to the Alsea Study, Brown and Krygier (1970) reported that the patch-cut watershed, with buffer strips of vegetation along the perennial stream channels, showed no significant increases in water temperature after logging. Burns (1972) reported that the maximum surface water temperature in Casper Creek, a California coastal stream, had increased from a pre-logging level of 13.9°C to 21.1°C after streamside canopy was harvested. Brown (1970) cautioned that results of stream temperature studies should not be broadly applied because many factors can influence a stream's water temperature and its response to vegetative alterations; most studies have not been designed to adequately assess all of these factors.

For the overall study period, intragravel water temperatures in Little Lost Man Creek were highly significantly less than in tributary to Lost Man Creek or Panther Creek. Intragravel water temperature has been found to be primarily influenced by the temperature of surface water which interchanges with intragravel water. Sheridan (1961) found a high correlation (r=0.99) between the temperatures of surface and intragravel water. Before logging had occurred in Oregon's Alsea Study, Coble (1961) found surface and intragravel water had nearly equal temperatures. In a recent study on a clear-cut stream in the Alsea Study, Ringler (1970) found that mean intragravel and surface water temperatures were about equal, but he found large diurnal fluctuations in both surface and intragravel water temperatures. He also found that changes in intragravel water temperature in response to changes in surface water temperature lagged from 2 to 6 hours. The Panther Creek thermograph record showed a similar 2 to 5 hour lag time, but there was no such lag time in either Little Lost Man Creek or tributary to Lost Man Creek.

Considering the variations in interaction of surface and intragravel water temperatures that Ringler (1970) found, I did not feel that I had sufficient data with which to compare differences in interchange among the sampling sites with regard to their temperature response patterns. The response patterns of intragravel and surface water temperatures were indicative of spatial variation within the streambed and not inherent differences in interchange among the three sampling sites.

Streamflow

Annual streamflow has been increased after logging operations, especially clear-cutting (Hibbert, 1967). Rothacher (1970) felt that removal of less than 20 percent of a watershed's forest cover would not result in any detectable changes in streamflow. Meehan, et al. (1969) found no significant increases in annual streamflow in two Alaskan streams whose watersheds had 25.4 and 19.8 percent of their forest cover removed.

Hibbert (1967) reported cases where summer streamflow had increased in response to the removal of substantial portions of forest vegetation. Increased streamflow, due mainly to lessened transpirational losses, may be short-lived where revegetation proceeds rapidly (Rothacher, 1970). The lack of prior streamflow data made it impossible to determine if summer streamflow had been augmented in the two logged watersheds of my study. The lesser percentage decline in streamflow in tributary to Lost Man Creek, as compared to Panther Creek, may be a result of the large differences in the amount of area logged on the two watersheds within the past 15 years. In that period, the study area of tributary to Lost Man Creek has had nearly 100 percent of its forest cover removed, while only about 20 percent of Panther Creek's watershed has been logged. In addition, the watershed area affecting the sampling site at Panther Creek is about three times as large as that affecting tributary to Lost Man Creek's; yet the latter maintained a greater minimum streamflow than did the former.

Fishery Implications

The four stream conditions investigated in this study, stream bottom composition, dissolved oxygen concentrations and temperatures of surface and intragravel waters, and streamflow, are subject to alteration by logging and associated road construction. Such alterations can have adverse effects on fish populations which reside in streams that drain logged watersheds, or use such streams for spawning and nursery grounds.

Excessive amounts of fine sediments in salmon streams have impaired development and survival of eggs and alevins incubating in the streambed (Cordone and Kelly, 1961). Koski

(1966), as cited by Ringler (1970), found that fine sediments (<3.33 mm in size) entombed coho salmon fry within the streambed, thereby reducing survival to emergence. Under laboratory conditions, Hall and Lantz (1969) found that the survival of coho salmon and steelhead trout alevins was reduced as the percentages of materials 1 to 3 mm in size was increased in the streambed, even though intragravel dissolved oxygen was maintained near saturation.

Streambed permeability was reduced as interstices among streambed materials became blocked by bedload and/or intercepted suspended sediments (Cooper, 1965). McNeil and Ahnell (1964) found an inverse relationship existed between permeability and the percentage of streambed materials <0.833 mm in size (Figure 21). Vaux (1962) stated that reduced permeability lessened the interchange of surface and intragravel water, thereby reducing intragravel dissolved oxygen concentration.

Another effect of streambed sedimentation has been the additional biochemical oxygen demand of organic matter contained in fine sediments. Ringler (1970) found a positive correlation (r=0.75) between the amount of organic material in stream bottom samples and the percentage of materials <3.327 mm in size in the streambed.

Intragravel water provides oxygen for the respiration of developing eggs and alevins, while apparent velocity of flow delivers that dissolved oxygen and transports metabolic wastes away from the eggs and alevins (Coble, 1961). Dissolved

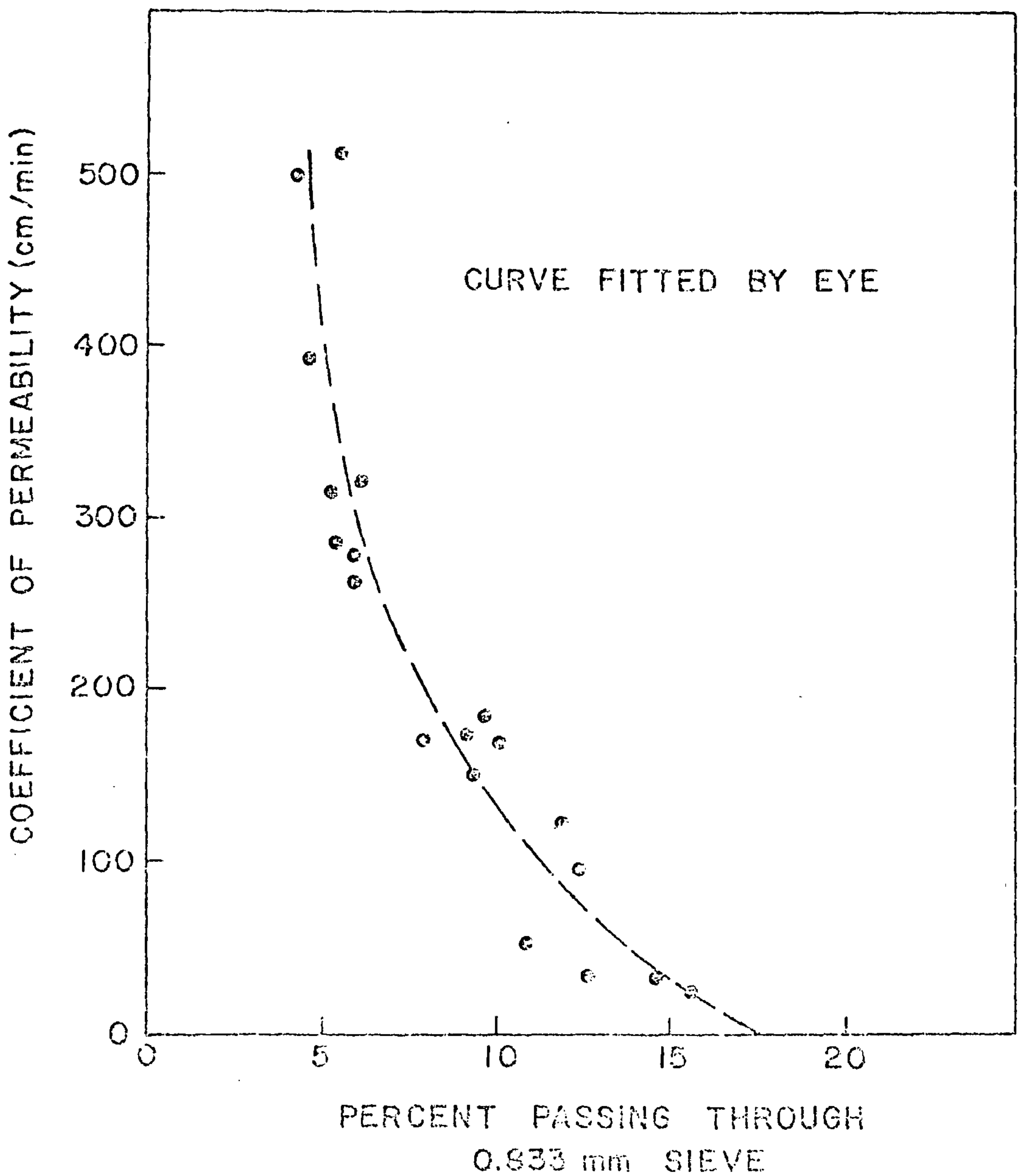

Figure 21. Effect of streambed materials <0.833 mm in size on streambed permeability (from McNeil and Ahnell, 1964, as cited by Philips, 1970)

oxygen concentration was more important to the growth of coho salmon and steelhead trout embryos than was apparent velocity of flow (Shumway, et al., 1964). Survival of steelhead trout eggs was positively correlated with intragravel dissolved oxygen concentration and apparent velocity of flow (Coble, 1961). Gangmark and Bakkala (1960) studied the relationship between mortality of king salmon embryos and intragravel dissolved oxygen concentration in artificial spawning channels. They found that when the dissolved oxygen concentration was less than 5 ppm, mortality was 37.8 percent, but when the dissolved oxygen concentration was greater than 13 ppm, mortality was reduced to only 3.9 percent. Under laboratory conditions, survival to emergence of steelhead trout and king salmon embryos has been achieved at low concentrations of intragravel dissolved oxygen (2.4 to 2.6 mg/l), but the embryos were much reduced in size as compared to those raised at 11 mg/l (Silver, et al., 1963). Under laboratory conditions, Shumway, et al. (1964) determined that reduced intragravel dissolved oxygen concentration and apparent velocity of flow resulted in delayed egg hatching, additional egg and alevin mortality, and reduced alevin size of steelhead trout and coho salmon. Mason (1969) found that coho salmon raised at low dissolved oxygen concentrations were not as competitive in an artificial stream as were other coho salmon raised at high dissolved oxygen concentrations of intragravel water.

The surface and intragravel water temperatures that I measured in my study were, in most cases, less than 20 °C, a temperature determined by Brett (1952) to be the upper limit for maintanence of normal physiological processes for Pacific salmon (Oncorhynchus spp.) and steelhead trout. On six occasions, tributary to Lost Man Creek exceeded 20 °C, and once the surface water temperature reached 21.7 °C, but none of the occasions lasted more than 2 hours.

Considering the summertime water temperatures that I measured, I would not expect wintertime temperatures to present any problems to salmonid eggs and alevins in any of the three study streams. I measured the temperature of surface and intragravel water in Little Lost Man Creek in the winter and found them to range between 5 and 10 °C. Combs and Burrows (1957) determined that king salmon embryos developed normally between 1.7 and 15.6 °C.

Streamflow increases, if only moderate, could improve intragravel conditions through increased interchange. Wickett (1954) reported that apparent velocity of intragravel water was directly related to stream gage height. McNeil (1962) found intragravel dissolved oxygen concentration in Alaskan streams was increased by greater streamflow.

If substantial streamflow increases occurred the effects on aquatic organisms could be harmful. Channel scour and sediment deposition may crush and suffocate eggs and alevins within the streambed (Chapman, 1962). Sheridan and McNeil (1960) blamed extensive gravel movement in an Alaskan stream for a 95 percent mortality rate for salmonid embryos. The instances of bedload movement I observed in tributary to Lost

Man Creek and Panther Creek indicated potential problems for salmonid eggs that may be spawned in those two streams.

For Pacific Coast streams in general, increased summer streamflow had the potential to yield more fish production (Chapman, 1961). He was not able to determine the specific reasons for this, but felt that additional stream surface area caught more terrestrial insects, increased streambed area provided for additional production of algae and aquatic insects, and fish had more living space. In a more recent opinion, Burns (1971) felt that due to natural fluctuations in fish populations any change from the observed mean that was less than 50 percent was difficult to attribute to watershed disturbances such as logging operations.

CONCLUSIONS

This research revealed differences in surface and intragravel water conditions between streams in logged and unlogged watersheds. Panther Creek and tributary to Lost Man Creek, both logged, had from one and a half to two times greater percentages of fine sediments (<0.833 mm in size) in their streambeds than did the unlogged stream, Little Lost Man Creek. In the two logged streams, the interchange of surface and intragravel water was impeded by the excessive quantities of fine sediments in their streambeds.

The three streams contained surface water dissolved oxygen concentrations near saturation, yet only Little Lost Man Creek contained intragravel water that was near saturation. Little Lost Man Creek also maintained a high interchange percentage. These two conditions indicated that a high rate of interchange existed in Little Lost Man Creek. In contrast, intragravel water percentage saturation and interchange percentage were reduced in the two logged streams.

Surface and intragravel water temperatures in Panther Creek and tributary to Lost Man Creek were warmer than those in Little Lost Man Creek. Due to the removal of streamside vegetation, the logged streams received more insolation than did the well-shaded, unlogged stream. Temperatures did not reach levels considered lethal or sub-lethal to salmonid fish.

No assessment of the fishery resources of these three streams has been made, but it would appear, in general, that salmonid production in the three streams would not be limited by streambed fine sediment levels, or surface and intragravel water dissolved oxygen concentrations and temperatures. Some localized problems could occur in spawning areas of the two logged streams because of the movement of bedload sediments which could create temporary reductions in intragravel dissolved oxygen concentrations.

LITERATURE CITED

American Public Health Association. 1965. Standard methods for the examination of water and wastewater. 12th ed. New York. 769 p.

Brett, J. R. 1952. Temperature tolerance of young Pacific salmon. J. Fish. Res. Board Can. 9: 265-323.

Brown, G. W. 1970. Predicting the effect of clear-cutting on stream temperature. J. Soil and Water Conservation. 25(1): 11-12.

———, and J. T. Krygier. 1967. Changing water temperatures in small mountain streams. J. Soil and Water Conservation. 22(6): 242-244.

———, and ———. 1970. Effects of clear-cutting on stream temperature. Water Resources Research. 6(4): 1133-1139.

Burns, J. W. 1970. Spawning bed sedimentation studies in northern California streams. Calif. Fish and Game. 56(4): 253-270.

———. 1971. The carrying capacity for juvenile salmonids in some northern California streams. Calif. Fish and Game. 57(1): 44-57

———. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Amer. Fish. Soc. 101(1): 1-17.

California Department of Water Resources. 1965. North coastal area investigation. Appendix C. Fish and wildlife. 364 p.

California State Water Resources Control Board. 1973. A method for regulating timber harvest and road construction activity for water quality protection in northern California. Vol. II. 96 p.

Chapman, D. W. 1961. Factors determining production of coho salmon, Oncorhynchus kisutch, in three Oregon streams. Ph. D. thesis. Oregon State University. Corvallis. 214 p.

———. 1962. Effects of logging upon fish resources of the west coast. J. Forestry. 60(8): 533-537.

Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on the survival of steelhead trout embryos. Trans. Amer. Fish. Soc. 90: 469-474.

Combs, B. D. and R. E. Burrows. 1957. Threshold temperatures for the normal development of chinook salmon eggs. Prog. Fish-Cult. 19: 3-6.

Cooper, A. C. 1965. The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevin. Int. Pacific Salmon Comm. Bull. 18. 71 p.

Cordone, A. J. and D. W. Kelly. 1961. The influences of inorganic sediment on the aquatic life of streams. Calif. Fish and Game. 47(2): 189-228.

Elford, R. C. and M. R. McDonough. 1964. The climate of Humboldt and Del Norte counties. Humboldt-Del Norte Counties Agricultural Extension Service. Univ. of Calif. Eureka, Calif. 34 p.

Gangmark, H. A. and R. G. Bakkala. 1958. Plastic standpipe for sampling streambed environment of salmon spawn. U. S. Fish Wildl. Serv., Spec. Sci. Rep.-Fish. No. 261. 21 p.

————, and ————. 1960. A comparative study of unstable and stable (artificial channel) spawning streams for incubating king salmon at Mill Creek. Calif. Fish and Game 46(2): 151-164.

Hall, J. D. and R. L. Lantz. 1969. The effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. pp. 355-375. In T. G. Northcote (ed.). Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries. Univ. of British Columbia. Vancouver.

Hibbert, A. R. 1067. Forest treatment effects on water yield. pp. 527-543. In Sopper and Lull (ed.). International symposium on forest hydrology. Pergamon Press. Oxford, England.

Hollander, M. and D. A. Wolfe. 1973. Nonparametric statistical methods. John Wiley and Sons. New York. 503 p.

Mason, J. C. 1969. Hypoxial stress prior to emergence and competition among coho salmon fry. J. Fish. Res. Board Can. 26: 63-91.

McNeil, W. J. 1962. Variations in the dissolved oxygen content of intragravel water in four spawning streams of Southeastern Alaska. U. S. Fish Wildl. Serv., Spec. Sci. Rep.-Fish. No. 402. 15 p.

————, and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U. S. Fish Wildl. Serv., Spec. Sci. Rep.-Fish. No. 469. 15 p.

Meehan, W. R., W. A. Farr, D. M. Bishop, and J. H. Patric. 1969. Some effects of clear-cutting on salmon habitat of two southeast Alaskan streams. USDA Forest Serv. Res. Pap. PNW-82. 45 p.

Philips, R. W. 1970. Effects of sediment on the gravel environment and fish production. pp. 64-74. In A symposium - forest land uses and stream environment. 1971. Continuing Education Publications. Oregon State Univ. Press. Corvallis.

Platts, W. S. 1972. Sediment in a salmon steelhead environment. Prog. Rep. II. U. S Forest Serv. 106 p.

Reid, G. K. 1961. Ecology of inland waters and estuaries. Van Nostrand Reinhold Co. New York. 375 p.

Ringler, N. H. 1970. Effects of logging on the spawning bed environment in two Oregon coastal streams. M.S. Thesis. Oregon State Univ. Corvallis. 96 p.

Rothacher, J. C. 1970. Regimes of streamflow and their modification by logging. pp. 40-54. In A symposium - forest land uses and stream environment. 1971. Continuing Education Publications. Oregon State Univ. Press. Corvallis.

Shapley, S. P. and D. M. Bishop. 1965. Sedimentation in a salmon stream. J. Fish. Res. Board Can. 22: 919-928.

Sheridan, W. L. 1961. Temperature relationships in a pink salmon stream in Alaska. Ecology 42: 91-98.

———, and W. J. McNeil. 1960. Effects of logging on the productivity of pink salmon streams in Alaska. pp. 21-23. In Research in Fisheries. 1959. Univ. Washington. College of Fish. Contrib. 51.

———, and ———. 1968. Some effects of logging on two salmon streams in Alaska. J. Forestry. 66(1): 128-133.

Shumway, D. L., C. E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Amer. Fish. Soc. 93: 342-356.

Silver, J., C. E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Amer. Fish. Soc. 92(4): 327-343.

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

U. S. Department of Agriculture. 1970. Water, land, and related resources, North Coastal area of California and portions of southern Oregon. Appendix No. 1. Sediment yield and land treatment. USDA. Portland, Ore. 143 p.

U. S. Fish and Wildlife Service. 1960. A preliminary survey of fish and wildlife resources of northwestern California. USDI. Portland, Ore. 104 p.

U. S. Geological Survey. 1969. Discharge measurement at gaging stations. 65 p.

Vaux, W. G. 1962. Interchange of stream and intragravel water in a salmon spawning riffle. U. S. Fish Wildl. Serv., Spec. Sci. Rep.-Fish. No. 405. 11 p.

———. 1968. Intragravel flow and interchange of water in a streambed. U. S. Fish Wildl. Serv. Fish. Bull. 66: 479-489.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Board Can. 11: 933-953.

———. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Board Can. 15: 1103-1126.

APPENDIX A

Summer and Winter Stream Bottom Composition at the Three Sampling Sites

Little Lost Man Creek[a]

Size class (mm)	Summer composition (%)				Winter composition (%)			
	Mean	SE	Max	Min	Mean	SE	Max	Min
26.67	39.2	3.8	58.6	22.1	39.6	4.0	56.7	12.0
13.50	12.4	1.2	20.7	8.3	11.2	1.2	18.5	6.4
6.73	11.5	1.0	18.2	8.3	10.2	1.1	16.0	6.6
3.33	9.0	0.7	12.4	6.7	8.9	1.0	16.0	5.5
1.70	8.8	0.8	13.7	6.1	6.8	0.5	9.4	4.3
0.833	4.0	0.5	6.8	2.3	5.8	0.6	8.6	3.8
0.104	4.2	0.6	7.1	1.6	6.9	1.0	11.7	2.3
<0.104	10.8	1.4	17.4	4.5	10.6	1.2	19.5	6.5
<3.33	27.9	2.9	43.6	15.3	30.1	2.6	45.7	21.4
<0.833	15.1	2.0	23.1	7.0	17.5	2.0	30.5	10.1

Tributary to Lost Man Creek[b]

Size class (mm)	Summer Mean	Summer SE	Summer Max	Summer Min	Winter Mean	Winter SE	Winter Max	Winter Min
26.67	13.2	1.0	15.3	10.1	15.5	4.6	27.0	3.2
13.50	14.8	1.2	17.6	11.3	12.8	1.0	13.0	12.6
6.73	14.4	0.5	15.5	12.6	12.9	0.4	13.9	11.7
3.33	12.2	0.8	13.8	9.3	10.7	0.4	12.0	9.5
1.70	12.1	1.1	15.5	9.3	9.8	0.8	12.6	7.9
0.833	8.8	1.1	12.4	6.4	12.1	1.0	15.6	10.5
0.104	17.3	1.3	21.2	13.8	20.4	2.1	24.9	14.9
<0.104	7.4	1.0	10.7	4.9	5.8	0.7	8.0	4.1
<3.33	45.5	1.1	48.5	42.4	48.1	4.0	58.6	38.2
<0.833	24.7	0.5	26.1	23.3	26.2	2.6	31.1	19.8

Panther Creek[a]

Size class (mm)	Summer Mean	Summer SE	Summer Max	Summer Min	Winter Mean	Winter SE	Winter Max	Winter Min
26.67	24.3	2.8	41.3	11.4	17.6	2.3	29.5	8.1
13.50	11.7	0.9	16.2	8.1	8.4	1.5	17.0	3.4
6.73	10.3	1.0	14.4	4.3	9.0	0.7	13.3	6.2
3.33	9.5	0.8	13.4	6.4	10.3	0.8	16.2	7.8

APPENDIX A (continued)

Size class (mm)	Summer composition (%)				Winter composition (%)			
	Mean	SE	Max	Min	Mean	SE	Max	Min
1.70	10.8	0.7	14.5	7.8	12.1	1.2	18.4	5.7
0.833	9.8	1.0	14.6	3.7	12.7	1.3	16.2	3.1
0.104	11.7	0.9	15.1	7.1	14.0	0.9	18.5	10.5
<0.104	11.9	1.0	16.2	5.6	15.9	0.8	19.4	11.1
<3.33	44.3	2.0	54.8	32.7	54.7	2.8	65.3	35.9
<0.833	23.6	1.4	31.3	18.9	29.8	1.2	34.4	21.8

[a]Summer and winter sample size was 10.

[b]Summer and winter sample size was five.

APPENDIX B

Weekly Dissolved Oxygen Concentration and Percent Saturation of Intragravel Water at the Three Sampling Sites

Little Lost Man Creek[a]

Date		Dissolved oxygen (ppm)				Percent saturation			
		Mean	SE	Max	Min	Mean	SE	Max	Min
June	27	9.82	0.1	10.00	9.52	90.8	0.8	92.5	88.0
July	5	9.64	0.1	9.93	9.35	93.6	1.1	96.5	91.0
	13	9.75	0.1	10.12	9.51	92.0	1.2	96.0	89.5
	21	9.54	0.1	9.89	9.22	92.6	1.3	96.0	89.5
	27	9.13	0.2	9.51	8.71	91.6	1.3	95.0	88.0
Aug	3	9.00	0.2	9.40	8.42	91.9	1.8	96.0	86.0
	15	9.38	0.1	9.80	9.05	91.0	1.3	95.0	88.0
	24	9.02	0.2	9.41	8.35	89.3	1.9	93.0	82.5
	29	9.00	0.1	9.27	8.75	87.4	0.8	90.0	85.0
Sept	6	9.18	0.1	9.45	8.85	91.0	1.2	93.0	87.5
	13	9.09	0.2	9.43	8.50	88.3	1.6	91.5	82.5
	21	9.41	0.1	9.65	9.26	90.7	0.7	93.0	89.0
	27	9.71	0.2	10.05	9.15	91.7	1.7	95.0	86.5
Oct	4	10.16	0.1	10.40	9.90	94.0	0.9	96.0	91.5
	11	9.97	0.1	10.15	9.75	91.8	0.5	93.0	90.5
	18	9.13	0.05	9.20	9.10	87.8	0.3	88.5	87.5
	25	9.65	0.1	9.80	9.55	88.5	0.8	90.0	87.5
Nov	9	10.68	0.1	10.90	10.35	97.8	0.3	99.0	97.0
	15	10.23	0.05	10.30	10.05	91.8	0.5	92.5	90.0
	22	11.17	0.05	11.25	11.15	97.2	0.2	98.0	97.0

Tributary to Lost Man Creek[b]

Date		Mean	SE	Max	Min	Mean	SE	Max	Min
June	27	7.71	0.9	9.18	4.19	76.3	9.2	91.0	41.0
July	5	7.39	1.3	9.20	2.69	71.1	12.1	88.5	26.0
	14	6.80	1.1	9.10	3.10	65.3	10.4	86.5	30.0
	21	6.65	1.2	8.99	2.30	66.5	12.1	90.0	23.0
	27	6.47	1.2	8.59	2.40	66.0	11.7	87.5	24.5
Aug	3	6.15	1.3	8.60	1.70	61.6	12.4	86.0	17.5

APPENDIX B (continued)

Date		Dissolved oxygen (ppm)				Percent saturation			
		Mean	SE	Max	Min	Mean	SE	Max	Min
Aug	15	6.54	1.2	8.70	2.30	66.9	12.6	89.0	23.5
	24	6.16	1.2	8.28	2.30	60.3	11.9	84.0	22.5
	29	5.85	1.2	8.55	2.05	57.4	12.0	84.0	20.0
Sept	6	6.27	1.3	8.46	2.35	60.6	12.2	82.0	23.0
	13	5.84	1.3	8.55	2.00	57.3	12.6	84.0	19.5
	21	6.55	1.4	9.10	2.35	61.4	13.2	85.0	22.5
	27	6.98	1.4	9.30	2.75	66.0	12.8	87.5	26.5
Oct	4	7.94	1.5	10.70	3.20	70.2	13.3	94.5	28.5
	11	7.06	1.4	9.65	3.35	65.9	12.7	90.0	31.5
	18	6.70	1.3	9.10	3.10	60.3	11.5	82.0	28.0
	25	7.25	1.4	9.70	3.30	65.5	12.3	88.0	30.0
Nov	9	6.89	1.6	10.15	2.20	62.7	14.9	92.5	20.0
	15	6.71	1.2	8.95	3.65	60.0	11.0	80.0	32.5
	22	3.24	0.9	4.10	1.85	28.7	3.8	36.5	16.5
Panther Creek[b]									
June	26	8.56	1.1	9.95	4.16	82.0	10.7	95.5	39.5
July	3	7.68	1.7	10.12	1.05	71.8	15.7	94.5	10.0
	11	7.41	1.4	9.62	2.00	72.1	13.8	94.5	19.0
	17	7.69	1.4	9.91	2.35	74.2	13.5	96.0	22.5
	26	6.99	1.3	9.00	2.20	74.5	13.8	96.5	22.0
Aug	4	6.74	1.2	9.20	2.39	71.1	13.7	99.0	24.0
	16	7.56	1.4	10.02	2.60	74.3	13.2	98.5	26.0
	23	7.26	1.3	9.77	2.85	72.6	12.5	97.5	28.5
	31	8.05	1.3	10.35	3.25	82.7	13.4	108.0	33.0
Sept	7	7.40	1.3	10.05	2.65	78.2	14.1	107.0	27.0
	14	8.38	1.4	10.95	3.05	81.5	13.5	107.0	30.0
	22	8.57	1.3	11.00	3.90	80.5	11.3	103.0	38.0
	28	9.08	1.3	11.15	4.05	83.6	11.4	102.0	39.0
Oct	5	9.20	1.1	10.70	5.00	89.0	10.3	103.5	48.5
	12	9.44	1.3	10.95	4.45	90.1	12.0	106.0	42.5

APPENDIX B (continued)

Date		Dissolved oxygen (ppm)				Percent saturation			
		Mean	SE	Max	Min	Mean	SE	Max	Min
Oct	19	9.22	1.3	11.10	4.30	81.2	10.8	97.5	39.0
	26	10.24	1.3	11.85	5.00	93.2	11.8	108.5	46.0
Nov	8	9.70	1.4	11.70	4.25	84.7	11.8	102.0	38.0
	15	9.73	1.4	11.70	4.25	86.3	12.2	103.5	38.0
	22	8.86	1.7	11.45	2.35	76.6	14.1	98.5	21.0

[a]Sample size per day was five, except for October 18 and 25 when it was three.

[b]Sample size per day was five.