EFFECTS OF ARTIFICIALLY REDUCED STREAMFLOW ON A SMALL STEELHEAD STREAM

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Abstract. San Pedro Creek, in Pacifica, California, has been subjected for the last three years to continuous water removals from the headwaters of one of the three main forks. This water, withdrawn at rates ranging from 0.56 to 1.12 cubic feet per second, has been used to supplement the city water supply. A study was conducted to determine the effects of this restricted streamflow on the creek and its local steelhead trout population. Weekly measurements were made of streamflow, temperature, and water quality characteristics. A fish population sample was taken, and the aerobic zone of the substrate was determined. Data for these measurements is presented. It appears that streamflow artificially reduced below a certain critical level could damage the trout habitat by lowering the dissolved oxygen and reducing the current in the spawning areas. Calcium and magnesium hardness might be reduced, while soluble orthophosphate content may increase. Additional management problems, resulting from the local residential development, are also discussed.

INTRODUCTION

A study of San Pedro Creek in Pacifica, California was begun in June 1972. The purpose of the study was to assess the impact of water withdrawal by the North Coast County Water District. The withdrawn water has been used to supplement the city water supply. For the past three years the Water District has taken water at an average rate of 0.56 cubic feet per second (cfs) in summer, and 1.12 cfs in winter at a point located near the headwaters of the South Fork (Figure 1).

The biological community of the stream includes a small, persistent population of steelhead trout (*Salmo gairdneri*). The main focus of the study concerns the effects of the water removal and resultant reduced streamflow on the trout population. Additional objectives were to determine a minimum acceptable streamflow, and to describe other problems affecting the environmental health of the creek. To the best of our knowledge, very little work has been done in determining the effects of water removal and reduced streamflow on coastal stream environments (Kraft 1972).

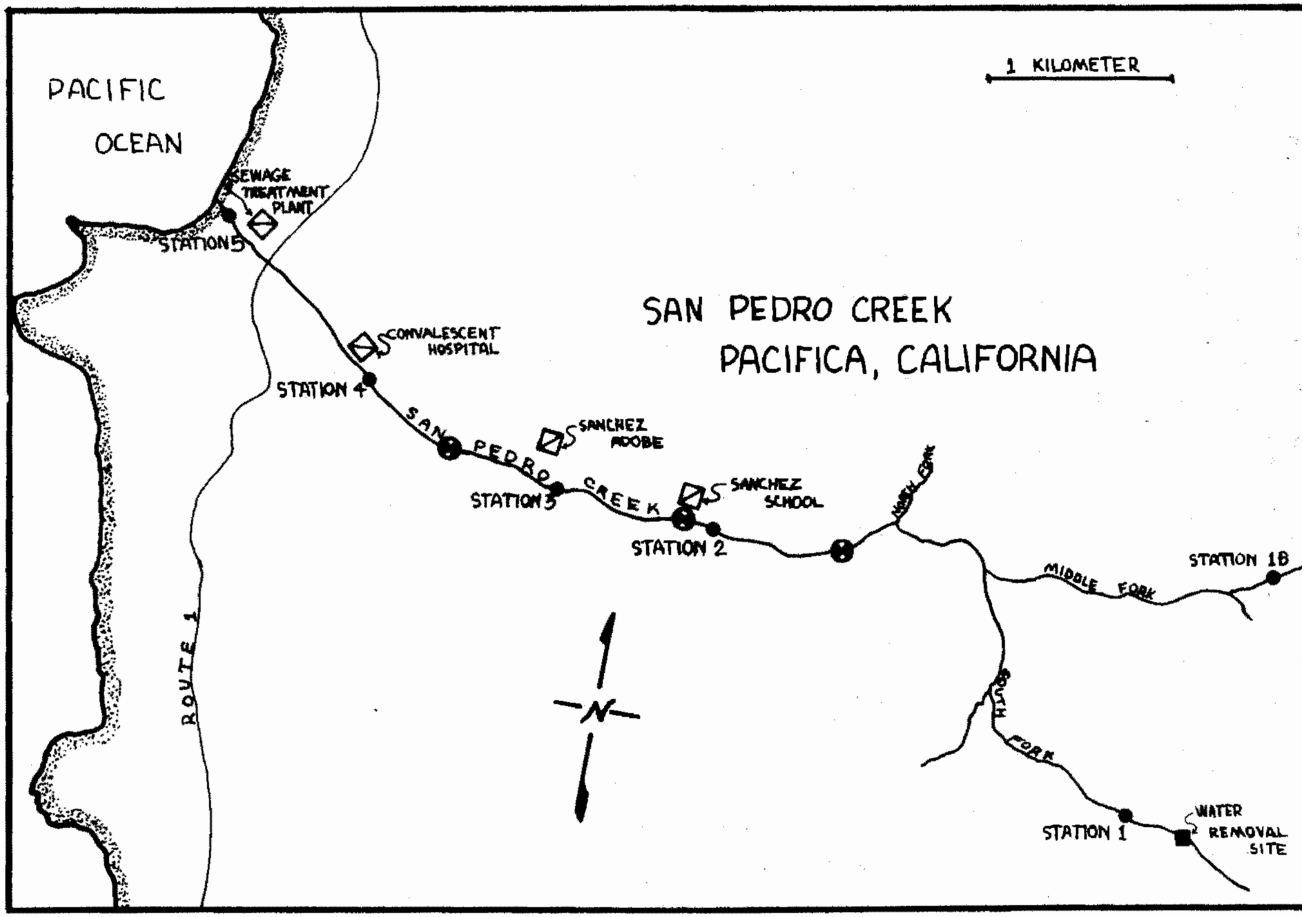

Figure 1 - Map showing Study Area, sampling stations, water removal site, and barriers to fish migration (⊗).

The problem that faces San Pedro Creek is not unlike that which faces countless small streams along the West Coast. The streams support substantial fish and invertebrate populations and often lie in areas under residential development. Such development threatens their biological existence. It is of paramount importance that these streams be managed in a manner which not only preserves their natural state but also their many beneficial properties to be explored.

This study was requested by the Save San Pedro Creek Committee of Pacifica, California. This committee provided background information on the situation, and obtained a court injunction halting water withdrawal from June 1 to December 1, during which time the study was conducted. Ecology Action of Pacifica provided financial support. Faculty sponsorship and guidance was provided by Don C. Erman, School of Forestry and Conservation, University of California, Berkeley. The help of Mr. Elden Dellanina is gratefully acknowledged.

DESCRIPTION OF STUDY AREA

San Pedro Creek is a small coastal stream located in the Linda Mar area of Pacifica, approximately 10 miles south of San Francisco. The mean summertime flow is approximately 1 cfs at the mouth. When the rainy season begins in October, the streamflow varies from approximately 2 to 15 cfs.

The upper portion of the creek is divided into three forks: the North, Middle, and South Forks (Figure 1). The Middle and South Forks are spring-fed and drain two canyons that are undeveloped public land and dominated by eucalyptus and native chaparral. However, the North Fork and main stream run through a residential area and receive drainage mostly from storm sewers. The water removal site is located on the South Fork.

Sampling stations were located on the South and Middle Forks and the main channel. Station 1 is located about 50 m downstream from the water removal site. The water is collected in a holding tank. From there it is either withdrawn by the water company, or directed into the streambed directly below the tank. During the period of our study disturbance to the normal flow of water was minimal. To the best of our knowledge, no water was withdrawn except on November 12, as described later.

Station 1 and 1b are fairly similar in size, streamflow, and water quality characteristics. However, Station 1b has no water removal site. At Station 1 the predominant streamside vegetation is the blue gum eucalyptus (*Eucalyptus globulus*). The canyon slopes are covered with chaparral, including *Baccharus* sp. and *Ceanothus* sp. The canyon of the Middle Fork is similar, but the streamside vegetation is composed of willows (*Salix* sp.), alders (*Alnus* sp.) and stinging nettles (*Urticaceae*). The valley of the Middle Fork was once farmed, but has now reverted to mostly annual grasses.

Stations 2 through 5 are located on the main stream. Station 2 situated next to a housing construction site, is characterized by slower current, lower dissolved oxygen content, and greater siltation than any of the other stations. Stations 3 and 4 are fairly similar, with swift current and high dissolved oxygen. Station 5 is located at the mouth of the creek, just inland of the beach proper, and is subject to tidal backflow.

One major problem is the storm sewer system which drains into the creek. This system contributes to the violent fluctuations in streamflow occurring during the autumn storms, resulting in flooding near the mouth of the creek. From this system street debris is washed directly into the creek, contributing to organic pollution in the main stream.

A septic sewage outfall is located above Station 2. During heavy rains, especially during the week of October 8, raw sewage was discharged into the creek. This situation is inexcusable, and may pose a public health hazard. There have been reported fish kills in the past. These pollution problems would be increased by removal of the high-quality water at Station 1, as this source serves to dilute the downstream pollution.

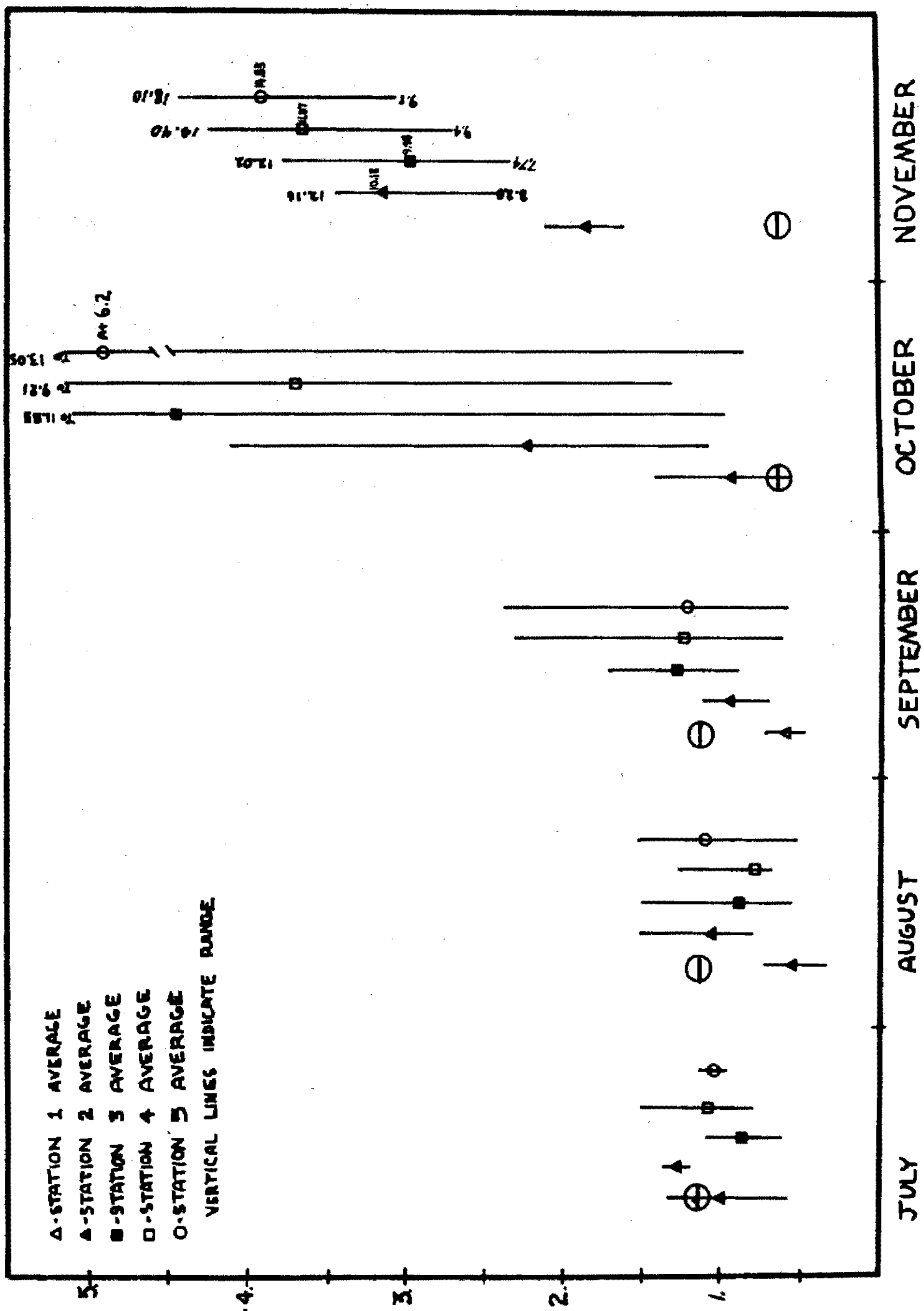

Figure 2 - Shown is the average streamflow for each month, by station. Applied for withdrawal amounts indicated by ⊖ at station 1.

Three bridges cross the main stream (see Figure 1). These bridges have culverts that raise the stream level abruptly by three to six feet, and may pose a barrier to the upstream migration of the adult steelhead. However, the fact that young fish are found at points upstream from these bridges indicates that the adults may be able to leap the barriers.

METHODS AND MATERIALS

Weekly samples were taken at Stations 1 through 5, from July 9 through November 11, 1972. Beginning on October 21, Station 1b was measured on a weekly basis with the other stations. Measurements were made of width, depth, current, streamflow, air and water temperature, dissolved oxygen, calcium and magnesium hardness, and soluble orthophosphate content.

Current was measured by timing a chip over a measured distance and streamflow was calculated from the width, depth, and current measurements (Lagler 1956).

Hardness (total calcium and magnesium carbonate) measurements were conducted in the field by the EDTA Titrimetric method (APHA 1965). pH was measured with an Analytic Measurements portable pH meter, series #6726. Dissolved oxygen and orthophosphate contents were determined in the laboratory by the Azide modification of the Winkler method for oxygen (APHA 1965), and the ascorbic acid-antimony molybdate method for orthophosphate (Golterman 1969).

Fish populations were sampled on November 5 at Stations 1, 1b, 3, and 4. At each station a section of stream was blocked with a seine at the downstream end. Three sweeps through each section were made using a variable voltage backpack shocker on direct current at Stations 1, 3, and 4. At Station 1b, after a shocker malfunction, a minnow seine was hauled twice through the section. Fish were measured for length and weight.

Aerobic limit in the gravel was measured because the quality of intergravel water is critical to salmonid hatching success. We hypothesized that one measure of the impact of reduced streamflows (i.e. water withdrawal) was a reduction in the depth of oxygenated intergravel water aerobic zone).

The aerobic limit was determined with the redwood stake method (Dendy 1965; Erman 1972). Freshly planed redwood stakes were driven into the substrate and allowed to remain for 30 minutes to an hour. The surface level of the substrate was marked on each stake. A black stain forms on the stakes as a result of a ferrous iron chelation with the tannins in the wood. The ferrous iron is produced as the redox potential drives Fe^{+++} to Fe^{++}. This reaction occurs only in the absence of oxygen. The distance from the substrate surface to the top of the stain (aerobic limit) represents the aerobic zone.

To obtain a complete picture of aerobic limits in the substrate, we set up a grid pattern with 2 feet between each stake. A 3 x 4 stake grid was used at Stations 1 and 1b, a 5 x 5 grid at Station 3, and a 4 x 5 grid at Station 4.

In order to determine the immediate effects of water removal, we requested the North Coast County Water District to withdraw water for 24 hours, beginning 6:00 p.m., November 11. Water was withdrawn at a rate of 0.33 cfs (however, the permit requests an average withdrawal rate of 0.56 cfs). On November 11 and 12, regular sampling runs were conducted, and aerobic limits were measured at Stations 1, 1b, 3 and 4. Aerobic limit data from the 4 stations on each day analyzed in a 4 x 2 factorial analysis of variance (fixed effects).

RESULTS

Streamflow

Figure 2 shows the mean and range of streamflow at each station by month. This data indicates that the South Fork contributes 64.5% of the total streamflow in the main

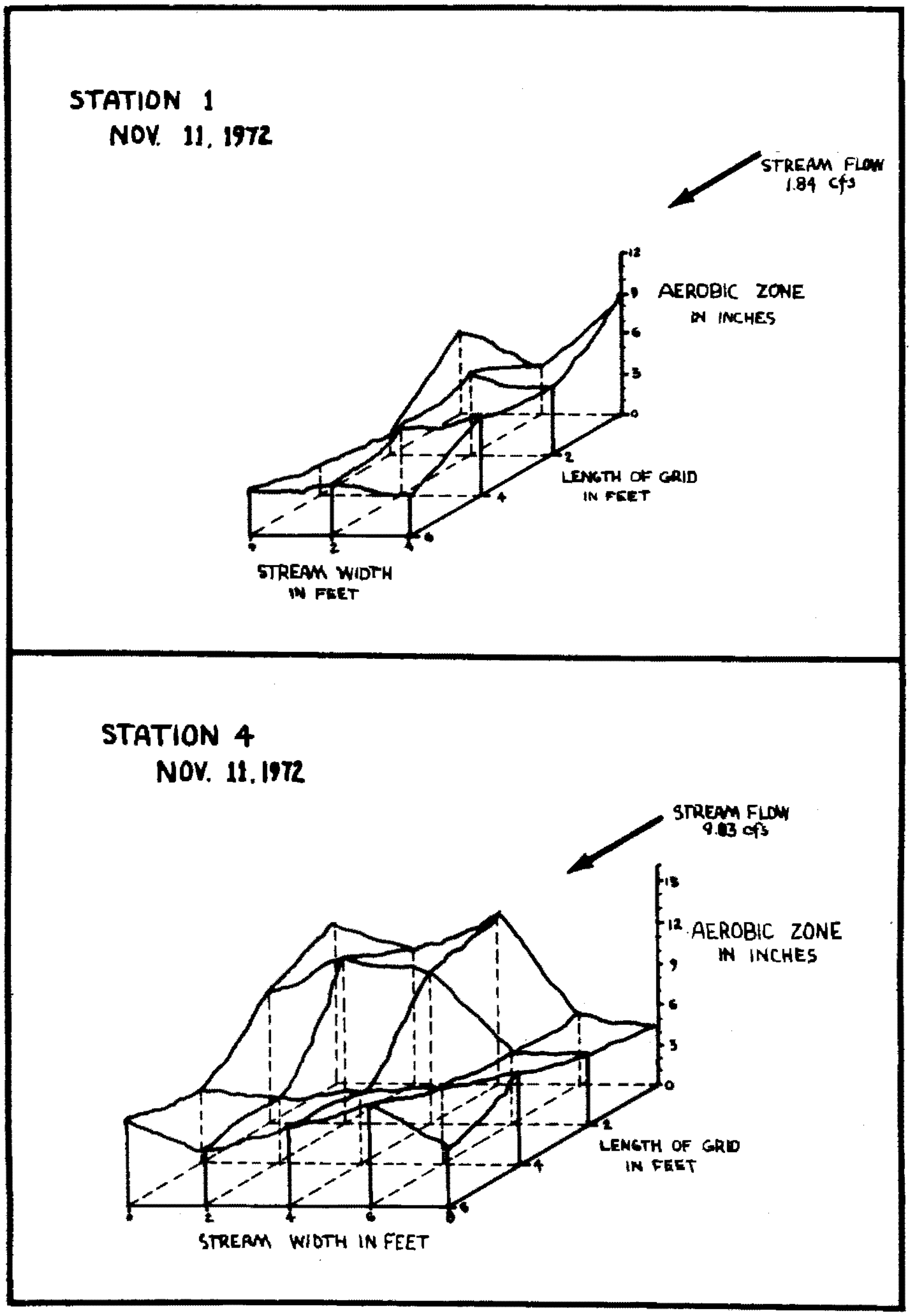

Figure 3 - Shown are aerobic zones of stations 1 and 4 for November 11, 1972.

stream during the summer months, but only 25.5% during the early winter months. A consistent drop in streamflow was observed between Stations 2 and 3. We have not been able to determine whether this drop in streamflow is caused by subsurface flow, or the use of the creek water for irrigation by horticultural nurseries located along this section of the stream, or a combination of these factors.

Aerobic Limit

Figure 3 illustrates aerobic limits on November 11 (before withdrawal) at Stations 1 and 4, This example shows the increased aerobic limit in the downstream area as well as differences from one side of the stream to the other. Mean aerobic limits, streamflow, and water depth on November 11 and 12 are given in Table 1. Analysis of variance of this data (Table 2) indicates that there was a significant difference (95% level) in mean aerobic limits between stations (i.e. deeper oxygenated gravel downstream) but no significant effect due to date or interaction of date and station.

On November 11 and 12, there was no significant difference in oxygen content or temperature at any of the 4 stations sampled. The only difference was increased streamflow in a downstream direction. Aerobic limit also increased downstream. Therefore, we assume that there is a direction relation between streamflow and aerobic limit.

During the November 11-12 withdrawal period, precipitation altered the runoff so that natural changes in the water level also occurred (mean difference in flow between dates, averaged across all stations was 2.9 cfs). Based on this limited test, we nevertheless concluded that removal of 0.33 cfs during a winter period had no significant effect on aerobic limit.

Fish

Table 3 gives results of fish sampling on November 5. Table 3 deals only with steelhead trout, although immature lamprey (Entosphenus tridentatus), sculpin (Cottus asper), and stickleback (Gasterosteus aculeatus) were found at Stations 4 and 3 but not at 1 or 1b.

There was 3.9 times as much steelhead trout biomass at Station 1b as there was at Station 1. This could be caused by many differences between the two stations, such as streambed sediments, physical barriers to migration or availability of food. It could also be caused by the fact that for the last two years, before the court injunction, the North Coast County Water District has taken water from the South Fork (Station 1). The timing and extent of removal is unknown, but the effect of this water removal may have been to drive steelhead trout from the South Fork.

Another factor to consider is the difference in total hardness between the two stations. Total hardness at Station 1 is only half that at Station 2 (see Physical and Chemical Factors). It has been shown (McFadden, et al 1965) that the fertility of a stream is directly related to the total hardness of the waters. A fertile stream attracts and supports more fish.

Other Physical and Chemical Factors

Average total hardness for Station 1 was 111.68 parts per million (ppm), with a range of 83.48 to 139.88 ppm. At Stations 1b, 2, 3, 4, and 5 average total hardness was 220.9 ppm, with a range of 156.2 to 287.8 ppm. At all stations there was a general trend towards increased total hardness after the rains began and runoff increased.

Averaged over the entire study period, the dissolved oxygen concentration was 9.4 ppm (s.d. = 1.98). Average percent saturation was 91.2 (s.d. = 15.9). During periods of extreme flood or siltation, the dissolved oxygen concentration was observed to fluctuate greatly.

When averaged over the study period the air temperature was 17.6 degrees C, the water temperature was 15.6 degrees C, and the pH was 7.44.

Table 1. The water flow and aerobic limits (in inches) measured on November 11 and 12.

	November 11				November 12			
	Flow (cfs)	Aerobic limit Mean	Aerobic limit S.E.	Mean Water Depth	Flow (cfs)	Aerobic limit Mean	Aerobic limit S.E.	Mean Water Depth
Station 1b	4.3	4.4	1.9	2.0	2.0	3.1	2.1	6.8
1	1.8	4.4	2.2	1.6	1.6	5.8	2.6	2.9
3	12.0	5.9	1.8	7.7	7.7	6.0	1.6	7.2
4	9.8	7.3	3.0	9.0	9.0	5.6	2.2	6.1

Table 2. Analysis of variance of the effect of station and time on aerobic limit in stream bottom of San Pedro Creek.

Source of Variation	df	Mean Square	F-test
Total	132	3.11	
Treatment	7		
Station	3	88.78	115.9*
Time	1	27.2	34.45
Station x time	3	7.09	9.23
Error	125	0.77	

*F (α = 0.05, df = 3, 125) = 13.9

Table 3. Results of steelhead trout (*Salmo gairdneri*) population sampling, San Pedro Creek, Pacifica, November 5, 1972.

Station	Number Caught	Mean Length (mm)	Mean Weight (g)	Area Sampled (Ft^2)	Number per Sq. Ft.	Grams per Sq. Ft.
1b	22	115.6	16.2	756.6	0.029	0.4705
1	3	131.7	29.3	735.4	0.004	0.1196
3	10	131.5	30.5	1236.0	0.008	0.2499
4	16	106.8	15.6	1532.5	0.010	0.1624

Soluble orthophosphate samples were taken October 7 and 14, and November 4 and 11. On October 14, November 4, and November 11, it rained. On these three occasions the sewage of Linda Mar overflowed into San Pedro Creek. The average soluble orthophosphate during these overflows was .101 ppm. In comparison, on October 7, a day when it did not rain, the average concentration was .033 ppm.

DISCUSSION

Effects of Reduced Streamflow

The physical effects of reduced streamflow involves reduction of water column, current, and the resulting reduction in the aerobic zone. The decrease in current may also reduce the scouring ability of the stream, thus increasing silt deposition. Numerous studies (Shapovalov and Taft 1954; Wickett 1954; Shumway, et al 1964; Orcutt, et al 1968; Wells and McNeil 1970) have shown that the survival of salmonid embryos, deposited in the gravel, is dependent upon sufficient oxygen for respiration and sufficient current for removal of metabolic wastes. Survival is also impaired by silt deposition (Hall and Lantz 1969).

Reduction of streamflow, particularly in the dry summer months, would result in the reduction of total living space available to aquatic organisms. This would seriously reduce the creeks carrying capacity, not only for fish but also for plants and invertebrates of the lower trophic levels.

The resulting decrease in surface area would also reduce area available for collection of terrestrial debris, such as leaf litter and terrestrial insects, which contributes to the total production of the creek ecosystem (Hynes 1970; Kraft 1972). Under environmental pressure from increased siltation, benthic fauna species composition would change. The biomass of benthic fauna would also be reduced.

Temperature is an importnat factor in the development of salmonid embryos (Garside 1959; Shumway, et al 1964). It is not relevant in this situation because we observed minimal fluctuations in temperature despite changes in season and streamflow.

CONCLUSION

It is the opinion of these researchers, after a five month study of San Pedro Creek, which included physical, biological, chemical, and sociological analysis, that the following minimum streamflow limits should be maintained throughout every year:

South Fork

November 15 to April 15; 1.0 cfs (450 gallons per minute)
April 16 to November 14; 0.5 cfs (225 gallons per minute)

Downstream of Confluence of South and Middle Forks

November 15 to November 15; 1.0 cfs (450 gallons per minute)

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