1995

Interchange of Surface and Intragravel Water in Redwood Creek, Redwood National Park, California

By PAUL F. WOODS

GEOMORPHIC PROCESSES AND AQUATIC HABITAT IN THE REDWOOD CREEK BASIN, NORTHWESTERN CALIFORNIA

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1454–T

CONTENTS

ILLUSTRATIONS

TABLE

INTERCHANGE OF SURFACE AND INTRAGRAVEL WATER IN REDWOOD CREEK, REDWOOD NATIONAL PARK, CALIFORNIA

By Paul F. Woods

ABSTRACT

The dissolved-oxygen concentrations of surface and intragravel water were sampled to investigate the interchange of surface and intragravel water in Redwood Creek, a major coastal stream that flows through Redwood National Park. Dissolved-oxygen concentrations were sampled weekly at three sites from June to November, 1974. In August 1974, streambed samples were taken at the three sites to determine the percentage composition of sediment particles, particularly those smaller than 0.833 millimeter.

There were no significant differences among the dissolved-oxygen concentrations of surface water at the three sampling sites. However, the intragravel water at the sampling site farthest downstream had significantly lower dissolved-oxygen concentrations than did the two upstream sampling sites. It was concluded, therefore, that the interchange of surface and intragravel water at the downstream sampling site was less efficient than at the two upstream sites.

The streambed samples revealed only slight differences in percentage composition of sediment particles smaller than 0.833 millimeter; thus, the data could not be used to explain the reduced interchange at the downstream sampling site. The reduced interchange at this sampling site was attributed to its smooth streambed surface, which was densely covered with periphytic algae.

INTRODUCTION

The commercial and sport fisheries of California's north coastal region rely on anadromous salmonid fish such as king salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and steelhead rainbow trout (*O. mykiss*). Streambed gravels used by these fish for spawning have been affected adversely by deposition of sediment attributable to timber harvest operations, another principal industry of the region (Cordone and Kelly, 1961; Hall and Lantz, 1969; California State Water Resources Control Board, 1973).

Extensive research has been conducted on the relation of streambed sediment to survival of salmonid eggs spawned in the streambed. While in the streambed, the developing eggs and alevins (newly hatched juveniles) require an adequate interchange of surface and intragravel water to provide them with dissolved oxygen and to flush away their metabolic wastes. Reductions in interchange have been found to reduce the survival rate of salmonid eggs and alevins (Coble, 1961; Shumway and others, 1964). McNeil and Ahnell (1964) found that permeability was reduced as the percentage composition of sediment finer than 0.833 mm increased in the streambed. Increased sedimentation of streambeds, therefore, has the potential to reduce survival of salmonid eggs and alevins.

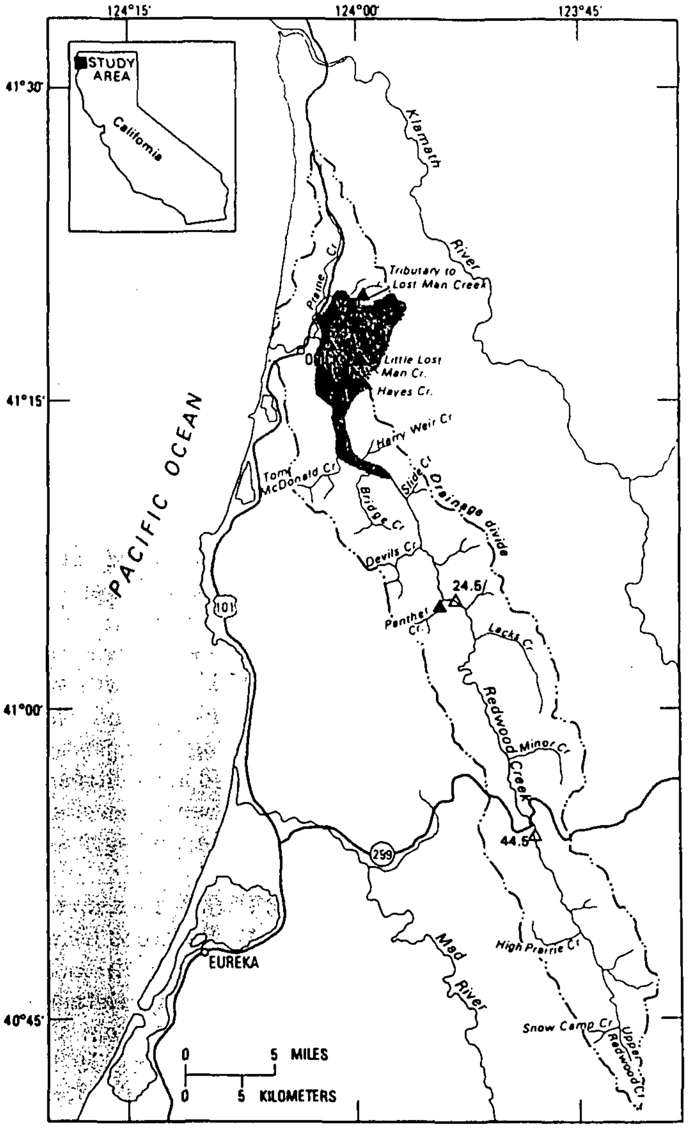
A major part of Redwood National Park lies within the Redwood Creek drainage basin (fig. 1). Redwood Creek is a major coastal stream accessible to anadromous salmonid fish via its mouth near Orick (fig. 1). Detailed descriptions of the Redwood Creek drainage basin and Redwood Creek are included in Janda and others (1975).

An assessment of the intragravel environment of Redwood Creek and some of its tributaries was included in a study of Redwood National Park. Intragravel water-quality conditions in the following three tributaries have been described by Woods (1980): tributary to Lost Man Creek, Little Lost Man Creek, and Panther Creek (fig. 1).

The study reported here was designed to collect data on intragravel water quality and to compare interchange of surface and intragravel water at three sampling sites on Redwood Creek. Samples were collected during 1974 and analyzed for dissolved-oxygen concentrations and temperatures of surface and intragravel water and the percentage composition of streambed sediment. The data were then used to assess interchange between surface and intragravel water.

METHODS

For this study, samples were collected in riffle areas at the following three sites on Redwood Creek: river mile



EXPLANATION

REDWOOD CREEK UNIT OF REDWOOD NATIONAL PARK

△5.3 SAMPLING SITE (this study) AND RIVER MILE

▲ SAMPLING SITE REPORTED IN WOODS (1980)

FIGURE 1.—Redwood Creek drainage basin showing locations of sampling sites.

5.3, downstream from the mouth of Hayes Creek; river mile 24.5, upstream from the mouth of Panther Creek; and river mile 44.5, adjacent to U.S. Geological Survey streamflow-measurement station number 11481500 (fig. 1). Samples were collected from June 26 to November 9, 1974. Large streamflow precluded sampling during the winter.

Dissolved-oxygen concentrations and temperatures of surface and intragravel water were sampled weekly. One

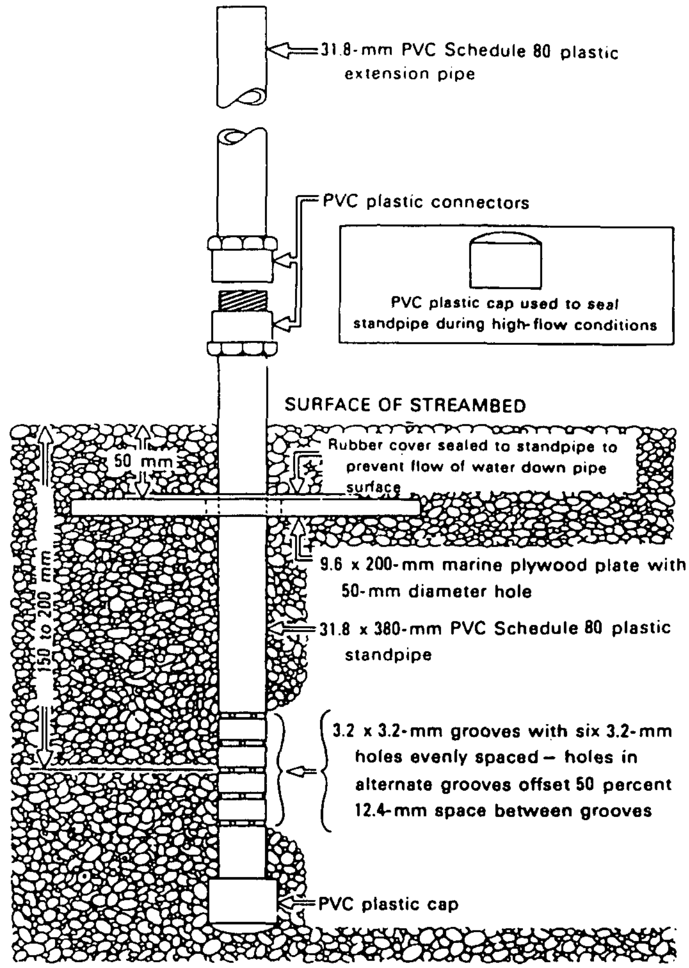


FIGURE 2.—Standpipe, extension, and sealing plate used to sample intragravel water for dissolved-oxygen concentration and temperature.

middepth sample of surface water was taken because water depths did not exceed 610 mm. Intragravel water was sampled in place using polyvinyl chloride (PVC) plastic standpipes (fig. 2). The standpipes were modifications of those described by Terhune (1958), Gangmark and Bakkala (1958), and Coble (1961). In early June, five standpipes were randomly placed in riffle areas at each sampling site. Prior to sampling, one standpipe volume of water was gently pumped from each standpipe to ensure a fresh sample. Dissolved-oxygen concentrations and temperatures were measured with a dissolved-oxygen meter and thermister lowered into the standpipe. The meter was calibrated with the Alsterburg-Azide modification of the Winkler dissolved-oxygen test (Brown and others, 1970) before and after each sampling trip. The interchange of surface and intragravel water was expressed as a percentage with the following equation:

$$P=\frac{I}{S}\times 100.0$$

where:

P is interchange percentage,

I is mean dissolved-oxygen concentration of intragravel water, in milligrams per liter, and

S is dissolved-oxygen concentration of surface water, in milligrams per liter.

During August 1974, the percentage composition of streambed materials at each sampling site was estimated by using procedures and equipment described by McNeil and Ahnell (1964). A core of the streambed was separated into size classes with seven sieves that ranged in mesh from 26.67 to 0.104 mm. These sieves were chosen to conform to previously reported methods used in intragravel research. The contribution of each size class to the core sample was determined by wet volumetric displacement. Materials that passed the 0.104-mm mesh were measured in a graduated settling cone. Results of streambed sampling were biased because the core sampler excluded materials larger than 152.4 mm.

Nonparametric statistical analysis was used to test for and locate significant differences in all the data. The tests included the Kruskal-Wallis test (Sokal and Rohlf, 1969) and two multiple comparison tests, one for equal sample sizes (Zar, 1974) and one for unequal sample sizes (Dunn, 1964, as cited by Hollander and Wolfe, 1973).

RESULTS

The dissolved-oxygen concentrations of surface water ranged from 8.3 to 11.6 mg/L among the three sampling sites, whereas the mean dissolved-oxygen concentrations of intragravel water ranged from 4.1 to 11.3 mg/L (fig. 3). The three sampling sites did not differ significantly in their surface-water dissolved-oxygen concentrations, but the mean concentrations of dissolved oxygen in intragravel water were significantly lower ($p < 0.01$) at river mile 5.3 than those measured at the other two sampling sites. River miles 24.5 and 44.5 showed no significant differences in their mean concentrations of intragravel dissolved oxygen.

Interchange percentages at river mile 5.3 ranged from 44.5 to 61.5; they were never less than 86 percent at the other two sampling sites (fig. 4). There were no significant differences in interchange percentages between river miles 24.5 and 44.5; however, both had significantly larger ($p < 0.01$) interchange percentages than did river mile 5.3.

Surface-water temperatures ranged from 9.0 to 26.0 °C, and mean temperatures of intragravel water ranged from 9.0 to 26.0 °C among the three sampling sites (fig. 5). Surface-water temperatures did not differ significantly among sampling sites.

Mean temperatures of intragravel water at river miles 24.5 and 44.5 were significantly warmer ($p < 0.05$) than those at river mile 5.3. The temperatures of surface and intragravel water frequently were equal or within 0.5 °C at each of the two upstream sampling sites; however, such was not the case at river mile 5.3. Prior to mid-September, intragravel water at river mile 5.3 generally was cooler than surface water, but after mid-September intragravel-water temperatures exceeded surface-water temperatures by as much as 5 °C.

The percentage composition of streambed material at the three sampling sites is listed in table 1. An additional size class, finer than 0.833 mm, was added to the table because an inverse correlation between streambed permeability and this size class has been reported by McNeil and Ahnell (1964). No statistical tests were applied to the data in table 1 because of the small sample size. River mile 44.5 had a larger percentage of streambed material finer than 0.833 mm than either of the other two sampling sites. Visual observations of the streambed revealed that cobbles and gravels predominated at river miles 24.5 and 44.5; pebbles and sand predominated at river mile 5.3.

DISCUSSION

This study compared dissolved-oxygen concentrations of surface and intragravel water to determine the percentage of interchange between the two kinds of water. A complete evaluation of such interchange, insofar as it can be determined by measurement of dissolved-oxygen concentrations, would require in-depth study of the many physical, chemical, and biological processes that affect dissolved-oxygen concentrations of water. Only selected physical processes were studied in this project.

Within the streambed, dissolved oxygen is physically supplied by inflow of surface and ground waters. Interchange of surface and intragravel water is largely controlled by three characteristics of the streambed: configuration, thickness of permeable material, and permeability (Vaux, 1962, 1968). Surface water moves into the streambed where the bed has a convex configuration; intragravel water moves out of the streambed at concave configurations. Vaux also found that the movement of surface water into the streambed is promoted by an increase in the thickness of permeable material or an increase in streambed permeability in the direction of flow. None of the three streambed characteristics discussed by Vaux (1962, 1968) were quantified in this study. However, streambed configuration was qualitatively assessed, and indirect evidence for permeability was provided by data on percentage composition (by size) of streambed sediment.

The streambeds at the three sampling sites did not have distinct concave or convex configurations. The

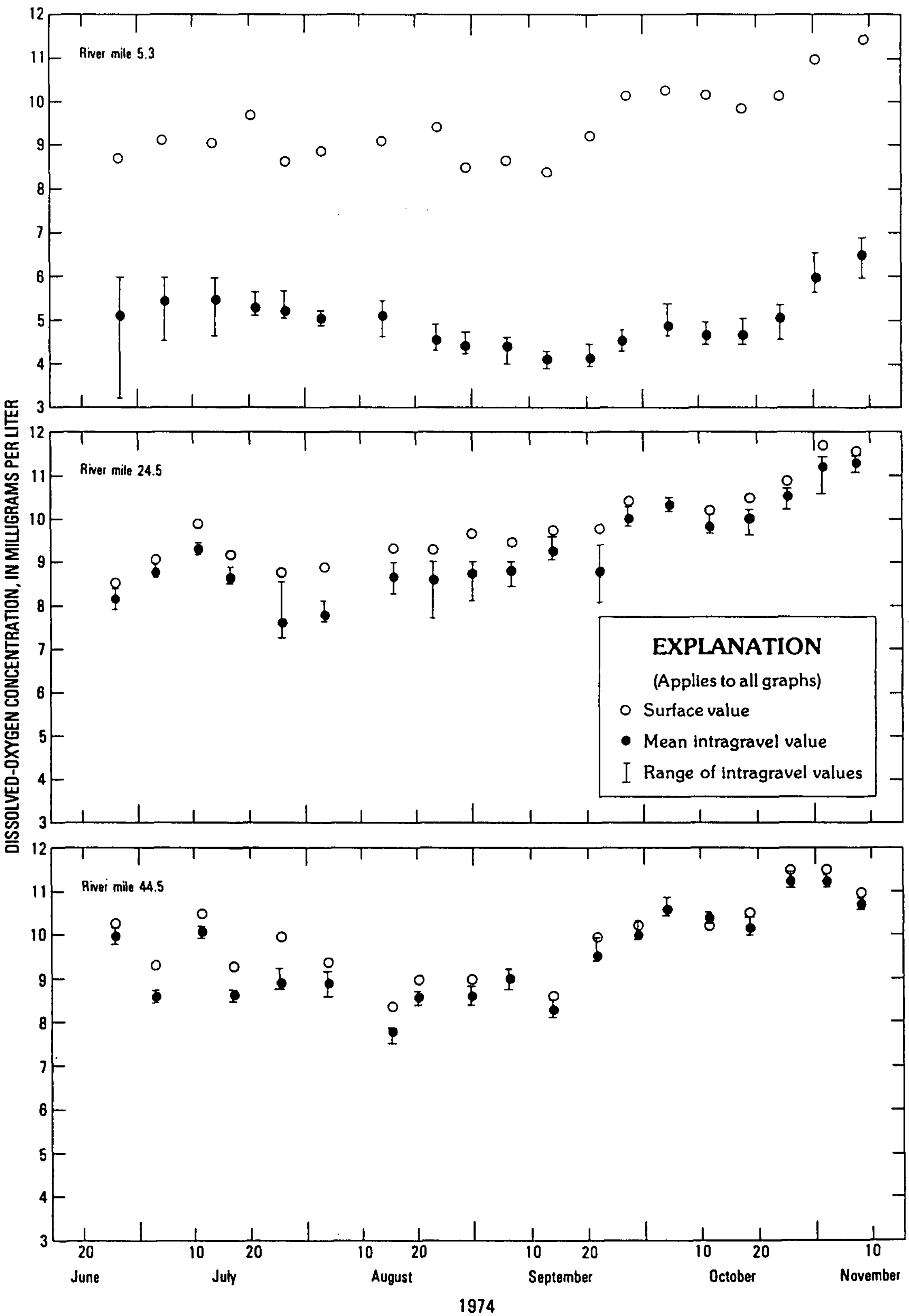


FIGURE 3.—Dissolved-oxygen concentrations of surface and intragravel water at three sampling sites.

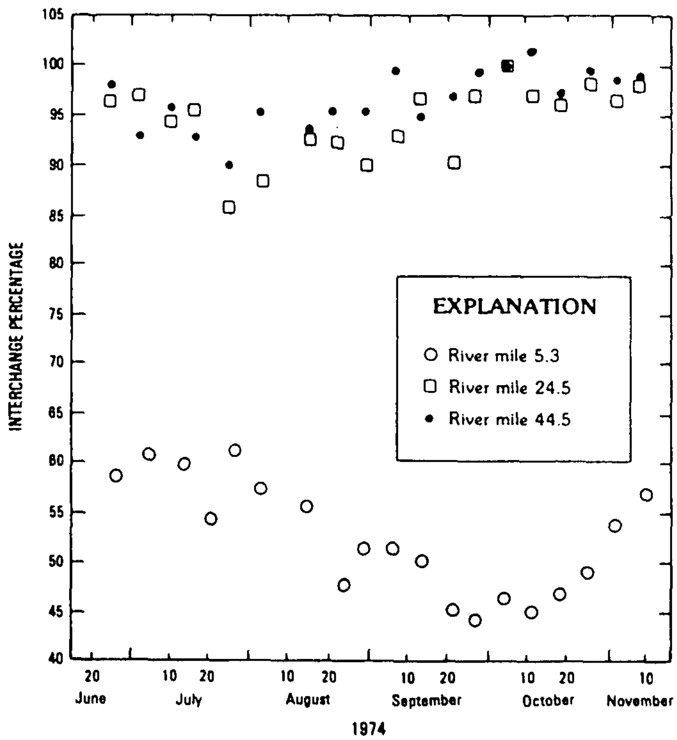


FIGURE 4.—Interchange percentages at the three sampling sites.

streambed surface at river mile 5.3 was relatively smooth, largely due to the predominance of pebbles and sand. Vaux (1962, 1968) determined experimentally that interchange would be minimized by a smooth streambed surface. The two upstream sampling sites had irregular streambed surfaces because they were predominated by cobbles and gravels. Cooper (1965) reported that irregularities at the streambed surface enhanced interchange.

Cooper (1965) found that streambed permeability could be reduced when sediments blocked interstices within the streambed. McNeil and Ahnell (1964) correlated reductions in interchange with increases in the percentage composition of streambed sediment finer than 0.833 mm. On the basis of these prior findings, one would expect the sampling site with the least interchange to possess the largest percentage of fine sediment. River mile 5.3 had the least interchange; however, it did not have the lowest percentage of streambed sediment finer than 0.833 mm. Therefore, the differences in interchange among the three sampling sites could not be explained by the inverse correlation between streambed permeability and the percentage of streambed sediment finer than 0.833 mm.

Interchange can also be impeded by mats of periphytic algae overlying the streambed (Sheridan, 1962). A mat of periphytic algae overlaid the sampling site at river mile 5.3 throughout the period of study and attained a maximum thickness of about 13 mm from mid-September until streamflow increased from a storm on October 27. River miles 24.5 and 44.5 also had mats of periphytic algae but to a much lesser degree than found at river mile 5.3. Because the five lowest values of interchange percentage at river mile 5.3 occurred during the period of maximum thickness of the periphyton mat, it appears that interchange may have been restricted by such mats.

Ground-water inflow was not directly measured at the three sampling sites, but water-temperature data provided some indirect evidence for such inflow at one site. The close correspondence in temperatures of surface and intragravel water at river miles 24.5 and 44.5 suggests that ground-water inflow was negligible. Such was not the case at river mile 5.3, however, where surface and intragravel water temperatures did not correspond and intragravel water temperatures did not respond to fluctuations in surface-water temperatures. This finding suggests that ground water, with less fluctuation in temperature than surface water, was flowing into the streambed at river mile 5.3.

The relatively low concentration of intragravel dissolved oxygen measured at river mile 5.3 may have been caused partly by inflow of oxygen-deficient ground water. This hypothesis cannot be tested because pertinent data were not collected during the study. However, shallow ground water in silty or clayey soils generally has a negligible dissolved-oxygen concentration (Freeze and Cherry, 1979). The soils of the Redwood Creek drainage basin typically are stony loams and stony-clay loams (Janda and others, 1975), and, therefore, ground water might be expected to be deficient in dissolved oxygen.

Once dissolved oxygen has physically entered the streambed, it can be consumed by respiring organisms and by oxidation of carbonaceous and nitrogenous materials. Because such chemical and biological processes were not measured in this study, the exact causes of the large differences in concentrations of intragravel dissolved oxygen between sites at river miles 24.5 and 44.5 and the site at river mile 5.3 cannot be determined. Any future investigators who propose to quantify the interchange of surface and intragravel waters would profit by collecting data applicable to evaluation of the chemical and biological, as well as the physical, processes that control dissolved-oxygen concentrations.

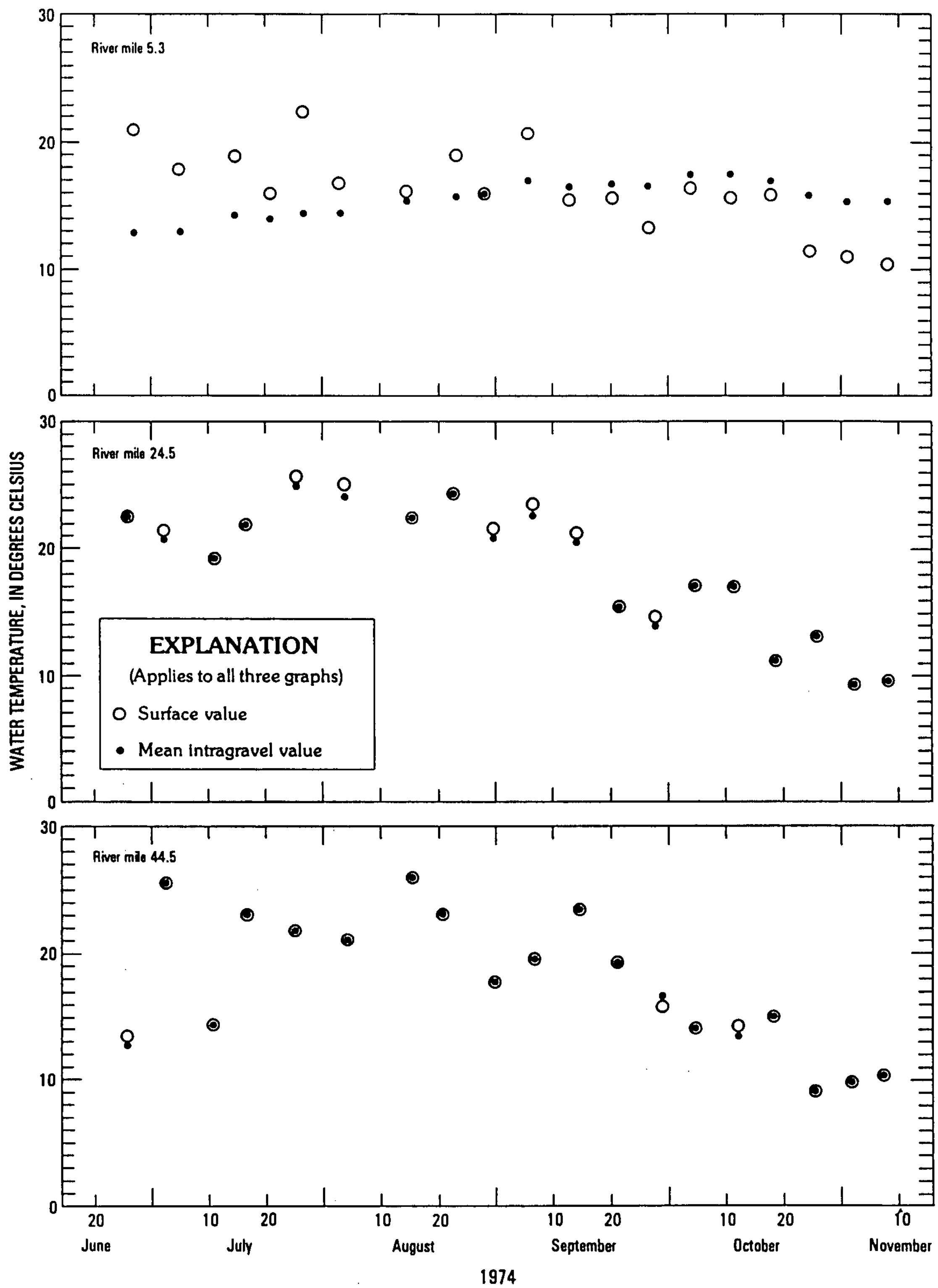


FIGURE 5.—Temperatures of surface and intragravel water at the three sampling sites.

TABLE 1.—*Percentage composition of streambed material at the three sampling sites*
[mm, millimeter; <, less than; five streambed cores were taken at each site]

Mesh size of sieve (mm)	River mile 5.3		River mile 24.5		River mile 44.5	
	Mean percent material retained	Standard deviation	Mean percent material retained	Standard deviation	Mean percent material retained	Standard deviation
26.67	4.5	3.6	13.0	4.7	22.5	8.1
13.50	14.8	6.0	15.5	2.4	12.8	2.8
6.73	20.6	4.0	16.5	2.0	12.2	2.1
3.33	18.7	5.7	12.9	1.9	10.8	2.3
1.70	13.6	4.2	11.9	1.0	11.8	1.6
.833	9.2	6.1	13.2	1.6	8.0	1.3
.104	14.3	1.7	9.4	1.9	11.9	2.0
<.104	4.3	2.5	7.6	1.6	10.0	2.8
[1]<.833	18.6	2.7	17.0	1.5	21.9	2.4

[1] McNeil and Ahnell (1964) found that permeability was reduced as the percentage composition of sediment finer than 0.833 mm increased.

CONCLUSIONS

Data for dissolved-oxygen concentrations and water temperatures revealed that the interchange of surface and intragravel water at river mile 5.3 was substantially less than at river miles 24.5 and 44.5. The presence at river mile 5.3 of a mat of periphytic algae on the streambed was a likely cause of the impeded interchange. The low concentrations of dissolved oxygen in intragravel water at river mile 5.3 may have resulted partly from inflow of oxygen-deficient ground water.

REFERENCES CITED

Brown, Eugene, Skougstad, M.W., and Fishman, M.J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 160 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: Sacramento, Calif., v. I, not paginated.

Coble, D.W., 1961, Influence of water exchange and dissolved oxygen in redds on the survival of steelhead trout embryos: Transactions of the American Fisheries Society, v. 90, p. 469–474.

Cooper, A.C., 1965, The effect of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins: International Pacific Salmon Commission Bulletin 18, 71 p.

Cordone, A.J., and Kelly, D.W., 1961, The influences of inorganic sediment on the aquatic life in streams: California Fish and Game, v. 47, no. 2, p. 189–228.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Gangmark, H.A., and Bakkala, R.G., 1958, Plastic standpipe for sampling streambed environment of salmon species: U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries, no. 261, 21 p.

Hall, J.D., and Lantz, R.L., 1969, The effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams, *in* Symposium of salmon and trout in streams: British Columbia University, Vancouver, H.R. MacMillan Lectures in Fisheries, p. 355–375.

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

Janda, R.J., Nolan, K.M., Harden, D.R., and Colman, S.M., 1975, Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California, as of 1973: U.S. Geological Survey Open-File Report 75–568, 266 p.

McNeil, W.J., and Ahnell, W.H., 1964, Success of pink salmon spawning relative to size of spawning bed materials: U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries, no. 469, 15 p.

Sheridan, W.L., 1962, Waterflow through a salmon spawning riffle in southeastern Alaska: U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries, no. 407, 20 p.

Shumway, D.L., Warren, C.E., and Doudoroff, P., 1964, Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos: Transactions of the American Fisheries Society, v. 93, no. 4, p. 342–356.

Sokal, R.R., and Rohlf, F.J., 1969, Biometry: San Francisco, W.H. Freeman and Co., 776 p.

Terhune, L.D.B., 1958, The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel: Fisheries Research Board of Canada Journal, v. 15, no. 5, p. 1027–1063.

Vaux, W.F., 1962, Interchange of stream and intragravel water in a salmon spawning riffle: U.S. Fish and Wildlife Service, Special Scientific Report—Fisheries, no. 405, 11 p.

———1968, Intragravel flow and interchange of water in a streambed: U.S. Fish and Wildlife Service, Fisheries Bulletin 66, p. 479–489.

Woods, P.F., 1980, Dissolved oxygen in intragravel water of three tributaries of Redwood Creek, Humboldt County, California: Water Resources Bulletin, v. 16, no. 1, p. 105–111.

Zar, J.H., 1974, Biostatistical analysis: Englewood Cliffs, N.J., Prentice-Hall, 620 p.