Relation of Urban Land-use and Land-surface Characteristics to Quantity and Quality of Storm Runoff in Two Basins in California

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CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. In the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric*
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
in. (inches)	2.540×10	mm (millimeters)
in./yr (inches per year)	2.540×10	mm/yr (millimeters per year)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)

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

RELATION OF URBAN LAND-USE AND LAND-SURFACE CHARACTERISTICS TO THE QUANTITY AND QUALITY OF STORM RUNOFF FOR TWO BASINS IN CALIFORNIA

By MARC A. SYLVESTER and WILLIAM M. BROWN III

ABSTRACT

Two basins (Castro Valley Creek, in Alameda County, and Strong Ranch Slough, in Sacramento County) in the San Francisco Bay and Sacramento-San Joaquin Delta region (Bay-Delta region) were sampled intensively (3–15 minute intervals) during three storms between October 1974 and April 1975. Both basins are primarily residential, but the Strong Ranch Slough basin is almost entirely urbanized and nearly flat, while the Castro Valley Creek basin possesses some rural areas and slopes greater than 70 percent in the headwaters. Water discharge and concentrations of suspended solids, chemical oxygen demand, 5-day biochemical oxygen demand, nitrite and nitrate, total Kjeldahl nitrogen, total orthophosphorus, and settleable matter were usually greater at the Castro Valley Creek basin than at the Strong Ranch Slough basin. Concentrations of these constituents and water discharge changed more rapidly at the Castro Valley Creek basin than at the Strong Ranch Slough basin. Of the four subbasins sampled (two in each basin), constituent concentrations in runoff from a residential subbasin were usually greatest.

Quantity and quality of runoff were related to environmental characteristics such as slope, perviousness, residential development and maintenance, and channel conditions. Greater water discharge and concentrations of constituents in the Castro Valley Creek basin seem to be partly due to steeper slopes, less perviousness, and smaller residential lot sizes than are in the Strong Ranch Slough basin. Erosion of steep slopes disturbed by grazing and residential development, poorly maintained dwellings and lots, and a mostly earthen drainage channel in the Castro Valley Creek basin are probably responsible for the greater concentrations of suspended solids and settleable matter in runoff from this basin.

In both basins, the highest observed concentrations of suspended solids, chemical oxygen demand, 5-day biochemical oxygen demand, settleable matter, total Kjeldahl nitrogen, and total orthophosphorus were observed at or near peak water discharges. Flow-weighted and arithmetic-mean concentrations of suspended solids in Castro Valley Creek exceed the arithmetic-mean concentration of suspended solids in medium-strength untreated sewage. These results indicate that control of urban storm runoff in the Bay-Delta region may be desirable to protect receiving water.

INTRODUCTION

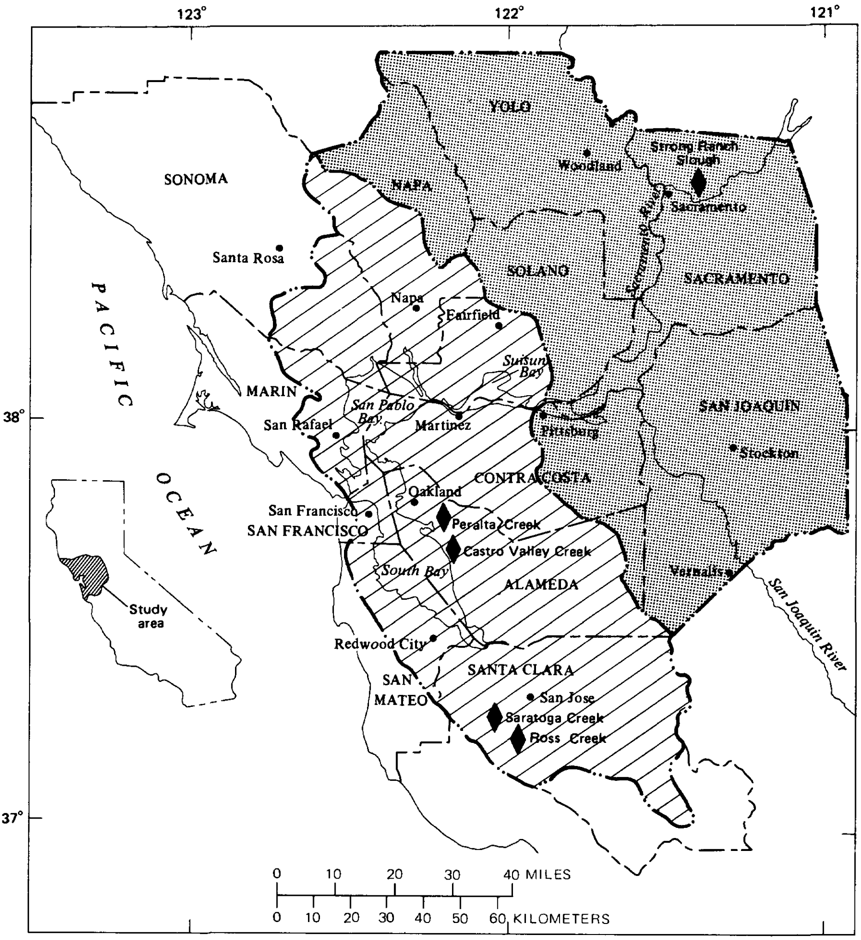
ADMINISTRATIVE DEVELOPMENT

The California State Water Resources Control Board (SWRCB) is developing "Comprehensive Water Quality Control Plans" for California that are intended to provide direction and guidance for future water-quality control. Parts of these plans will be devoted to the protection of State water through the control and abatement of pollution originating from nonpoint sources, which include urban storm runoff. In the San Francisco Bay and Sacramento-San Joaquin Delta region (Bay-Delta region) (fig. 1), the Association of Bay Area Governments (ABAG) is developing an Environmental Management Plan that will include plans for managing storm runoff. Such plans are mandated by the Federal Water Quality Control Act Amendments of 1972, Public Law 92–500 (U.S. Congress, 1972). Section 208 of this law requires that areawide waste-treatment management plans include urban storm-runoff control systems.

On March 8, 1972, the SWRCB, the U.S. Environmental Protection Agency, and the U.S. Army Engineer District, San Francisco, Corps of Engineers, specified by interagency agreement that the Corps of Engineers would provide planning assistance to the State of California for preparation of the "Comprehensive Water Quality Control Plans" for stream basins in the Bay-Delta region. One aspect of such assistance, determining the feasibility of collecting and treating urban storm-runoff from stream basins tributary to the Bay-Delta region, is the responsibility of the Corps of Engineers, San Francisco District. Prior to this, in September 1971, the San Francisco District requested the assistance of the Hydrologic Engineering Center, which asked the U.S. Geological Survey to participate in the design of a storm runoff data-collection program and to collect and analyze the water samples. A data-collection program began in October 1971. The Hydrologic Engineering Center intends to use the data for calibrating and verifying digital computer models capable of predicting the quantity and quality of storm runoff. In addition, the data collected are intended to assist SWRCB and ABAG in formulating plans for managing storm runoff in the Bay-Delta region. A desirable ingredient in the formulation of these plans is the relationship between land-use and land-surface characteristics[1] and the quantity and quality of urban runoff. During the summer 1974, personnel of the Corps of Engineers and the Geological Survey developed an approach to determine these relationships in selected study basins in the Bay-Delta

[1]Land-use and land-surface characteristics are the extent and kinds of land covers and their pervious or impervious character, land slope, basin configuration and area, character of the storm-runoff channel, interception storage, infiltration, depression storage including manmade detention and retention basins, sanitary condition of parcels and buildings, construction activities, and traffic density and composition.

region. This report describes the study program that resulted, presents the data collected, and explains the relationships between environmental characteristics[2] and the quantity and quality of urban storm runoff.



EXPLANATION

Area of drainage basins in study area tributary to Sacramento-San Joaquin Delta

Area of drainage basins tributary to San Francisco Bay

Sampling location

FIGURE 1.—The San Francisco Bay and Sacramento-San Joaquin Delta region, county boundaries, and sampling sites.

[2]Environmental characteristics are land-use and land-surface characteristics plus rainfall characteristics, antecedent moisture conditions, and seasonal changes in vegetation such as leaf fall from deciduous plants.

PURPOSE AND SCOPE

The two purposes of this study are to provide data useful for the calibration and verification of urban runoff models and to determine relationships between land-use and land-surface characteristics and the quantity and quality of urban storm runoff. The second objective requires (1) comparing and contrasting the quantity and quality of urban storm runoff from selected drainage basins in the Bay-Delta region and (2) assessing the land-use and land-surface characteristics in the selected drainage basins. A third element of the study is determining whether control of urban storm runoff is necessary to meet water-quality objectives in the region.

This report compares and contrasts the quantity and quality of urban storm runoff from two basins in the Bay-Delta region: the Castro Valley Creek basin and the Strong Ranch Slough basin. Data from October 1974 to April 1975 were used because high-frequency sampling during comparable storm periods was done in both basins only during this period. Intensive sampling is necessary to permit valid comparisons. Data were collected on a less frequent basis from October 1971 to April 1974 and are available from the U.S. Army Corps of Engineers (1972–74) and the U.S. Geological Survey (1972–74).

This report describes the general geology, soils, topography, hydrology, climate, vegetation, and human activities in the Castro Valley Creek and Strong Ranch Slough basins. These factors are used to compare the basins. The relations of land-use or land-surface characteristics to the quantity and quality of urban storm runoff are described, and an attempt is made to determine the need for control measures.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Dr. Richard Ellefsen, Chairman of the Department of Geography, California State University, San Jose, for consultation on remote-sensing applications to urban land-use mapping and direct work on multispectral land-cover analysis of the Castro Valley Creek basin. J. W. Abbott, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, Calif., made valuable suggestions on study design and provided coordination with the Corps of Engineers, San Francisco District.

SAMPLING PROGRAM

PRELIMINARY SAMPLING

A preliminary water-quality sampling program began in October 1971 in the Castro Valley Creek basin. This basin was selected because it was considered typical of basins in the Bay-Delta region. In October a continuous-record stream gage and a continuous-record precipitation gage were installed in the basin.

Samples were collected during seven storms from November 1971 through April 1972 at the Survey gaging station near the mouth of the basin (11181008, Castro Valley Creek at Hayward). The sampling schedule is shown in table 1. Information gained from this initial sampling was used to determine which constituents were important for assessing the quality of storm runoff, concentration ranges of these constituents, and changes in sampling format that would improve sampling efficiency.

TABLE 1.—*Sampling schedule, October 1971–April 1972*
[Modified from U.S. Army Corps of Engineers, 1972]

Constituent	Sampling frequency
Water discharge	Continuous
Specific conductance	12 samples (half hour on rise and hourly on fall)
Dissolved oxygen (DO)	Rise, peak, fall
5-day biochemical oxygen demand (BOD_5)	Peak
Chemical oxygen demand (COD)	Rise, peak, fall
Suspended solids	Rise, peak, fall
Volatile solids	Rise, peak, fall
Dissolved solids	Hourly on rise, peak, bihourly on fall
Nutrients	Hourly on rise, peak, bihourly on fall
Heavy metals	Rise, peak
Oil and grease	Rise, peak
Pesticides	Rise, peak
Total and fecal coliform	Rise, peak, fall
pH	12 samples (half hour on rise and hourly on fall)
Detergents—methylene blue active substances (MBAS)	Rise, peak, fall
Major ions	Peak
Organic carbon	Rise, peak, fall
Temperature	12 samples (half hour on rise and hourly on fall)
Floatable material	Visual description
Alkalinity (as $CaCO_3$, total)	12 samples (half hour on rise and hourly on fall)
Suspended sediment	Peak, fall

EXPANDED SAMPLING

The sampling program was expanded in September 1972 to include Peralta Creek in Oakland, Ross Creek in San Jose, and Strong Ranch Slough in Sacramento (fig. 1). These basins and the Castro Valley Creek basin were selected because it was thought that they were representative in terms of land-use and land-surface characteristics of residential basins within the Bay-Delta region.[3] It was thought

[3]An analysis of the land-use and land-surface characteristics in the Bay-Delta region is necessary before the representativeness of these basins can be confirmed. This has not yet been done for the entire Bay-Delta region, but a preliminary assessment of these characteristics in two basins is given in this report ("Castro Valley Creek Basin" and "Strong Ranch Slough Basin").

that results from the studied basins could be extrapolated to other study area basins having similar characteristics, but which were not sampled. A nonurbanized watershed (Saratoga Creek in Santa Clara County) was sampled to compare the quality of storm runoff from this basin with the urbanized basins.

Generally, the sampling program from September 1972 to April 1973 was the same as that used during the first year at the Castro Valley Creek basin except that samples for organic carbon, total coliform, floatable material, and suspended and volatile solids were not taken. Samples were obtained at Survey gaging stations (11181008, Castro Valley Creek at Hayward; 11181300, Peralta Creek at Oakland; 11167700, Ross Creek below Jarvis Road; 11447030, Strong Ranch Slough at Sacramento; and 11169500, Saratoga Creek at Saratoga).

During the sampling program from October 1973 to April 1974, water-quality and suspended-sediment samples were taken only at Ross Creek and Strong Ranch Slough. Continuous-discharge records were obtained for Ross Creek, Strong Ranch Slough, and Castro Valley Creek. Peralta Creek and Saratoga Creek were not sampled during this period. Seven storms were sampled at Ross Creek, and six storms were sampled at Strong Ranch Slough.

INTENSIVE SAMPLING

To satisfy the data needs for calibrating and verifying STORM, a digital computer model, and to make valid comparisons of the quantity and quality of runoff between basins, high-frequency sampling was necessary. STORM has been documented by the Hydrologic Engineering Center, Corps of Engineers, Davis, Calif., and is available to the public (U.S. Army Corps of Engineers, 1976). The intensive sampling program from October 1974 to April 1975 was designed to obtain depth-integrated, centroid (center of flow volume) samples at approximately 10-min intervals during rising and peak water stages. Depth-integrated, centroid samples were taken because stormflows from urban areas can change rapidly, making multivertical sampling difficult or impossible. Stormflows also tend to be turbulent, mixing the water and making it fairly homogeneous horizontally. The water is also mixed vertically, but certain constituents, such as oil and grease, tend to stay near the surface while other constituents, such as the larger particulate material, tend to stay near the bottom of the storm channel. Usually only two or three samples were taken during receding water stages. Field determinations were made for water temperature, specific conductance, pH, and alkalinity. Laboratory analyses were made for settleable matter, 5-day biochemical oxygen demand (BOD_5), suspended solids, chemical oxygen demand (COD), total nitrite plus nitrate as N, total Kjeldahl nitrogen as N, and total orthophosphorus as P.

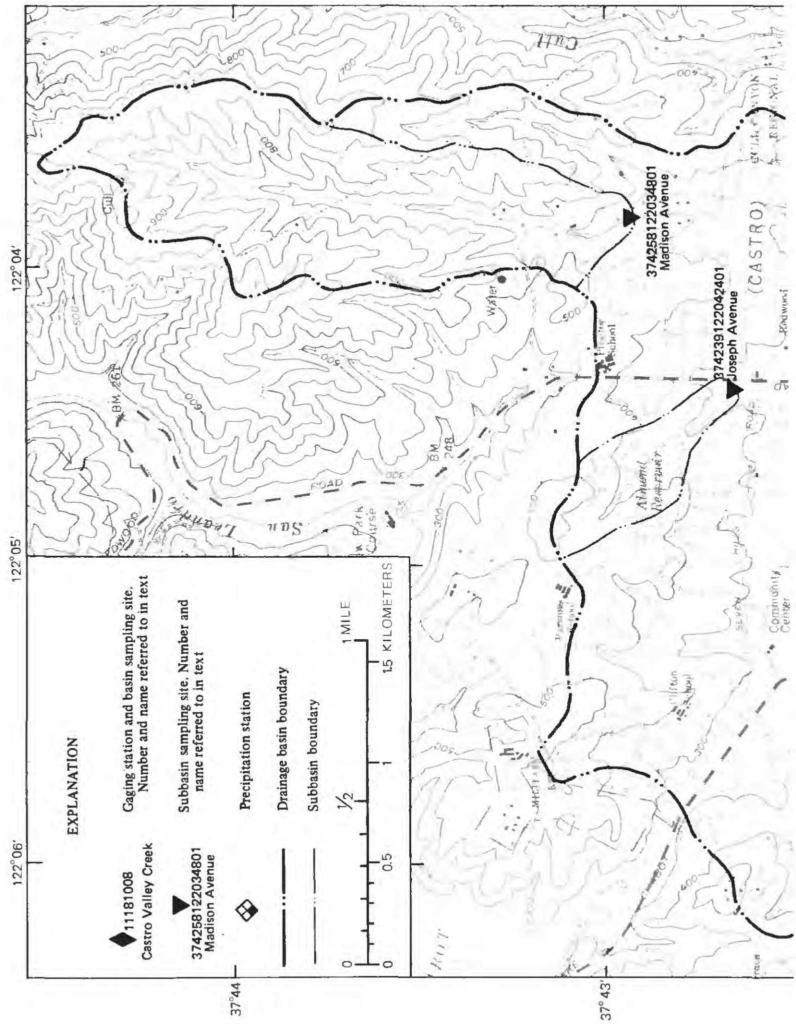
Sampling sites for the Castro Valley Creek and Strong Ranch Slough basins were Geological Survey stream-gaging stations 11181008 (Castro Valley Creek at Hayward) and 11447030 (Strong Ranch Slough at Sacramento). Within each basin two subbasins were selected, each having a discrete homogeneous land use. The purpose of subbasin sampling was to explore for differences in the quantity and quality of storm runoff from areas different in land-use and land-surface characteristics. In Castro Valley a residential (374239122042401, Joseph Avenue (Castro Valley City)) and a rural (374258122034801, Madison Avenue (Castro Valley City)) subbasin were chosen (fig. 2). In the Strong Ranch Slough basin a shopping center representative of commercial land uses (383626121230800, Strong Ranch Slough at Country Club Center, near Sacramento) and a schoolyard representative of institutional land uses (383630121214300, Strong Ranch Slough at El Camino High School, near Sacramento) were chosen (fig. 6).

The sampling program at the subbasins was designed to obtain two or three samples during each storm sampled at the basin gaging station. Analyses were made for suspended solids, settleable matter, BOD_5, COD, total nitrite plus nitrate as N, total Kjeldahl nitrogen as N, and total orthophosphorus as P. Water discharge was estimated. Methods for sample preservation and analysis were the same as for samples obtained at the basin gaging station.

Methods.—Streamflow measurements were made at gaging stations using bubble-gage sensors with both 5-min digital and continuous strip-chart recording. Water temperatures were measured with a handheld thermometer. Portable meters were used for measuring pH and specific conductance. Alkalinity measurements were obtained by the potentiometric titration method.

Analyses for settleable matter and BOD_5 were made at the Geological Survey Subdistrict office laboratories in Menlo Park and Sacramento, Calif. After collection, samples were transported to the Menlo Park and Sacramento laboratories and immediately placed in a refrigerator until analyzed. Sample analyses were started the next day and were usually completed within 1 week. Serial dilutions of nonseeded samples were analyzed for BOD_5. Samples were brought to 20°C and vigorously stirred to assure dissolved-oxygen (DO) saturation. Dilution water blanks were run with the serial diluted samples. For calculations, serial dilutions were used which showed a residual DO concentration greater than 2 mg/L (milligrams per liter) and produced at least a 2 mg/L concentration difference between initial DO and final DO (after 5 days). Samples for settleable matter were poured into Imhoff cones to the liter mark. After settling for 45 min the samples in the cones were stirred with a glass rod. After settling for 15 min more, the volume of settleable matter in the cones was recorded in milliliters per liter.

Samples for suspended solids, total nitrite plus nitrate as N, total



Kjeldahl nitrogen as N, total orthophosphorus as P, and COD were packed in ice and sent to the U.S. Geological Survey Central Laboratory in Salt Lake City, Utah, for analyses. Methods for analyses of these constituents are those given in Brown, Skougstad, and Fishman (1970).

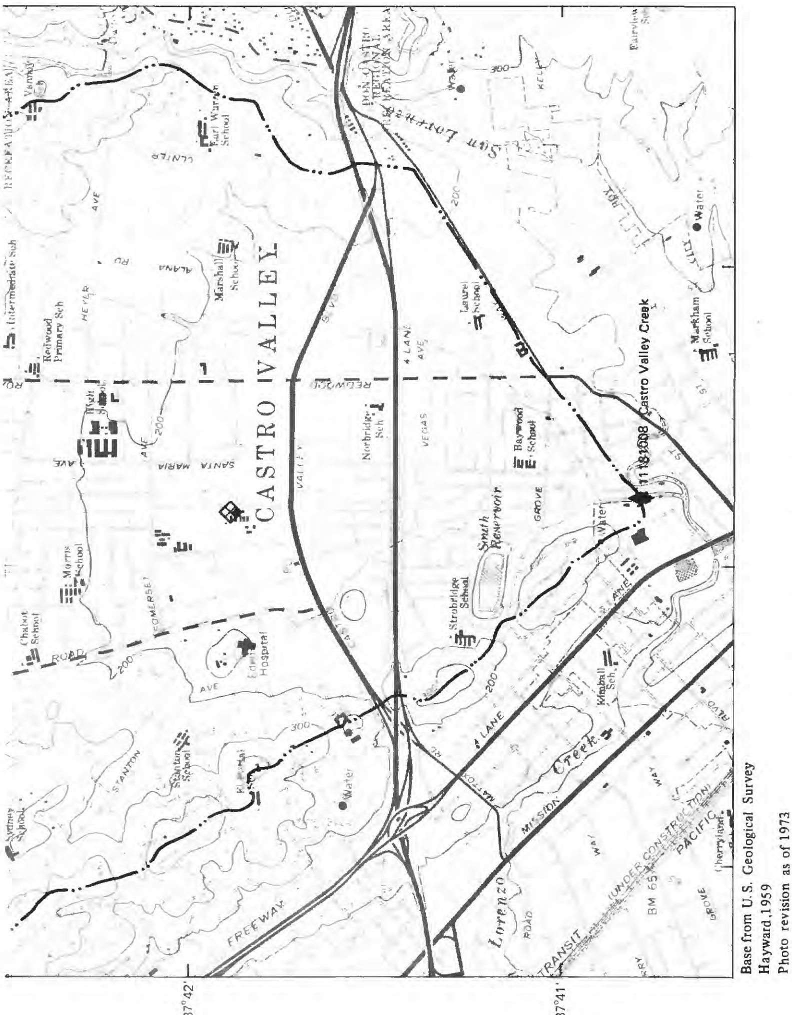


FIGURE 2.—Castro Valley Creek basin and sampling sites.

CHARACTERIZATION OF URBAN-SUBURBAN TERRAIN

DRAINAGE IN THE BAY-DELTA REGION

An understanding of the scope of storm-runoff problems in the Bay-Delta region begins with an understanding of drainage patterns in the region. Under natural conditions, the San Francisco Bay potentially receives runoff from about 63,000 mi^2 (163,000 km^2), or about 40 percent of the land area of California. Of that land, the Bay-Delta region contains about 7,700 mi^2 (19,900 km^2). Drainage to the bay within the Bay-Delta region can be conveniently divided into two major subareas (fig. 1). Using the confluence of the Sacramento and San Joaquin Rivers as a reference point, 3,200 mi^2 (8,300 km^2) of the region drains directly into the bay, and 4,500 mi^2 (11,700 km^2) drains into the rivers tributary to the Sacramento-San Joaquin Delta.

This report deals with two drainage basins: (1) The Castro Valley Creek basin representing the subarea draining directly to the San Francisco Bay and (2) the Strong Ranch Slough basin representing the subarea tributary to the Sacramento-San Joaquin Delta.

CASTRO VALLEY CREEK BASIN

The Castro Valley Creek basin (fig. 2) comprises 5.5 mi^2 (14.2 km^2) of urban, suburban, and rural terrain in the flats and hills bordering San Francisco Bay south of Oakland. The basin is predominantly residential, although a part of the basin in the hills is rural with grass and woodlands. The basin is underlain primarily by deeply weathered shale, sandstone, and conglomerate mantled by soft, crumbly, clayey soil. Drainage is mostly southward. The valley slopes therefore face mostly east or west and range from nearly flat in the downstream reaches to greater than 70 percent in the headwaters. The climate is characterized by a dry summer followed by a winter with irregularly spaced, frontal rainstorms that may produce intense rainfall.

Figure 3 shows a part of the basin that is rural, with grass and woodlands that are being replaced by suburban development. Figure 4 shows the dominantly residential part of the basin, and figure 5 shows the part of the basin containing mixed commercial, industrial, and residential terrain. Ellefsen (written commun., 1975) found by interpreting large-scale aerial photography that residential terrain composed about 75 percent of the basin, commercial-industrial terrain composed about 7 percent, and rural and open space within urban terrain composed about 16 percent (table 2). About 2 percent of the basin was identified as pavement, mostly freeways (fig. 5). Other

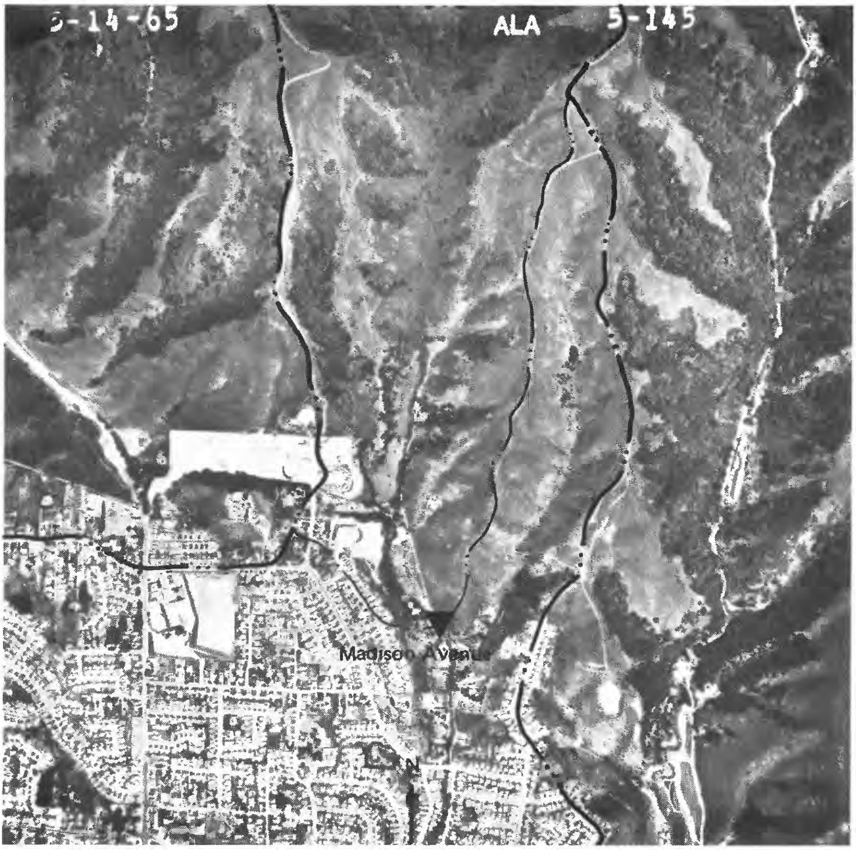


FIGURE 3.—Vertical aerial photograph of the Castro Valley Creek basin showing residential and rural terrain. (Photograph from U.S. Soil Conservation Service, series 5, frame 145, taken May 14, 1965.)

pavement such as that on parking lots and streets was included with residential and commercial-industrial terrain. The percentage values for open space, woods, brush, and grass were slightly higher when the mapping was done with the LANDSAT–1 data and image-enhancing electronic density slicer[4] (table 2). This occurs because the multispectral scanner on LANDSAT–1 and the density slicer tend to pick up vegetated open space within built-up terrain that might be assigned to other uses by a photointerpreter. Despite these variations,

[4]The electronic density slicer converts density levels of a photographic transparency into a wide spectrum of colors. The extent of any color signal in this spectrum may be recorded, thus giving an indication of area. Because the process is nearly instantaneous, areas of a given density (interpreted as a particular land cover) may be readily determined.

the relative values in table 2 suggest that the basin is about 80 percent residential, commercial and industrial buildings, freeways, and parking lots.

Mean annual precipitation in the vicinity of the basin is about 22 to 24 in./yr (560 to 610 mm/yr), which compares with a range of about 10 to 80 in./yr (250 to 2,000 mm/yr) for the Bay-Delta region as a whole (Rantz, 1971). Rantz (1971, p. C237) noted that the depth, duration,

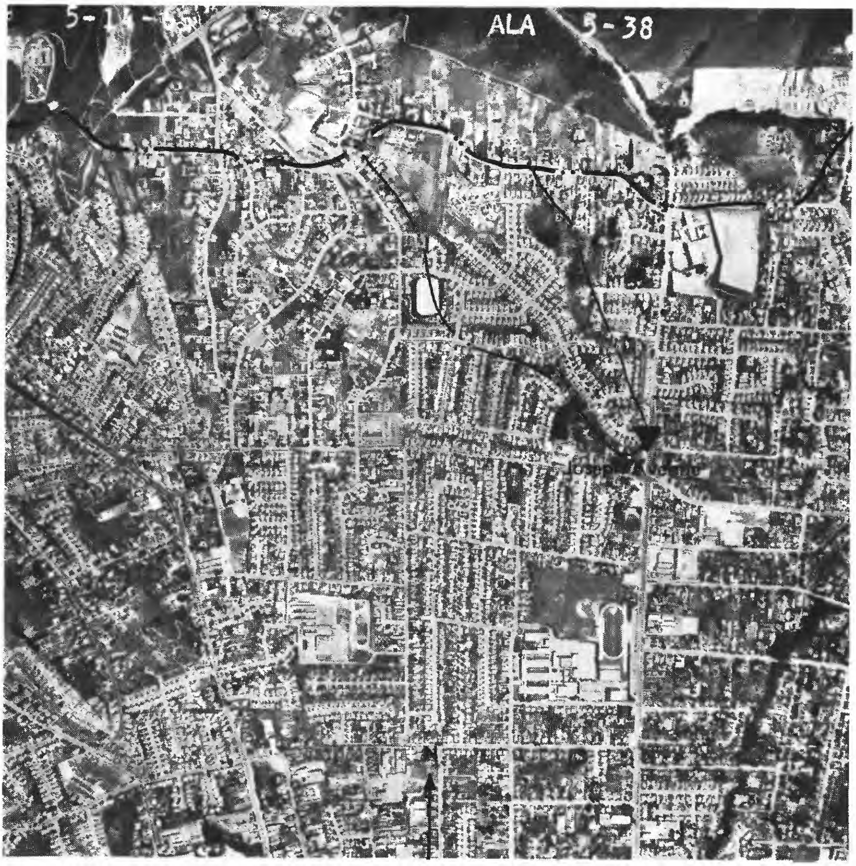


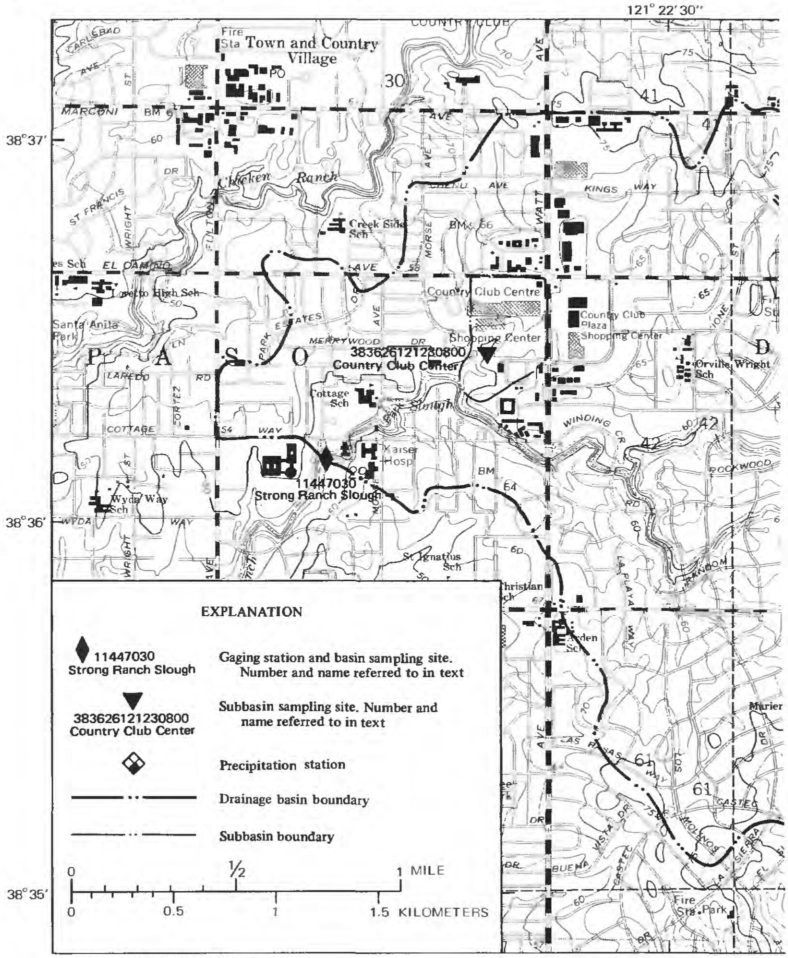
FIGURE 4.—Vertical aerial photograph of the Castro Valley Creek basin showing dominantly residential terrain. (Photograph from U.S. Soil Conservation Service, series 5, frame 38, taken May 14, 1965.)

and frequency characteristics of precipitation for a site in the region are closely related to the mean annual precipitation for that site. The quantity of runoff is related to the depth, duration, and frequency of precipitation; thus, mean annual precipitation may be considered a representative climatological index for considerations of storm runoff on a regional scale.

FIGURE 5.—Vertical aerial photograph of the Castro Valley Creek basin showing residential and commercial terrain. (Photograph from U.S. Soil Conservation Service, series 5, frame 41, taken May 14, 1965.)

STRONG RANCH SLOUGH BASIN

The Strong Ranch Slough basin (fig. 6) comprises about 5.0 mi² (13.0 km²) of urban and suburban terrain on the flats and low hills of northeastern Sacramento. The basin is predominantly residential. There are virtually no rural areas. The basin is underlain primarily by poorly consolidated alluvium and sedimentary rocks mantled by deep, permeable, clayey and sandy soils.

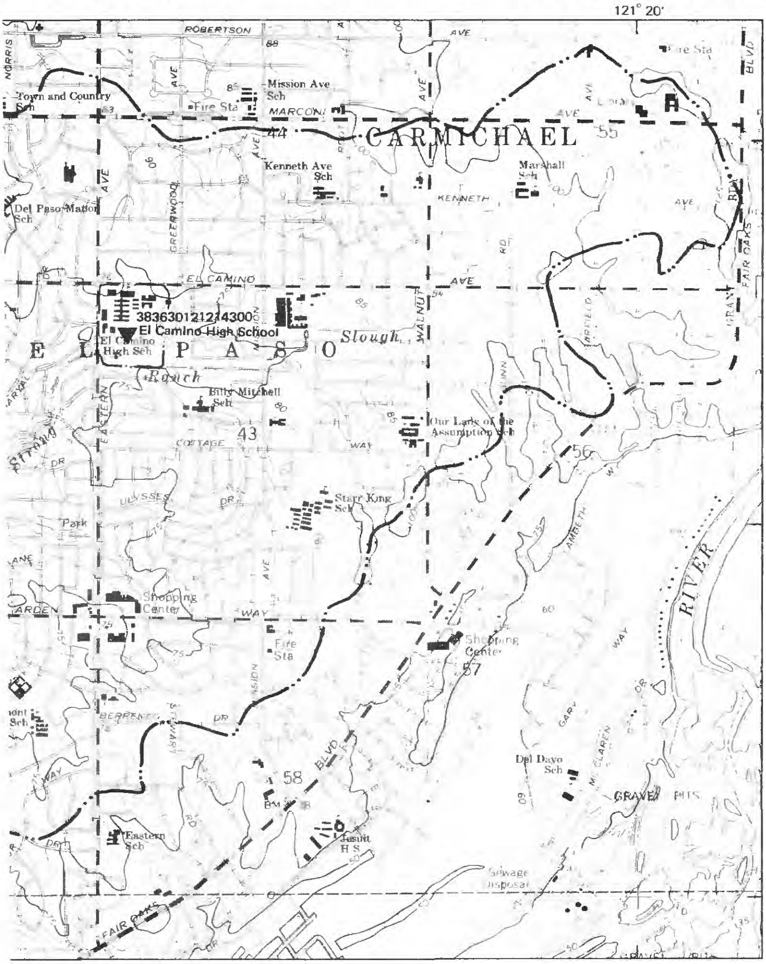


Base from U.S. Geological Survey
Carmichael and Sacramento East, 1967

FIGURE 6.—Strong Ranch Slough

The soils retain considerable amounts of water where they are not covered by impervious surfaces. The underlying bedrock is not exposed to the extent that it would affect storm runoff significantly. As in the case of the Castro Valley Creek basin, the extensive artificial cover nearly negates geology and soils as important factors in storm-runoff studies.

Slopes range from nearly flat in the downstream reaches to less than 5 percent in the headwaters and show no significant orientation.



basin and sampling sites.

TABLE 2.—*Land use and land cover in the Castro Valley Creek basin as evaluated by three methods*
[Modified from Ellefsen, written commun., 1975]

Method	Land use and land cover as percentage of total area						
	Residential	Commercial and industrial	Pavement	Open space (irrigated)	Woods	Brush	Grass
A. Interpretation of aerial photography	75.0	7.0	2.0	2.0	3.0	4.0	7.0
B. Computer processing of satellite- (LANDSAT–1 MSS) digital data	71.8	5.2	2.7	.4	10.9	With woods	8.8
C. Electronic density slicer	69.2	7.9	With commercial and industrial	With grass	8.2	3.1	14.4

The basin climate is characterized by occasional thunderstorms during the summer months and by irregularly spaced, frontal rainstorms that may produce intense rainfall during the winter. Mean annual precipitation in the basin is about 18 to 20 in./yr (460 to 510 mm/yr), and mean annual runoff is about 4 to 5 in./yr (100 to 130 mm/yr).

Large-scale aerial photography of the basin shows principally residential use. Detached residential buildings on large lots predominate, and numerous grass-covered areas such as parks and playing fields are apparent. Several shopping centers having large parking lots constitute most of the commercial development in the basin. Although several major four-lane thoroughfares pass through the basin, there are no freeways. There are virtually no industrial buildings, major reservoirs, or rural grassland, brushland, or woodland.

COMPARISON OF STORM-RUNOFF QUANTITY AND QUALITY BETWEEN THE CASTRO VALLEY CREEK AND STRONG RANCH SLOUGH BASINS

BASIN RESULTS

RAINFALL SAMPLING

Daily rainfall data and runoff sampling dates for the Castro Valley Creek and Strong Ranch Slough basins from July 1974 to April 1975 are shown in figures 7 and 8. In the Bay-Delta region the first significant storm[5] of the July 1974–June 1975 rainy season occurred

[5]The authors believe that in the Bay-Delta region storms causing at least 0.5 in. (13 mm) of rainfall in 24 hours will result in appreciable runoff from urban areas and hence can be considered significant storms.

July 8, 1974. The Castro Valley Creek rain gage recorded 0.60 in. (15 mm) of rainfall in 11 hours. No rainfall was recorded at the Strong Ranch Slough rain gage. Samples were not obtained at either basin during this storm. The next measurable rainfall occurred October 27–28, 1974; 0.40 in. (10 mm) of rainfall accumulated in 11 hours at the Castro Valley Creek gage, and 0.82 in. (21 mm) of rainfall accumulated in 14 hours at the Strong Ranch Slough rain gage.

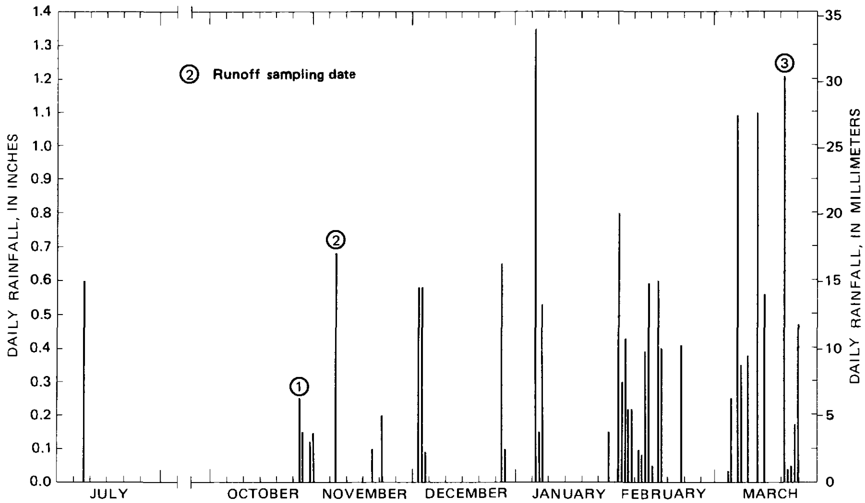


FIGURE 7.—Daily rainfall and runoff sampling dates for Castro Valley Creek basin.

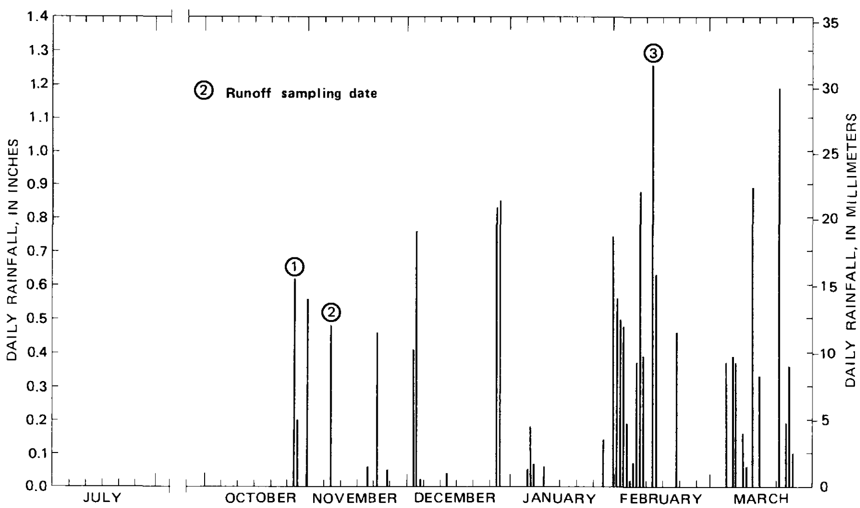


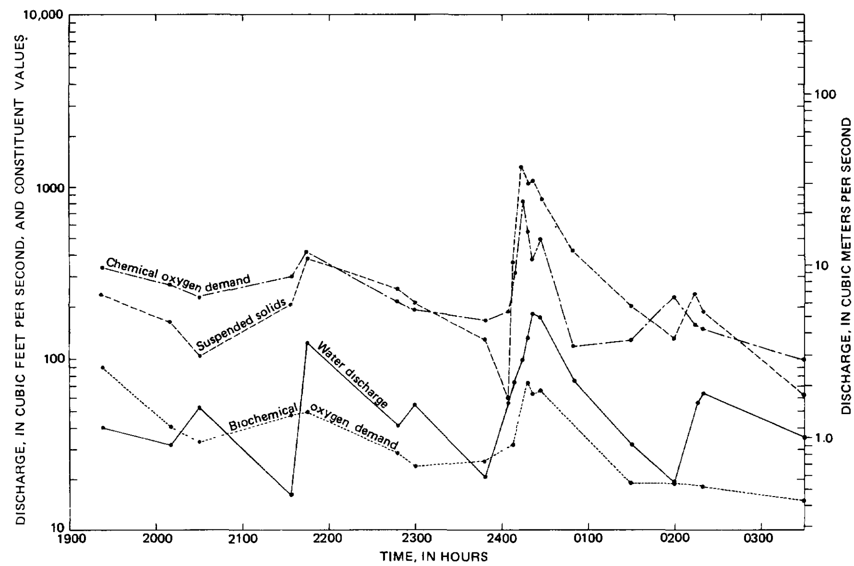
FIGURE 8.—Daily rainfall and runoff sampling dates for Strong Ranch Slough basin.

The second significant storm of the season occurred November 7, 1974. At Castro Valley Creek an intense rainfall of short duration, 0.68 in. (17 mm) in 4 hours, resulted in a sharply rising hydrograph. Less intense rainfall, 0.48 in. (12 mm) in 6 hours, resulted in a more moderately rising hydrograph at Strong Ranch Slough. No significant rainfall occurred in the Castro Valley Creek basin between the October and November storms; at Strong Ranch Slough a significant storm on October 31, 1974, resulted in 0.56 in. (14 mm) of rainfall in 11 hours.

At both study basins, the third storm sampled was preceded by a series of storms. The third storm sampled at Strong Ranch Slough was February 12, 1975, and was the largest of fiscal year 1975, 1.89 in. (48 mm) of rainfall in 24 hours. At Castro Valley Creek the third storm sampled, March 21, 1975, was the second largest of fiscal year 1975, 1.25 in. (32 mm) of rainfall in 15 hours. The largest, January 6, 1975, caused 1.35 in. (34 mm) of rainfall in 8 hours.

RUNOFF SAMPLING

From October 1971 to April 1974 a large number of constituents were analyzed, but usually only three or four samples were obtained per storm. Mass emission curves were difficult to construct from these data. In addition, changes in constituent values corresponding to



changes in the hydrograph for each storm could not be determined. Peak constituent values were usually missed. With high-frequency sampling from October 1974 to April 1975 these difficulties were largely overcome. Figures 9 through 20 are plots of water-discharge and water-quality constituents as a function of time. Plots are shown for all three storms sampled at the basin gaging station Castro Valley Creek at Hayward (11181008) to show the relationships among water-quality constituents and between these constituents and water discharge. Plots for the third storm at the basin gaging station Strong Ranch Slough at Sacramento (11447030) are sufficient to illustrate constituent relationships for this basin and to show differences in the quantity and quality of runoff from the Castro Valley Creek and Strong Ranch Slough basins.

Generally, data for Castro Valley Creek (figs. 9–17) show rapidly changing constituent values during rising water stages. For example, figure 9 shows that suspended solids rose from 61 to 1,310 mg/L in 9 min. Clearly, even a 10-min sampling interval was not sufficient to assess the rapidly changing conditions at Castro Valley Creek during rising water stages. For this reason, instead of following the 10-min sampling interval as planned, samples were obtained as quickly as possible during rising water stages at Castro Valley Creek. The collection interval depended on the time needed to fill sample bottles and retrieve the next set of bottles for sampling. This resulted in a sampling frequency of about 3–5 min.

EXPLANATION (Figures 9-20)

Concentrations or values for constituents are plotted using the ordinate value for water discharge in cubic feet per second. The following gives the units in which each constituent is reported.

Suspended solids	milligrams per liter
Chemical oxygen demand	milligrams per liter
Biochemical oxygen demand	milligrams per liter
Alkalinity, as $CaCO_3$	milligrams per liter
Specific conductance	micromhos at 25° Celsius
pH	units
Settleable matter	milliliters per liter
Total nitrite plus nitrate, as N	milligrams per liter
Total Kjeldahl nitrogen, as N	milligrams per liter
Total nitrogen, as N	milligrams per liter
Total orthophosphorus, as P	milligrams per liter

FIGURE 9.—Changes in water discharge, biochemical oxygen demand, chemical oxygen demand, and suspended solids with time, Castro Valley Creek basin, October 27–28, 1974 (first storm sampled).

The relationships between water-quality constituents and water discharge at Castro Valley Creek are summarized as follows:

1. COD, BOD_5, suspended solids, settleable matter, total nitrogen, total Kjeldahl nitrogen, and total orthophosphorus usually increase during rising water stages and decrease during receding water stages (figs. 9–12, 15–17).
2. Total nitrite plus nitrate generally decreases during rising water stages and increases during receding stages (figs. 11, 17, and 20).
3. Specific conductance and alkalinity decrease during the first flush (first rising hydrograph of storm) but may increase with subsequent rises in water stages (figs. 13 and 16).
4. After the first flush, changes in pH are slight and follow no discernible pattern (figs. 10, 13, and 16) (see also "Water-Quality Data").

These observations are supported by the correlation coefficients given in table 3. Correlation coefficients for water-quality constituents with water discharge are high for suspended solids (0.91 and 0.85), settleable matter (0.77 and 0.76), COD (0.72), BOD_5 (0.79),

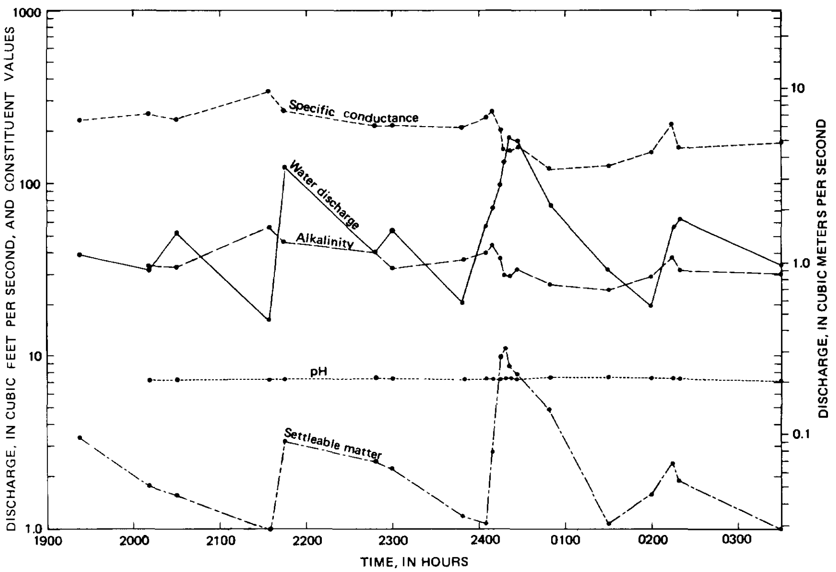


FIGURE 10.—Changes in water discharge, specific conductance, alkalinity, pH, and settleable matter with time, Castro Valley Creek basin, October 27–28, 1974 (first storm sampled).

specific conductance (−0.81), and alkalinity (−0.76). The relation of other water-quality constituents to water discharge is not very strong, as shown by the low correlation coefficients.

The relationships observed at Castro Valley Creek between water-quality constituents and water discharge do not always apply at Strong Ranch Slough. BOD_5 decreased from 31 to 20 mg/L ("Water-Quality Data") during the first flush of the second storm sampled and from 12 to 5.8 mg/L during the first flush of the third storm sampled (fig. 18). Relationships for the first storm sampled at

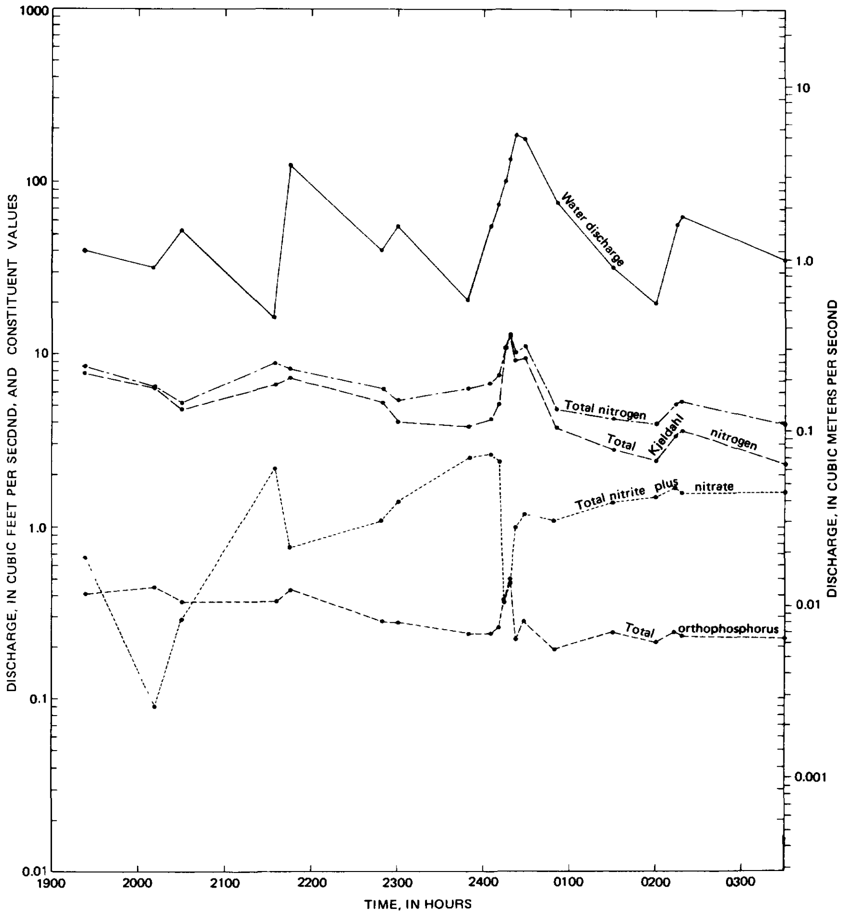


FIGURE 11.—Changes in water discharge, total nitrogen, total Kjeldahl nitrogen, total nitrite plus nitrate as N, and total orthophosphorus as P with time, Castro Valley Creek basin, October 27–28, 1974 (first storm sampled).

Strong Ranch Slough cannot be determined because of insufficient data for the rising portion of the hydrograph. Specific conductance and alkalinity initially decreased during the first flush of the second and third storms sampled but increased during rising flows near the peak of the first flush (fig. 19). Total orthophosphorus initially increased during the first flush of the second and third storms sampled but decreased during rising flows near the peak of the first flush (fig. 20). Total nitrate plus nitrate decreased during the first flush of the third storm (fig. 20) but initially increased during the first flush of the second storm and then remained fairly constant ("Water-Quality Data"). Total nitrogen and total Kjeldahl nitrogen decreased during

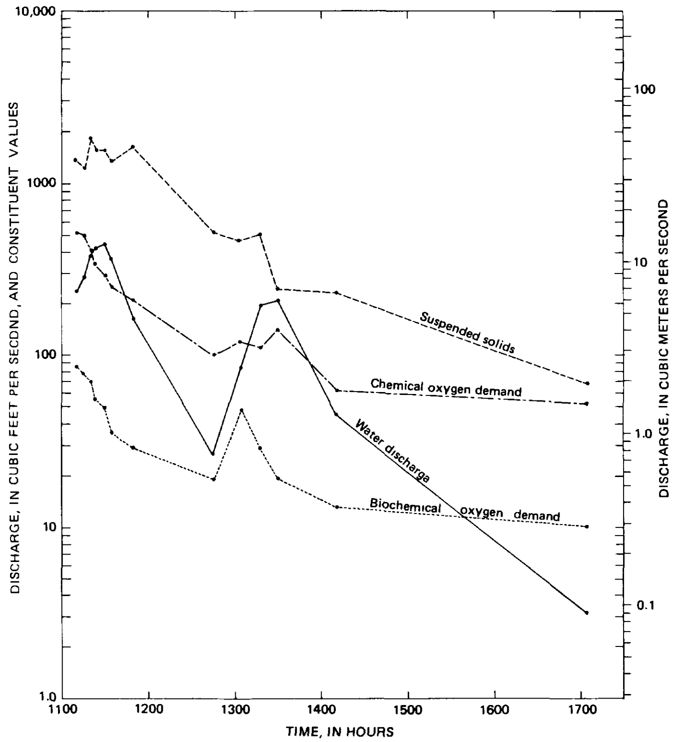


FIGURE 12.—Changes in water discharge, biochemical oxygen demand, chemical oxygen demand, and suspended solids with time, Castro Valley Creek basin, November 7, 1974 (second storm sampled).

the first flush of the third storm (fig. 20) but increased during the first flush and a subsequent rising hydrograph of the second storm ("Water-Quality Data").

Suspended solids, COD, and settleable matter increased during rising flows and decreased during receding flows of the second and third storms sampled, corresponding with the general pattern noted for these constituents for the three storms sampled at Castro Valley Creek. Also, correlation coefficients for suspended solids, settleable matter, and COD with water discharge are high (table 3).

Relationships between water-quality constituents were also determined (table 3). Specific conductance and alkalinity curves are very

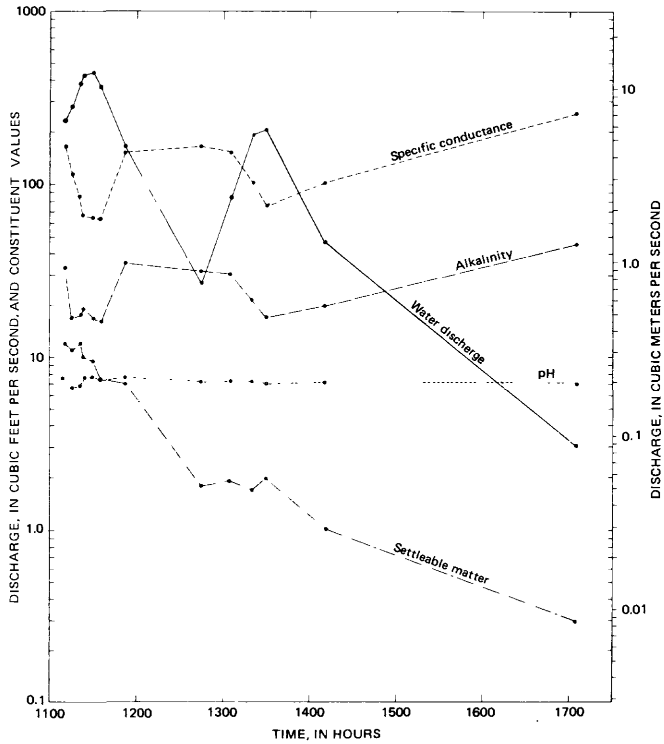


FIGURE 13.—Changes in water discharge, specific conductance, alkalinity, pH, and settleable matter with time, Castro Valley Creek basin, November 7, 1974 (second storm sampled).

similiar for all three storms and both basins sampled (figs. 10, 13, 16, and 19). Correlation coefficients for alkalinity with specific conductance are 0.96 at Castro Valley Creek and 0.89 at Strong Ranch Slough. Other constituents having high correlations at both basins are: settleable matter, total Kjeldahl nitrogen, and COD with suspended solids; total Kjeldahl nitrogen, total nitrogen, settleable matter, and BOD_5 with COD; and total Kjeldahl nitrogen with total nitrogen.

At Castro Valley Creek curvilinear correlations among variables were usually higher than linear correlations. The converse was true at Strong Ranch Slough.

Comparison of figures 9 through 17 with figures 18 through 20

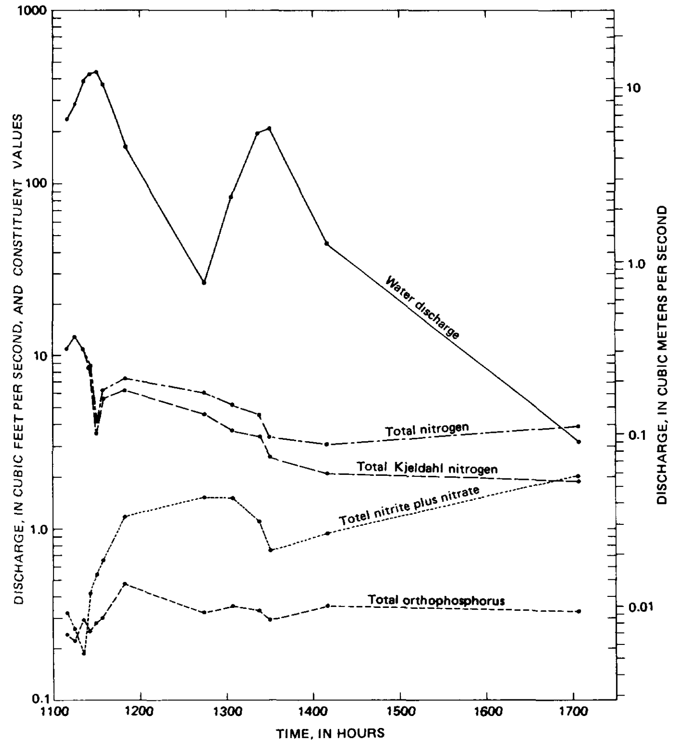


FIGURE 14.—Changes in water discharge, total nitrogen, total Kjeldahl nitrogen, total nitrite plus nitrate as N, and total orthophosphorus as P with time, Castro Valley Creek basin, November 7, 1974 (second storm sampled).

shows that there are basin variations in storm runoff. Peak stormflows at Castro Valley Creek were always greater and hydrographs showed sharper rises than at Strong Ranch Slough. Except for the first storm, average stormflows were also greater at Castro Valley Creek than at Strong Ranch Slough ("Water-Quality Data"). Except for total orthophosphorus during the third storm, maximum and mean concentrations of all water-quality constituents sampled were greater in the runoff at Castro Valley Creek than at Strong Ranch Slough ("Water-Quality Data"). Also, constituent values changed less rapidly at Strong Ranch Slough. Hence, 10- to 15-min sampling intervals were sufficient to measure the changes in constituent values at Strong Ranch Slough.

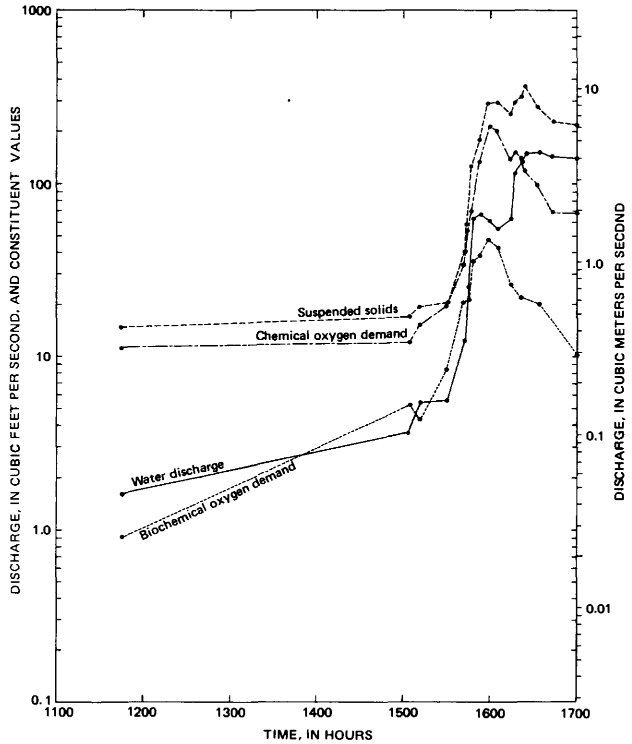


FIGURE 15.—Changes in water discharge, biochemical oxygen demand, chemical oxygen demand, and suspended solids with time, Castro Valley Creek basin March 21, 1975 (third storm sampled).

SUBBASIN RESULTS

Based on the limited number of samples taken (maximum of three per storm, see "Water-Quality Data"), values for all constituents except suspended solids were usually greatest in runoff from the residential subbasin in the Castro Valley Creek basin. Storm flows from the rural subbasin generally had greater concentrations of suspended

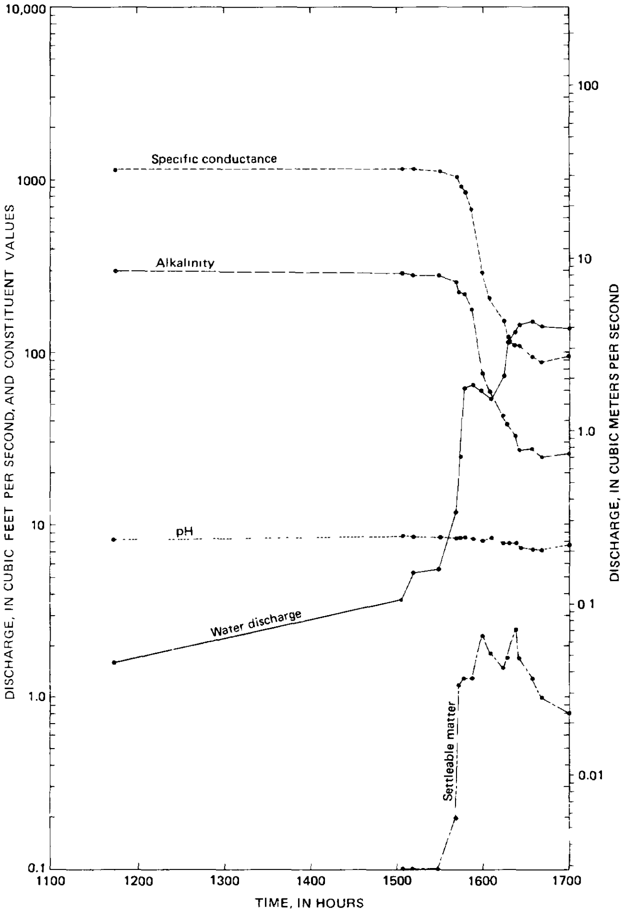


FIGURE 16.—Changes in water discharge, specific conductance, alkalinity, pH, and settleable matter with time, Castro Valley Creek basin, March 21, 1975 (third storm sampled).

solids than stormflows from the residential subbasin. The largest value for suspended solids, however, was measured in a sample taken during the third storm at the commercial subbasin in the Strong Ranch Slough basin. The largest estimated water discharges for all three storms were at the commercial subbasin in the Strong Ranch Slough basin. This subbasin is a shopping center, and nearly the entire subbasin is covered by impervious surfaces.

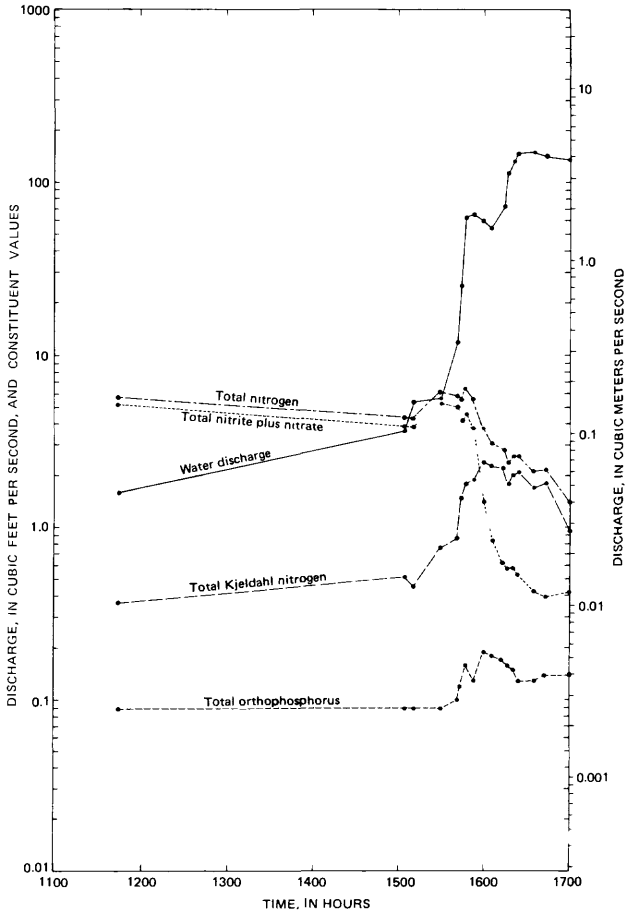


FIGURE 17.—Changes in water discharge, total nitrogen, total Kjeldahl nitrogen, total nitrite plus nitrate as N, and total orthophosphorus as P with time, Castro Valley Creek basin, March 21, 1975 (third storm sampled).

Based on the concentration of pollutants observed in the stormflows for the three storms sampled, the subbasins can be ranked as follows: Residential, commercial, rural, and institutional where the residential subbasin has the greatest concentration of pollutants in stormflows and the institutional has the least.

RELATIONSHIPS BETWEEN ENVIRONMENTAL CHARACTERISTICS AND THE QUANTITY AND QUALITY OF URBAN STORM RUNOFF

This section of the report describes relationships between environmental characteristics and the quantity and quality of storm runoff. Results from this study are compared with results from studies done

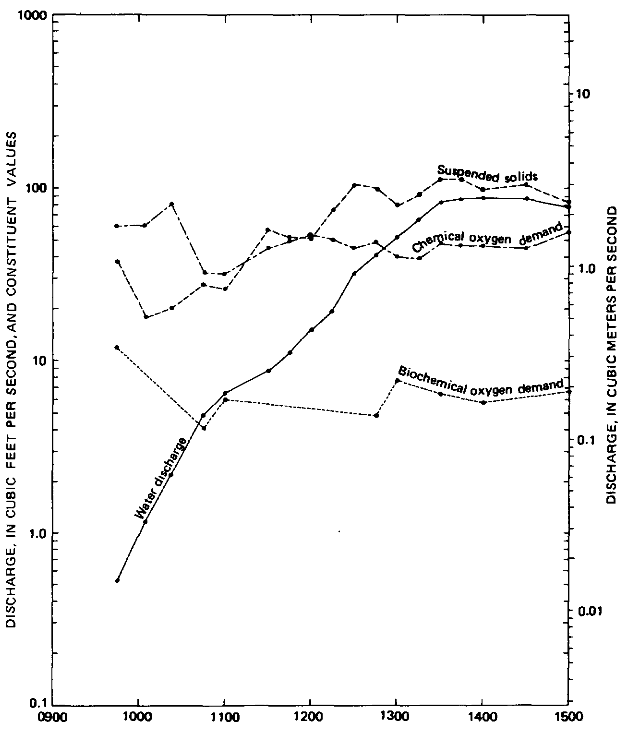


FIGURE 18.—Changes in water discharge, biochemical oxygen demand, chemical oxygen demand, and suspended solids with time, Strong Ranch Slough basin, February 12, 1975.

elsewhere. A conceptualized view of urban storm runoff (fig. 21) and a listing of the sources of water-quality constituents in urban runoff (table 4) should help the reader understand the following discussion.

THE FIRST-FLUSH EFFECT

The first flush from an urban area sometimes carries the greatest concentration of pollutants. Pollutants are defined for this report as water-quality constituents such as those listed in table 4 that, at increased concentrations, would degrade the quality of Bay-Delta water. Such an effect was observed for the second storm (November 7, 1974) at the Castro Valley Creek gaging station. The sampling periods for the first and third storms at the Castro Valley Creek

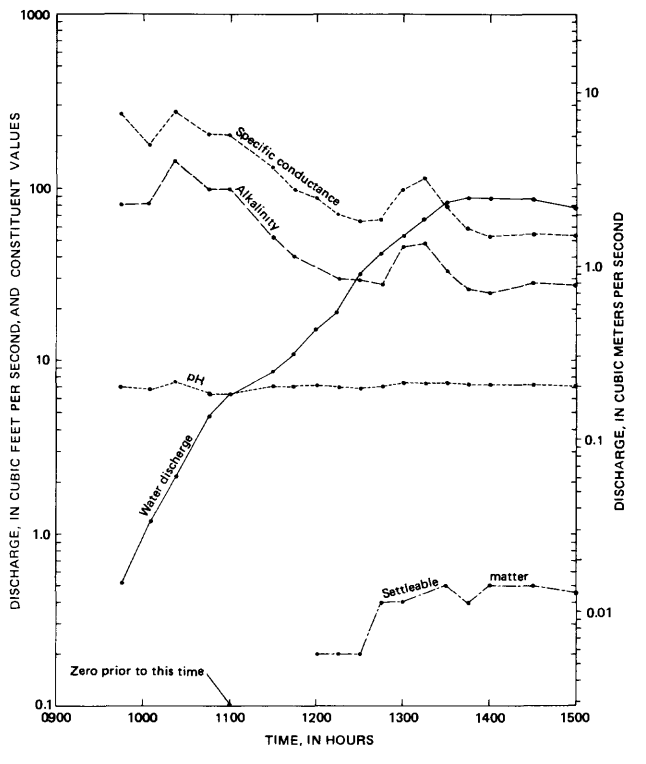


FIGURE 19.—Changes in water discharge, specific conductance, alkalinity, pH, and settleable matter with time, Strong Ranch Slough basin, February 12, 1975.

gaging station and the three storms sampled at the Strong Ranch Slough gaging station were not sufficient to compare first-flush pollutant concentrations with concentrations during subsequent flows.

The first-flush effect is not always observed. Palmer (1963, p. 164) reported for stormflows in Detroit: "In some cases the quality became worse as the storm progressed and in others it became better, and in still others no pattern was apparent." First-flush water quality is probably dependent on the time period between storms, rainfall characteristics (depth, intensity, duration, and distribution), seasonal variations in the accumulation of pollutants on land surfaces, and land-use and land-cover characteristics of the basin.

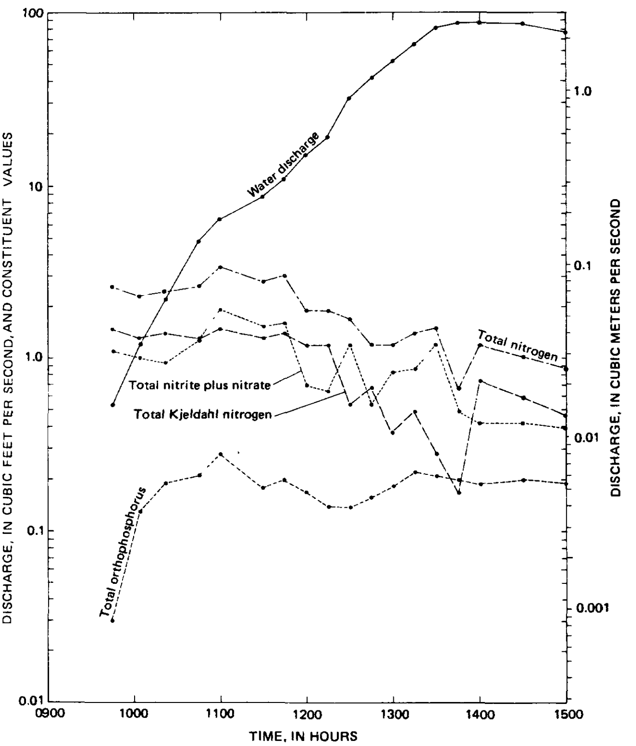


FIGURE 20.—Changes in water discharge, total nitrogen, total Kjeldahl nitrogen, total nitrite plus nitrate as N, and total orthophosphorus as P with time, Strong Ranch Slough basin, February 12, 1975.

TABLE 3.—*Correlations among variables measured and sampled at Castro Valley Creek at Hayward (11181008) and Strong Ranch Slough at Sacramento (11447030)*

[Linear correlation equations are: Dependent variable = $a + b$ (Independent variable), where a and b are regression parameters. Curvilinear correlation equations are: Dependent variable = k (Independent variable^n), where k and n are regression parameters; a log transformation will convert this equation to linear form]

Variables, correlated as shown	Castro Valley Creek		Strong Ranch Slough	
	Linear correlation coefficients	Curvilinear correlation coefficients	Linear correlation coefficients	Curvilinear correlation coefficients
With discharge:				
Total nitrite plus nitrate	−0.54	−0.64	−0.15	−0.08
Total Kjeldahl nitrogen	.51	.57	.63	.15
Total nitrogen	.32	.12	.58	.11
Total orthophosphate	.14	.20	−.09	.20
Suspended solids	.85	.91	.85	.68
Settleable matter	.77	.76	.75	.85
Chemical oxygen demand (COD)	.47	.72	.72	.44
5-day biochemical oxygen demand (BOD_5)	.54	.79	.52	.35
Specific conductance	−.54	−.81	−.35	−.66
Alkalinity	−.51	−.76	−.31	−.55
pH	−.44	−.51	.43	.33
With total nitrogen:				
Total nitrite plus nitrate	−.09	−.01	.20	.04
Total Kjeldahl nitrogen	.90	.66	.95	.93
With suspended solids:				
Total nitrite plus nitrate	−.51	−.65	−.20	−.25
Total Kjeldahl nitrogen	.74	.73	.80	.31
Total nitrogen	.60	.31	.72	.31
Total orthophosphate	.35	.40	.06	.02
Settleable matter	.94	.79	.79	.56
Chemical oxygen demand (COD)	.70	.80	.85	.59
5-day biochemical oxygen demand (BOD_5)	.65	.82	.62	.32
Specific conductance	−.45	−.77	−.16	−.23
Alkalinity	−.44	−.77	−.22	−.26
pH	−.38	−.50	.24	.22
With chemical oxygen demand (COD):				
Total nitrite plus nitrate	−.53	−.64	−.20	−.23
Total Kjeldahl nitrogen	.92	.91	.94	.80
Total nitrogen	.79	.47	.87	.75
Total orthophosphate	.49	.61	.07	−.03
Settleable matter	.82	.83	.85	.43
5-day biochemical oxygen demand (BOD_5)	.89	.87	.93	.93
Alkalinity	−.47	−.69	−.19	−.26
pH	−.39	−.51	.18	.15
With specific conductance:				
Total nitrite plus nitrate	.90	—	.45	—
Total Kjeldahl nitrogen	−.44	—	.01	—
Total nitrogen	−.06	—	.14	—
Total orthophosphate	−.40	—	−.21	—
Settleable matter	−.41	—	−.29	—
Chemical oxygen demand (COD)	−.45	—	−.05	—
5-day biochemical oxygen demand (BOD_5)	−.45	—	−.15	—
Alkalinity	.96	—	.89	—
pH	.72	—	−.11	—

TIME BETWEEN STORMS

Between storms, pollutants accumulate on urban basins at rates that presumably vary according to such factors as land use, population density, climate, and human activities. Not counting municipal removal (street sweeping, garbage collection) pollutants continue to collect until removed by wind or rain. Thus, as the time between storms increases so should the accumulated amount of pollutants. Given the same rainfall depth, duration, and intensity, the concentration of pollutants in urban storm runoff should also be greater as the time between storms increases.

Gameson and Davidson (1962), Pravoshinsky and Gatillo (1969), and Wilkinson (1956) all concluded that the concentration of pollutants in runoff generally increased with the duration of antecedent dry period. Weibel and others (1964) and Bryan (1972) could not find conclusive proof to support this concept.

The effect of antecedent dry periods cannot be determined for this study because pollutant accumulation rates were not determined. Also, among the three storms sampled at each basin, rainfall characteristics, runoff discharges, and the shapes of the hydrographs are dissimilar.

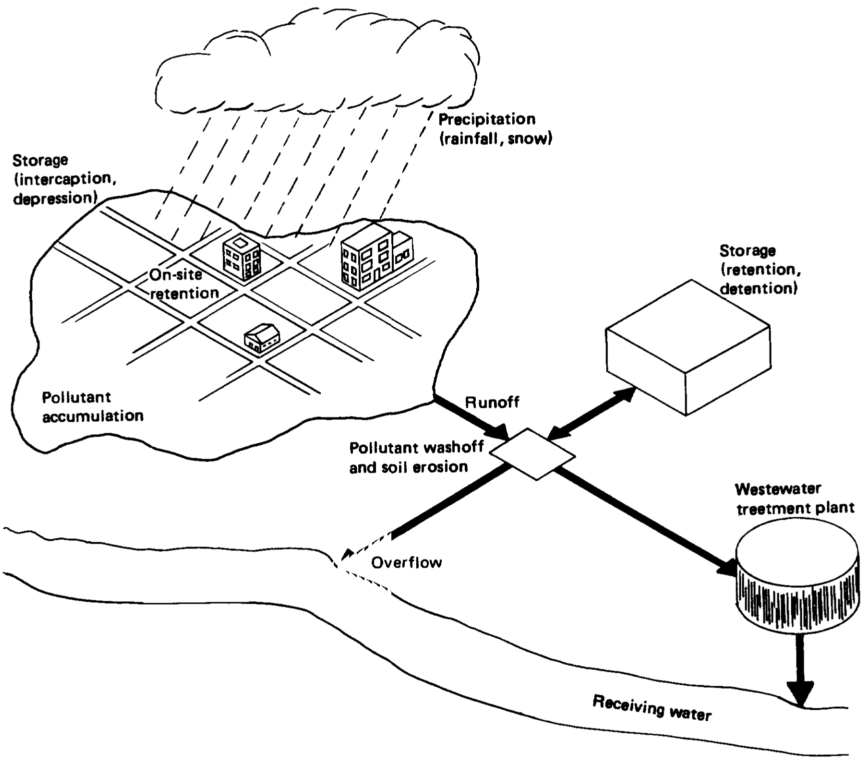


FIGURE 21.—Urban storm runoff and treatment processes (modified from Feldman and Abbott, 1974).

TABLE 4.—*Water-quality constituents and their sources in urban runoff*
[Modified from Wells, Austin, and Cook, 1971, p. 48]

Source area	Examples	Water-quality constituents
Atmosphere	Wind erosion	Suspended, settleable, and dissolved solids
	Combustion of natural gas and high-sulfur fuels	Sulfur oxides
	Automobiles	Nitrogen oxides, hydrocarbons
Ground surfaces	Water erosion	Suspended, settleable, and dissolved solids
	Automobiles	Oils and grease; suspended, settleable, and dissolved solids; heavy metals
	Rubbish and litter (leaves, grass clippings, trash, garbage, etc.)	Suspended, settleable, and dissolved solids; soluble and insoluble organics and nutrients
	Animal wastes	Bacteria and viruses, soluble and insoluble organics and nutrients
	Lawns and gardens	Fertilizers (nutrients) and pesticides
Subsurface	Industry (accidental and surreptitious discharges to covered storm sewers)	Acids; heavy metals; nutrients; organics; suspended, settleable, and dissolved solids; bacteria
	Covered storm sewers and material collected in catch basins during low flow and previous storm periods	Bacteria; organics; suspended, settleable, and dissolved solids

RAINFALL CHARACTERISTICS

Rainfall characteristics that affect runoff are depth, intensity, duration, and distribution. The distribution of rainfall depth, intensity, and duration is determined by climatic and topographical features that, in turn, determine the type of storm received. For a study area in Louisiana, R. J. Lobell (written commun., 1975) found that rainfall varied to a greater extent over small areas in convective storms (thundershowers) than in frontal storms. Typically, the Bay-Delta region receives frontal storms, but intense rainfall is not rare. For example, the second storm sampled (November 7, 1974) at Castro Valley Creek was a localized cell causing high intensity rainfall at and near the gage house, while subbasins within the drainage basin received very little precipitation. Thus, this rainfall had characteristics of a convective storm. Apparently, rainfall intensity varies across even a small urban watershed (like Castro Valley Creek) within the Bay-Delta region.

SEASONAL VARIATIONS

The rate of accumulation of pollutants on urban basins may vary seasonally. Dust and dirt are generally the most important components of solids accumulation. Autumn leaf fall may, however, be a significant factor in temperate climates. In a study made in Chicago, the American Public Works Association (1969) found that, in autumn, leaf material in residential streets accounted for over half the total street litter found.

Large quantities of macerated leaf material were observed in runoff during the second storm (autumn season) at Castro Valley Creek. This material may have been responsible for the suspended solids and COD values being highest for the second storm.

Other studies have not reported pronounced changes in constituent concentrations due to seasonal factors that affect pollutant accumulation (Weibel and others, 1964; Cleveland and others, 1970).

LAND-SURFACE CHARACTERISTICS

The authors believe that meaningful correlations between conventional land-use classifications (such as residential, commercial, and industrial) and the quantity and quality of urban storm runoff are not possible without first assessing, for each conventionally designated land-use area, the land-surface and land-use characteristics that affect pollutant accumulation and removal. Land-surface characteristics that affect the quantity and quality of urban storm runoff are perviousness, interception and depression storage, slope, basin area and configuration, condition of the drainage channel, and geology and soils where not covered by artificial surfaces such as concrete and asphalt.

There is a rapid response time of runoff to rainfall in the Castro Valley Creek basin (runoff closely follows the onset of rainfall and peaks and recedes rapidly). This may be because a high percentage of the basin is covered with impervious surfaces, and there is probably little interception and depression storage. Built-up areas in the hilly part of the basin have steep slopes that increase the rate of runoff.

In contrast, the Strong Ranch Slough basin is considerably less responsive to rainfall. Although the percentage of the basin that is impervious is unknown, there seems to be some depression storage resulting from the low slopes.

Basin area affects runoff quantity and quality because large basins have a greater probability of producing large volumes of runoff. Basin configuration also affects runoff. The first flushes from various tributary subbasins may arrive at the sampling point at different times. A more polluting first flush from one subbasin may be mixed with recession flow from other subbasins. The resulting runoff will be less polluting than if first flushes from all tributary subbasins arrived simultaneously at the sampling site. Basin areas for Castro Valley Creek and Strong Ranch Slough are similar, but basin configurations are much different (figs. 2 and 6). This difference probably accounts for some of the differences in the quantity and quality of runoff between the two basins, although the specific influence of basin configuration is presently unknown.

Most of the Strong Ranch Slough is an open, concrete channel, while most of Castro Valley Creek is an open, earthen channel. The capacity of storm runoff to erode channel banks is greater for earthen channels than for concrete channels. Thus, storm runoff from earthen channels should have higher concentrations of suspended solids and settleable matter. Although the concentrations of suspended solids and settleable matter were always greater in runoff from the Castro Valley Creek basin than from the Strong Ranch Slough basin, the proportion derived from channel banks was not determined.

Geology and soils are important factors affecting runoff from the wooded, northeastern part of the Castro Valley Creek basin. No runoff was recorded at the Madison Avenue sampling site (fig. 3) during the first storm sampled of the 1974–75 rainy season that produced considerable runoff at the basin gaging station. The Madison Avenue subbasin absorbed the rainfall without contributing runoff due to the perviousness of the terrain and despite steep slopes in the subbasin.

LAND-USE CHARACTERISTICS

Land-use characteristics that affect pollutant accumulation and removal are sanitary conditions, construction activities, and traffic density and composition. Sanitary conditions refer to exterior housing quality, water supply, disposal of human waste, litter and trash accumulations, junked cars, dilapidated sheds, vacant-lot sanitation, poor-drainage areas, vector harborage (places where insect carriers of disease such as mosquitoes are harbored), and the presence of livestock, poultry, and dogs. After studying urban storm runoff in Lubbock, Tex., Wells, Austin, and Cook (1971, p. 49) concluded: "The presence of poorly maintained dwellings, inadequate storage areas for refuse and garbage, human and animal wastes sources, poorly maintained vacant lots and other unsanitary situations all tend to increase the quantity of pollutants available for removal by storm water."

A Tulsa storm runoff study by AVCO Economic Systems Corporation (1970) found that stormwater pollutant concentrations were correlated with sanitary conditions.

Current streetsweeping practices in the Castro Valley Creek and Strong Ranch Slough basins were determined from interviews with officials in public works departments. Their responses generally indicated that street-cleaning practices in both study basins are designed to remove the bulk of street litter but are not frequent or thorough enough to remove the fine silty material that represents a large proportion of the overall pollution potential of street-surface litter.

The Castro Valley Creek basin is unincorporated; the Strong Ranch Slough basin is within the community of Carmichael. Unlike the Strong Ranch Slough basin, the Castro Valley Creek basin has some areas where houses are poorly maintained, with refuse scattered on the property. Some of these areas are adjacent to the drainage channel. Constituent concentrations in runoff were greatest during the second storm sampled (November 7, 1974) at the Castro Valley Creek basin when intense rainfall occurred at and near the gaging station. The area around the gaging station has many poorly maintained houses and lots where refuse is scattered. Large quantities of refuse and macerated leaf material were observed in the runoff during the second storm. Hence, the high constituent concentrations observed during the second storm are probably due to a combination of intense rainfall, unkempt property, and leaf fall from deciduous trees during autumn.

In an urban environment, building and roadway construction are human activities that affect erosion. Such construction increases the quantity of suspended solids and sediment in storm runoff. AVCO Economic Systems Corporation (1970) concluded that construction of an apartment complex (particularly the removal of ground cover) increased concentrations of suspended solids in runoff eight to nine times over the average for other test areas. In areas undergoing rapid urbanization near Baltimore, Md., and Washington, D.C., Wolman and Schick (1967) determined:

1. "The equivalent of many decades of natural or even agricultural erosion may take place during a single year from areas cleared for construction." (p. 451)
2. "The quantity of sediment derived from areas undergoing construction is from 2 to 200 times as large as that derived from comparable areas in rural or wooded condition." (p. 455)

For Bel Pre Creek basin, Md., Yorke and Davis (1971, p. B223) found:

"1. The storm runoff from the basin during a 30-month period of active construction was about 30 percent higher than that expected with the original grass and forest cover.

"2. Construction increased the amount of sediment available for transport and resulted in an average suspended-sediment concentration 12 times greater than that expected with preurbanization land-use conditions.

"3. Urban construction that averaged 15 percent of the basin between March 1965 and August 1967 resulted in a basin sediment yield 14 times more than that expected with the preurbanization land-use conditions.

"4. The yield from the construction sites was 90 times more than that expected with the original grass and forest cover."

The potential for surface disturbance from construction activity is greater in the Castro Valley Creek basin, where a large part of the basin near its headwaters is rural, than in the Strong Ranch Slough basin, which is virtually all developed. Many of the newer residential areas in the Castro Valley Creek basin are on hills in the headwaters of the basin. A protective vegetational cover has not been established on some of the steeper slopes disturbed by construction. During the period of this study little construction was observed in either basin. The rural part of the Castro Valley Creek basin is grazed by cattle and horses.

Sylvester and Dewalle (1972) discussed the influence of traffic density and composition on the quality of urban storm runoff. They concluded that highway runoff is similar to urban area runoff but may be higher in heavy metals and oil. Traffic density and composition and their effect on runoff quality were not assessed for the Castro Valley Creek and Strong Ranch Slough basins.

CONTROL MEASURES FOR URBAN STORM RUNOFF

There are three kinds of control measures that can be used to protect receiving waters from being impaired in quality by urban runoff: (1) detention and retention of runoff; (2) conventional wastewater treatment; and (3) institutional measures such as subdivision regulations, zoning and flood-control ordinances, and building codes. The objective of this section of the report is to determine if control measures are required for urban storm runoff in the Bay-Delta region. Control measures are discussed in other publications such as Poertner (1974).

One way to determine if control measures are required for urban storm runoff is to compare constituent concentrations in runoff with those in wastewater that must be treated under present water-quality control statutes. This comparison is made in table 5. Arithmetic- and flow-weighted-mean concentrations of suspended solids in runoff from the Castro Valley Creek basin exceed the arithmetic-mean concentration of suspended solids in medium-stregth untreated

TABLE 5.—*Comparison of storm-runoff quality from study basins with medium-strength untreated sewage*

[Concentrations in milligrams per liter. Values for untreated sewage and typical secondary treatment effluent are from Pound and Crites, 1973]

Constituent	Untreated sewage (arithmetic-mean concentration)	Typical secondary treatment effluent (arithmetic-mean concentration)	Castro Valley Creek basin			Strong Ranch Slough basin		
			Arithmetic-mean concentration	Concentration range	Flow-weighted mean	Arithmetic-mean concentration	Concentration range	Flow-weighted mean
Total nitrogen	40	20	5.9	1.4–13	5.1	2.8	0.66–6.3	2.6
Suspended solids	200	25	465	15–1,810	519	111	14–369	118
Chemical oxygen demand	500	70	210	11–810	184	85	32–220	83
Biochemical oxygen demand, 5-day	200	25	35	0.9–90	31	17	4.2–42	24

sewage. Mean concentrations of suspended solids in runoff from the Strong Ranch Slough basin are about one-half the mean concentration of suspended solids in untreated sewage. For both basins, mean concentrations of total nitrogen, COD, and BOD_5 are less than mean concentrations of these constituents in untreated sewage.

For both basins, maximum concentrations of suspended solids, COD, and BOD_5 are substantially greater than mean concentrations of these constituents in typical secondary treatment effluent. Maximum concentrations of these constituents were observed during runoff periods of greatest water discharge (figs. 9, 11, 15, 17; see "Water-Quality Data"). Therefore, substantial loadings of these constituents occur for short periods. The effect of these "shock" loadings on San Francisco Bay is presently unknown. Because of high concentrations during peak runoffs, control of shock loads to reduce concentrations of suspended solids, COD, and BOD_5 seems advisable. High values for total orthophosphorus suggest that control measures to reduce this constituent may also be advisable. If these observations are representative of other urban basins in the Bay-Delta region, control measures for urban storm runoff in the region would seem to be advisable.

CONCLUSIONS

Storm runoff from the Castro Valley Creek and the Strong Ranch Slough basins was quite different in quantity and quality.

Peak stormflows from the Castro Valley Creek basin were always greater and hydrographs showed sharper rises than from the Strong Ranch Slough basin. Except for total orthophosphorus during the third storm sampled, maximum and mean concentrations of all water-quality constituents sampled were greater from the Castro Valley Creek basin than from the Strong Ranch Slough basin. Also, constituent values changed less rapidly in runoff from the Strong Ranch Slough basin.

The difference in runoff quantity and quality between basins seems to be due partly to steeper slopes in the Castro Valley Creek basin. Also, there is probably more pervious area in residential parts of the Strong Ranch Slough basin because of the predominance of large lots containing detached buildings. Furthermore, Castro Valley Creek is mostly an earthen channel, whereas Strong Ranch Slough is mostly concrete lined.

Erosion of Castro Valley Creek's earthen channel and erosion of steep slopes disturbed by grazing and residential development in the hills near the basin headwaters are probably partly responsible for the greater concentrations of suspended solids and settleable matter. The Castro Valley Creek basin also has some residential areas where houses are poorly maintained and refuse is scattered on the property. Some of these areas are adjacent to the drainage channel. These areas are probably contributing to the concentration of suspended solids and settleable matter in Castro Valley Creek during storm runoff.

Constituent concentrations were greatest during the second storm sampled (November 7, 1974) at the Castro Valley Creek basin when intense rainfall occurred at and near the gaging station. The high constituent concentrations observed were probably due to a combination of factors: intense rainfall, unkempt property, and leaf fall from deciduous trees.

For both basins, correlation coefficients for suspended solids, settleable matter, and COD with water discharge are high. For the Castro Valley Creek basin, correlation coefficients for BOD_5, specific conductance, and alkalinity with water discharge are also high. Constituents having high correlations for both basins are: Alkalinity with specific conductance; settleable matter, total Kjeldahl nitrogen, and COD with suspended solids; total Kjeldahl nitrogen, total nitrogen, settleable matter, and BOD_5 with COD; and total Kjeldahl nitrogen with total nitrogen.

Of the subbasins sampled, the most polluted runoff was derived from the residential subbasin; runoff from the commercial, rural, and institutional subbasins was successively less polluted. The largest estimated water discharges for all three storms sampled were observed at the commercial subbasin in the Strong Ranch Slough basin. The amount of impervious surface cover is greatest in that subbasin.

Control of urban storm runoff from the Castro Valley Creek and Strong Ranch Slough basins may be desirable because of the large concentrations of suspended solids and lesser but significant concentrations of COD, BOD_5, and total orthophosphorus. Also, the greatest concentrations of these constituents occur at or near peak water discharges. If this is generally applicable to Bay-Delta region urban basins, storm runoff could have a degrading effect on the water quality of San Francisco Bay.

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WATER-QUALITY DATA

CASTRO VALLEY CREEK AND STRONG RANCH SLOUGH BASINS, INCLUDING SUBBASIN DATA, OCTOBER 1974 THROUGH SEPTEMBER 1975

DATE	TIME	INSTANTANEOUS DISCHARGE (FT^3/S)	ALKALINITY AS CACO3 (MG/L)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)
11181008 - CASTRO VALLEY CREEK AT HAYWARD							
OCT.							
01...	2200	0.27	264	--	--	--	--
07...	1600	.17	274	2.5	1.3	3.8	0.43
27...	1925	40	--	.67	7.9	8.6	.41
27...	2010	32	34	.09	6.4	6.5	.45
27...	2030	53	34	.29	4.8	5.1	.37
27...	2135	15	58	2.2	6.7	8.9	.37
27...	2145	126	47	.78	7.4	8.2	.43
27...	2250	44	41	1.1	5.2	6.3	.28
27...	2300	54	34	1.4	4.0	5.4	.28
27...	2350	21	37	2.5	3.7	6.2	.24
28...	0004	56	41	2.6	4.2	6.8	.24
28...	0008	73	45	2.4	5.1	7.5	.26
28...	0014	100	38	.37	11	11	.38
28...	0018	134	30	.48	13	13	.50
28...	0023	186	30	1.0	9.3	10	.22
28...	0028	178	33	1.2	9.7	11	.28
28...	0052	77	27	1.1	3.6	4.7	.19
28...	0130	33	25	1.4	2.8	4.2	.24
28...	0200	20	30	1.5	2.4	3.9	.21
28...	0215	58	38	1.7	3.4	5.1	.24
28...	0220	65	33	1.6	3.6	5.2	.23
28...	0330	35	31	1.6	2.3	3.9	.22
28...	1135	3.8	77	2.0	1.9	3.9	.21
26...	1835	3.8	220	2.6	2.6	5.2	.15
30...	2210	10	290	--	--	--	--
30...	2220	9.6	280	--	--	--	--
30...	2255	26	80	--	--	--	--
NOV.							
07...	1110	236	36	.32	11	11	.24
07...	1115	286	17	.26	13	13	.22
07...	1120	389	18	.19	11	11	.29
07...	1125	430	19	.42	8.3	8.7	.25
07...	1130	441	17	.54	3.6	4.1	.28
07...	1135	370	16	.66	5.6	6.3	.30
07...	1150	163	36	1.2	6.3	7.5	.47
07...	1245	27	33	1.5	4.6	6.1	.32
07...	1305	84	30	1.5	3.7	5.2	.35
07...	1320	196	23	1.1	3.4	4.5	.33
07...	1330	208	17	.75	2.6	3.4	.29
07...	1410	45	20	.95	2.1	3.1	.35
07...	1705	3.2	45	2.0	1.9	3.9	.32
08...	0820	.35	140	3.6	2.2	5.8	.25
JAN.							
06...	1030	168	210	--	--	--	--
31...	1140	.27	300	--	--	--	--
MAR.							
17...	1035	2.9	240	--	--	--	--
19...	1115	2.1	300	--	--	--	--
19...	1200	3.2	270	--	--	--	--
21...	1145	1.7	300	5.4	.37	5.8	.09
21...	1505	3.6	290	3.9	.51	4.4	.09
21...	1512	5.3	280	3.9	.46	4.4	.09
21...	1530	5.8	280	5.3	.77	6.1	.09
21...	1540	12	260	5.0	.86	5.9	.10
21...	1543	25	230	4.2	1.5	5.7	.12
21...	1548	62	220	4.6	1.8	6.4	.16
21...	1553	65	180	3.7	1.9	5.6	.13
21...	1600	60	75	1.4	2.4	3.8	.19
21...	1606	54	59	.84	2.3	3.1	.18
21...	1615	73	43	.62	2.2	2.8	.17
21...	1617	114	38	.58	1.8	2.4	.16
21...	1621	131	33	.58	2.0	2.6	.15
21...	1625	149	28	.52	2.1	2.6	.13
21...	1635	150	28	.43	1.7	2.1	.13
21...	1641	142	25	.40	1.8	2.2	.14
21...	1700	141	26	.42	.96	1.4	.14
MEANS							
OCT. 27	1925-	70	36	1.3	5.8	7.1	.30
OCT. 28	0330						
NOV. 7		221	25	.88	5.9	6.75	.31
MAR. 21		70	140	2.5	1.5	4.0	.13

DATE	SUS- PENDED SOLIDS (MG/L)	SETTLE- ABLE MATTER (ML/L /HR)	SPE- CIFIC CON- DUCT- ANCE (MICRO- MHOS)	PH (UNITS)	TEMPER- ATURE (DEG C)	CHEM- ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO- CHEM- ICAL OXYGEN DEMAND 5 DAY (MG/L)
11181008 - CASTRO VALLEY CREEK AT HAYWARD - CONTINUED							
OCT.							
01...	--	--	1130	8.1	19.5	--	--
07...	2	--	992	8.3	16.0	26	1.1
27...	239	3.4	232	--	17.5	340	90
27...	164	1.8	254	7.3	17.0	270	41
27...	103	1.6	236	7.4	17.0	230	34
27...	216	1.0	345	7.5	16.5	300	48
27...	399	3.2	270	7.4	17.0	410	50
27...	252	2.5	218	7.7	16.0	220	29
27...	208	2.3	218	7.4	16.0	200	24
27...	131	1.2	212	7.4	16.0	170	26
28...	61	1.1	248	7.5	16.0	190	--
28...	374	2.8	260	7.4	16.0	320	32
28...	1310	10	208	7.4	16.5	810	--
28...	1040	11	160	7.5	16.0	550	72
28...	1100	9.0	157	7.5	16.0	380	64
28...	834	8.0	165	7.5	16.0	500	67
28...	431	5.0	127	7.8	16.0	120	--
28...	203	1.1	130	7.6	15.0	130	19
28...	134	1.6	151	7.5	15.0	230	19
28...	244	2.4	223	7.5	15.0	160	--
28...	194	1.9	165	7.5	15.5	150	18
28...	61	1.0	174	7.3	15.0	100	15
28...	13	.5	340	7.8	14.5	84	13
28...	14	.4	536	7.7	14.5	100	13
30...	--	--	1400	7.9	10.0	--	--
30...	--	--	1270	8.0	10.0	--	--
30...	--	--	425	7.5	11.0	--	--
NOV.							
07...	1410	12	165	7.7	14.0	510	84
07...	1240	11	114	6.6	14.0	500	78
07...	1810	12	86	6.8	14.0	410	70
07...	1570	10	67	7.5	14.0	340	55
07...	1530	9.5	65	7.7	14.0	290	48
07...	1350	7.5	64	7.4	13.5	250	35
07...	1630	7.0	156	7.5	13.0	210	29
07...	508	1.8	163	7.2	14.0	100	19
07...	467	1.9	151	7.2	14.0	120	48
07...	501	1.7	104	7.2	14.0	110	29
07...	248	2.0	76	7.0	14.0	140	19
07...	233	1.0	102	7.1	14.0	62	13
07...	68	.3	254	7.0	14.0	52	10
08...	11	.2	603	7.5	11.0	19	6.0
JAN.							
06...	--	--	133	7.1	12.0	--	--
31...	--	--	1230	8.5	7.0	--	--
MAR.							
17...	--	--	878	8.2	12.0	--	--
19...	--	--	1060	7.9	12.0	--	--
19...	--	--	1050	7.6	12.0	--	--
21...	15	.0	1130	8.1	10.0	11	.9
21...	17	.1	1130	8.6	10.0	12	6.2
21...	19	.1	1130	8.5	10.0	15	4.8
21...	20	.1	1110	8.4	10.5	19	8.4
21...	40	.2	1040	8.4	10.5	34	20
21...	58	1.2	904	8.4	10.5	53	21
21...	126	1.3	822	8.4	11.0	68	35
21...	178	1.3	685	8.3	11.0	130	38
21...	294	2.3	295	8.0	11.0	210	48
21...	294	1.8	206	8.4	11.0	200	42
21...	251	1.5	151	7.9	11.0	140	26
21...	290	1.7	123	7.9	11.0	150	--
21...	320	2.5	110	7.8	11.0	140	22
21...	362	1.7	110	7.6	11.0	120	--
21...	277	1.3	96	7.3	11.0	99	20
21...	230	1.0	89	7.2	11.0	68	--
21...	217	.8	96	7.6	11.0	67	10
MEANS							
OCT. 27-OCT. 28	385	3.6	208	7.3-7.8	16.0	290	41
NOV. 7	967	6.0	121	6.6-7.7	14.0	240	41
MAR. 21	177	1.1	543	7.2-8.6	11.0	90	22

DATE	TIME	INSTANTANEOUS DISCHARGE (FT3/S)	ALKALINITY AS CACO3 (MG/L)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)
		11447030 - STRONG RANCH SLOUGH AT SACRAMENTO					
OCT.							
27...	2215	156	28	0.78	5.5	6.3	0.15
27...	2230	161	33	.06	5.3	5.4	.28
27...	2245	159	34	1.0	5.0	6.0	.15
27...	2300	156	30	1.1	4.6	5.7	.15
27...	2315	139	31	1.0	3.7	4.7	.16
27...	2330	122	35	.99	3.5	4.5	.18
27...	2400	90	34	.76	2.6	3.4	.22
28...	0030	61	26	1.1	2.5	3.6	.22
28...	0100	48	25	1.0	2.3	3.3	.24
28...	0200	42	22	.90	1.9	2.8	.22
28...	0300	48	32	.95	2.3	3.3	.28
28...	0500	33	25	.75	1.8	2.6	.22
NOV.							
07...	1230	24	17	.29	2.6	2.9	.25
07...	1235	31	--	.73	3.0	3.7	.32
07...	1245	35	11	.00	3.4	3.4	.48
07...	1250	36	--	.00	2.6	2.6	.39
07...	1300	35	11	.00	1.7	1.7	.30
07...	1315	32	13	.74	2.0	2.7	.14
07...	1325	31	18	.78	2.3	3.1	.16
07...	1340	46	18	.70	1.8	2.5	.18
07...	1355	62	33	.74	2.4	3.1	.01
07...	1415	68	25	.63	2.6	3.2	.20
07...	1430	65	21	.72	2.5	3.2	.21
07...	1445	62	19	.67	2.1	2.8	.22
07...	1515	53	17	.65	1.9	2.6	.21
07...	1545	43	18	.60	1.4	2.0	.22
07...	1615	33	19	.57	1.7	2.3	.23
07...	1715	34	18	.55	1.3	1.9	.22
07...	1730	37	18	.51	1.3	1.8	.20
07...	2035	12	20	.49	1.2	1.7	.22
FEB.							
12...	0940	.52	80	1.1	1.5	2.6	.03
12...	1005	1.2	82	1.0	1.3	2.3	.13
12...	1025	2.2	148	.97	1.4	2.4	.19
12...	1045	4.8	100	1.3	1.3	2.6	.21
12...	1100	6.4	100	1.9	1.5	3.4	.28
12...	1130	8.8	52	1.5	1.3	2.8	.18
12...	1145	11	40	1.6	1.4	3.0	.20
12...	1200	15	--	.70	1.2	1.9	.17
12...	1215	19	30	.65	1.2	1.9	.14
12...	1230	32	30	1.2	.54	1.7	.14
12...	1245	42	28	.53	.68	1.2	.16
12...	1300	52	46	.82	.37	1.2	.18
12...	1315	67	48	.86	.49	1.4	.22
12...	1330	82	33	1.2	.28	1.5	.21
12...	1345	87	26	.49	.17	.66	.20
12...	1400	88	25	.42	.73	1.2	.19
12...	1430	87	28	.42	.59	1.0	.20
12...	1500	78	27	.40	.46	.86	.19
MEANS							
OCT. 27-28		101	30	.87	3.4	4.3	.21
NOV. 7		41	18	.52	2.1	2.6	.23
FEB. 12		38	54	.95	.91	1.9	.18

DATE	SUS- PENDED SOLIDS (MG/L)	SETTLE- ABLE MATTER (ML/L /HR)	SPE- CIFIC CON- DUCT- ANCE (MICRO- MHOS)	PH (UNITS)	TEMPER- ATURE (DEG C)	CHEM- ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO- CHEM- ICAL OXYGEN DEMAND 5 DAY (MG/L)
	11447030 - STRONG RANCH SLOUGH AT SACRAMENTO--CONTINUED						
OCT.							
27...	346	2.5	100	6.8	17.0	220	42
27...	369	2.5	101	6.8	16.5	220	--
27...	340	3.5	94	7.0	16.5	180	--
27...	338	--	85	7.1	16.0	170	--
27...	248	1.8	84	7.1	16.0	160	31
27...	212	1.8	84	7.1	16.0	140	--
27...	172	--	84	7.1	16.0	120	29
28...	95	--	86	7.3	16.0	110	--
28...	83	1.1	85	7.2	16.0	100	25
28...	51	--	79	7.1	16.0	81	27
28...	66	.8	98	7.1	15.5	90	23
28...	29	--	85	6.8	16.0	75	16
NOV.							
07...	138	1.5	111	6.4	14.5	120	31
07...	192	1.5	--	--	--	120	--
07...	180	1.3	102	6.5	14.5	110	--
07...	156	1.4	--	--	--	110	--
07...	118	1.0	66	6.2	14.5	100	--
07...	90	.8	63	6.8	14.5	84	--
07...	14	.9	65	7.2	14.5	94	22
07...	37	2.0	71	7.3	14.5	89	--
07...	164	1.0	154	7.3	14.5	120	--
07...	140	1.9	106	7.3	14.5	99	20
07...	32	1.4	78	7.4	14.5	90	20
07...	82	1.3	81	7.1	14.5	47	--
07...	66	1.1	66	7.1	14.5	74	16
07...	75	1.0	66	7.1	14.5	64	--
07...	84	.7	67	7.2	14.5	57	14
07...	20	.7	62	7.2	14.5	54	12
07...	58	.4	62	7.2	14.5	56	--
07...	43	.5	64	7.4	13.0	44	7.1
FEB.							
12...	38	.0	267	7.0	11.0	60	12
12...	18	.0	178	6.8	11.0	61	--
12...	20	.0	274	7.4	11.0	81	--
12...	28	.0	208	6.5	10.5	33	4.2
12...	26	.1	202	6.3	--	32	6.1
12...	58	.0	137	7.1	11.0	45	--
12...	52	.2	99	7.1	11.0	49	--
12...	52	.2	89	7.2	11.0	54	--
12...	76	.2	71	7.0	11.0	51	--
12...	104	.4	64	6.9	11.0	45	--
12...	100	.4	67	7.0	11.0	49	4.9
12...	80	--	99	7.3	11.0	40	7.7
12...	93	.5	116	7.3	11.0	39	--
12...	114	--	79	7.3	11.0	47	6.5
12...	116	.4	58	7.2	11.0	46	5.8
12...	100	.5	52	7.2	11.0	46	--
12...	109	.5	55	7.2	11.0	45	--
12...	84	.4	53	7.1	11.0	56	6.7
MEANS							
OCT. 27-28	196	2.0	89	6.8-7.3	16.0	140	28
NOV. 7	94	1.1	80	6.4-7.4	14.5	85	18
FEB. 12	70	.2	120	6.3-7.4	11.0	49	6.7

DATE	TIME	INSTANTANEOUS DISCHARGE (FT³/S)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)
374239122042401 - JOSEPH AVENUE						
OCT.						
27...	2355	E0.10	1.6	1.2	2.8	0.10
28...	0240	E.10	.61	1.7	2.3	.10
NOV.						
07...	1150	E.10	5.3	2.5	7.8	.31
07...	1305	E.10	.88	1.6	2.5	.51
JAN.						
06...	1045	--	3.4	1.3	4.7	.29
MAR.						
21...	1350	E.05	.71	4.5	5.2	.25
21...	1520	E.10	.40	.77	1.2	.14
21...	1600	E.20	.19	.46	.65	.07
MEANS ALL DATA EXCEPT JAN. 6		E.11	1.4	1.8	3.2	.21

E. ESTIMATED.

DATE	TIME	INSTANTANEOUS DISCHARGE (FT³/S)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)
374258122034801 - MADISON AVENUE						
NOV.						
07...	1205	E0.70	1.4	1.8	3.2	0.33
JAN.						
06...	1105	--	4.9	2.0	6.9	.70
MAR.						
21...	1425	E.80	.85	.19	1.0	.12
21...	1540	E1.5	.80	.58	1.4	.13
21...	1635	E1.7	.53	1.2	1.7	.17
MEANS ALL DATA EXCEPT JAN. 6		E1.2	.90	.94	1.8	.19

E. ESTIMATED.

DATE	TIME	INSTANTANEOUS DISCHARGE (FT³/S)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)
383626121230800 - STRONG RANCH SLOUGH AT COUNTRY CLUB CENTER						
OCT.						
27...	2215	E4.0	0.27	0.96	1.2	0.10
27...	2400	E2.0	.51	1.5	2.0	.12
NOV.						
07...	1230	E1.0	.63	1.8	2.4	.12
07...	1430	E.50	.53	1.4	1.9	.13
FEB.						
12...	1150	E2.5	.59	.37	.38	.12
12...	1400	E1.0	.02	.46	.47	.05
MEANS		E1.8	.42	1.1	1.4	.11

E. ESTIMATED.

DATE	TIME	INSTANTANEOUS DISCHARGE (FT³/S)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)	TOTAL ORTHO PHOSPHORUS (P) (MG/L)
383630121214300 - STRONG RANCH SLOUGH AT EL CAMINO HIGH SCHOOL						
NOV.						
07...	1300	E0.25	0.13	0.74	0.87	0.05
FEB.						
12...	1210	E.50	.12	.46	.47	.04
MEANS		E.38	.13	.60	.67	.04

E. ESTIMATED.

DATE	SUS-PENDED SOLIDS (MG/L)	SETTLE-ABLE MATTER (ML/L /HR)	TEMPER-ATURE (DEG C)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)
374239122042401 - JOSEPH AVENUE--CONTINUED					
OCT.					
27...	10	0.2	--	58	5.0
28...	12	.0	--	90	4.5
NOV.					
07...	5	.2	--	44	18
07...	31	.5	--	16	10
JAN.					
06...	0	.1	--	48	4.4
MAR.					
21...	157	4.2	10.5	200	36
21...	66	.2	10.0	47	10
21...	101	.4	10.0	44	5.2
MEANS ALL DATA EXCEPT JAN. 6	55	.8	10.0	71	13

DATE	SUS-PENDED SOLIDS (MG/L)	SETTLE-ABLE MATTER (ML/L /HR)	TEMPER-ATURE (DEG C)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)
374258122034801 - MADISON AVENUE--CONTINUED					
NOV.					
07...	87	0.6	--	47	14
JAN.					
06...	7	.4	--	54	6.8
MAR.					
21...	15	.0	9.5	9	3.2
21...	62	.4	9.5	27	7.5
21...	163	.5	10.0	56	11
MEANS ALL DATA EXCEPT JAN. 6	82	.5	9.5	35	8.9

DATE	SUS-PENDED SOLIDS (MG/L)	SETTLE-ABLE MATTER (ML/L /HR)	TEMPER-ATURE (DEG C)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)
383626121230800 - STRONG RANCH SLOUGH AT COUNTRY CLUB CENTER--CONTINUED					
OCT.					
27...	32	0.2	15.0	34	4.7
27...	8	.4	15.0	58	6.5
NOV.					
07...	10	.4	15.0	49	6.8
07...	2	.4	15.0	52	10
FEB.					
12...	305	.2	10.5	34	4.8
12...	70	<.1	11.0	18	3.2
MEANS	71	.3	13.5	41	6.0

DATE	SUS-PENDED SOLIDS (MG/L)	SETTLE-ABLE MATTER (ML/L /HR)	TEMPER-ATURE (DEG C)	CHEM-ICAL OXYGEN DEMAND (HIGH LEVEL) (MG/L)	BIO-CHEM-ICAL OXYGEN DEMAND 5 DAY (MG/L)
383630121214300 - STRONG RANCH SLOUGH AT EL CAMINO HIGH SCHOOL--CONTINUED					
NOV.					
07...	8	0.3	15.0	30	1.9
FEB.					
12...	3	.0	11.0	12	3.2
MEANS	6	.2	13.0	21	2.6