STREAM QUALITY IN THE SAN LORENZO RIVER BASIN, SANTA CRUZ COUNTY, CALIFORNIA

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 78-19

Prepared in cooperation with the
Santa Cruz County Flood Control
and Water Conservation District

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16. Abstracts
Stream quality was studied from November 1973 through June 1975 in the San Lorenzo River basin, Calif., a rapidly developing mountainous area. Dissolved-ion concentrations indicate the basin can be divided into three water-quality areas corresponding to three geologic areas. Pronounced changes in water quality occurred during storms when streamflow, turbidity, nitrogen, phosphorus, potassium, and fecal-coliform bacteria concentrations increased, while dissolved-ion concentrations decreased owing to dilution. Total nitrogen and fecal-coliform concentrations exceeded State objectives in the Zayante and Branciforte Creek drainages probably because of domestic sewage from improperly operating septic-tank systems or the primary-treated sewage effluent discharged into a pit near Scotts Valley. Diel studies did not show appreciable dissolved-oxygen depletion in streams. Greater streamflows and residential development appear responsible for reduced diversity of benthic invertebrates downstream of the residential areas in the basin.

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April 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Metric units are used in this report. For those readers who may prefer to use English units rather than metric units, the conversion factors for the terms used in this report are listed below.

Metric	*Multiply by*	*English*
hm^3/yr (cubic hectometers per year)	8.110×10^2	acre-ft/yr (acre feet per year)
km (kilometers)	6.215×10^{-1}	mi (miles)
km^2 (square kilometers)	3.861×10^{-1}	mi^2 (square miles)
m (meters)	3.281	ft (feet)
m^2 (square meters)	10.76	ft^2 (square feet)
m^3/s (cubic meters per second)	3.531×10^1	ft^3/s (cubic feet per second)
mm (millimeters)	3.937×10^{-2}	in (inches)

Use the following to convert degrees Celsius (°C) to degrees Fahrenheit (°F): 9/5C+32

STREAM QUALITY IN THE SAN LORENZO RIVER BASIN,

SANTA CRUZ COUNTY, CALIFORNIA

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ABSTRACT

Stream quality in the San Lorenzo River basin, Calif., was studied from November 1973 through June 1975 to determine areal and temporal variations in water quality, problem areas and times of water quality degradation, and compliance with State and local water-quality objectives. Sampling from November 1973 through July 1974 was done at five stations in the Zayante Creek drainage basin and at one station on the San Lorenzo River at Big Trees. Sampling from August 1974 through June 1975 was done at 15 stations in the San Lorenzo River basin, including one station in the Zayante Creek subbasin. Properties and constituents measured were water temperature, specific conductance, pH, alkalinity, dissolved oxygen, turbidity, fecal-coliform and fecal-streptococcal bacteria, major dissolved ions, nutrients (nitrogen and phosphorus), chemical and biochemical oxygen demand, and trace elements. Benthic invertebrates were collected during autumn 1974 and spring 1975 at two stations.

Results show that the water in most streams in the basin can be classified as calcium bicarbonate, but based on the dissolved-ion concentrations the basin can be divided into three water-quality areas that correspond generally to three geologic areas. The most pronounced change in water quality occurs during storms when streamflow, turbidity, and total Kjeldahl-nitrogen, total-phosphorus, dissolved-potassium, and fecal-coliform concentrations increase, while concentrations of most dissolved ions decrease owing to dilution of the nonstorm part of the flow. Late winter and early spring nonstorm flows yield water of the best quality because the concentrations of most dissolved ions and fecal-coliform and fecal-streptococcal bacteria are relatively low, whereas turbidity values are the same as, or not appreciably greater than, during the summer low-flow period.

Dissolved-ion concentrations exceeded objectives at stations on east-side streams north of the Zayante fault, probably because of lower-than-normal streamflows during water year 1975. Total-nitrogen and fecal-coliform concentrations exceeded objectives in the Zayante Creek and Branciforte Creek drainage basins, probably because of domestic sewage from improperly operating septic-tank systems. The high total-nitrogen and fecal-coliform concentrations in the Zayante Creek basin might also result from the primary-treated effluent discharged by the city of Scotts Valley into an old sand pit.

Results of diel studies (intensive sampling for a 24-hour period) made at two stations on the San Lorenzo River indicate that residential areas between the stations do not contribute sufficient quantities of oxygen-demanding wastes to the river during low streamflow to cause appreciable dissolved-oxygen depletion. Greater streamflows and residential development seem to be responsible for unstable streambed substrates and reduced diversity of benthic invertebrates during the spring at a station downstream of most of the residential areas in the San Lorenzo River valley.

INTRODUCTION

Population growth in the San Lorenzo River basin (fig. 1) is increasing the demand on water resources and sewage-disposal capabilities of the basin. Increases in housing and private road construction are accelerating erosion in the basin. Population growth and resultant water-supply and water-quality problems have prompted the need to study additional sources of water supply and alternatives of waste disposal and to develop a comprehensive watershed-management plan. This plan is being prepared by the Santa Cruz County Office of Watershed Management and the California Department of Fish and Game. To supplement these studies and to provide data useful for developing a watershed-management plan, the Santa Cruz County Flood Control and Water Conservation District requested that the U.S. Geological Survey design and implement a water-quality study of the San Lorenzo River basin. This report describes the results of that study. The authors express their appreciation to Jon M. Anderson (Hydrologist, U.S. Geological Survey, from 1972 to 1973) for his work in the planning and design of this study.

Problem Definition

The resident population of the San Lorenzo River basin, excluding the city of Santa Cruz, increased from 11,000 in 1960 to 31,000 in 1976 (Santa Cruz County, 1976). During the same period the population of the city of Santa Cruz service area increased from 26,000 to 32,500 (Gruen, Gruen and Associates, 1976).

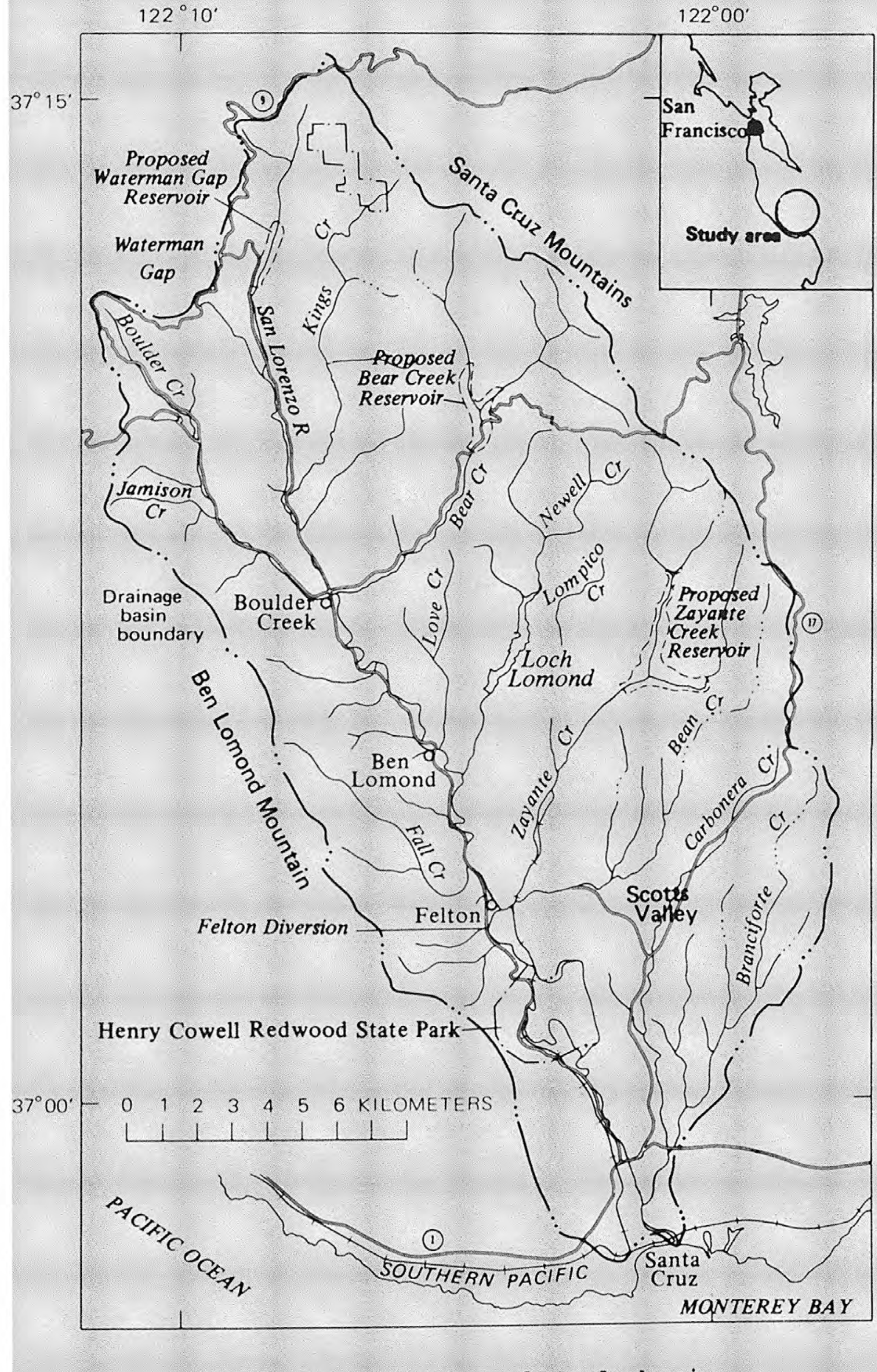

FIGURE 1.--Location of study basin.

Residents in the San Lorenzo River basin obtain their water supply by importing water from coastal streams and wells, from the San Lorenzo River and its tributaries, from Loch Lomond, and from springs and wells. These water supplies are barely adequate to meet summer water demands (Montgomery, 1973). Summer water shortages have caused water purveyors in the basin to ration water. One purveyor, the San Lorenzo Valley County Water District, has had a moratorium on water connections since 1973. Plans to augment the water supply include construction of reservoirs on Zayante Creek, Bear Creek, and the main stem of the San Lorenzo River near Waterman Gap (fig. 1). The Felton Diversion Project is used during high flow to divert 3.7 hm^3/yr of water from the San Lorenzo River near Felton to Loch Lomond to supplement water storage.

About 98 percent of the population of the San Lorenzo River basin upstream from Santa Cruz disposes of domestic sewage by the use of onsite, individual systems. One reason for water-quality problems in the basin is that these systems (primarily septic-tank systems) have operated improperly because of lack of maintenance, overloading, installation on lots of insufficient size, poor soil conditions, poor construction, and high ground-water levels (Yoder, Trotter, Orlob and Associates, 1975) (fig. 2). Bacterial contamination of surface water in the basin resulting from septic-tank system failure has been documented by various Santa Cruz County Health Department surveys (Butt and Hurst, 1974). Plans to remedy the problem have generally advocated the elimination of septic-tank systems, the construction of sewer systems in the San Lorenzo River valley and Scotts Valley areas, and the transport of collected wastes to the city of Santa Cruz for treatment prior to disposal in the ocean (Yoder, Trotter, Orlob and Associates, 1975). An interim solution that has been proposed is to form septic-tank system management districts in the basin and to use reclaimed effluent from three extended aeration package plants within 4-5 km of Boulder Creek (Bear Creek Estates, Boulder Creek Country Club, and Big Basin Woods) for irrigation and streamflow augmentation (California State Water Resources Control Board, 1975).

Another reason for water-quality problems in the San Lorenzo River basin is accelerated erosion caused by housing and private road construction. Brown (1973) concluded that roadbuilding in the central and upstream parts of the Zayante Creek subbasin caused excessive suspended-sediment yields. During 1975, erosion and siltation caused subdivision development near Ben Lomond to be halted and plugged a community water system on Bracken Brae Creek (a tributary of Boulder Creek).

FIGURE 2.--Areas of septic-tank system failures (from Yoder, Trotter, Orlob and Associates, 1975).

Purpose

The objectives of this study were to:

1. Establish a water-quality sampling program in the San Lorenzo River basin;
2. Determine areal and temporal variations in water quality;
3. Provide data for determining compliance with State and local water-quality objectives;
4. Delineate problem areas and times of water-quality degradation; and
5. Suggest modifications in the sampling program to satisfy better the data needs for preparing management plans to aid in the prevention and control of water-quality degradation in the basin.

The results of this study should be useful to decisionmakers in developing additional water supplies, selecting waste-disposal alternatives, and preparing a watershed-management plan for the San Lorenzo River basin.

LOCATION AND DESCRIPTION OF STUDY AREA

The 357-km^2 San Lorenzo River basin (fig. 1) is on the central coast of California in Santa Cruz County. The boundaries of the basin are the Santa Cruz Mountains on the north and east, Ben Lomond Mountain on the west, and Monterey Bay on the south. The largest community, Santa Cruz, is near the mouth of the basin on Monterey Bay. Other communities in the basin, upstream of Santa Cruz, are on the main stem of the San Lorenzo River or its tributaries. The main communities in this area are Felton, Scotts Valley, Ben Lomond, and Boulder Creek. The principal tributaries of the San Lorenzo River are Branciforte Creek, Zayante Creek, and Bear Creek on the east and Fall Creek and Boulder Creek on the west.

The basin is mountainous with slopes commonly exceeding 30 percent. Elevations range from 914 m on the northern boundary of the basin to sea level at the city of Santa Cruz. The San Lorenzo River valley is narrow--generally less than 0.8 km wide, except in the vicinity of Felton and Ben Lomond where the valley broadens to more than 1.5 km.

The basin can be divided into three geologic areas (fig. 3). The area west of the Ben Lomond fault is underlain primarily by water-bearing igneous formations of granite, quartz diorite, and gabbro. The second area, mostly north of the Zayante fault, is underlain primarily by non-water-bearing, consolidated sedimentary rocks (sandstone, mudstone, and shale). The third area, south of the Zayante fault and east of the Ben Lomond fault, is underlain primarily by unconsolidated to consolidated sandstone, siltstone, and shale deposits which are generally water bearing.

Because of the steep slopes upon which the soils occur, most of the basin is subject to active or severe erosion (Livingston and Blayney, 1967). Exceptions are the relatively flat lowlands at the city of Santa Cruz and along the San Lorenzo River near the communities of Felton and Boulder Creek.

Basin vegetation is mainly conifer and mixed conifer-broadleaf evergreen forests. The principal trees are redwood, Douglas fir, California live oak, madrone, and alder. Most of the basin has been logged; thus, existing forests are second or third growth. Grasslands and brushlands are found in the vicinity of Felton and Scotts Valley, east of Ben Lomond along Quail Hollow Road (approximately 1.6 km south of Loch Lomond), and on some ridge tops in the eastern and northern parts of the basin. Generally, the forests adjacent to the river form a thick canopy which shades the water from direct sunlight.

Rainfall occurs mostly from November through April and ranges from a mean annual value of 737 mm at Santa Cruz to about 1,270 mm at higher elevations in the mountains (Montgomery, 1973). The days are mainly clear and sunny throughout the year except for winter rainstorms and early morning fog.

DATA COLLECTION AND METHODS

Reconnaissance and Routine Sampling

Reconnaissance sampling began in May 1973 as an aid in the selection of stations and properties and constituents to be sampled. Reconnaissance data are not included in this report. Routine sampling began in November 1973 at the stations shown in figure 4 and for the properties and constituents and sampling frequencies shown in table 1. The first year of sampling was restricted to one station on the San Lorenzo River and stations in the Zayante Creek subbasin because this area had been identified as having significant fecal bacterial problems (Butt and Hurst, 1974) and sediment problems (Brown, 1973). After sampling in the Zayante Creek subbasin for about 1 year (November 1973-July 1974), the sampling program was expanded to include the stations shown in figure 5. These stations were sampled from August 1974 through June 1975 for the properties and constituents and sampling frequencies shown in table 2.

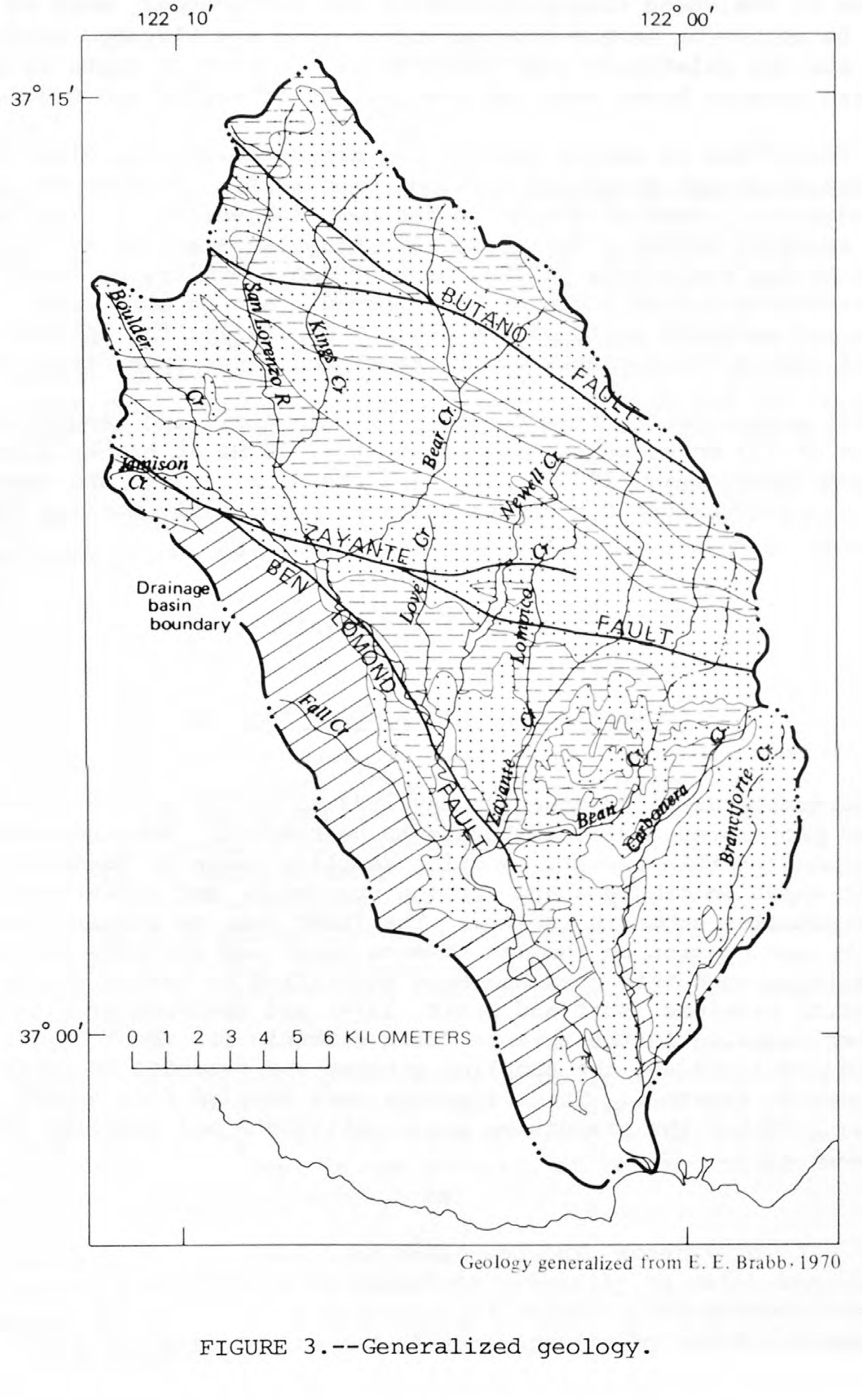

FIGURE 3.--Generalized geology.

EXPLANATION

Alluvial and terrace deposits of unconsolidated gravel, sand, silt, and clay of Quarternary age.

Primarily mudstone and shale of Tertiary age. Includes the Santa Cruz Mudstone of Clark (1966), Monterey Shale, Lambert Shale, and the San Lorenzo Formation. Formations are generally described as siliceous, organic mudstone, shale, and thin beds of discontinuous silty sandstone.

Primarily sandstone of Tertiary age. Includes the Purisima Formation, Santa Margarita Sandstone, Lompico Sandstone of Clark (1966), Vaqueros Sandstone, Zayante Sandstone, Butano Sandstone, and the Locatelli Formation as used by Cummings and others (1962). Formations are generally described as arkosic and poorly consolidated sandstone, with interbeds of shale, siltstone, mudstone, and conglomerate.

Consolidated granitic rocks of Cretaceous and Jurassic age and metamorphic rocks of Paleozoic (?) age.

FIGURE 3.--Generalized geology--Continued.

Diel Studies and Benthic-Invertebrate Sampling

In addition to routine sampling, low flow, diel studies were made in late September and early October 1974 at two U.S. Geological Survey continuous-record gaging stations: San Lorenzo River near Boulder Creek (11160020, studied September 30-October 1) and San Lorenzo River at Big Trees (11160500, studied October 3-4) (fig. 5). Field determinations of water temperature, specific conductance, pH, alkalinity, and dissolved-oxygen concentration were made every 2 hours from 0800 to 1800, at 15-minute to 30-minute intervals from 1800 to 2000, every 2 hours from 2000 to 0400, and at 30-minute to hourly intervals from 0400 to 0800. During the diel studies benthic-invertebrate samples were collected. Samples from riffles, pools, and various substrates (cobbles, pebbles, sand, silt, submerged vascular plants, and algal mats) were obtained at each diel station. Benthic-invertebrate samples were also collected at the diel stations in April 1975.

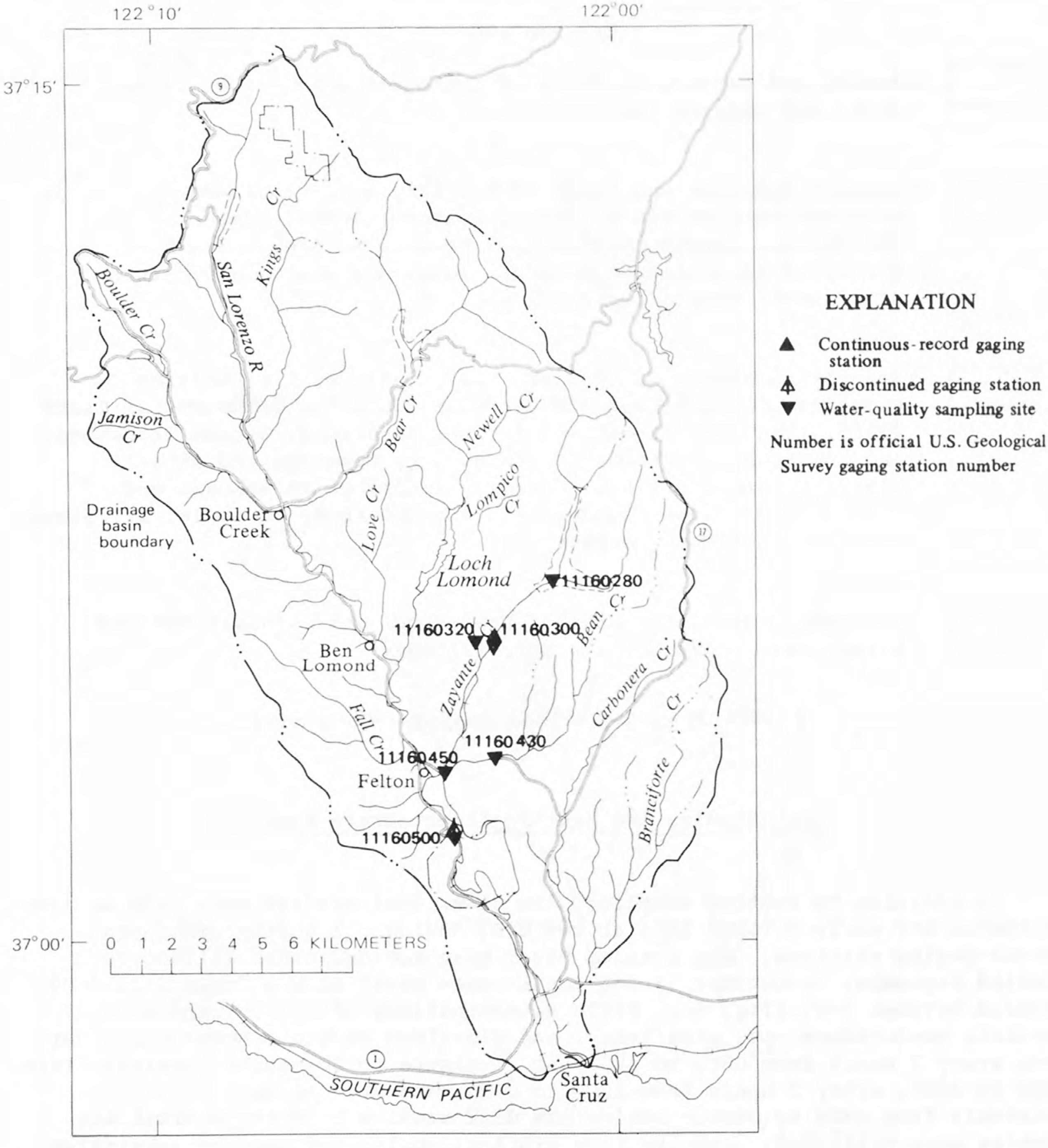

FIGURE 4.--Location of routine sampling stations, November 1973-July 1974.

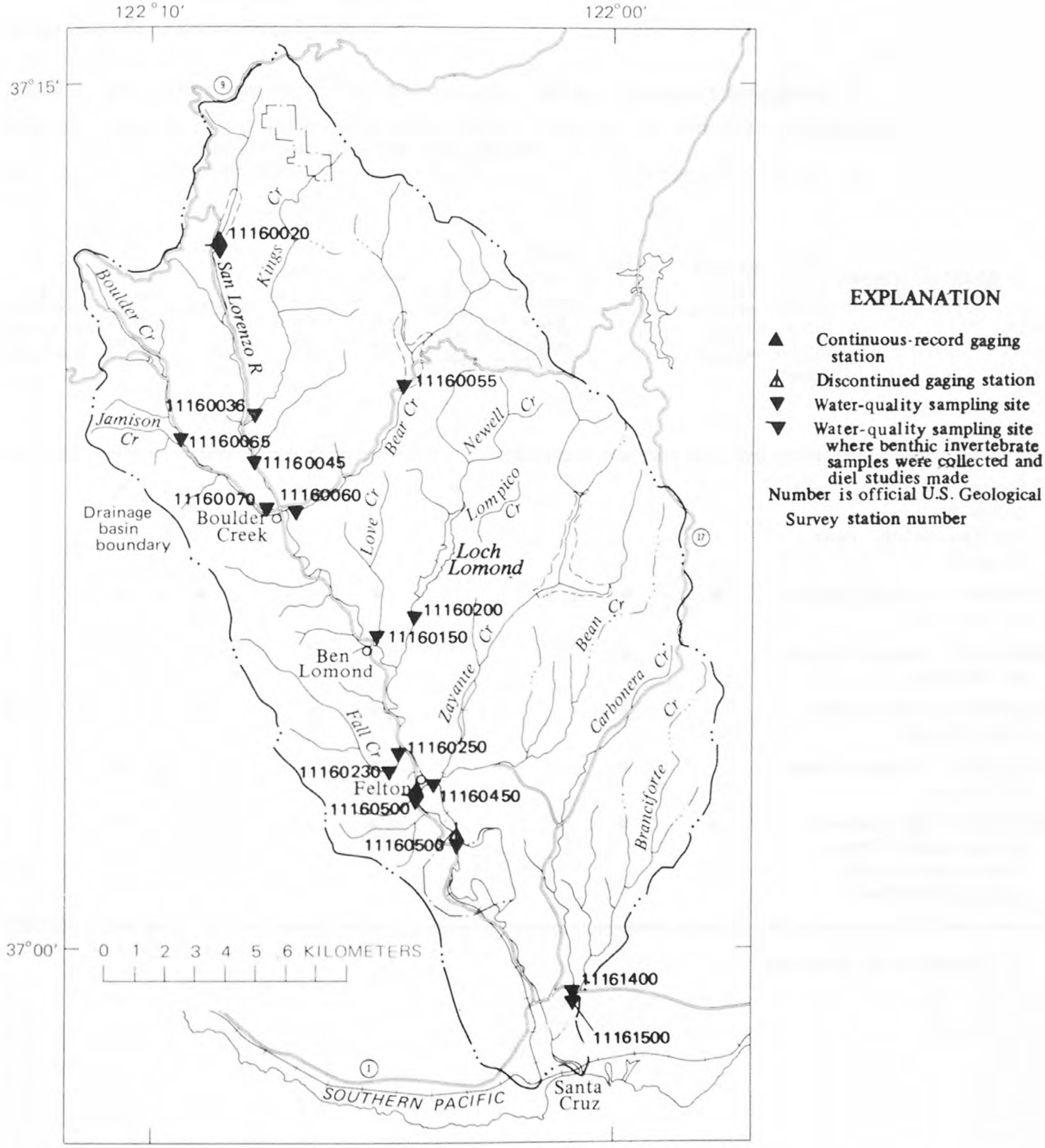

FIGURE 5.--Location of routine sampling stations, diel sampling stations, and benthic-invertebrate sampling stations, August 1974-June 1975. (Diel study and benthic-invertebrate sampling for station 11160500 done at site of active gaging station. All other water-quality sampling for this station done at site of discontinued gaging station.)

TABLE 1.--*Routine sampling program, November 1973-July 1974*

[Sampling frequency: number of samples collected per year. Field determinations include water temperature, specific conductance, pH, and dissolved oxygen]

Station number and name	Reason for station selection										Sampling frequency										
	Historical streamflow data	Historical water-quality data	Existing streamflow gaging station	Nonurbanized drainage	Urbanized drainage	Proposed reservoir	Geology	Sediment problem	Bacterial contamination problem	Nutrient problem	Streamflow	Field determinations	Fecal coliform bacteria	Fecal streptococcal bacteria	Dissolved sulfate, chloride, calcium, and magnesium	Dissolved nitrite plus nitrate (as N)	Total nitrite plus nitrate (as N)	Total ammonia and Kjeldahl nitrogen (as N)	Total phosphorus and total orthophosphorus (as P)	Chemical oxygen demand	5-day biochemical oxygen demand
11160280 Zayante Creek below Mountain Charlie Gulch, near Zayante				•		•	•	•			8	8	4	1	8	8		1	1		1
11160300 Zayante Creek at Zayante	•	•	•		•		•	•	•		(1)	8	4	1	8	8		1	1		1
11160320 Lompico Creek at Zayante		•			•		•		•		8	8	4	1	8	8		1	1		1
11160430 Bean Creek near Felton		•			•		•			•	8	8	4	1	8	8	1	5	5	4	4
11160450 Zayante Creek at Felton		•			•			•	•	•	8	8	4	1	8	8		1	1		1
11160500 San Lorenzo River at Big Trees (at discontinued gaging station)	•	•			•			•			8	8	4	1	8	8	1	5	5	4	1

[1]Continuous recorder.

TABLE 2.--*Routine sampling program, August 1974-June 1975*

[Sampling frequency: number of samples collected per year. Field determinations include water temperature, specific conductance, pH, alkalinity, dissolved oxygen, fecal-coliform, and fecal-streptococcal bacteria. Major ions include bicarbonate, sulfate, chloride, calcium, magnesium, sodium, and potassium. Analyses for dissolved boron, total nitrite plus nitrate, total ammonia nitrogen, total Kjeldahl nitrogen, and total phosphorus were made 10 times per year at station 11160500 only]

Station number and name	Reason for station selection										Sampling frequency							
	Historical streamflow data	Historical water-quality data	Existing streamflow gaging station	Non-urbanized drainage	Urbanized drainage	Existing or proposed reservoir	Geology	Sediment problem	Bacterial contamination problem	Nutrient problem	Streamflow	Field determinations	Turbidity	Major ions	Dissolved silica, fluoride, iron, and manganese	Dissolved nitrite plus nitrate (as N)	Dissolved orthophosphorus (as P)	5-day biochemical oxygen demand
11160020 San Lorenzo River near Boulder Creek	•	•	•	•		•					(1)	10	10	10	5	5	5	3
11160036 Kings Creek near Boulder Creek		•		•							10	10	10	10	5	5	5	3
11160045 San Lorenzo River at Boulder Creek		•			•						10	10	10	10	5	5	5	3
11160055 Bear Creek near Boulder Creek		•		•		•					10	10	10	10	5	5	5	3
11160060 Bear Creek at Boulder Creek		•			•						10	10	10	10	5	5	5	3
11160065 Boulder Creek above Jamison Creek, near Boulder Creek		•			•		•				10	10	10	10	5	5	5	3
11160070 Boulder Creek at Boulder Creek		•			•		•		•		10	10	10	10	5	5	5	3
11160150 Love Creek at Ben Lomond		•			•				•	•	10	10	10	10	5	5	5	3
11160200 Newell Creek at Ben Lomond	•	•		•		•					10	10	10	10	5	5	5	3
11160230 Fall Creek below Bennett Creek, at Felton				•							10	10	10	10	5	5	5	3
11160250 Fall Creek at Felton		•			•						10	10	10	10	5	5	5	3
11160450 Zayante Creek at Felton		•			•			•	•	•	10	10	10	10	5	5	5	3
11160500 San Lorenzo River at Big Trees (at discontinued gaging station)	•	•			•	(2)		•			10	10	10	10	10	10	10	3
11161400 Carbonera Creek at Santa Cruz		•			•		•		•		10	10	10	10	5	5	5	3
11161500 Branciforte Creek at Santa Cruz	•	•			•		•			•	10	10	10	10	5	5	5	3

[1]Continuous record. [2]Felton Diversion.

Field Methods

Portable meters were used for making field measurements of specific conductance and pH. Water-temperature measurements were made with a hand-held, mercury-filled thermometer. Alkalinity determinations were made using the electrometric titration method (Brown and others, 1970, p. 42 and 43). Dissolved-oxygen concentrations in water were determined by the Alsterberg azide modification of the Winkler method (Brown and others, 1970, p. 126-128). Fecal coliform and fecal streptococcal determinations were made by the membrane filter method using MFC broth as the culture medium for fecal coliform and M-Enterococcus agar as the culture medium for fecal streptococci (Slack and others, 1973, p. 45-54). Instantaneous-discharge measurements using the current-meter method (Carter and Davidian, 1968, p. 6 and 7) were made at stations without continuous recorders. At continuous-record stations, water stages were measured using bubble-gage sensors with digital recorders. Water discharges were derived from the water-stage record and the stage-discharge relation developed from current-meter measurements.

During the diel studies a multiparameter water-quality monitor was used to measure water temperature, pH, specific conductance, and dissolved-oxygen concentration (polarographic-membrane electrode method, American Public Health Association and others, 1971, p. 484-487). Portable specific-conductance and pH meters were used to check readings from the water-quality monitor.

Benthic-invertebrate samples were collected by placing a Surber square-foot sampler with a 1,050-micrometer mesh net firmly against the substrate and directed into the water current. The substrate area enclosed by the sampler was then stirred by hand and the larger rocks scrubbed with a nylon brush. The benthic invertebrates collected in the net bag of the Surber sampler were then transferred to a glass bottle containing a preservative (70-percent ethyl alcohol). To reduce the possibility of missing organisms, a portion of the substrate dislodged by stirring and collected in the Surber sampler was also transferred to the glass bottle.

Water samples for laboratory analysis (tables 1 and 2) were obtained by depth integration at the centroid of flow. Samples for dissolved constituents were filtered in the field through 0.45-micrometer membrane filters. Cation, trace element, and chemical oxygen demand (COD) samples were acidified to a pH of less than 2 immediately after collection. Samples for nutrients (nitrogen and phosphorus constituents) and 5-day biochemical oxygen demand (BOD_5) were chilled immediately after collection. All laboratory analyses were made at the U.S. Geological Survey Water Quality Laboratory in Salt Lake City, Utah.

Laboratory Methods

Constituent analyses for the samples sent to the Salt Lake City laboratory were done according to methods given in Brown and others (1970).

Turbidity measurements were made with a nephlometer (Hach Model 1860A)[1] using the manufacturer's instructions to calibrate the instrument. Samples for turbidity were chilled immediately after collection, and measurements were made by the authors within 24 to 48 hours.

Benthic-invertebrate samples were sorted and keyed by the authors. The keys used were Usinger (1968) and Pennak (1953). BOD_5 samples were also analyzed by the authors. Nonseeded samples were brought to 20°C and stirred vigorously to assure dissolved-oxygen saturation. Samples were incubated in the dark for 5 days at 20°C. BOD_5 was calculated from the difference between the initial (after stirring and before incubation) and the final (after 5 days) dissolved-oxygen concentration of the samples.

ROUTINE-SAMPLING RESULTS AND DISCUSSION

Areal Variation in Water Quality

Trilinear diagrams (Piper, 1944) were used as an aid in determining the chemical character of water in the San Lorenzo River basin. The diagrams showed that streams in the basin generally can be classified as having calcium bicarbonate water. The exceptions are Boulder, Carbonera, and Branciforte Creeks, which are mixed water of calcium, sodium, and magnesium cations and bicarbonate, sulfate, and chloride anions.

Water-Quality Areas

On the basis of property and constituent values shown in table 3, the San Lorenzo River basin can be divided into water-quality areas that generally correspond to the geologic areas described previously. The hardness classification used in this report is that given in Hem (1970, p. 225). West-side streams draining the granitic formations of the Ben Lomond Mountain area are relatively low in dissolved-ion concentrations and can be classified as soft to moderately hard water. East-side streams north of the Zayante fault drain undifferentiated, consolidated sedimentary deposits and contain the highest concentrations of dissolved ions found in the streams of the basin. This water can be classified as hard to very hard. East-side streams south of the Zayante fault drain primarily Santa Margarita Sandstone (water-bearing sandstone), the Purisima Formation (water-bearing shale), and Monterey Shale (consolidated, non-water-bearing shale). This water can be classified as moderately hard to very hard, being intermediate in dissolved-ion concentrations between water of west-side streams and water of east-side streams north of the Zayante fault.

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[1]The use of the brand name in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

TABLE 3.--*Areal variations of water quality*

[Values are in milligrams per liter, except specific conductance which is in micromhos at 25° Celsius]

Properties and constituents	Water-quality area					
	West-side streams draining Ben Lomond Mountain area[1]		East-side streams north of Zayante fault[2]		East-side streams south of Zayante fault[3]	
	Mean	Range	Mean	Range	Mean	Range
Specific conductance	216	175-247	517	353-782	368	216-520
Alkalinity as $CaCO_3$	89	51-120	169	110-230	113	67-150
Bicarbonate	112	64-140	203	133-266	138	75-189
Dissolved sulfate	11	6.6-24	83	50-110	50	19-80
Dissolved chloride	9.5	7.8-13	22	11-62	20	13-37
Dissolved calcium	29	16-37	63	43-82	43	24-63
Dissolved magnesium	5.4	4.2-6.7	13	9.8-17	9.4	4.6-15
Hardness	94	57-110	213	150-270	146	81-220
Dissolved sodium	10	8.5-13	29	17-53	22	14-36
Dissolved solids (sum of dissolved ions)	143	113-164	331	256-398	252	179-317

[1]Fall Creek (11160230, 11160250) and Boulder Creek downstream of Jamison Creek (11160070).

[2]Main stem of the San Lorenzo River upstream of Boulder Creek (11160020, 11160045), Kings Creek (11160036), Bear Creek (11160055, 11160060), and Zayante Creek upstream of Lompico Creek (11160280, 11160300).

[3]Love Creek (11160150), Newell Creek (11160200), Lompico Creek (11160320), Bean Creek (11160430), Zayante Creek downstream of Lompico Creek (11160450), and Branciforte Creek (11161500).

Carbonera Creek and Boulder Creek upstream of Jamison Creek are anomalous with respect to the three categories named. Boulder Creek upstream of Jamison Creek drains consolidated, sedimentary rocks on the north and east (the same formations found on the east side of the basin north of the Zayante fault) and granitic rocks of the Ben Lomond Mountain area on the west. Hence, the water in Boulder Creek upstream of Jamison Creek is a composite of water from both sedimentary and granitic formations and exhibits characteristics of each. It is not surprising, then, to find that water in Boulder Creek upstream of Jamison Creek is similar to the water of east-side streams south of the Zayante fault: moderately hard with dissolved-ion concentrations intermediate between west-side streams and east-side streams north of the Zayante fault (table 5).

Carbonera Creek drains primarily Santa Margarita Sandstone, Purisima Formation, and granitic rocks. Granitic rocks, uncommon in the east part of the basin, underlie a significant part of the Carbonera Creek drainage, and this is probably the reason that Carbonera Creek is lower in dissolved-ion concentration and hardness than other east-side streams (table 5).

A minor difference in sodium and chloride concentrations exists between Carbonera and Branciforte Creeks and other east-side streams south of the Zayante fault (table 5). This may be because Carbonera and Branciforte Creeks are nearer the ocean and its salt-laden fog and breezes.

Comparison of Water Quality Between Stations

A comparison of water quality between stations was done using Analysis of Variance (ANOVA) (Dixon and Massey, 1969, p. 150-162). ANOVA is a statistical method to test whether means are alike or not. For this study the single classification and 5-percent level of significance were used. The test allowed comparison of means between stations. The results of these tests are given in table 4. A statistical summary of data used is given in table 5. ANOVA tests were done if statistical criteria were met (indicated in table 4 by symbols not in parentheses). If a valid ANOVA test could not be made (symbols in parentheses), the mean and range of the property or constituent for the stations of interest were compared visually. For stations and properties or constituents for which an ANOVA test was done, a zero was entered in the column labeled Mean if the test indicated that apparent differences in the means were not statistically significant. A plus sign or a minus sign was entered in the column labeled Mean for the stations and property or constituent tested if there was a significant difference in means. A plus sign indicates that the mean is significantly greater at the first station listed in the column than at the second station listed. A minus sign indicates that the mean is significantly less at the first station listed in the column than at the second station listed. For example, under the column labeled Main stem and for the property specific conductance there is a plus sign which indicates that the mean specific conductance (482 micromhos) at station San Lorenzo River near Boulder Creek (11160020) is significantly greater than the mean specific conductance (324 micromhos) at station San Lorenzo River at Big Trees (11160500).

If an ANOVA test was not done and comparisons were visual, a zero in parentheses was entered in the column labeled Mean if the means and ranges were judged to be approximately equal at both stations. If the mean and range at the first station listed were judged to be greater than the mean and range at the second station listed, a plus sign in parentheses was entered in the column labeled Mean. When the mean and range at the first station listed were judged to be less than the mean and range at the second station listed, a minus sign in parentheses was entered in the column labeled Mean. If no judgment could be made because of the extreme variability of the property or constituent value at one or both of the stations compared, a question mark was entered in the column labeled Mean.

Columns labeled Mean having mostly zeros indicate the stations compared are similar in water quality. Columns labeled Mean having mostly plus signs or minus signs indicate the stations compared are dissimilar in water quality.

Main-stem gaging stations.--Even though calcium bicarbonate water is found at both main-stem gaging stations, San Lorenzo River near Boulder Creek (11160020) and San Lorenzo River at Big Trees (11160500), the water quality is much different, as shown in tables 4 and 5. Station 11160020 is near the basin headwaters in an area of consolidated, sedimentary formations and is upstream of virtually all residential areas. Station 11160500 is downstream of most of the residential areas in the basin, and the water found at this point on the main stem is a composite of water from the three water-quality areas described earlier. A mixing of water from these areas would produce water with lower concentrations of dissolved ions and lower hardness than the water from consolidated sedimentary rocks north of the Zayante fault. This is the case at station 11160500 where the water is only moderately hard to hard with concentrations of dissolved ions intermediate between west-side streams and east-side streams north of the Zayante fault.

Septic-tank system failures in the basin between stations 11160020 and 11160500 (Yoder, Trotter, Orlob and Associates, 1975) are well documented. There is some evidence that septic-tank system effluent is responsible for bacterial contamination in the basin (Butt and Hurst, 1974). Dissolved nitrite plus nitrate, chloride, and fecal-coliform concentrations (constituents normally found in septic-tank system effluent) are greater at station 11160500 than at station 11160020, which supports the contention that septic-tank system effluent may be reaching streams and affecting the quality of the water.

Natural conditions explain the similarity of temperature and turbidity at stations 11160020 and 11160500. Water temperatures are controlled primarily by the amount (number of hours) and kind (direct or diffuse) of sunlight received. Riparian woodlands form a dense canopy in the headwaters and near Henry Cowell Redwoods State Park. Hence, the river water at both stations is shaded and receives only diffuse sunlight most of the day. This is generally the case throughout the main stem of the San Lorenzo River and its tributaries and explains the similarities of water temperature throughout the basin. With the exception of stormflows, turbidity values are also similar (less than 10 JTU, Jackson turbidity units) throughout the basin. Because rainfall is the principal weathering agent in the basin, little erosion takes place, and turbidities are low except during storms. Thus, turbidities at stations 11160020 and 11160500 can be expected to be similar, except during storms.

TABLE 4.--*Comparison of water quality between stations*

[Comparisons based on data collected during study (November 1973-June 1975) except as follows: Stations 11160020 and 11160500, 11160070 and 11160250, 11160150 and 11160200, 11160200 and 11160450, 11160200 and 11161500 based on data collected August 1974-June 1975 excluding data collected during November 1974 storm; stations 11160150 and 11160450, 11160450 and 11161500 based on all data collected August 1974-June 1975. Symbols not in parentheses indicate criteria for ANOVA test were met. Symbols in parentheses indicate criteria were not met and comparisons were made visually. Plus sign indicates mean at first station is greater than at second. Minus sign indicates mean at first station is less than at second. Zero indicates means at two stations not significantly different. Question mark indicates no judgment made because of extreme variability of data]

Property or constituent	Main stem	West-side streams draining Ben Lomond Mountain area	East-side streams north of Zayante fault	Boulder Creek	Fall Creek	Bear Creek
	11160020 and 11160500	11160070 and 11160250	11160036 and 11160060	11160065 and 11160070	11160230 and 11160250	11160055 and 11160060
	Mean	Mean	Mean	Mean	Mean	Mean
Streamflow	(-)	(+)	0	(-)	0	0
Water temperature	0	0	0	0	0	0
Specific conductance	+	-	+	(+)	0	0
Turbidity	0	(+)	(0)	+	0	(+)
Fecal coliform	(-)	+	(+)	0	0	-
Fecal streptococci	0	0	(+)	0	0	0
Alkalinity as $CaCO_3$	(+)	-	0	0	0	0
Bicarbonate	(+)	-	0	0	0	0
Dissolved sulfate	+	(+)	+	+	(0)	+
Dissolved chloride	-	+	0	(+)	0	0
Dissolved calcium	(+)	-	(+)	+	0	+
Dissolved magnesium	+	+	(0)	0	0	+
Hardness	(+)	-	(+)	+	0	+
Dissolved sodium	0	+	0	(+)	0	0
Dissolved potassium	-	(0)	0	0	0	0
Dissolved silica	-	-	0	(0)	0	-
Dissolved iron	0	+	0	+	0	0
Dissolved manganese	(+)	(+)	0	(+)	(+)	(+)
Dissolved solids (sum of dissolved ions)	+	-	0	+	0	0
Dissolved nitrite plus nitrate as N	(-)	+	0	-	(0)	0
Dissolved orthophosphorus as P	0	0	0	0	0	0

TABLE 4.--*Comparison of water quality between stations*--Continued

Property or constituent	East-side streams south of Zayante fault					
	11160150 and 11160200	11160150 and 11160450	11160150 and 11161500	11160200 and 11160450	11160200 and 11161500	11160450 and 11161500
	Mean	Mean	Mean	Mean	Mean	Mean
Streamflow	(0)	(-)	(-)	(-)	(-)	(+)
Water temperature	0	0	0	0	0	0
Specific conductance	-	(-)	-	+	(0)	(0)
Turbidity	0	0	0	0	(-)	0
Fecal coliform	(+)	(0)	(?)	(-)	(-)	0
Fecal streptococci	0	0	0	0	0	0
Alkalinity as $CaCO_3$	(0)	(0)	0	+	(0)	0
Bicarbonate	(0)	(0)	0	+	(0)	(0)
Dissolved sulfate	-	-	-	+	+	0
Dissolved chloride	+	0	-	-	(-)	-
Dissolved calcium	-	(-)	0	+	(+)	(+)
Dissolved magnesium	-	-	-	(0)	(-)	-
Hardness	-	(-)	0	+	(+)	(0)
Dissolved sodium	(0)	-	-	-	(-)	(-)
Dissolved potassium	-	0	-	+	-	-
Dissolved silica	+	0	0	-	-	-
Dissolved iron	+	+	0	0	(-)	(-)
Dissolved manganese	0	0	-	0	0	-
Dissolved solids (sum of dissolved ions)	0	0	0	0	(-)	(-)
Dissolved nitrite plus nitrate as N	(0)	(-)	(-)	-	-	-
Dissolved orthophosphorus as P	+	0	0	-	-	+

TABLE 4.--*Comparison of water quality between stations*--Continued

Property or constituent	Branciforte Creek	Zayante Creek			
	11161400 and 11161500	11160280 and 11160300	11160300 and 11160320	11160300 and 11160430	11160320 and 11160430
	Mean	Mean	Mean	Mean	Mean
Streamflow	(-)	0	(+)	0	(-)
Water temperature	0	0	0	0	0
Specific conductance	(-)	0	+	(+)	(?)
Turbidity	0				
Fecal coliform	0	(?)	(?)	(?)	(?)
Fecal streptococci	0				
Alkalinity as $CaCO_3$	(-)				
Bicarbonate	(-)				
Dissolved sulfate	0	0	+	+	-
Dissolved chloride	0	0	0	0	0
Dissolved calcium	-	0	+	+	(?)
Dissolved magnesium	-	0	+	+	(0)
Hardness	-	0	+	+	(?)
Dissolved sodium	-				
Dissolved potassium	0				
Dissolved silica	0				
Dissolved iron	0				
Dissolved manganese	0				
Dissolved solids (sum of dissolved ions)	-				
Dissolved nitrite plus nitrate as N	(+)	(-)	0	-	-
Dissolved orthophosphorus as P	0				

TABLE 5.--*Water-quality data summary*

[Means and ranges are for period of study (November 1973-June 1975) except stations 11160150, 11160250, 11160450, 11160500, and 11161500, for which two values are given; the second value is for data collected August 1974-June 1975, excluding data collected during November 1974 storm. Streamflow is in cubic meters per second. Property and constituent values are in milligrams per liter, except water temperature, in degrees Celsius; specific conductance, in micromhos at 25° Celsius; pH, in units; turbidity, in Jackson Turbidity Units; fecal-coliform and fecal-streptococcal concentrations, in colonies per 100 milliliters; iron, manganese, and boron, in micrograms per liter. Dash indicates insufficient or no data]

11160020--San Lorenzo River near Boulder Creek
11160045--San Lorenzo River at Boulder Creek
11160060--Bear Creek at Boulder Creek
11160036--Kings Creek near Boulder Creek
11160055--Bear Creek near Boulder Creek

Property or constituent	11160020		11160036		11160045		11160055		11160060	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Streamflow	0.09	0.02-0.37	0.09	0.01-0.45	0.27	0.03-1.2	0.14	0.02-0.62	0.19	0.03-0.82
Water temperature	10.0	7.0-14.0	10.0	7.0-15.0	11.5	6.0-18.0	12.0	8.0-18.0	10.5	5.0-16.0
Specific conductance	482	417-520	561	432-637	579	353-782	533	417-605	494	408-529
pH	-	7.9-8.7	-	7.5-8.4	-	7.8-8.5	-	7.4-8.5	-	7.3-8.4
Turbidity	3	1-6	3	2-5	4	2-6	10	1-45	4	2-10
Fecal coliform (arithmetic)	21	a3-56	160	a23-680	230	40-a1,200	36	a8-a140	79	a34-150
Fecal coliform (geometric)	14		86		120		23		72	
Fecal streptococci (arithmetic)	50	a7-210	250	a5-1,000	200	a28-650	130	a13-520	120	a12-310
Fecal streptococci (geometric)	22		66		120		50		59	
Alkalinity as $CaCO_3$	200	140-230	170	120-200	160	110-190	170	120-210	150	110-180
Bicarbonate	231	181-266	202	151-242	193	135-262	206	146-248	183	133-213
Dissolved sulfate	60	50-74	93	86-100	74	62-84	93	90-98	82	71-89
Dissolved chloride	15	13-18	27	19-35	37	17-62	19	11-26	22	13-27
Dissolved calcium	71	57-78	70	55-82	63	45-79	67	53-79	58	49-63
Dissolved magnesium	12	9.8-14	14	11-16	12	9.8-13	15	13-17	13	12-14
Hardness	230	180-250	230	180-270	210	150-250	230	190-260	200	170-210
Dissolved sodium	20	17-23	32	22-41	35	22-53	29	18-37	30	21-36
Dissolved potassium	1.4	1.1-1.6	2.2	1.8-3.0	2.2	1.9-3.0	2.0	1.7-2.6	2.1	1.5-3.1
Dissolved silica	22	21-23	22	21-23	23	22-24	20	17-21	22	21-22
Dissolved fluoride	0.3	0.2-0.4	0.3	0.3-0.4	0.4	0.3-0.7	0.4	0.3-0.4	0.3	0.2-0.4
Dissolved iron	70	30-150	90	60-140	60	40-80	50	10-110	60	40-90
Dissolved manganese	1,100	0-5,500	20	5-50	260	10-1,200	1,200	10-6,100	20	0-50
Dissolved boron	-	-	-	-	-	-	-	-	-	-
Dissolved solids (sum of dissolved ions)	315	273-337	354	290-398	322	256-367	343	279-378	317	269-343
Dissolved nitrite plus nitrate	0.02	0-0.09	0.03	0.01-0.05	0.02	0-0.06	0.02	0.01-0.03	0.01	0-0.03
Total nitrite plus nitrate	-	-	-	-	-	-	-	-	-	-
Total ammonia nitrogen as N	-	-	-	-	-	-	-	-	-	-
Total Kjeldahl nitrogen as N	-	-	-	-	-	-	-	-	-	-
Dissolved orthophosphorus as P	0.12	0.10-0.14	0.08	0.06-0.10	0.09	0.05-0.16	0.08	0.04-0.13	0.08	0.04-0.12
Total phosphorus	-	-	-	-	-	-	-	-	-	-
Total orthophosphorus	-	-	-	-	-	-	-	-	-	-
Dissolved oxygen (concentration)	10.8	9.6-11.8	10.8	9.2-12.3	10.6	8.8-12.3	10.5	9.0-11.5	10.4	8.4-12.4
Dissolved oxygen (percent saturation)	100	99-103	101	97-105	102	98-105	102	99-106	96	76-101
Chemical oxygen demand	-	-	-	-	-	-	-	-	-	-
5-day biochemical oxygen demand	-	0.9-1.2	-	1.3-1.5	-	1.4-2.5	-	2.2-8.0	-	1.2-2.1

See footnote at end of table.

TABLE 5.--*Water-quality data summary*--Continued

11160065--Boulder Creek above Jamison Creek, near Boulder Creek
11160150--Love Creek at Ben Lomond
11160070--Boulder Creek at Boulder Creek
11160200--Newell Creek at Ben Lomond

Property or constituent	11160065		11160070		11160150				11160200	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Streamflow	0.07	0.0008-0.34	0.22	0.06-0.88	0.06	0.01-0.24	0.04	0.01-0.11	0.03	0.02-0.04
Water temperature	9.5	5.5-14.0	11.5	7.0-19.0	11.0	5.0-15.0	11.0	5.0-15.0	12.0	8.0-15.0
Specific conductance	297	213-346	199	175-216	332	216-377	334	262-377	410	363-454
pH	-	7.2-8.0	-	7.3-8.2	-	7.8-8.3	-	7.9-8.3	-	7.4-8.2
Turbidity	6	3-10	3	1-6	15	1-65	6	1-20	5	2-10
Fecal coliform (arithmetic)	53	a6-a150	90	a23-210	2,500	40-a24,000	120	40-210	30	a2-84
Fecal coliform (geometric)	38		73		170		99		19	
Fecal streptococci (arithmetic)	230	a5-820	170	a28-440	280	a17-870	-	-	98	a5-380
Fecal streptococci (geometric)	63		83		120				37	
Alkalinity as $CaCO_3$	66	46-92	70	51-84	110	67-140	120	87-140	120	100-130
Bicarbonate	83	57-111	87	64-102	133	75-169	140	105-169	145	133-156
Dissolved sulfate	46	31-58	17	9.9-24	34	25-41	36	30-41	71	62-80
Dissolved chloride	22	13-28	11	9.3-13	19	14-24	19	14-24	14	13-18
Dissolved calcium	27	20-33	21	16-25	40	25-46	42	33-46	51	46-59
Dissolved magnesium	6.2	5.2-7.2	5.9	4.2-6.7	7.0	4.6-8.1	7.3	5.9-8.1	9.6	8.8-10
Hardness	93	71-110	76	57-88	130	81-150	140	110-150	170	160-190
Dissolved sodium	23	17-27	12	11-13	19	14-22	19	14-22	20	17-21
Dissolved potassium	2.2	1.6-3.2	1.9	1.4-2.8	1.8	1.3-3.3	1.6	1.3-2.1	2.2	1.7-2.8
Dissolved silica	20	15-22	20	19-21	31	24-34	-	-	16	13-20
Dissolved fluoride	0.2	0.1-0.2	0.1	0.1	0.2	0.2	-	-	0.3	0.2-0.3
Dissolved iron	200	130-280	70	40-100	100	70-150	-	-	60	40-90
Dissolved manganese	290	30-1,200	7	0-20	20	10-30	-	-	40	20-60
Dissolved boron	-	-	-	-	-	-	-	-	-	-
Dissolved solids (sum of dissolved ions)	187	155-210	130	113-137	224	179-245	-	-	255	243-288
Dissolved nitrite plus nitrate	0.04	0.01-0.09	0.11	0.07-0.19	0.07	0.05-0.08	-	-	0.09	0.04-0.20
Total nitrite plus nitrate	-	-	-	-	-	-	-	-	-	-
Total ammonia nitrogen as N	-	-	-	-	-	-	-	-	-	-
Total Kjeldahl nitrogen as N	-	-	-	-	-	-	-	-	-	-
Dissolved orthophosphorus as P	0.04	0.01-0.06	0.05	0.02-0.07	0.21	0.17-0.25	-	-	0.06	0.03-0.09
Total phosphorus	-	-	-	-	-	-	-	-	-	-
Total orthophosphorus	-	-	-	-	-	-	-	-	-	-
Dissolved oxygen (concentration)	9.8	7.1-12.1	10.9	9.2-12.0	10.8	9.2-12.3	-	-	10.0	8.9-11.0
Dissolved oxygen (percent saturation)	91	73-100	103	98-112	100	95-104			96	86-103
Chemical oxygen demand	-	-	-	-	-	-	-	-	-	-
5-day biochemical oxygen demand	-	1.0-1.8	-	0.9-1.7	-	0.8-2.4	-	-	-	0.8-2.2

See footnote at end of table.

TABLE 5.--*Water-quality data summary*--Continued

11160230--Fall Creek below Bennett Creek, at Felton
11160280--Zayante Creek below Mountain Charlie Gulch, near Zayante
11160250--Fall Creek at Felton
11160300--Zayante Creek at Zayante

Property or constituent	11160230		11160250		11160280		11160300	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Streamflow	0.14	0.07-0.31	0.16	0.09-0.34	0.15	0.09-0.34	0.24	0.05-0.59	0.34	0.03-0.71
Water temperature	11.0	8.5-14.0	11.5	8.0-15.5	11.5	8.0-15.5	10.0	6.0-16.0	11.0	6.0-18.0
Specific conductance	222	200-241	228	197-247	230	197-247	474	403-545	481	363-587
pH	-	7.7-8.4	-	7.6-8.5	-	7.6-8.5	-	7.2-8.1	-	7.2-8.6
Turbidity	3	1-15	3	1-10	1	1-2	-	-	-	-
Fecal coliform (arithmetic) (geometric)	94 42	a7-460	82 35	a2-420	39 26	a2-a83	540 170	a27-a1,800	1,500 850	a160-3,800
Fecal streptococci (arithmetic) (geometric)	72 13	a2-410	72 31	a3-240	-	-	-	-	-	-
Alkalinity as $CaCO_3$	99	80-110	100	89-120	100	89-120	-	-	-	-
Bicarbonate	125	116-139	124	108-140	125	108-140	-	-	-	-
Dissolved sulfate	8.1	7.0-8.7	8.6	6.6-9.9	8.8	6.6-9.9	94	74-110	90	68-100
Dissolved chloride	8.7	7.8-11	9.1	8.0-11	9.2	8.0-11	18	12-28	17	12-25
Dissolved calcium	33	28-37	32	28-36	33	28-36	54	43-62	58	44-72
Dissolved magnesium	5.2	4.7-5.7	5.0	4.2-5.5	5.0	4.2-5.5	15	12-17	14	12-17
Hardness	104	89-110	102	92-110	102	92-110	200	160-220	210	170-250
Dissolved sodium	9.2	8.5-9.8	9.2	8.5-9.8	9.2	8.5-9.8	-	-	-	-
Dissolved potassium	2.0	1.8-2.3	2.0	1.8-2.6	1.9	1.8-2.1	-	-	-	-
Dissolved silica	23	22-23	23	22-24	-	-	-	-	-	-
Dissolved fluoride	0.1	0.1	0.1	0.0-0.1	-	-	-	-	-	-
Dissolved iron	30	10-40	40	10-50	-	-	-	-	-	-
Dissolved manganese	5	0-20	1	0-5	-	-	-	-	-	-
Dissolved boron	-	-	-	-	-	-	-	-	-	-
Dissolved solids (sum of dissolved ions)	150	133-162	150	135-164	-	-	-	-	-	-
Dissolved nitrite plus nitrate	0.01	0.0-0.02	0.02	0-0.08	-	-	0.04	0.01-0.09	0.14	0.03-0.63
Total nitrite plus nitrate	-	-	-	-	-	-	-	-	-	-
Total ammonia nitrogen as N	-	-	-	-	-	-	-	-	-	-
Total Kjeldahl nitrogen as N	-	-	-	-	-	-	-	-	-	-
Dissolved orthophosphorus as P	0.04	0.03-0.05	0.04	0.02-0.06	-	-	-	-	-	-
Total phosphorus	-	-	-	-	-	-	-	-	-	-
Total orthophosphorus	-	-	-	-	-	-	-	-	-	-
Dissolved oxygen (concentration)	10.8	10.1-11.7	10.7	9.4-11.9	-	-	11.1	9.7-12.7	11.2	9.9-12.2
Dissolved oxygen (percent saturation)	102	98-107	102	98-110			104	100-108	105	98-116
Chemical oxygen demand	-	-	-	-	-	-	-	-	-	-
5-day biochemical oxygen demand	-	0.6-1.6	-	0.2-2.2	-	-	-	-	-	-

See footnote at end of table.

TABLE 5.--*Water-quality data summary*--Continued

11160320--Lompico Creek at Zayante 11160430--Bean Creek near Felton
11160450--Zayante Creek at Felton

Property or constituent	11160320		11160430		11160450			
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Streamflow	0.06	0.02-0.11	0.28	0.12-0.74	0.65	0.17-1.7	0.48	0.17-1.6
Water temperature	11.0	8.0-17.0	11.5	8.0-18.0	12.5	8.0-18.0	13.0	8.0-18.0
Specific conductance	338	232-496	357	323-384	369	311-424	376	351-424
pH	-	7.2-8.2	-	6.6-7.9	-	7.1-8.5	-	7.6-8.5
Turbidity	-	-	-	-	15	3-75	5	3-9
Fecal coliform (arithmetic) (geometric)	4,800 930	210-a1,800	560 340	a130-a1,500	1,300 270	46-a7,500	860 170	46-a7,400
Fecal streptococci (arithmetic) (geometric)	-	-	-	-	240 160	44-660	250 170	44-660
Alkalinity as $CaCO_3$	-	-	-	-	110	93-110	110	93-110
Bicarbonate	-	-	-	-	134	122-143	134	122-143
Dissolved sulfate	30	19-41	59	46-71	56	42-70	54	42-67
Dissolved chloride	17	13-22	19	14-24	20	14-26	22	16-26
Dissolved calcium	41	26-63	43	32-49	43	36-49	45	42-49
Dissolved magnesium	10	6.7-14	9.0	6.4-10	9.1	6.5-11	8.7	6.5-10
Hardness	150	93-220	150	120-160	150	120-160	150	140-160
Dissolved sodium	-	-	-	-	23	19-25	23	19-25
Dissolved potassium	-	-	-	-	2.1	1.5-4.1	1.8	1.5-2.0
Dissolved silica	-	-	-	-	29	27-31	-	-
Dissolved fluoride	-	-	-	-	0.3	0.2-0.3	-	-
Dissolved iron	-	-	-	-	60	40-80	-	-
Dissolved manganese	-	-	-	-	20	0-30	-	-
Dissolved boron	-	-	-	-	-	-	-	-
Dissolved solids (sum of dissolved ions)	-	-	-	-	256	242-270	-	-
Dissolved nitrite plus nitrate	0.17	0.04-0.66	0.42	0.08-0.64	0.39	0.24-0.58	0.42	0.27-0.52
Total nitrite plus nitrate	-	-	-	-	-	-	-	-
Total ammonia nitrogen as N	-	-	0.05	0.01-0.12	-	-	-	-
Total Kjeldahl nitrogen as N	-	-	0.32	0.20-0.45	-	-	-	-
Dissolved orthophosphorus as P	-	-	-	-	0.23	0.15-0.27	-	-
Total phosphorus	-	-	0.38	0.35-0.43	-	-	-	-
Total orthophosphorus	-	-	0.30	0.24-0.39	-	-	-	-
Dissolved oxygen (concentration) (percent saturation)	10.2 96	8.5-11.4 88-110	10.4 99	9.2-11.0 96-106	10.6 104	9.1-11.8 98-112	-	-
Chemical oxygen demand	-	-	9	0-18	-	-	-	-
5-day biochemical oxygen demand	-	-	1.2	0.7-2.0	2.2	0.6-4.3	-	-

See footnote at end of table.

TABLE 5.--*Water-quality data summary*--Continued

11160500--San Lorenzo River at Big Trees (at discontinued gaging station)
11161400--Carbonera Creek at Santa Cruz 11161500--Branciforte Creek at Santa Cruz

Property or constituent	11160500				11161400		11161500			
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Streamflow	2.6	0.62-7.96	1.6	0.62-4.33	0.07	0.02-0.25	0.16	0.05-0.65	0.16	0.05-0.65
Water temperature	12.0	6.5-18.0	12.5	6.5-18.0	11.5	7.0-17.0	11.5	7.0-16.5	11.5	7-16.5
Specific conductance	324	271-369	344	289-369	296	246-362	401	272-520	408	272-520
pH	-	6.8-8.3	-	7.5-8.3	-	7.2-8.0	-	7.5-8.1	-	7.5-8.1
Turbidity	20	2-130	4	2-5	10	3-40	15	3-55	9	3-30
Fecal coliform (arithmetic)	950	44-6,200	100	44-200	750	a8-6,000	800	44-6,400	180	44-330
(geometric)	210		87		170		220		150	
Fecal streptococci (arithmetic)	120	a23-310	110	a23-310	200	50-300	250	44-480	250	44-480
(geometric)	82		76		180		180		180	
Alkalinity as $CaCO_3$	100	75-110	100	82-110	65	46-72	120	69-150	120	69-150
Bicarbonate	129	95-144	133	115-144	79	55-91	140	86-189	144	86-189
Dissolved sulfate	43	31-53	42	32-53	41	32-46	47	34-58	47	34-58
Dissolved chloride	18	13-23	19	14-23	26	19-38	29	20-37	29	20-37
Dissolved calcium	39	31-47	42	38-47	26	21-32	38	24-49	39	24-49
Dissolved magnesium	7.8	6.1-9.0	8.0	6.1-9.0	7.4	5.8-9.1	12	8.4-15	12	8.4-15
Hardness	130	100-150	140	120-150	98	79-120	150	95-180	150	95-180
Dissolved sodium	20	17-22	20	17-22	23	16-32	28	18-36	29	18-36
Dissolved potassium	2.0	1.8-2.6	2.0	1.8-2.1	2.8	2.0-4.1	3.3	2.2-4.7	3.1	2.2-3.7
Dissolved silica	23	17-26	24	22-26	30	26-33	33	29-37	-	-
Dissolved fluoride	0.2	0.2-0.3	0.2	0.2-0.3	0.2	0.1-0.2	0.2	0.2-0.4	-	-
Dissolved iron	70	20-140	60	20-140	140	60-210	160	60-300	-	-
Dissolved manganese	20	0-40	-	-	50	40-70	50	30-60	-	-
Dissolved boron	65	60-70	-	-	-	-	-	-	-	-
Dissolved solids (sum of dissolved ions)	221	183-239	225	214-239	204	172-243	270	190-317	-	-
Dissolved nitrite plus nitrate	0.21	0.08-0.64	0.25	0.13-0.64	1.0	0.67-1.7	0.64	0.53-0.82	-	-
Total nitrite plus nitrate	0.27	0.14-0.65	-	-	-	-	-	-	-	-
Total ammonia nitrogen as N	0.04	0.00-0.13	-	-	-	-	-	-	-	-
Total Kjeldahl nitrogen as N	0.33	0.08-0.80	-	-	-	-	-	-	-	-
Dissolved orthophosphorus as P	0.12	0.07-0.18	0.12	0.07-0.18	0.14	0.08-0.24	0.17	0.14-0.20	-	-
Total phosphorus	0.18	0.01-0.38	-	-	-	-	-	-	-	-
Total orthophosphorus	0.15	0.09-0.19	-	-	-	-	-	-	-	-
Dissolved oxygen (concentration)	10.7	9.1-12.3	-	-	10.3	8.9-11.8	10.2	9.0-11.9	-	-
(percent saturation)	103	93-116			96	92-101	95	90-104		
Chemical oxygen demand	9	1-21	-	-	-	-	-	-	-	-
5-day biochemical oxygen demand	1.4	1.1-2.0	-	-	-	1.2-2.7	-	1.5-2.2	-	-

[a]Indicates that results are based on colony counts outside the acceptable range (20-60 colonies per filter for fecal coliform and 20-100 colonies per filter for fecal streptococci).

West-side stations.--The consolidated, sedimentary rocks (primarily Vaqueros Sandstone, Butano Sandstone, and San Lorenzo Formation) in the Boulder Creek drainage upstream from Jamison Creek seem to be partly responsible for the greater concentrations of sulfate, chloride, and sodium at the station Boulder Creek at Boulder Creek (11160070) than at the station Fall Creek at Felton (11160250) (tables 4 and 5). These deposits are not found in the Fall Creek drainage, and streams draining these deposits north of the Zayante fault have the greatest dissolved-ion concentrations of any in the San Lorenzo River basin.

Bank seeps at Boulder Creek above Jamison Creek, near Boulder Creek (11160065) are probably responsible for greater concentrations of iron and manganese and may partly account for greater concentrations of sulfate at the downstream station Boulder Creek at Boulder Creek than at Fall Creek. Judging from their appearance (a rusty-red color) and smell (rotten-egg odor) these seeps contain high concentrations of iron and sulfur. Iron concentrations at Boulder Creek above Jamison Creek were high compared to other stations studied, and sulfate concentrations were much greater than at the station Boulder Creek at Boulder Creek (table 5). Relatively high concentrations of manganese at the station Boulder Creek above Jamison Creek indicate that these seeps may also contain high concentrations of manganese (table 5).

The reason for the lower values of specific conductance, alkalinity, bicarbonate, calcium, hardness, and dissolved solids at the station Boulder Creek at Boulder Creek than at Fall Creek at Felton has not been determined.

Greater nitrite plus nitrate and fecal-coliform concentrations at the station Boulder Creek at Boulder Creek than at Fall Creek at Felton may be due to the influence of septic-tank systems because there is more residential development in the Boulder Creek drainage than in the Fall Creek drainage. However, the nitrite plus nitrate concentrations are low at both stations and only one sample at the station Boulder Creek at Boulder Creek yielded a fecal-coliform concentration in excess of the pre-April 1975 basin standard of 200 col/100 mL (colonies per 100 milliliters) of water (the pre-April 1975 standard, California Water Resources Control Board, 1975).

East-side stations north of Zayante fault.--The water quality of Kings Creek and Bear Creek is similar. Slightly greater values of specific conductance, sulfate, calcium, and hardness at Kings Creek near Boulder Creek (11160036) than at Bear Creek at Boulder Creek (11160060) may be due to the different geologic formations drained. Kings Creek drains Vaqueros Sandstone and San Lorenzo Formation; Bear Creek drains mostly Vaqueros Sandstone. The amount of residential development is similar in both drainages, but fecal-coliform and fecal-streptococcal concentrations were greater at Kings Creek near Boulder Creek than at Bear Creek at Boulder Creek. Septic-tank system effluent was observed downslope of one residence near the sampling station on Kings Creek. This and possibly other septic-tank system failures along Kings Creek could be responsible for the greater fecal-coliform and fecal-streptococcal concentrations at Kings Creek near Boulder Creek.

East-side stations south of Zayante fault.--Differences in water quality between Love Creek at Ben Lomond (11160150) and Newell Creek at Ben Lomond (11160200) cannot be explained by geologic differences because these drainage basins are similar geologically. Much of the flow at Newell Creek at Ben Lomond is release water from Loch Lomond (just upstream from the station). But differences in water quality between the Love Creek and Newell Creek stations do not seem to be due to retention of Newell Creek water in Loch Lomond because specific conductance and hardness values are less in Loch Lomond than at the Newell Creek station. The reasons for lower values of specific conductance, most cations, and sulfate at the Love Creek station than at the Newell Creek station are not known. Greater fecal-coliform concentrations at the Love Creek station than at the Newell Creek station may be related to septic-tank effluent because Love Creek flows through a residential area, whereas the area upstream from the Newell Creek station is virtually undeveloped except for Loch Lomond. Also, septic-tank system failures have been identified in the Love Creek drainage basin (Butt and Hurst, 1974).

Comparison of Love Creek with Zayante Creek at Felton (11160450) and with Branciforte Creek at Santa Cruz (11161500) shows that concentrations of most dissolved ions are lowest in Love Creek. Differences in dissolved-ion concentrations are probably not attributable to geologic differences. A comparison of Zayante Creek and Branciforte Creek with Newell Creek, which has a drainage basin similar geologically to the Love Creek basin, shows dissolved-ion concentrations are highest in Newell Creek, instead of lowest as with Love Creek.

Greater fecal-coliform and nitrite plus nitrate concentrations in Zayante and Branciforte Creek than in Newell Creek (station 11160200) may be related to septic-tank effluent because Zayante Creek and Branciforte Creek flow through residential areas where septic-tank system failures have been identified (Butt and Hurst, 1974).

Zayante Creek and Branciforte Creek are similar in water quality. The lower concentrations of sodium and chloride at Zayante Creek at Felton than at Branciforte Creek at Santa Cruz may be due to the proximity of the Branciforte Creek drainage basin to the ocean and its salt-laden breezes and fog. Lower concentrations of minor ions and silica may be due to geologic differences between the drainage basins.

Boulder Creek stations.--The geology of the Boulder Creek basin upstream of Jamison Creek is greatly different from that of the rest of the Boulder Creek drainage basin. This difference is reflected in the water quality at Boulder Creek above Jamison Creek, near Boulder Creek (11160065) (table 4). Boulder Creek downstream from Jamison Creek receives flow from tributaries that drain granitic formations of Ben Lomond Mountain. This results in lower concentrations of most dissolved ions at the downstream station. Also, bank seeps such as those noticed at Boulder Creek above Jamison Creek, near Boulder Creek were not observed at the downstream station. The seeps made the water murky and accounted for the greater turbidities at Boulder Creek above Jamison Creek, near Boulder Creek than at the station Boulder Creek at Boulder Creek.

Fall Creek stations.--Fall Creek below Bennett Creek, at Felton (11160230) and Fall Creek at Felton (11160250) have similar water quality (tables 4 and 5). The intervening residential area apparently is not affecting the water quality of this creek.

Bear Creek stations.--The differences in chemical quality between Bear Creek near Boulder Creek (11160055) and Bear Creek at Boulder Creek (11160060) are probably not due to geology because the geology in the vicinity of these stations is similar. The reason for the differences in chemical quality is not known. Fecal-coliform concentrations were greater at Bear Creek at Boulder Creek, indicating that the intervening residential area may be affecting the bacterial quality of this creek. But the concentrations at both stations were usually less than the pre-April 1975 basin standard of 200 col/100 mL of water (the pre-April 1975 standard, California Water Resources Control Board, 1975).

Zayante Creek stations.--The only chemical quality differences between stations in the Zayante Creek drainage basin that may be due to geologic differences are the greater constituent values at Zayante Creek at Zayante (11160300) than at Bean Creek near Felton (11160430). Bean Creek drains primarily Santa Margarita Sandstone and Santa Cruz Mudstone of Clark (1966); Zayante Creek upstream of Zayante Creek at Zayante drains primarily Monterey Shale, Butano Sandstone, Vaqueros Sandstone, and Zayante Sandstone.

Nitrite plus nitrate concentrations are much greater at Bean Creek near Felton than at other stations in the Zayante Creek drainage basin. Seepage from septic-tank systems or primary-treated domestic sewage discharged at the city of Scotts Valley pit may be the source of the higher nitrite plus nitrate concentrations in Bean Creek; ground water in the pit area moves toward Bean Creek (Wire, 1977), and there is no evidence that high nitrite plus nitrate concentrations are found in the Santa Margarita Sandstone or Santa Cruz Mudstone.

The reasons for the similarities and differences between other stations in the Zayante Creek drainage basin are not known.

Branciforte Creek Stations.--Geologic differences are probably responsible for the differences in water quality between Carbonera and Branciforte Creeks. Carbonera Creek drains primarily Santa Margarita Sandstone and granitic rocks; Branciforte Creek drains primarily the Purisima Formation.

Temporal Variation in Water Quality

Seasonal Changes in Water Quality

Changes during storms.--Samples were taken at seven stations during a November storm. Comparison of prestorm and storm data shows that streamflow, turbidity, and total Kjeldahl-nitrogen, total-phosphorus, dissolved-potassium, and fecal-coliform concentrations increased markedly as a result of the storm (table 6). In contrast, values of specific conductance, hardness, and dissolved solids were substantially less in the stormflow than in prestorm flows (table 6).

The magnitude of turbidity increases was much less in the Fall Creek drainage basin, which is mostly undeveloped, than in other drainage basins shown in table 6, which have substantial residential development. Also, Fall Creek drains granitic rocks that are more resistant to weathering than the sandstone, mudstone, and shale that are drained by the other streams shown in table 6. This suggests that residential development and relatively unstable geologic formations on the east side of the San Lorenzo River basin are causing increased turbidities in the basin during storms.

One possible source of increased concentrations of total Kjeldahl nitrogen, total phosphorus, and dissolved potassium during the storm is the leaching and suspension of vegetation (especially fallen leaves) by surface runoff. Another possible source of these constituents and of fecal-coliform bacteria from feces of domestic animals is surface runoff from residential areas. Increased concentrations of total Kjeldahl nitrogen and fecal-coliform bacteria during storms also may be due to flushing of septic-tank systems by rising water tables and surface runoff. The magnitude of increase in fecal-coliform bacteria was less in the Fall Creek drainage basin (mostly undeveloped) than in other basins (table 6).

The decrease in specific conductance, hardness, and dissolved-solids values during the storm is most likely due to surface runoff from rainfall which has low concentrations of dissolved constituents and thus dilutes the prestorm concentrations of these constituents.

TABLE 6.--*Changes in water quality as a result of November 21, 1974, storm*

[Streamflow, in cubic meters per second, and properties and constituents, in milligrams per liter, except for specific conductance, in micromhos at 25° Celsius; turbidity, in Jackson Turbidity Units; fecal-coliform concentration, in colonies per 100 milliliters. Dash indicates no storm value for comparison or constituent was not sampled. Stations 11160020-11160070 and 11160200 not included because they were sampled prior to storm]

Property or constituent	Stations													
	Love Creek		Fall Creek				Zayante Creek		San Lorenzo River		Carbonera Creek		Branciforte Creek	
	11160150		11160230		11160250		11160450		11160500		11161400		11161500	
	Mean pre-storm value[1]	Storm value	Mean pre-storm value	Storm value	Mean pre-storm value	Storm value	Mean pre-storm value	Storm value	Mean pre-storm value	Storm value	Mean pre-storm value	Storm value	Mean pre-storm value	Storm value
Streamflow	0.017	0.24	0.08	0.16	0.10	0.22	0.25	1.4	1.0	2.0	0.025	0.07	0.06	0.14
Specific conductance	353	216	238	213	243	213	372	359	332	289	281	257	407	337
Turbidity	7	65	3	15	2	10	5	75	2	130	4	40	3	55
Fecal coliform	120	a24,000	22	460	21	420	91	a7,400	44	6,200	81	6,000	95	6,400
Hardness	140	81	110	98	110	100	140	140	130	100	79	80	130	110
Dissolved potassium	2.0	3.3	1.9	2.3	2.0	2.6	1.6	4.1	1.9	2.6	2.8	4.1	3.3	4.7
Dissolved solids (sum of dissolved ions)	-	-	-	-	-	-	-	-	216	183	-	-	-	-
Total Kjeldahl nitrogen	-	-	-	-	-	-	-	-	.20	.78	-	-	-	-
Total phosphorus	-	-	-	-	-	-	-	-	.16	.32	-	-	-	-

[1]Mean prestorm values for all stations are for low-flow period May 1974-October 1974.
[a]Indicates that colony counts are outside the acceptable range (20-60 colonies per filter for fecal coliform).

Annual pattern of streamflow and water quality.--Although there are some variations between stations, the annual pattern of streamflow and water quality in the San Lorenzo River basin during the period of study is generally as shown for station 11160500 (San Lorenzo River at Big Trees) (figs. 6-8) and can be described as follows:

1. Streamflows increase during the rainy season, markedly during storms.
2. Water temperatures follow seasonal air temperature patterns, decreasing from autumn through winter and increasing in spring and summer.
3. Specific conductance values and most dissolved-ion concentrations decrease during the rainy season, probably in response to dilution by storm runoff.
4. Turbidities increase during storms but otherwise are less than or equal to 10 JTU.
5. Fecal-streptococcal concentrations decrease during the rainy season; the highest measured concentrations occur in September or October when streamflows are usually lowest. Fecal-coliform concentrations are greatest during storms. Data on fecal-streptococcal concentrations during storms were not obtained.
6. Concentrations of fluoride and boron are fairly constant throughout the year. BOD_5 values were fairly constant during the study and were usually less than 3 mg/L (milligrams per liter) at all stations sampled.
7. Dissolved-oxygen concentrations increased during the rainy season, probably in response to lower water temperatures. Percent saturation oxygen values were fairly constant and close to 100.

These findings show that water-quality degradation occurs during late summer and early autumn and during rainstorms. The best water quality was observed during late winter to early spring nonstorm flows because the concentrations of dissolved constituents, fecal coliform, and fecal streptococci were low and turbidities were similar to those during summer low flows. Low BOD_5 values suggest that the concentration of oxygen-demanding material is low in streams throughout the basin.

EXPLANATION
(FIGURES 6, 7, AND 8)

Values for properties and constituents are plotted using the ordinate value shown. The following gives the units in which each is reported.

Water discharge	cubic meters per second
Turbidity	Jackson Turbidity Units
Fecal coliform	colonies per 100 milliliters
Fecal streptococci	colonies per 100 milliliters
5-day biochemical oxygen demand	milligrams per liter
Dissolved fluoride	milligrams per liter
Dissolved solids (calculated sum)	milligrams per liter
Specific conductance	micromhos at 25 degrees Celsius
Dissolved boron	micrograms per liter
Dissolved oxygen	milligrams per liter
Water temperature	degrees Celsius

(Figures 6, 7, and 8 follow on pages 40, 41, and 42.)

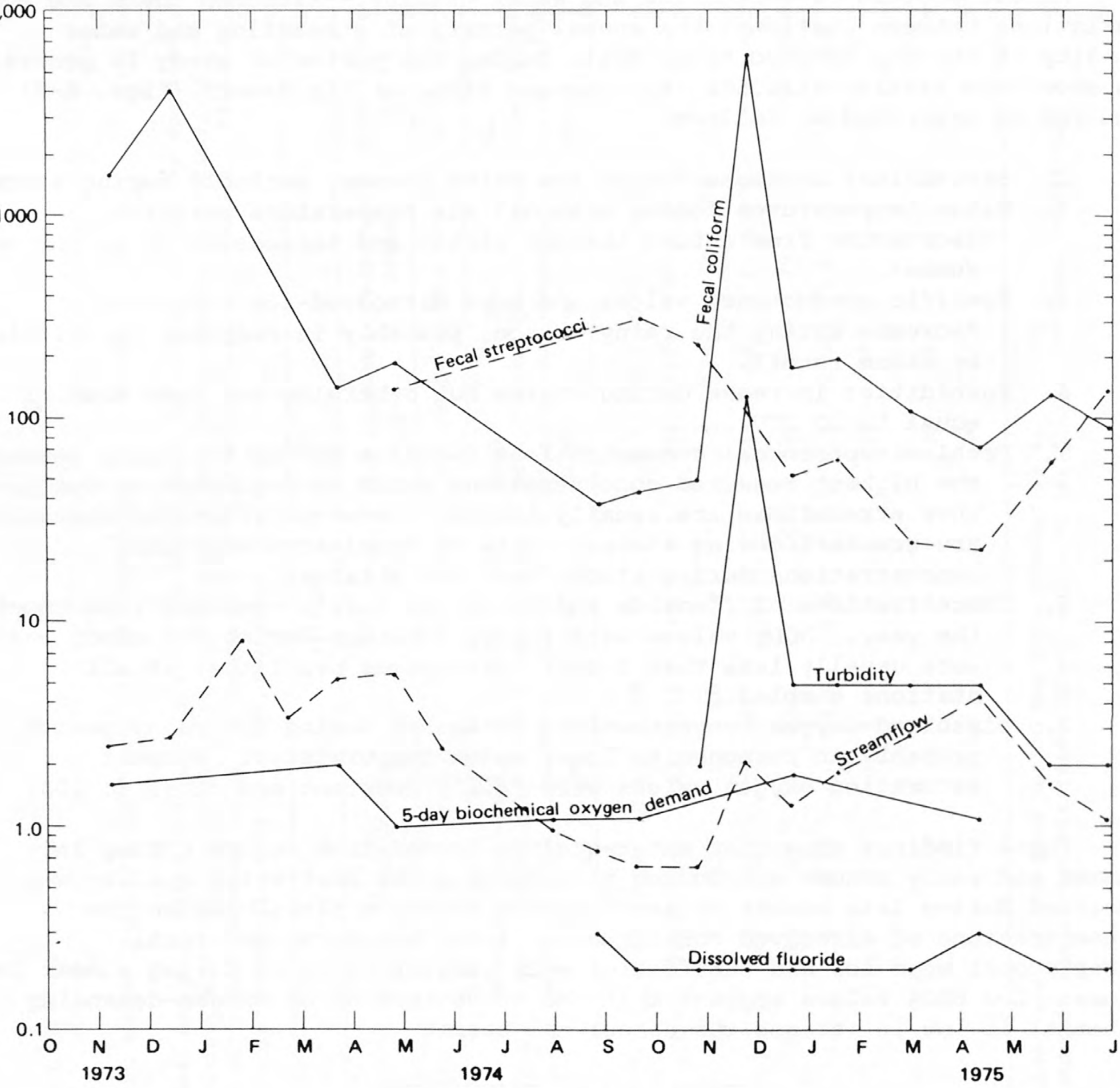


FIGURE 6.--Annual pattern of streamflow, fecal-coliform and fecal-streptococcal concentrations, tubidity, 5-day biochemical oxygen demand, and dissolved fluoride, San Lorenzo River at Big Trees (11160500).

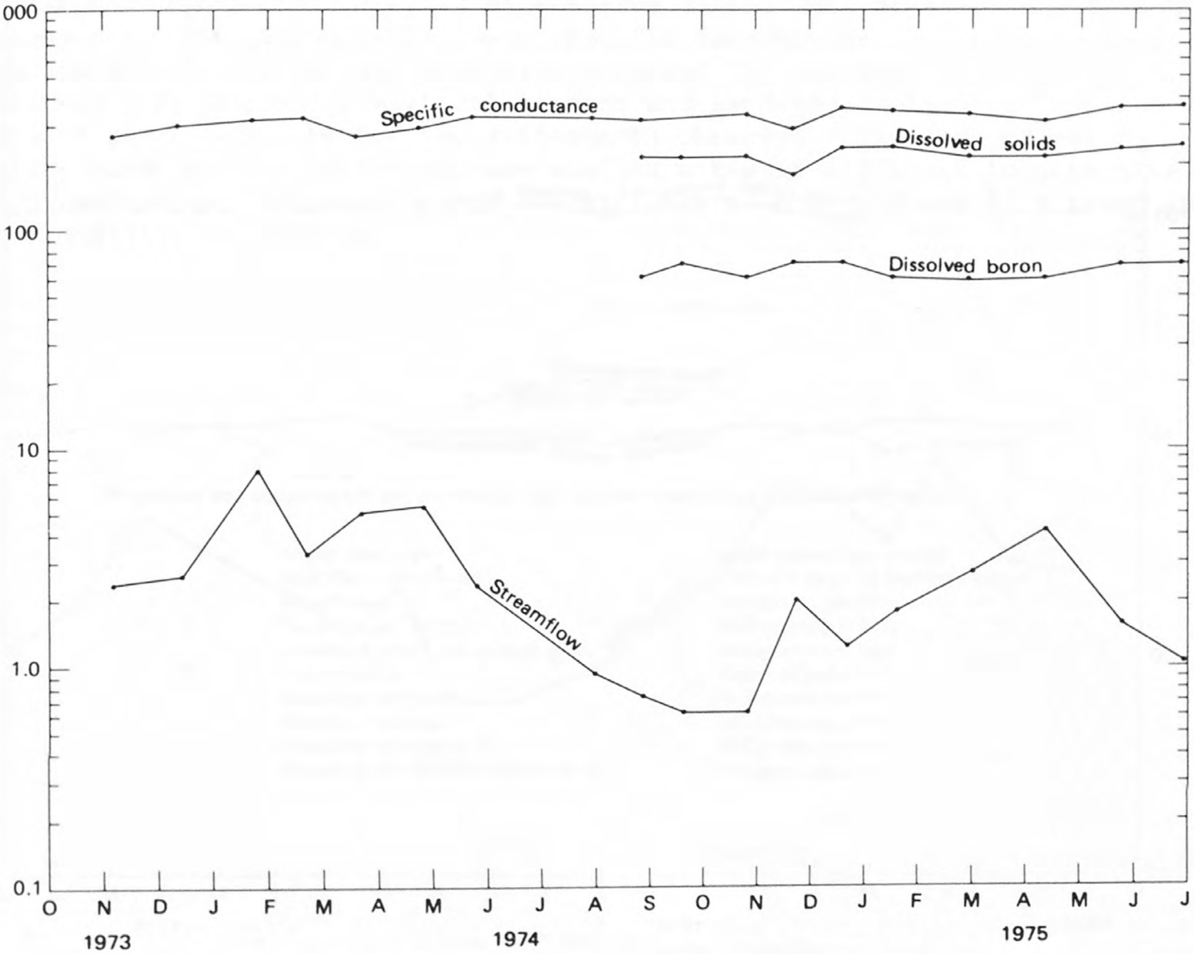


FIGURE 7.--Annual pattern of streamflow, specific conductance, dissolved solids, and dissolved boron, San Lorenzo River at Big Trees (11160500).

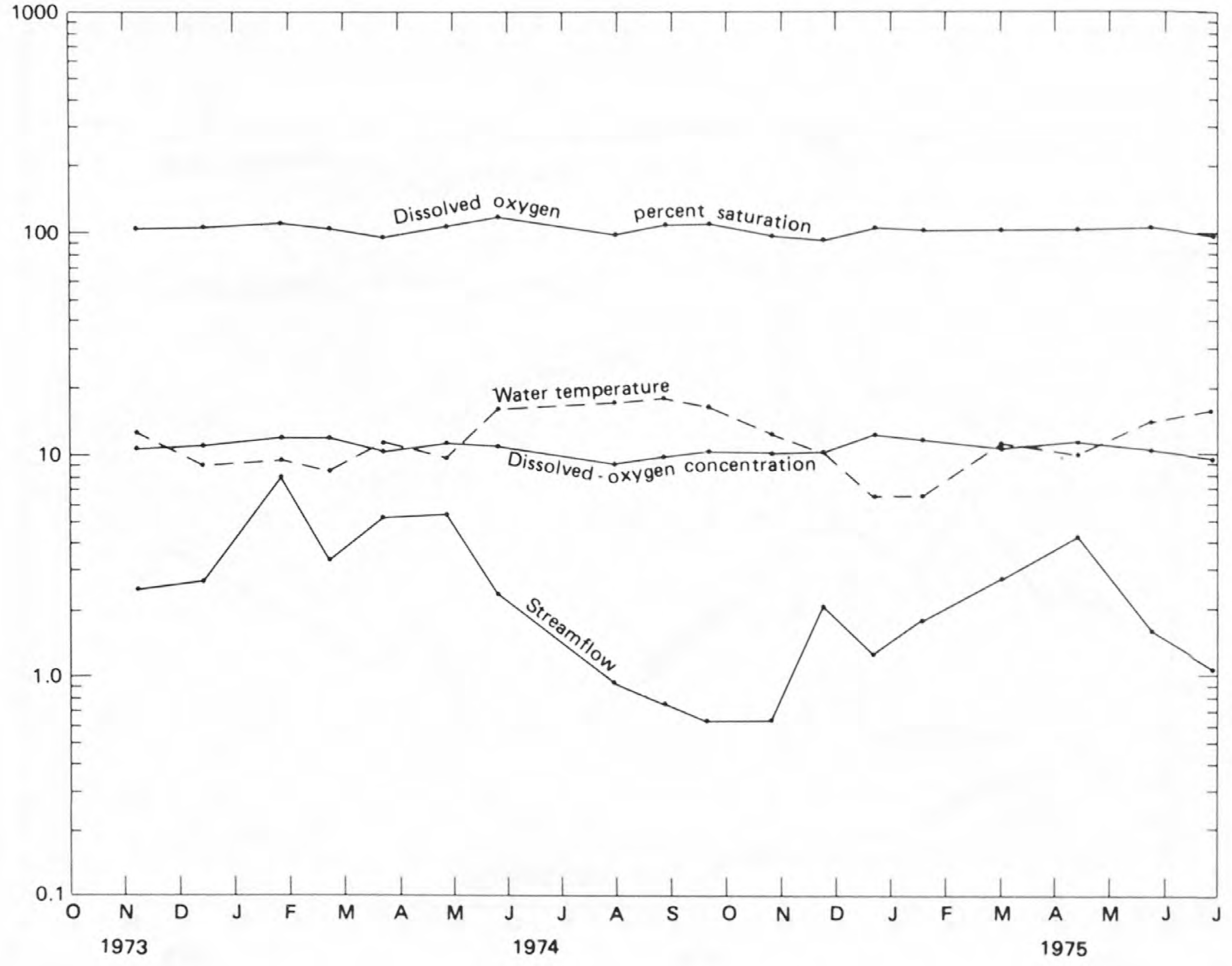


FIGURE 8.--Annual pattern of streamflow, water temperature, and dissolved oxygen, San Lorenzo River at Big Trees (11160500).

Comparison of Present Data with 1963 and 1964 Data

The California Department of Water Resources (DWR) collected water-quality data in the San Lorenzo River basin from August 1963 through December 1964 (California Department of Water Resources, 1966). The DWR data and the data collected during this study were compared to determine changes and possible degradation in water quality over a period of years. Because streamflow was measured only at Zayante Creek at Zayante (11160300) and San Lorenzo River at Big Trees (11160500) during 1963 and 1964, the comparison of data was restricted to these stations. Analysis of Variance (ANOVA) single classification and 5-percent level of significance were used.

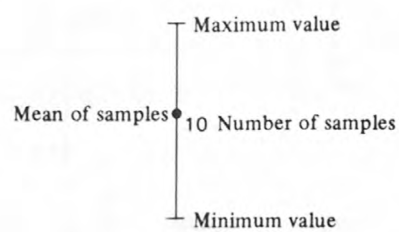
Because of the inverse relation between streamflow and the concentration of most dissolved ions, greater streamflows during this study than during the 1963-64 study may account for lower specific conductance, hardness, and chloride values during this study (figs. 9 and 10). Other factors, such as different sampling and analytical methods and land-use or land-cover changes, may also be responsible for the differences observed. The lack of water-quality data for the period between studies makes it difficult to determine which factors are responsible for the differences observed and if a trend in water quality is indicated.

EXPLANATION

(FIGURES 9 AND 10)

Properties and constituents are plotted on the ordinate scale using the following units

Water discharge	cubic meters per second
Specific conductance	micromhos at 25 degrees Celsius
Bicarbonate	milligrams per liter
Hardness as $CaCO_3$	milligrams per liter
Dissolved solids (calculated sum)	milligrams per liter
Temperature	degrees Celsius
Dissolved sodium	milligrams per liter
Dissolved chloride	milligrams per liter
Dissolved nitrate, as N	milligrams per liter
Dissolved nitrite plus nitrate, as N	milligrams per liter



D Assumptions for ANOVA test not satisfied but based on visual comparison, mean and range of 1974 or 1974 and 1975 data are different from mean and range of 1963 and 1964 data

ASD Assumptions for ANOVA test satisfied and difference between means is significant at 0.05 level

ANSD Assumptions for ANOVA test satisfied and difference between means is not significant at 0.05 level

The bar on the left of each pair represents 1973 and 1974 or 1974 and 1975 data. The bar on the right represents 1963 and 1964 data

(Figures 9 and 10 follow on pages 44 and 45.)

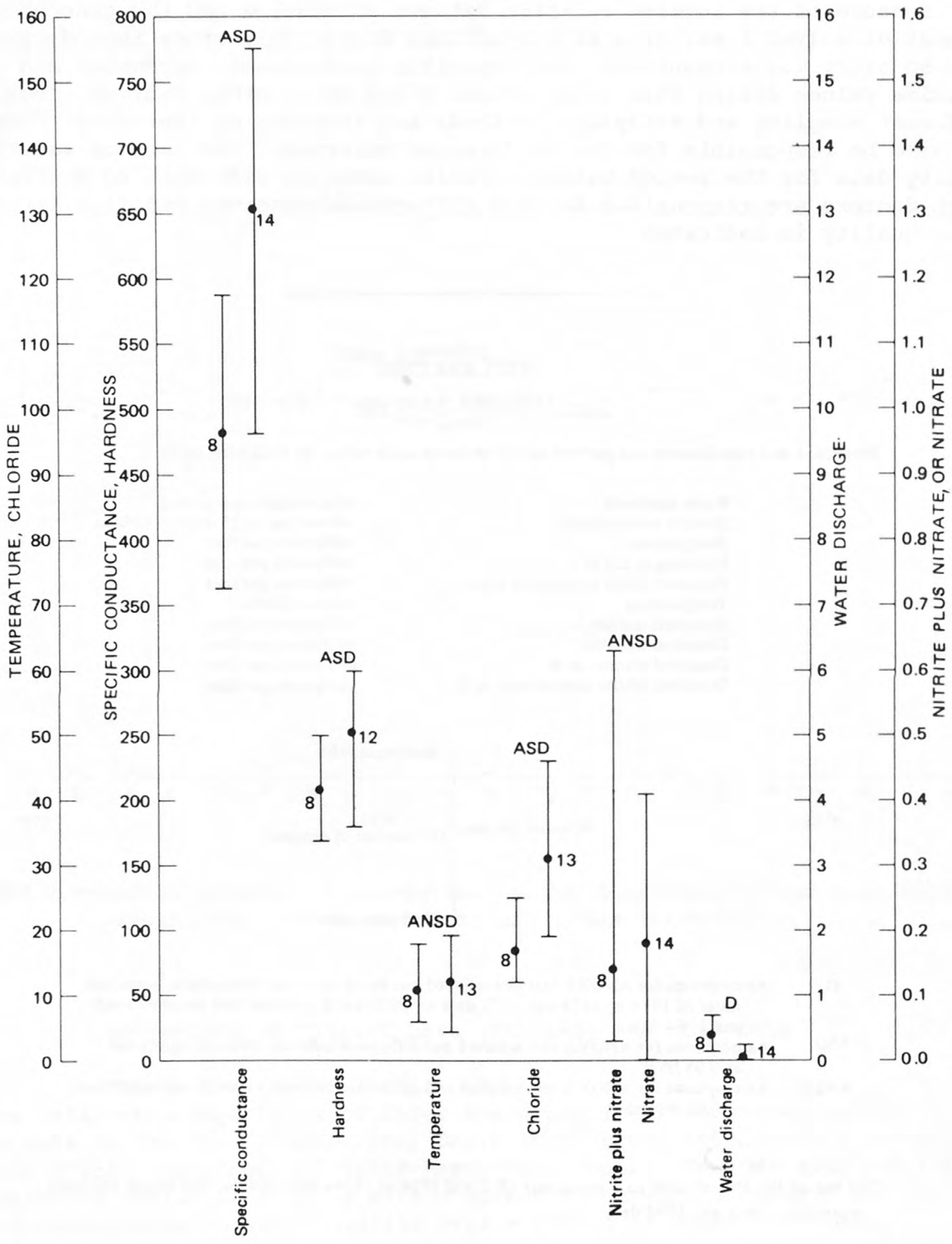


FIGURE 9.--Comparison of November 1973-July 1974 data with 1963-64 data, Zayante Creek at Zayante (11160300).

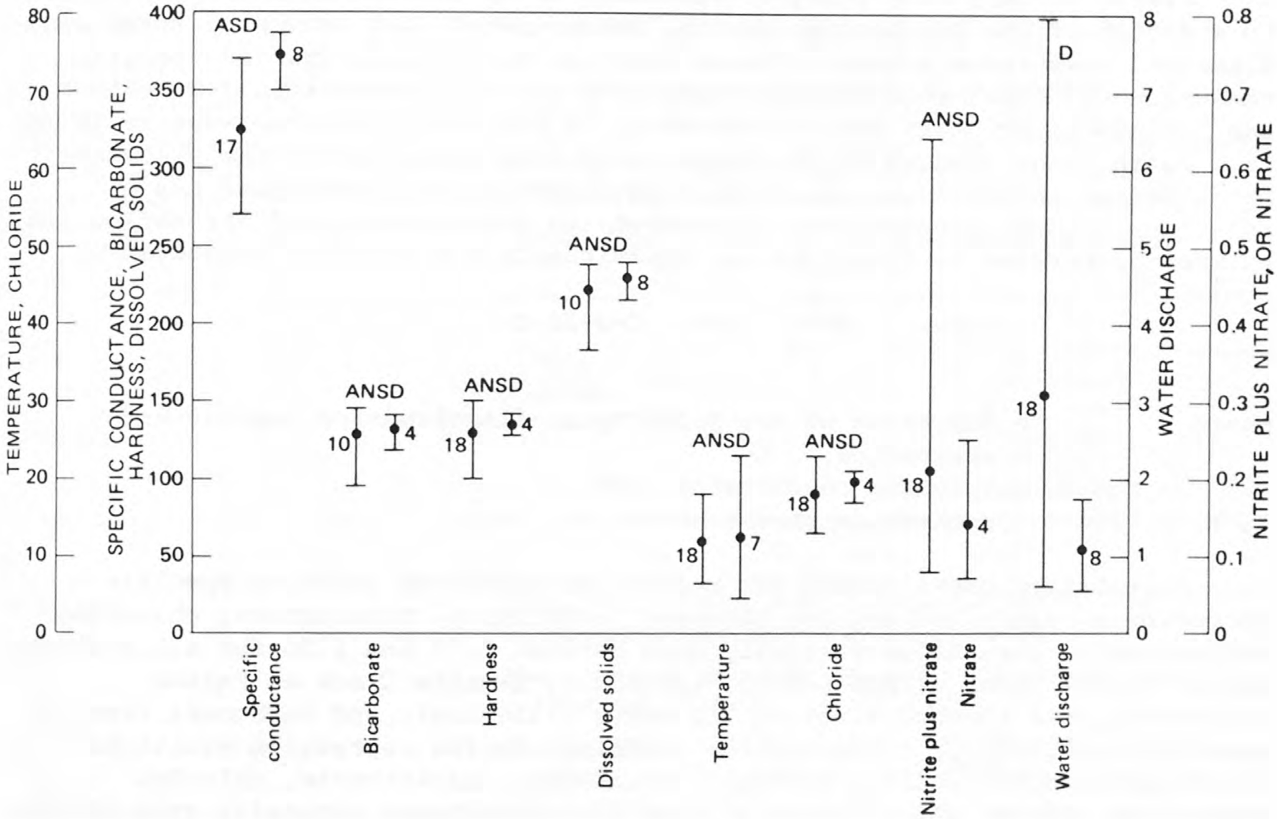


FIGURE 10.--Comparison of August 1974-June 1975 data with 1963-64 data, San Lorenzo River at Big Trees (11160500).

Trends in Water Quality

The preceding section of this report has shown that 1- to 2-year studies are not sufficient to determine long-term trends in water quality. Thus, the discussion on trends will be restricted to describing relations between streamflow, specific conductance, and dissolved constituents with the intent that the relations observed can be used to predict constituent values based on the measurement of streamflow and specific conductance.

Steele (1968), in a study of Pescadero Creek (a coastal drainage adjacent to and west of the San Lorenzo River), demonstrated that many properties and dissolved constituents have a linear relation with streamflow and specific conductance. Similar comparisons were made for the November 1973-June 1975 San Lorenzo River basin data to determine if the same relations were valid for this basin. The results of the comparisons show that, as for the Pescadero Creek basin, the following regression equations usually described the relations between properties or dissolved-ion constituents and streamflow and between properties or dissolved-ion constituents and specific conductance.

$$C=\frac{K}{Q^{R}} \quad \text{and} \quad C=a+bS.C.$$

where C = the value of the property or dissolved-ion constituent,
Q = streamflow,
$S.C.$ = specific conductance, and
R, K, a, and b = regression parameters.

Correlation coefficients for regression equations relating specific conductance, dissolved solids, hardness, alkalinity, bicarbonate, chloride, and sodium to streamflow generally were between 0.70 and 1.00 for all stations except Newell Creek at Ben Lomond (11160200), Zayante Creek at Felton (11160450), San Lorenzo River at Big Trees (11160500), and Carbonera Creek at Santa Cruz (11161400). Correlation coefficients for regression equations relating dissolved solids, hardness, alkalinity, bicarbonate, calcium, magnesium, sodium, and chloride to specific conductance generally were between 0.70 and 1.00 for all stations except Boulder Creek at Boulder Creek (11160070), Newell Creek at Ben Lomond (11160200), and Zayante Creek at Felton (11160450).

Compliance with State and Local Water-Quality Objectives

State and local water-quality objectives have been established for the San Lorenzo River basin to maintain water suitable for the present and anticipated beneficial uses of water in the basin. The water-quality objectives for the San Lorenzo River basin are based mostly on State requirements (California State Water Resources Control Board, 1975), but Santa Cruz County also has a "Turbidity and Settleable Solids Ordinance" (Santa Cruz County, 1974) which is applicable to the San Lorenzo River basin. Many of the State objectives are based on its policy of maintaining existing water quality. Hence, historical data, where available, have been used to formulate objectives. The State and local water-quality objectives for the properties and constituents sampled in this study are given in table 7.

TABLE 7.--*Water-quality objectives for the San Lorenzo River basin*

[Concentrations, in milligrams per liter; pH, in units; turbidity, in Jackson Turbidity Units; fecal-coliform concentration, in colonies per 100 milliliters, settleable solids, in milliliters per liter; and dissolved oxygen, in percent saturation. Sources: settleable solids, Santa Cruz County Ordinance, 1974; all others except turbidity, California State Water Resources Control Board, 1975; turbidity, combined objective from both sources]

Property or constituent	Objective						
	Minimum	Geometric mean	Maximum	Median			
				Boulder Creek	Zayante Creek	San Lorenzo River: Upstream of Bear Creek	San Lorenzo River: At Check Dam
pH	7.0		8.5				
Turbidity	1. Where natural turbidity is between 0 and 50 JTU, increases shall not exceed 20 percent. 2. Where natural turbidity is between 50 and 100 JTU, increases shall not exceed 10 JTU. 3. Where natural turbidity is greater than 100 JTU, increases shall not exceed 10 percent.						
Fecal coliform		a200	b200				
Dissolved sulfate				10	100	80	60
Dissolved chloride				10	50	80	80
Dissolved sodium				20	40	50	20
Dissolved boron				0.2	0.2	0.2	0.2
Dissolved solids				150	500	400	250
Settleable solids		0.5					
Total nitrogen			0.5				
Total phosphorus			0.05				
Dissolved oxygen	7.0						
Dissolved oxygen (percent saturation)				85	85	85	85

a Post-April 1975 objective applies to all surface water in the San Lorenzo River basin except Carbonera Creek and is based on a minimum of not less than five samples for any 30-day period; also specifies that no more than 10 percent of total samples in any 30-day period shall exceed a concentration of 400 colonies/100 mL.

b Pre-April 1975 objective.

The San Lorenzo River median objectives seem to apply only to the main stem, but for the purpose of this discussion it was decided to apply these objectives also to tributaries of the main stem not otherwise accounted for in table 7. Thus, tributaries such as Kings Creek, which enter the San Lorenzo River upstream of Bear Creek, are included in the "Upstream of Bear Creek" objectives while tributaries such as Love Creek are included in the "At Check Dam" objectives. Bear Creek is at the dividing point for the two sets of San Lorenzo River objectives. Because Bear Creek is generally similar in water quality to Kings Creek and the main stem of the San Lorenzo River upstream of Boulder Creek (table 3), it was decided to include it with the "Upstream of Bear Creek" objectives.

A consideration of compliance or noncompliance with objectives should be prefaced with the understanding that streamflows from October 1973 through September 1974 were greater than normal (1.3 times the mean annual flow at Zayante Creek at Zayante and 1.4 times the mean annual flow at San Lorenzo River at Big Trees), while streamflows from October 1974 through September 1975 were less than normal (0.72 of the mean annual flow at San Lorenzo River near Boulder Creek and 0.78 of the mean annual flow at San Lorenzo River at Big Trees) (U.S. Geological Survey, 1974 and 1975).

Those streams or stream segments not in compliance with the objectives given in table 7 are shown in table 8. Boulder Creek upstream of Jamison Creek is not in compliance with median objectives, but its dissolved-ion concentrations are geologically determined and probably characteristic of this segment of Boulder Creek when streamflows are about three-fourths of normal. Two sets of objectives might be established for Boulder Creek. The objectives given in table 7 could be retained for Boulder Creek downstream of Jamison Creek with consideration for raising the dissolved-sulfate objective to an apparently natural background figure (data collected in this study indicate that this figure would be 20-25 mg/L). A less stringent set of dissolved-ion objectives might be formulated for Boulder Creek upstream of Jamison Creek.

The dissolved-sulfate objective for the San Lorenzo River upstream of Bear Creek also may not be attainable because the sulfate concentrations of streams in this area are probably geologically determined and characteristic of years with below-normal streamflows. The "At Check Dam" dissolved-sodium objective may be too stringent for Carbonera and Branciforte Creeks because of their proximity to the ocean and salt-laden fog and breezes. The expanded data base available from this study should help to establish attainable objectives for these drainages. The median objectives should take into consideration the relation of dissolved-ion concentrations to streamflow.

A sample for total nitrogen was taken regularly only at San Lorenzo River at Big Trees from August 1974 through June 1975. In addition, one sample for total-nitrogen was taken at stations in the Zayante Creek drainage basin and at San Lorenzo River at Big Trees from November 1973 through July 1974. A sample for dissolved nitrite plus nitrate was taken regularly at all stations. Based on these data, the total-nitrogen objective was usually exceeded at Bear Creek near Felton (11160430), San Lorenzo River at Big Trees (11160500), Carbonera Creek at Santa Cruz (11161400), and Branciforte Creek at Santa Cruz (11161500) (table 8). Also, dissolved nitrite plus nitrate concentrations at Zayante Creek at Felton (11160450) were frequently just below the total-nitrogen objective. In these cases, the total-nitrogen objective would probably have been exceeded if samples for organic nitrogen had been taken and the results added to the dissolved nitrite plus nitrate concentration.

The relatively high nitrogen concentrations at these stations may be due to septic-tank system failures. Zayante and Branciforte Creek drainage basins have a history of septic-tank system failures in residential areas (Butt and Hurst, 1974) and high nitrogen concentrations usually found in septic tanks are not appreciably reduced by filtration in leach fields (Franks, 1972). There is no evidence to indicate that the relatively high nitrogen concentrations in these drainages are of geologic origin.

A sample for total phosphorus was taken regularly only at Bean Creek near Felton (11160430) and San Lorenzo River at Big Trees (11160500). Table 8 shows that the total-phosphorus objective was usually exceeded at these stations. The samples taken for total phosphorus at Zayante Creek below Mountain Charlie Gulch, near Zayante (11160280), Zayante Creek at Zayante (11160300), and Lompico Creek at Zayante (11160320) also exceeded the objective. Dissolved-orthophosphorus concentrations (the inorganic part of total phosphorus) usually exceeded the total-phosphorus objective at the other stations except for those in the Boulder Creek and Fall Creek basins. Although most of the drainage basins in the San Lorenzo River basin exceed the total-phosphorus objective, harmful effects such as nuisance algal growths were not noticed. The phosphorus concentrations observed may be of geologic origin and are, therefore, natural background levels. If so, the total-phosphorus objective may not be attainable.

Noncompliance with the pH objective is infrequent and not significant because the noncomplying pH values are only slightly out of the 7.0-8.5 objective range.

TABLE 8.--*Streams or stream segments not complying with State or local water-quality standards*

[Explanation: ●, objective exceeded; first number is number of times objective exceeded, second number is number of samples; dash indicates stream not sampled for property or constituent. Analyses for boron were made only for San Lorenzo River at Big Trees, and the concentrations met the standard. Objectives for dissolved oxygen were met at all stations]

Station number and name	Property or constituent and objective								
	pH		Fecal coliform	Dissolved sulfate	Dissolved chloride	Dissolved sodium	Dissolved solids	Total nitrogen	Total phosphorus
	Minimum	Maximum	Maximum	Median	Median	Median	Median	Maximum	Maximum
11160020 San Lorenzo River near Boulder Creek		3/10							5/5
11160036 Kings Creek near Boulder Creek			2/10	●					5/5
11160045 San Lorenzo River at Boulder Creek			2/10						4/5
11160055 Bear Creek near Boulder Creek				●					3/5
11160060 Bear Creek at Boulder Creek				●					4/5
11160065 Boulder Creek above Jamison Creek, near Boulder Creek				●	●	●	●		1/5
11160070 Boulder Creek at Boulder Creek			1/10	●					2/5
11160150 Love Creek at Ben Lomond			2/10						5/5
11160200 Newell Creek at Ben Lomond				●					3/6
11160230 Fall Creek below Bennett Creek, at Felton			1/9						
11160250 Fall Creek at Felton			1/9						1/4
1160280 Zayante Creek below Mountain Charlie Gulch, near Zayante			2/4			-	-		1/1
11160300 Zayante Creek at Zayante		1/8	3/4			-	-	1/8	1/1
11160320 Lompico Creek at Zayante			4/4			-	-	1/8	1/1
11160430 Bean Creek near Felton	2/7		2/4			-	-	6/8	5/5
11160450 Zayante Creek at Felton			5/14					3/13	6/6
11160500 San Lorenzo River at Big Trees (at discontinued gaging station)	1/17		3/14					8/16	14/15
11161400 Carbonera Creek at Santa Cruz			5/10			●		5/5	5/5
11161500 Branciforte Creek at Santa Cruz			4/10			●	●	5/5	5/5

Prior to April 1975 when the present State water-quality objectives were published (California State Water Resources Control Board, 1975), the fecal-coliform objective for the San Lorenzo River basin was 200 or fewer col/100 mL of water. A minimum number of samples per month was not specified. Thus, during this study the collection of only one fecal-coliform sample per month was considered sufficient for evaluating the bacterial quality of the streams sampled. These data do not satisfy the minimum number of samples per month requirement of the present objective and thus can be compared only with the pre-April 1975 objective. The results of these comparisons are shown in the last column of table 8.

Noncompliance with the pre-April 1975 fecal-coliform objective is most prevalent in the Zayante and Branciforte Creek drainages. Noncompliance with the fecal-coliform and total-nitrogen objectives in these drainage basins suggests that septic-tank effluent was reaching streams in these basins during the study. Noncompliance with the pre-April 1975 fecal-coliform objective at San Lorenzo River at Big Trees (11160500) may be due to the influence of Zayante Creek or septic-tank system failures in communities bordering the main stem of or tributaries to the San Lorenzo River downstream of Boulder Creek.

Dissolved-oxygen concentrations were always greater than 7 mg/L, and percent-saturation values were rarely less than 85 except at Boulder Creek above Jamison Creek (11160065) where iron and sulfur seeps may be responsible for the lower oxygen values. Nevertheless, all of the stations sampled were in compliance with the dissolved-oxygen objectives (table 8).

Turbidity values for nonstorm flows were less than or equal to 10 JTU at all stations sampled. If this is considered the natural turbidity of the streams sampled, then a turbidity value greater than 12 JTU would constitute a violation of the turbidity objectives (table 7, turbidity objective 1). Stormflows with turbidities greater than 12 JTU would not comply with the turbidity objectives. It is doubtful that the turbidity objective is intended to apply both to stormflows and nonstorm flows; there should be separate objectives for the two types of flow.

DIEL STUDIES RESULTS AND DISCUSSION

The routine sampling program was designed to collect data representative of daylight conditions which can underestimate water-quality degradation. Daylight is favorable for most biological activity. Photosynthesis continually replenishes the aquatic environment with dissolved oxygen which, along with increased water temperature, encourages aquatic floral and faunal metabolism. Deleterious effects of toxic materials can be mitigated during the daytime when dissolved oxygen is plentiful. The effect of oxygen-demanding wastes on the dissolved-oxgyen concentration of the water may not be noticed during daylight. During the night when photosynthesis is much reduced and respiratory processes (oxygen-utilizing processes) dominate, oxygen-demanding wastes may reduce the supply of dissolved oxygen to critical levels, below which certain floral and faunal species perish.

Diel studies, intensive sampling for a 24-hour period, are valuable for determining the presence of oxygen-demanding wastes and their effect on the supply of dissolved oxygen in an aquatic environment. Diel studies were made at two U.S. Geological Survey gaging stations (fig. 5). San Lorenzo River near Boulder Creek (11160020) was studied September 30-October 1, 1975. San Lorenzo River at Big Trees (11160500) was studied October 3-4, 1975. The station near Boulder Creek is upstream of most of the residential development in the basin, and the Big Trees station is downstream of most of this development. If the residential areas between these two stations are contributing oxygen-demanding wastes (such as effluent from septic-tank systems) to surface water a significant nighttime depletion of dissolved oxygen should be observed only at the downstream station (11160500).

During the diel studies, dissolved-oxygen concentrations did not go below 9.0 mg/L at station 11160020 and 8.2 mg/L at station 11160500. At both stations, percent-saturation values decreased at night but were never below the 85-percent saturation water-quality objective (fig. 11). Percent-saturation values taken near the streambed at station 11160500, while less than near the stream surface, did not go below the 85-percent saturation objective. These results indicate either oxygen-demanding wastes are not present at the stations studied or, if they are present, they are not in sufficient concentrations to cause appreciable dissolved-oxygen depletion at night. Reaeration of the water from diffusion and stream turbulence may be sufficient to satisfy the oxygen demand resulting from decomposition of wastes and aquatic floral and faunal respiration.

The temporal pattern of monitored properties and constituents (water temperature, specific conductance, pH, alkalinity, and dissolved oxygen) were similar at both stations during the diel studies (figs. 11 and 12). Streamflows were fairly constant during the diel study at station 11160020, ranging from 0.020 to 0.034 m^3/s. Streamflows at station 11160500 during the diel study were more variable, ranging from 0.68 to 1.39 m^3/s.

BENTHIC-INVERTEBRATE SAMPLING RESULTS AND DISCUSSION

Benthic invertebrates are animals without backbones that live in or on the bottom of an aquatic environment. They include organisms such as insects, worms, snails, clams, and crayfish. The species composition of benthic invertebrate communities can be used to evaluate water-quality conditions over a period of months to a year because most benthic invertebrates have life cycles of at least 1 year, are restricted in movement, and are sensitive to changes in the aquatic environment. The relative diversity of benthic invertebrates at sites in a river indicates the relative degree to which suitable water-quality and stable substrate conditions are maintained at these sites. Where water-quality conditions are usually unfavorable or substrate conditions unstable, the diversity of benthic invertebrates is usually low.

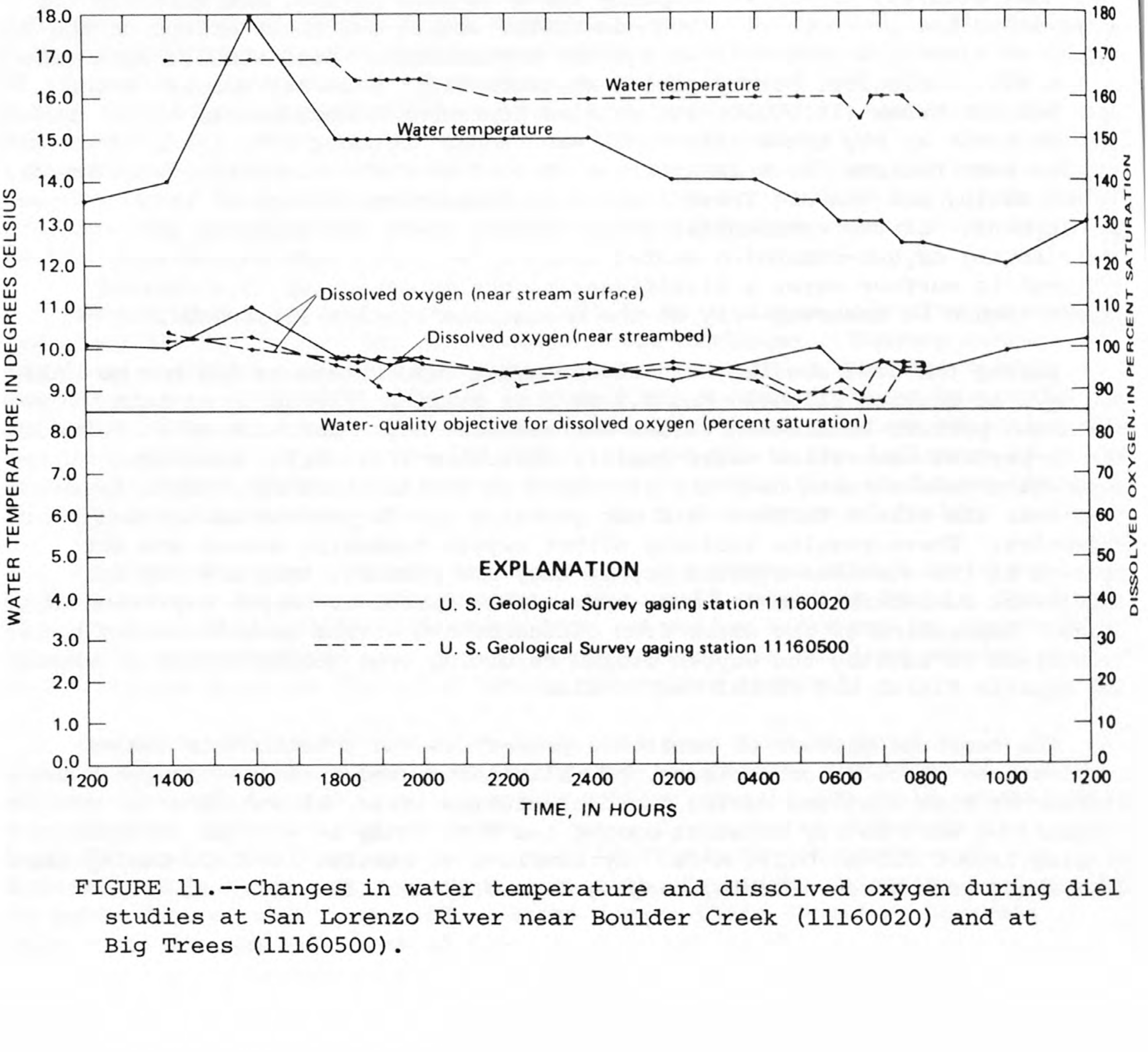


FIGURE 11.--Changes in water temperature and dissolved oxygen during diel studies at San Lorenzo River near Boulder Creek (11160020) and at Big Trees (11160500).

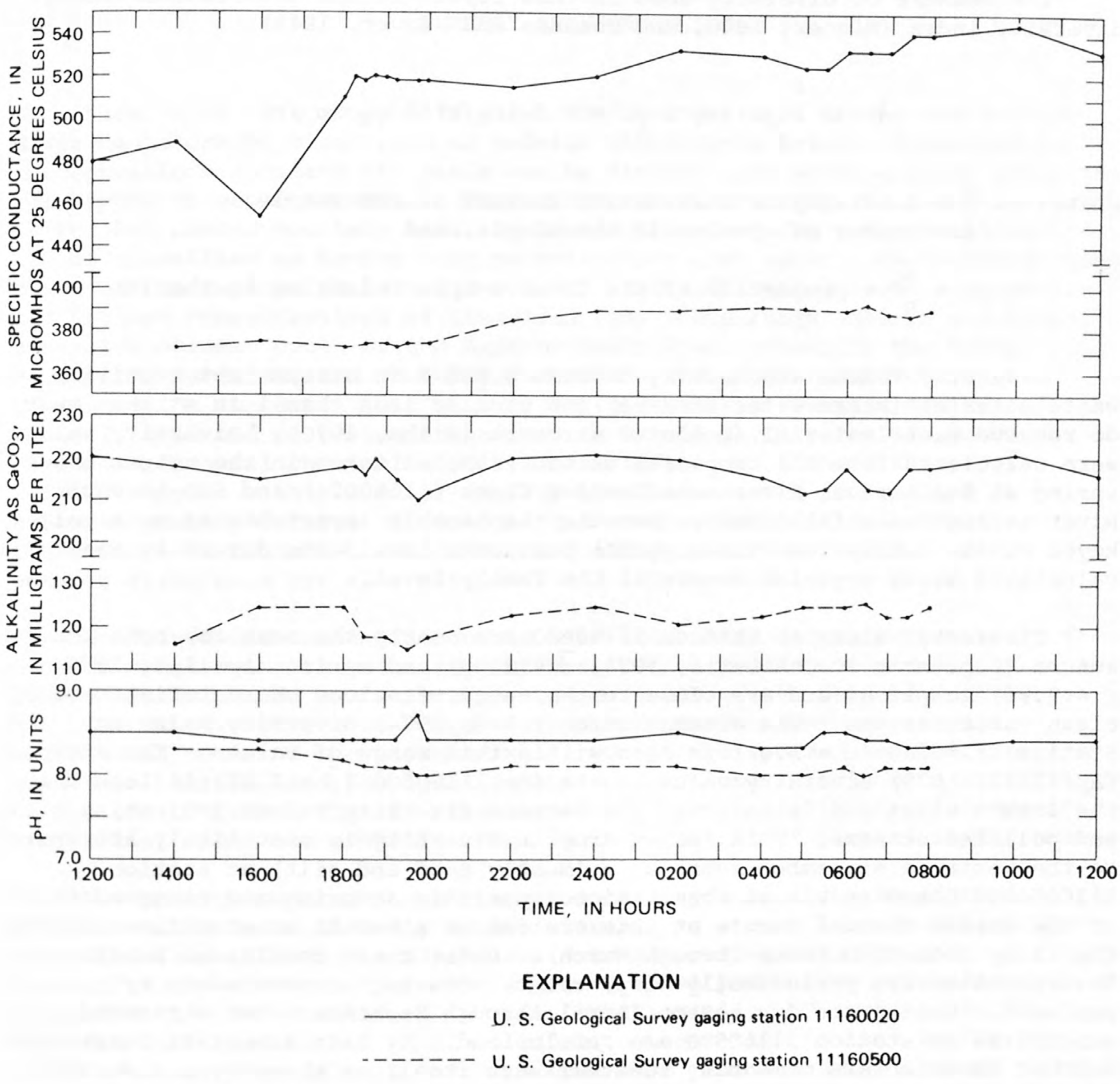


FIGURE 12.--Changes in specific conductance, alkalinity, and pH during diel studies at San Lorenzo River near Boulder Creek (11160020) and at Big Trees (11160500).

The measure of diversity used in this report is the information theory diversity index (Wiener, 1948, and Shannon and Weaver, 1949):

$$\bar{d} = - \sum_{i=1}^{s} pi \log 2\, pi = - \sum (n_i/n) \log_2 (n_i/n)$$

where $\bar{d}$ = diversity or information content of the sample,
s = number of species in the sample, and

$pi = \frac{ni}{n}$ = proportion of the total sample belonging to the ith species.

Diversity values are usually between 3 and 4 in streams not receiving waste material (clean-water streams) and usually less than 1 in streams that do receive waste material (polluted streams) (Wilhm, 1970). Diversity values were calculated from the composite of four samples taken in the autumn and spring at San Lorenzo River near Boulder Creek (11160020) and San Lorenzo River at Big Trees (11160500). Because the benthic invertebrates were only keyed to the family (sometimes genus) taxonomic level, the diversity was calculated using organism counts at the family level.

Diversity values at station 11160020 are nearly the same for both the autumn (September 30-October 1, 1974, $\bar{d}$ = 2.90) and spring (April 8, 1975, $\bar{d}$ = 2.96) samplings and are close to the range of values characteristic of clean-water streams. The autumn (October 3-4, 1974) diversity value at station 11160500 ($\bar{d}$ = 3.02) is also within this range of values. The spring (April 11, 1975) diversity value at station 11160500 ($\bar{d}$ = 2.17) is less than the autumn value and is intermediate between diversity values indicating clean and polluted streams. This spring drop in diversity is most likely attributed to the unstable streambed substrates (mostly sand and silt) at station 11160500. Based on visual observations, periodic scouring and reaggradation of the stream channel occurs at this station as a result of stormflows (during the rainy season, October through March). Under these conditions benthic invertebrates are periodically displaced by scouring or covered up by sediment. During the dry season (April through September) the streambed substrates at station 11160500 are recolonized. By late summer or autumn the benthic invertebrate community reestablishes itself as shown by a diversity value comparable to the values observed at station 11160020. Stormflows apparently have less impact on the benthic community at station 11160020 because the spring and autumn diversity values are nearly the same.

SUMMARY AND CONCLUSIONS

Results of this study have shown that most streams in the San Lorenzo River basin can be classified as calcium bicarbonate water. Dissolved-ion concentrations indicate the basin can be divided into water-quality areas that correspond to geologic areas. West-side streams draining the granitic rocks of the Ben Lomond Mountain area are low in dissolved-ion concentrations and can be classified as having soft to moderately hard water. East-side streams north of the Zayante fault drain consolidated sedimentary rocks and contain the highest concentrations of dissolved ions found in streams in the basin. East-side streams south of the Zayante fault drain primarily the Santa Margarita, Purisima, and Monterey Formations and are intermediate in dissolved-ion concentrations between west-side streams in the Ben Lomond Mountain area and east-side streams north of the Zayante fault. Although having the general chemical-quality characteristics of their area, most streams sampled within a water-quality area have subtle differences in chemical quality because of geologic differences among drainage basins. Differences in bacterial and nutrient quality of streams sampled within a water-quality area are also evident.

Dissolved-ion concentrations in main-stem water decrease downstream from Boulder Creek owing to tributary inflows from west-side streams from the Ben Lomond Mountain area and east-side streams south of the Zayante fault which are lower in dissolved-ion concentrations than main-stem headwaters and tributaries north of the Zayante fault. Greater dissolved nitrite plus nitrate, chloride, and fecal-coliform concentrations in main-stem water downstream of Felton than in main-stem headwaters indicate that intervening residential areas are probably affecting the quality of streams in the basin.

The most pronounced change in water quality occurs during storms. Streamflows increase markedly during storms. As streamflows increase, the concentrations of most dissolved ions decrease while turbidity and concentrations of total Kjeldahl nitrogen, total phosphorus, dissolved potassium, and fecal coliform increase substantially. The magnitude of increase in turbidity and fecal-coliform concentration is less in the Fall Creek drainage than in more developed drainage basins such as Zayante Creek.

Turbidity values during nonstorm periods are less than or equal to 10 JTU at all the stations sampled. The greatest fecal-coliform concentrations were obtained during stormflows. Fecal-streptococcal concentrations increased markedly during September and October, perhaps owing to a concentrating effect from the lowest flows of the year.

Late winter-early spring nonstorm flows yield water of best quality because (1) the concentrations of dissolved ions are decreased from low-flow periods; (2) fecal-coliform and fecal-streptoccocal concentrations are low; and (3) turbidity values are about the same as during the summer low-flow period.

A comparison of data collected in this study with data collected by the California Department of Water Resources in 1963 and 1964 shows that specific conductance, hardness, and chloride values were less during this study. This may be due to greater streamflows during this study or to other factors, such as different sampling and analytical methods and land-use or land-cover changes. The lack of water-quality data for the period between studies makes it difficult to determine which factors are responsible for the observed differences or if a trend in water-quality is indicated.

Problem areas of water-quality degradation were determined by comparing constituent values with State and local water-quality objectives. Noncompliance with the dissolved-sulfate objective is probably due to lower than normal streamflows during water year 1975. Owing to the relation between dissolved-ion concentrations and streamflow, more consideration might be given to streamflow when promulgating median dissolved-ion objectives. Noncompliance with total-nitrogen and fecal-coliform objectives in the Zayante and Branciforte Creek drainage basins suggests that domestic sewage is degrading streams in these basins. The turbidity objectives could be reworded so that they differentiate between stormflows and nonstorm flows.

Diel studies at two stations on the main stem of the San Lorenzo River indicate that during low-flow periods residential areas between the two stations are not contributing sufficient quantities of oxygen-demanding wastes to the river to cause appreciable dissolved-oxygen depletion.

The diversity of benthic invertebrates is less during spring (April) than during autumn (October) at San Lorenzo River at Big Trees, which is downstream of most of the existing and developing residential areas in the basin. Streambed substrates are fairly stable near the headwaters, where streamflows and residential development are much less. Apparently, these conditions provide a favorable habitat for benthic invertebrates because spring and autumn diversity values at San Lorenzo River near Boulder Creek are nearly the same and are close to the range of values characteristic of clean-water streams. Greater streamflows and more residential development seem to be responsible for the unstable streambed substrates and reduced diversity of benthic invertebrates during spring in the San Lorenzo River at Big Trees.

SUGGESTIONS FOR FUTURE STUDIES

One of the objectives of this study was to evaluate the sampling program and to recommend modifications that will better satisfy data needs for preparing management plans to aid in the prevention and control of water-quality degradation in the basin. Short-term studies are not sufficient to determine long-term trends in water quality. Thus, a sampling program should be continued.

Routine monthly sampling at fixed sampling locations for a period of at least 10 years will probably be necessary to obtain meaningful data to determine trends in water quality. The stations sampled from August 1974 through June 1975 are recommended for further routine sampling, except for Fall Creek below Bennett Creek (11160230) which has been shown to be similar in water quality to Fall Creek at Felton (11160250) and could be excluded. Another station on Bean Creek upstream of the city of Scotts Valley pit could help determine the source of the relatively high nitrite plus nitrate and fecal-coliform concentrations in this drainage basin.

The properties and constituents measured in future studies should include the ones measured during this study. If and when equations relating concentrations of dissolved ions to streamflow and specific conductance become reliable, these equations may be used to predict property and constituent values based on streamflow and specific conductance values; the number of properties and constituents actually measured could then be reduced.

Intensive sampling programs can be applied on a priority basis to identified problem areas. These programs may include diel studies and the sampling of biological constituents such as benthic invertebrates.

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