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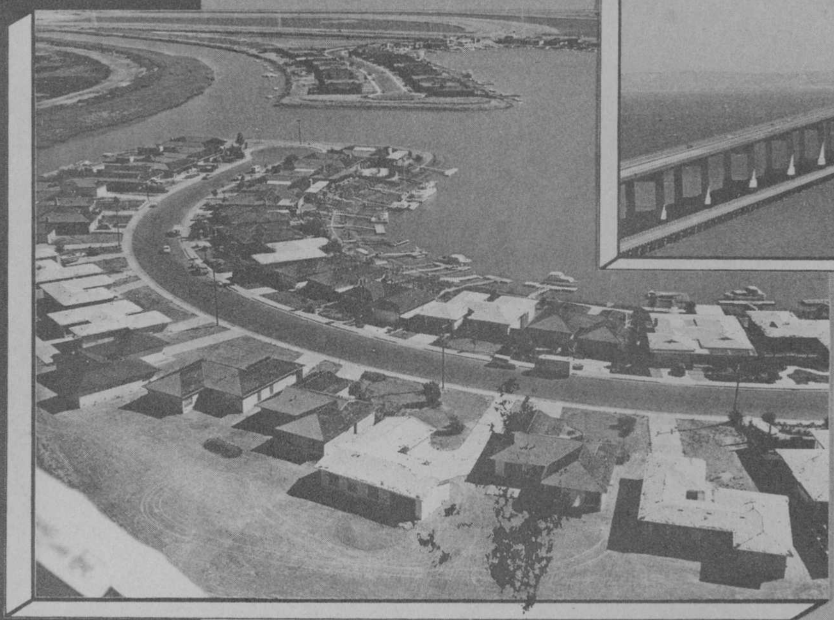

EFFECTS OF URBANIZATION ON SEDIMENTATION AND FLOODFLOWS IN COLMA CREEK BASIN, CALIFORNIA

(open-file report)

by

J. M. Knott

1973

SAN FRANCISCO BAY REGION ENVIRONMENT AND RESOURCES PLANNING STUDY

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
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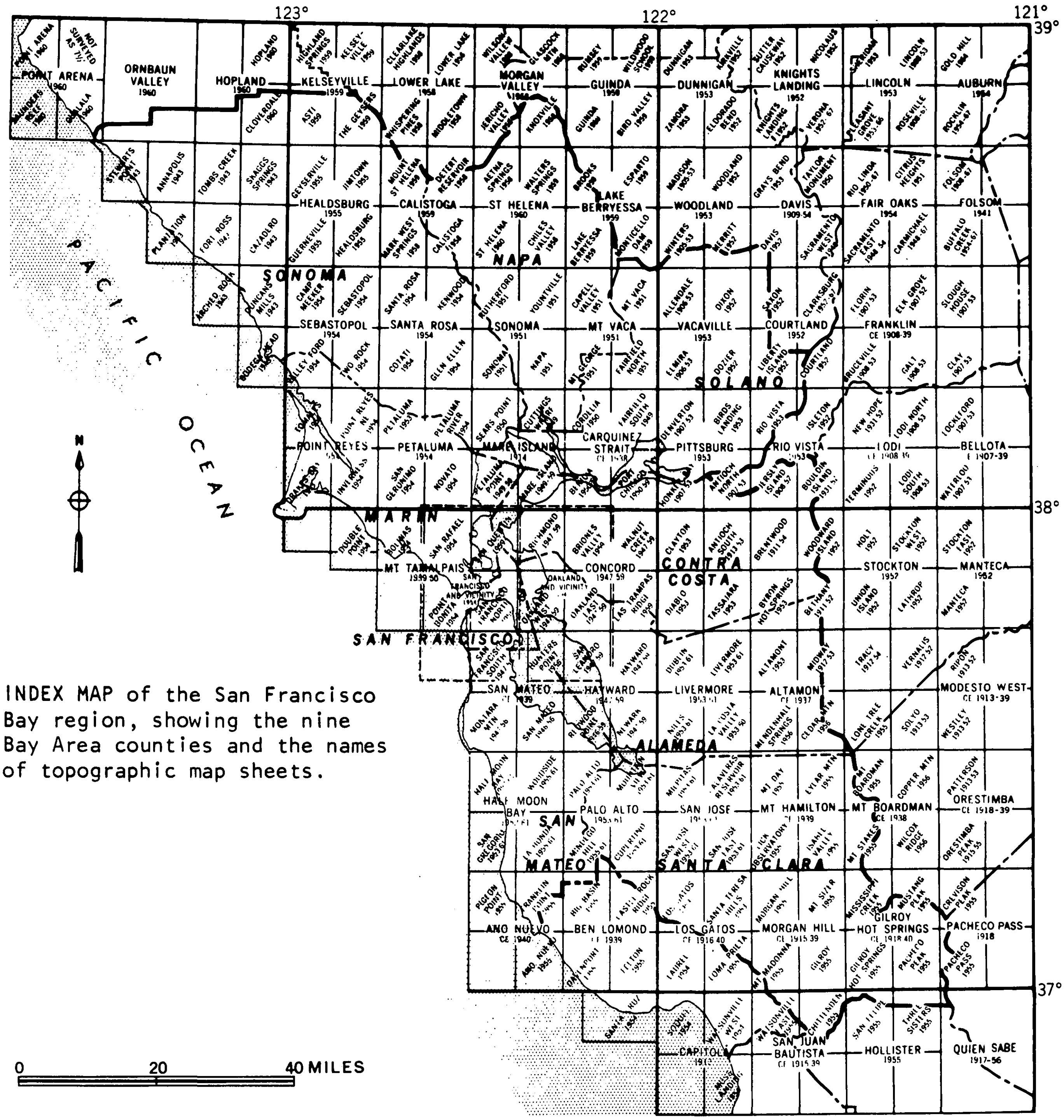

INDEX MAP of the San Francisco Bay region, showing the nine Bay Area counties and the names of topographic map sheets.

FURTHER INFORMATION and a listing of publications pertaining to the San Francisco Bay Region Environment and Resources Planning Study may be obtained from the Geological Survey Public Inquiries Office, 504 Custom House, 555 Battery Street, San Francisco, California 94111 or from the U. S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025.

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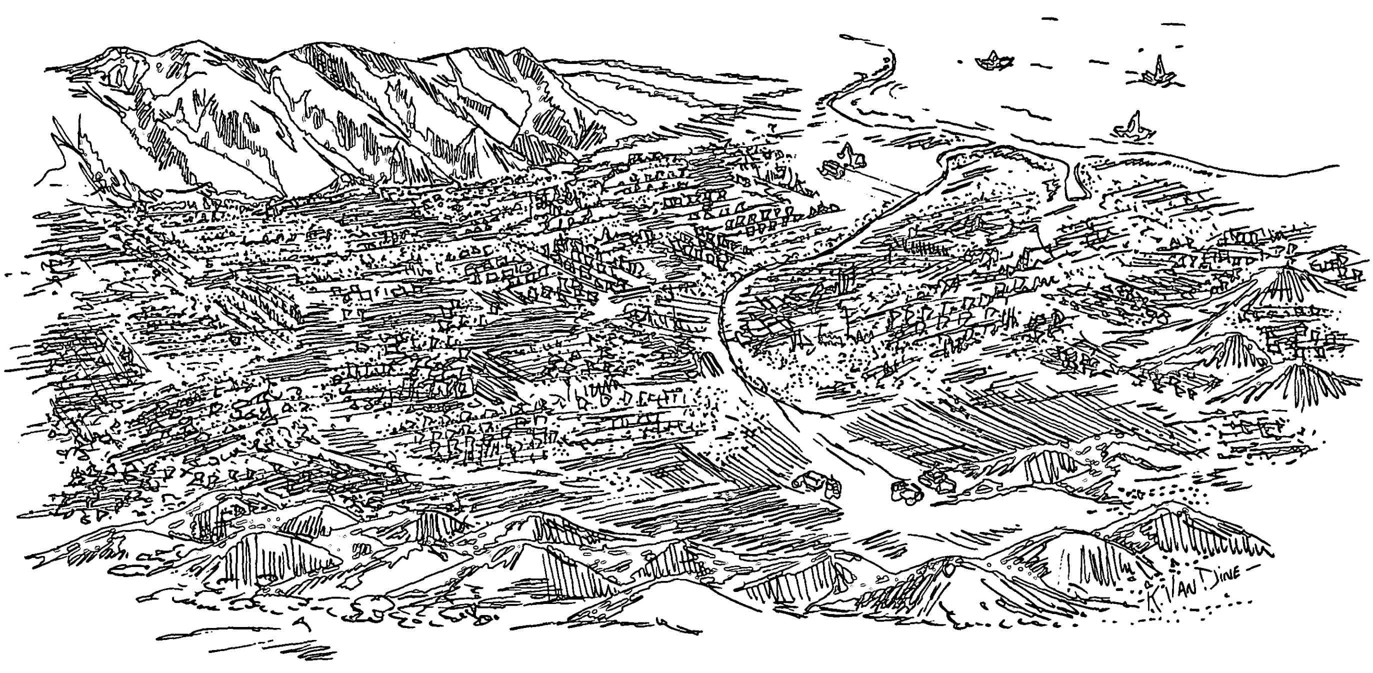

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

Menlo Park, California, 1973
OPEN-FILE REPORT
PREPARED IN COOPERATION WITH THE
COUNTY OF SAN MATEO

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

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EFFECTS OF URBANIZATION ON SEDIMENTATION AND FLOODFLOWS IN COLMA CREEK BASIN, CALIFORNIA

By J. M. Knott

ABSTRACT

This report describes some of the changes in water and sediment discharge that occurred in the Colma Creek basin during a period of major urban expansion. Hydrologic data collected from 1964 to 1971 were used to evaluate trends and relations between sediment yield and land use. Land use in the basin was estimated from aerial photographs, generally taken annually.

Rainfall and runoff data for 72 selected storms indicated that storm runoff at the Colma Creek gaging station probably was larger in 1970 than in 1964. However, no significant change in the magnitude of peak flows was detected. Highly urbanized or developing areas generally yielded more than twice the storm runoff of undeveloped areas.

Sediment discharge rates (1970) are currently decreasing in response to reductions in construction activity. Much sediment introduced to the streams is trapped in various debris basins. Surveys of the two largest debris basins indicate that 25 to 45 percent of the sand yield and 14 to 21 percent of the silt-clay yield is trapped annually.

In the next decade (1971-80), sediment yields in the Colma Creek basin may decrease substantially because construction activity is declining. The yield for a year of average rainfall may decline from 44,000 tons in the early part of this period to about 19,000 tons when existing construction projects are completed. If the basin becomes completely urbanized (65 percent urban and 35 percent open space), sediment yields should range from 9,700 tons for a year of average rainfall to 25,000 tons for a year of extremely high rainfall.

INTRODUCTION

The Colma Creek basin is typical of many areas in the vicinity of San Francisco Bay that have experienced rapid rates of urbanization in recent years. Conversion of the land from rural to urban use has resulted in significant changes in the quality and distribution of surface runoff and water problems have intensified.

Since the early development of the basin the frequency of flooding along Colma Creek has increased (Wilsey, Ham, and Blair, 1961). Large quantities of sediment have been eroded from the highlands and deposited along the flat reaches of leveed stream channels that traverse former marsh and tidelands bordering San Francisco Bay. Sediment deposits in these channels early in the storm season and extensive dredging is required to prevent subsequent flooding (fig. 1). Small quantities of sediment are deposited in the upper reaches of Colma Creek because stream gradients are steep and stream velocities are high. Most of the stream channels in the upper reaches are lined with masonry or concrete. Flooding generally occurs in the upper reaches less frequently than in the lower reaches.

FIGURE 1.--Dredging operations in the lower reach of Colma Creek subsequent to major storms.

The objectives of this study are to document the water and sediment discharge of streams in the basin during the period of active development and to estimate the probable effect of urbanization on floodflows and sediment yield. Special emphasis was placed on determining the quantity of sand transported by Colma Creek, because the sand fraction of the sediment discharge is the fraction that deposits in the lower reach of Colma Creek during each storm and contributes to flooding.

Streamflow and sediment data used in the study include records of water discharge for 1964-71, records of suspended-sediment discharge for 1966-70, simultaneous measurements of water and total-sediment discharge during four storm events at areas representing dissimilar types of land use, and surveys of several debris basins.

The sediment yield of the entire basin was estimated by adjusting the yield measured at the Colma Creek sediment station (fig. 2) to include sediment trapped in upstream debris basins and sediment contributed from areas downstream. Relative index values of sediment-yield for specific types of land use were estimated by determining concurrently the yield from several subbasins with different land use.

This report was prepared by the U.S. Geological Survey, in cooperation with San Mateo County, as part of an investigation of the water resources of the county.

The author appreciates the assistance in basic data collection and report preparation provided by George Porterfield and G. O. Balding. The author is also grateful to V. K. Sanders of the San Mateo County Flood Control District, who provided data from surveys of various debris basins, and L. H. Goss, of the Public Works Department, South San Francisco, for providing historical information on land use changes in the basin. The report received valuable review and criticism from H. P. Guy, L. M. Nelson, V. K. Sanders, L. H. Goss, and H. E. Pape, Jr.

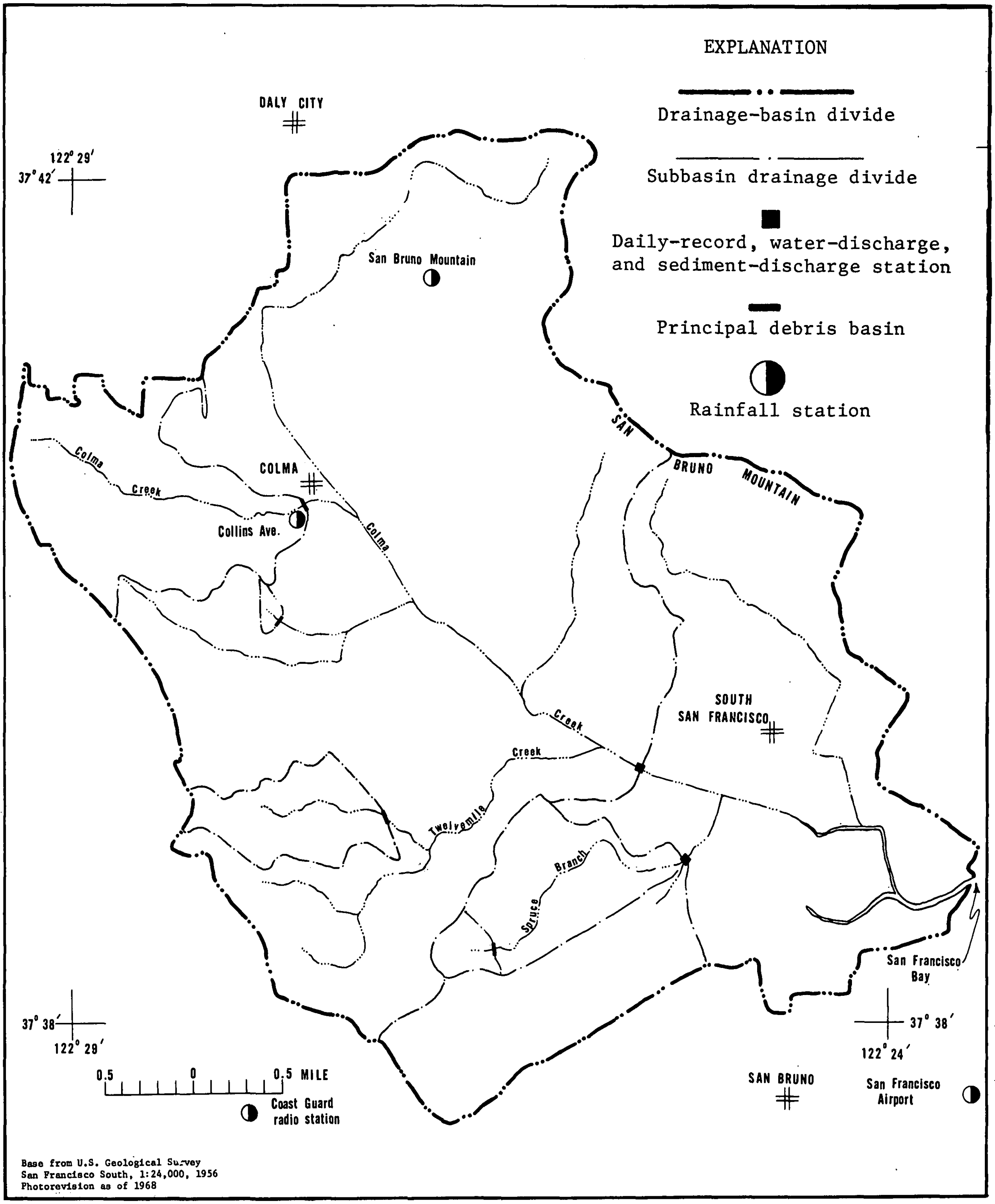


FIGURE 2.--Hydrologic data stations in the Colma Creek basin.

DESCRIPTION OF AREA

General Features

Colma Creek, a tributary to San Francisco Bay, drains a 16.3-square-mile area (fig. 3) on the east side of the San Francisco Peninsula. The basin is bounded on the northeast by San Bruno Mountain and on the west by the ridge traced by Skyline Boulevard. Elevations range from sea level at the mouth of Colma Creek to more than 1,300 feet above mean sea level on the San Bruno Mountain. Dominant topographic features of the drainage basin include two relatively straight mountain ridges that diverge toward the southeast and that are connected by a low ridge at the northern boundary of the area. The valley enclosed by the ridges widens toward the southeast where it drains into San Francisco Bay.

Most of the population of the area is centered in the cities of Daly City and South San Francisco. The remaining population is divided among Colma, Pacifica, and San Bruno.

Geology

Preliminary geologic maps by M. G. Bonilla (1971) show that the northeastern part of the area along San Bruno Mountain is underlain by relatively resistant sandstone and shale of Jurassic and Cretaceous age. The highlands along the western boundary are formed of much younger and less resistant rock. The younger material in the western highlands is marine sediment of Tertiary and Quaternary age containing friable to firmly cemented sand, silt, clay, and minor quantities of gravel. Material deposited within the valley is mostly of Quaternary age and is similar to the material underlying the western highlands.

FIGURE 3.--Aerial photograph of the Colma Creek basin (1971). Drainage divide is indicated approximately by dashed line. Photograph by Air-Photo Co., Inc.

Vegetation and Soils

Vegetal cover consists primarily of lawns, parks, and native grasses in urban and foothill areas, and chaparral at higher elevations in the undeveloped areas. Exotic trees and shrubs, although present in many varieties, cover a small part of the basin. Flowers and vegetables are grown commercially in areas adjacent to Colma Creek and in foothill areas adjacent to San Bruno Mountain.

With the exception of soils occurring on the steep rocky slopes of San Bruno Mountain, most of the soils are altered, in varying degrees, from original conditions. Original soils, in areas where urbanization has been extensive, commonly have been removed or mixed with other soils or subsoils (fig. 4). Agriculture and mining of topsoil, in the past, have resulted in significant losses of soil and have created gullying on steeper slopes (fig. 5). Recent surveys by the Soil Conservation Service, U.S. Department of Agriculture (1970) describe 10 general soil associations which occur in the Colma Creek basin. Selected soil characteristics of these associations and their distribution are given in table 1 and figure 6 (p. 11).

TABLE 1.--*Characteristics of soils occurring in the Colma Creek basin*

Soil association	No.	Profile			Topography	Land slope (percent)	Erosion hazard
		Surface	Subsoil	Parent material			
Tunitas-Lockwood	1	Clay loam, loam	Clay, clay loam	Sedimentary alluvium	Gently sloping fans	0-5	None to slight
Sunnyvale-Castro	2	Silty clay, clay	Silty clay, clay	Clay alluvium	Level, low valley bottoms	≥0	None
Elkhorn-Colma	3	Sandy loam	Sandy clay loam, loam	Coastal sediments, marine sediments	Terraces	5-15	Slight to moderate
Tierra-Colma	4	Sandy loam	Sandy clay, loam	Coastal sediments, marine sediments	Terraces	9-15	Moderate
Tierra-Colma	5	Sandy loam	Sandy clay, loam	Coastal sediments, marine sediments	Terraces	15-30	High
Los Gatos-Hulls	6	Loam	Clay loam, loam	Sandstone and shale, sandstone and chert	Hilly, mountainous	30-50	High
Gaviota-Rockland	7	Loam, sandstone and shale	Loam, sandstone and shale	Sandstone and shale	Mountainous	30-70	High
Sweeney-Mindego	8	Clay loam	Sandy clay loam, clay	Basic igneous rock, basalt	Mountainous	30-70	High
Made soils, over bay muds	9	Sand, silt, clay, and crushed rock	Sand, silt, clay, and crushed rock	Clay	Tidal marshes	≥0	None
Made soils	10	(Variable textured unconsolidated material)			Benched hills	--	High

Land Use

In 1946, about 70 percent of the land in the Colma Creek basin was used for agriculture or was undeveloped. About half of the remaining land was set aside for open spaces (cemetaries and parks) and half was developed (urban and industrial). Most of the urban and industrial areas were located near the mouth of Colma Creek where harbor facilities were available.

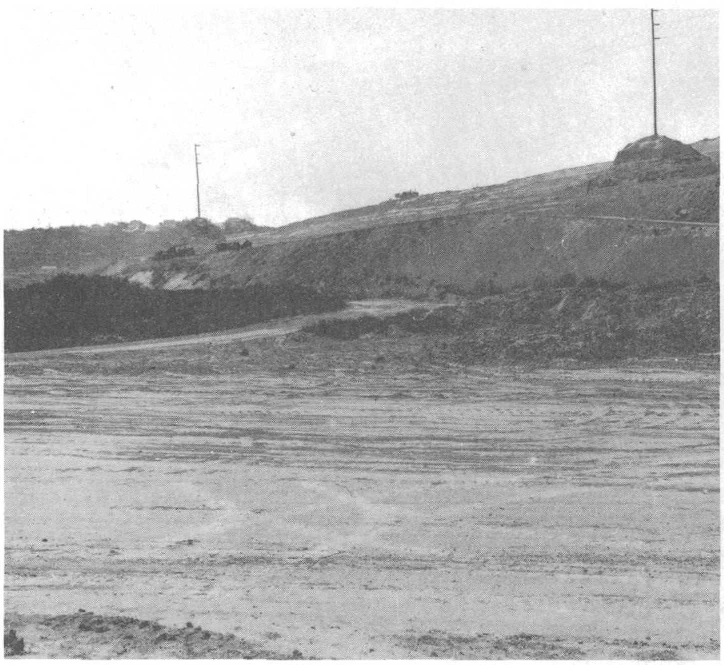


FIGURE 4.--Construction areas in the Colma Creek basin where soils and subsoils undergo considerable mixing and alteration during development. The extent of alteration caused by development can be observed by comparing the elevation of soil mounds at the base of power poles (in lower photograph) with soil elevations between poles.

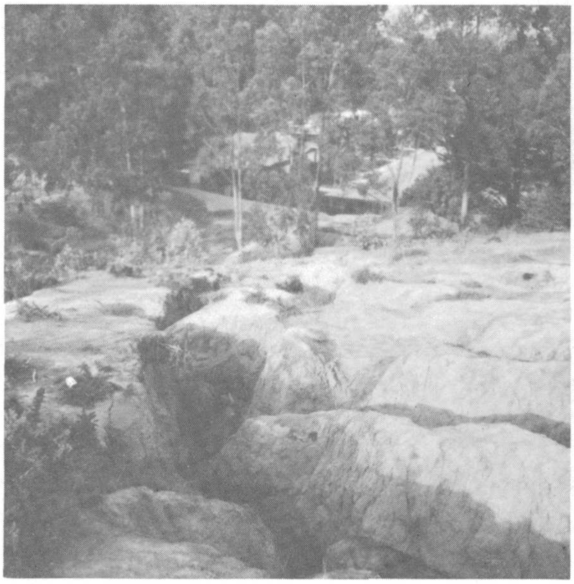


FIGURE 5.--Gullied areas in highly erosible marine sediments prior to urban development.

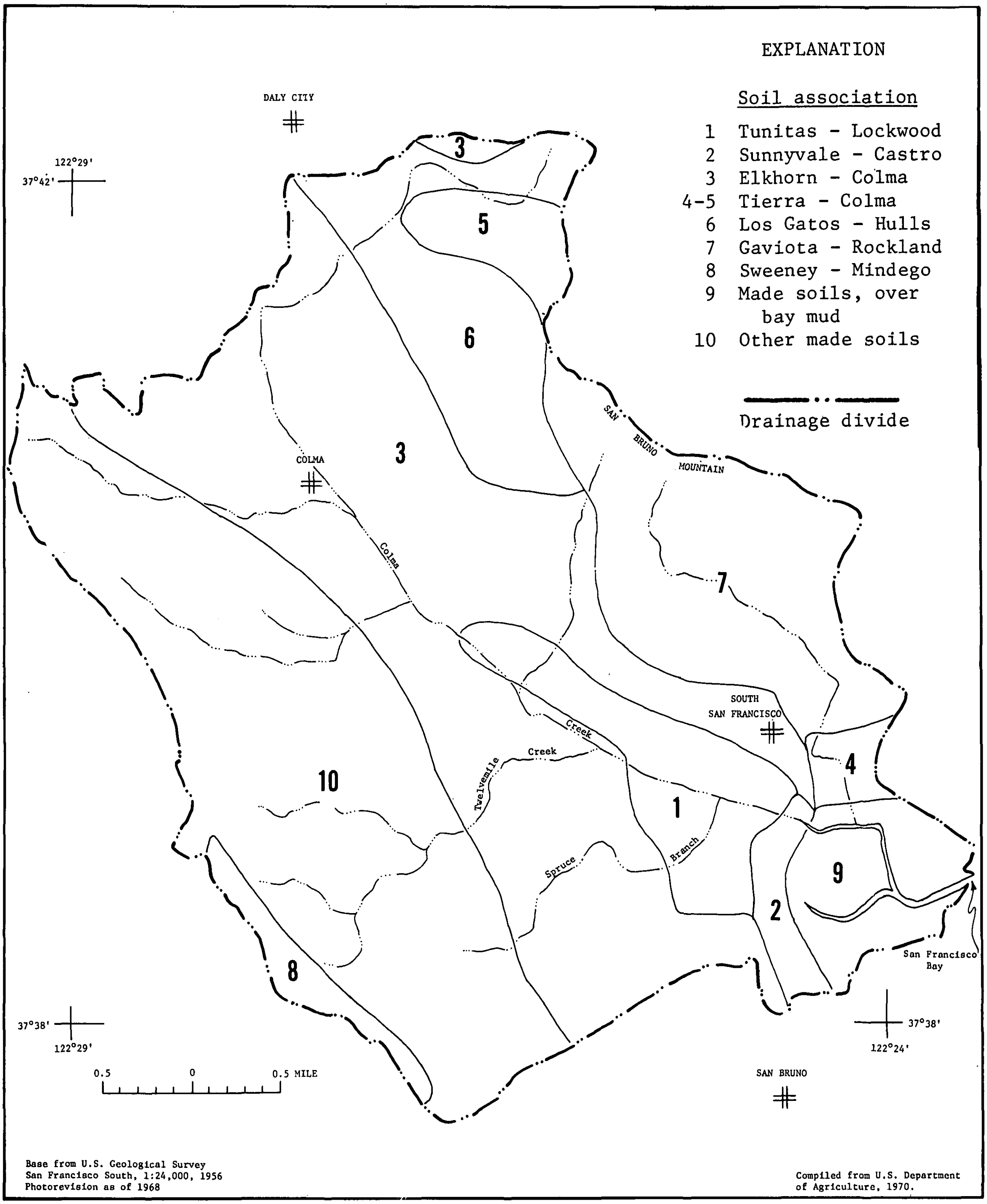


FIGURE 6.--Distribution of soils in the Colma Creek basin.

After 1950, urbanization progressed along the flatter valley lands between South San Francisco and Daly City. By 1956 (fig. 7) about 34 percent of the basin was urbanized, 51 percent was open space, 12 percent was agriculture, and 3 percent was under construction. By 1970 (fig. 8), at the end of this study, 54 percent of the basin was urbanized, 37 percent was open space, 3 percent was used for agriculture, and 6 percent was under construction. During the next decade (1971-80) construction and open space areas are expected to be reduced and urban areas are expected to increase. Land use during the latter part of the decade is expected to be about 62 percent urban, 35 percent open space, and 3 percent agriculture.

Climate

The climate of the Colma Creek basin is typical of the San Francisco Peninsula. Summers are characterized by long periods of warm, dry weather with little precipitation, and winters are mild and humid. About 85 percent of the annual rainfall occurs during the 5-month period from November through March. Monthly average temperatures range from 18°C in September to 9°C in January.

Rainfall records are available from four precipitation stations within or adjacent to the Colma Creek basin (table 2 and fig. 2). Long-term data are available at two stations: near the Christen Ranch and at the San Francisco Airport. The Christen Ranch station was established by the U.S. Geological Survey in November 1961 and was at an elevation of approximately 200 feet. In September 1965 the station was reestablished at the San Mateo County Maintenance Yard on Collins Avenue and at an elevation of approximately 170 feet. Precipitation data for the Collins Avenue site subsequent to December 1968 were collected and compiled by San Mateo County.

TABLE 2.--*Summary of precipitation data in the Colma Creek basin*

Station location	Period of record (water year)	Elevation above mean sea level (feet)	Average annual precipitation (inches)	Range in monthly precipitation (inches)	Station location	Period of record (water year)	Elevation above mean sea level (feet)	Average annual precipitation (inches)	Range in monthly precipitation (inches)
San Francisco	1927-70	8	[2]18.69	0.00-12.30	Collins Avenue	1965-70	170	[4]22.5	0-10.8
Airport near	1964		12.72	Trace- 4.38	maintenance				
South San	1965		20.80	Trace- 5.42	yard at Colma[3]				
Francisco[1]	1966		17.65	Trace- 5.40	Coast Guard	Dec.1968-	930	24.1	0-9.6
	1967		30.75	Trace-10.43	radio station	Feb.1971			
	1968		15.88	Trace- 5.25	near Pacifica				
	1969		28.24	Trace- 8.92	San Bruno	Oct.1970-	970	--	0-4.7
	1970		19.56	Trace- 8.33	Mountain near	Feb.1971			
	1971		18.71	Trace- 6.41	Colma				
	1964-71		20.33	Trace-10.43					

[1]U.S. Weather Bureau station.
[2]Standard normal precipitation (1931-60).
[3]Records maintained by San Mateo County subsequent to December 1968.
[4]Includes precipitation data for Christen Ranch (1961-65).

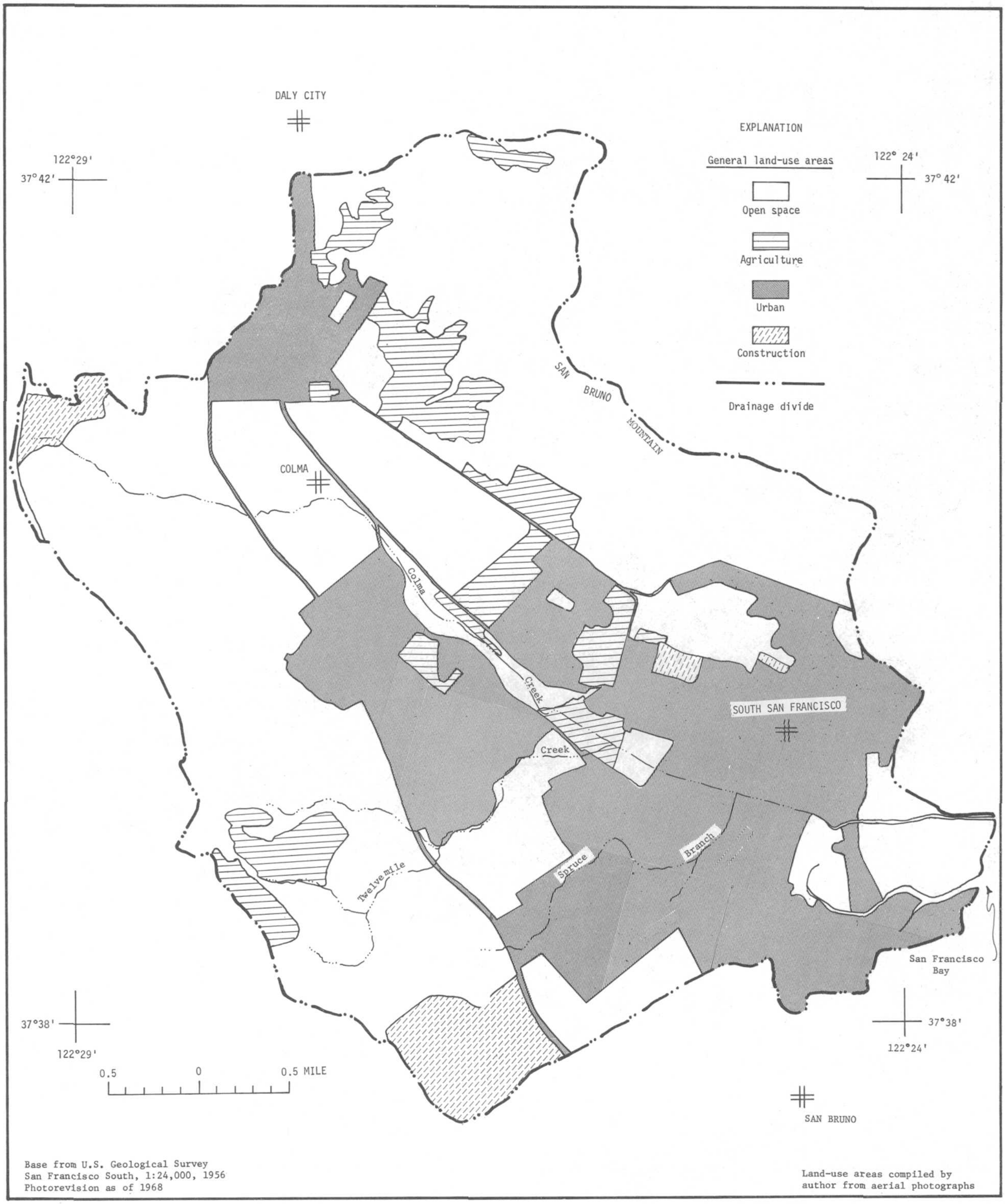


FIGURE 7.--Generalized land use in the Colma Creek drainage basin, 1956.

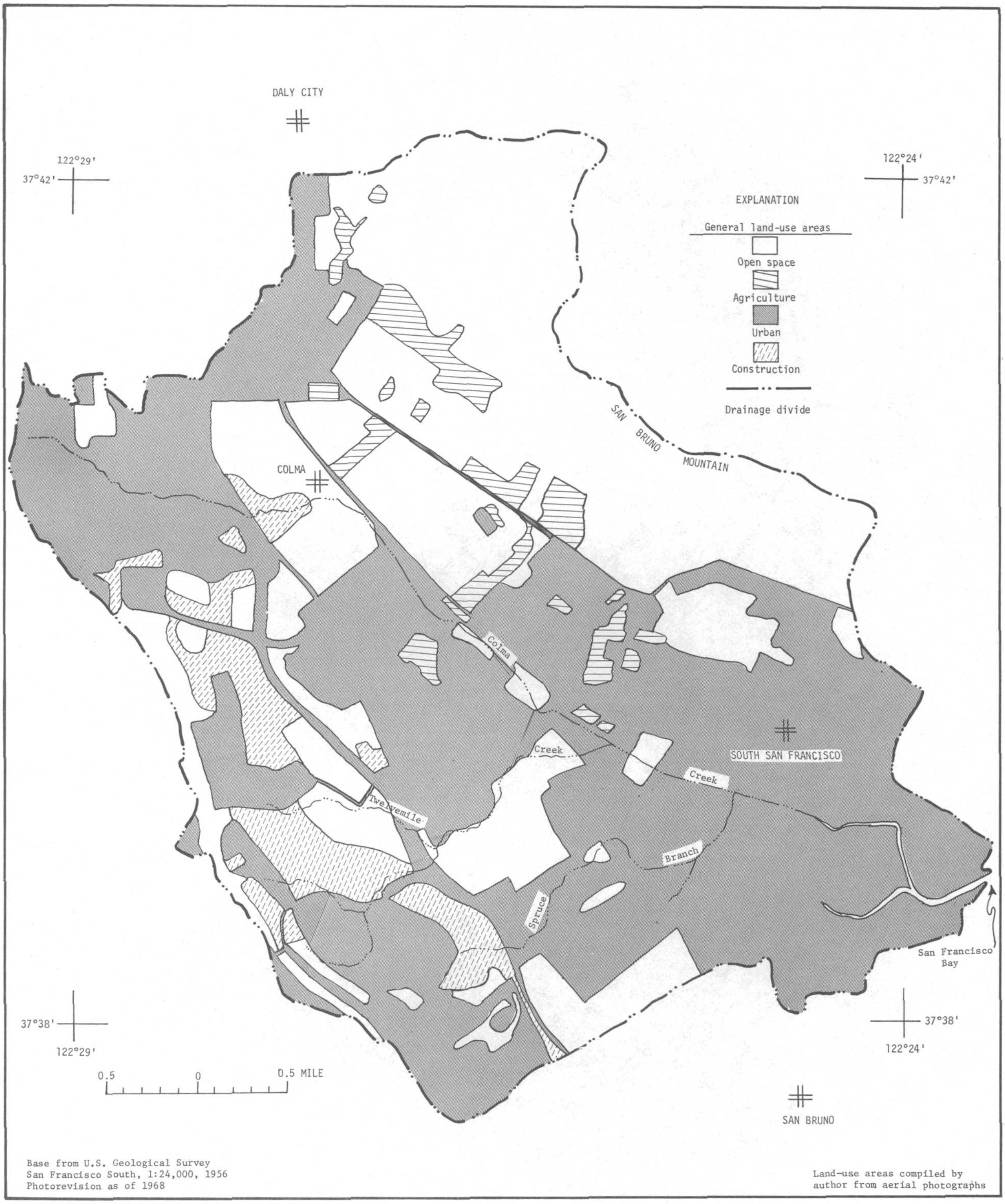


FIGURE 8.--Generalized land use in the Colma Creek drainage basin, 1970.

Rainfall measured by the U.S. Weather Bureau at San Francisco Airport is considered representative of the average rainfall within the Colma Creek basin. The airport station is within 2 miles of the mouth of Colma Creek and has been in operation for more than 40 years. Although the airport site is at a considerably lower altitude (8 ft above mean sea level) than the Collins Avenue site, the recorded precipitation at each is similar (Knott, 1969).

Short-term data compiled for concurrent periods in 1970-71 (table 3) suggests that rainfall is probably uniformly distributed throughout most of the basin except for the northeastern part along San Bruno Mountain where rainfall may be significantly lower.

TABLE 3.--*Areal variation of rainfall in the Colma Creek basin*

Station and location	1970			1971		1970-71
	October	November	December	January	February	Total
San Francisco Airport near South San Francisco (southeastern)[1]	0.75	6.41	6.21	1.27	0.26	14.90
Collins Avenue maintenance yard at Colma (central)[2]	.88	7.81	6.70	2.02	.35	17.76
Coast Guard radio station near Pacifica (far western)	.80	8.20	5.45	1.19	.34	15.98
San Bruno Mountain near South San Francisco (northeastern)	.24	4.70	3.02	1.15	.28	9.39

[1]U.S. Weather Bureau.
[2]San Mateo County station.

STREAMFLOW

There is little, if any, regulation of streamflow in the Colma Creek basin. High flows, however, are affected by factors associated with urban development such as changes in impervious areas, storm drains, and debris basins. Low flows are augmented by return flow from urban and agricultural irrigation.

One of the two stream-gaging stations within the study area was established in October 1963 on Colma Creek in the Orange Memorial Park of South San Francisco (fig. 2). The drainage area upstream from this station is 10.8 square miles and includes most of the highland and urban areas. The other gaging station was established on Spruce Branch in February 1965. In 1969, the drainage area upstream from the Spruce Branch station was reduced from 1.68 to 0.70 square mile by a diversion. The drainage areas upstream from the two gaging stations are representative of about 85 percent of the Colma Creek basin (prior to 1969). The ungaged area downstream includes a small part of the San Bruno highlands, an urban area, and a highly industrialized zone near the mouth of Colma Creek.

Water discharge at the Colma Creek gaging station averaged 4,880 acre-feet per year for 1964-71 (table 4). Most of the annual discharge results from storm runoff occurring from November through March. Colma Creek stormflows seldom remain at high levels for more than 6 hours.

TABLE 4.--*Water discharge of Colma Creek and Spruce Branch at South San Francisco*

Station	Drainage area (sq mi)	Water year(s) (Oct. 1 to Sept. 30)	Water discharge			
			Annual		Maximum	
			Cfs-days	Acre-feet	Daily (cfs)	Instantaneous (cfs)
Colma Creek at South San Francisco	10.8	1964	853	1,690	236	1,050
		1965	2,040	4,060	113	671
		1966	1,700	3,360	160	818
		1967	3,640	7,220	462	1,120
		1968	1,920	3,800	198	1,260
		1969	3,890	7,710	162	1,180
		1970	2,900	5,750	205	918
		1971	2,750	5,450	203	1,980
		1964-71	2,460	4,880	-	-
Spruce Branch at South San Francisco	1.68	[1]1966	416	825	43	219
		1967	740	1,470	113	372
		1968	364	722	60	389
	.70	[2]1969	304	603	13	137

[1]Water discharge records began February 20, 1965.
[2]Station discontinued September 30, 1969.

Two of the larger floods (figs. 9 and 10) during the study period (1964-71) occurred on January 21, 1967, and November 28, 1970. In each instance, flooding resulted when runoff from a high intensity storm was superimposed on runoff from moderate antecedent storms. Colma Creek is extremely sensitive to small amounts of rainfall, even when antecedent dry conditions exist. Moderate runoff generally results from rainfall intensities of less than 0.1 inch per hour.

Several other floods have occurred during recent years which have resulted in variable amounts of damage. Notable among these were the floods of January 24 and March 11, 1967; January 30, 1968; and January 26 and February 23, 1969.

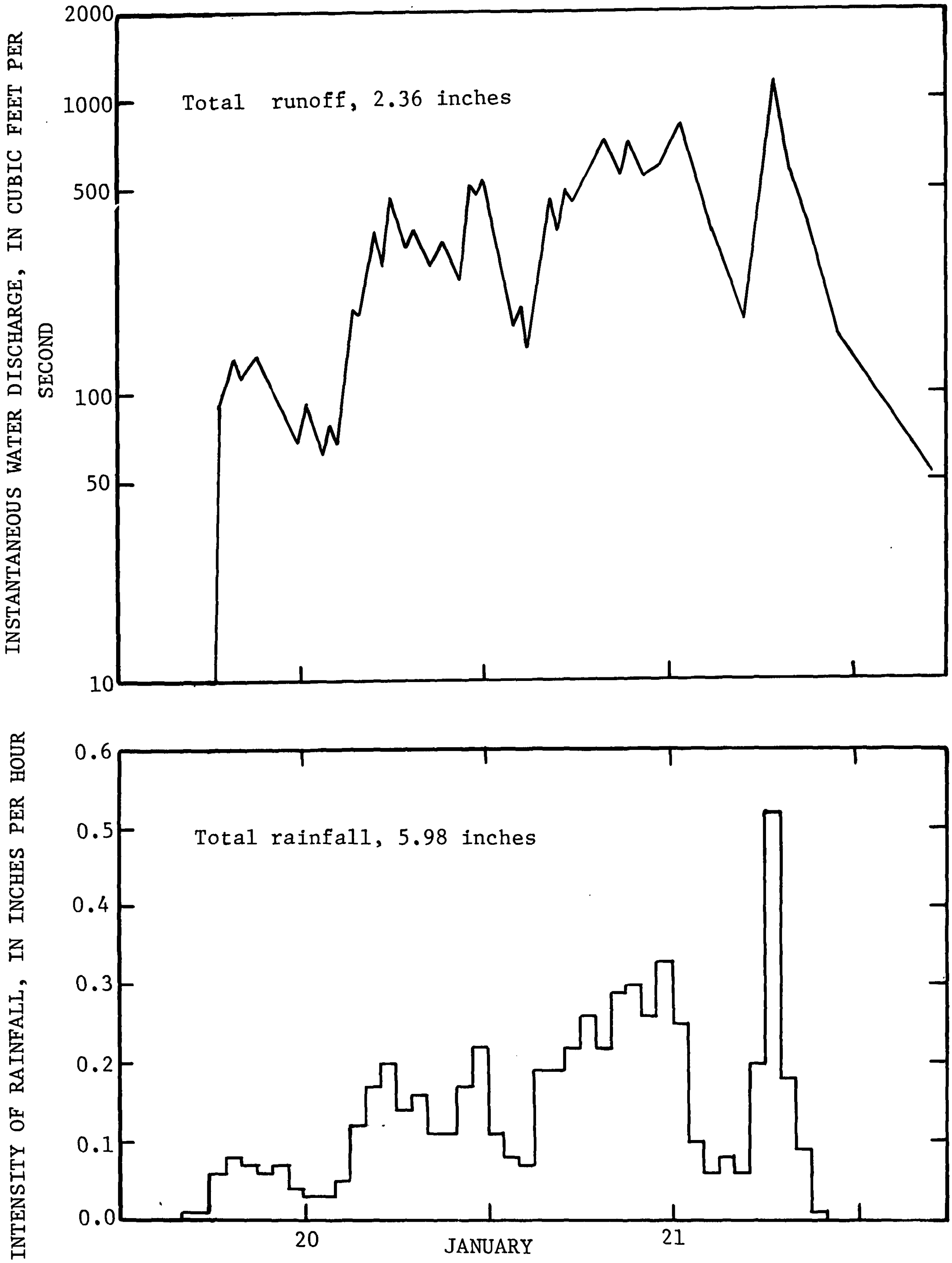


FIGURE 9.--Water discharge at Colma Creek gaging station and rainfall at San Francisco Airport during the storm of January 20-21, 1967.

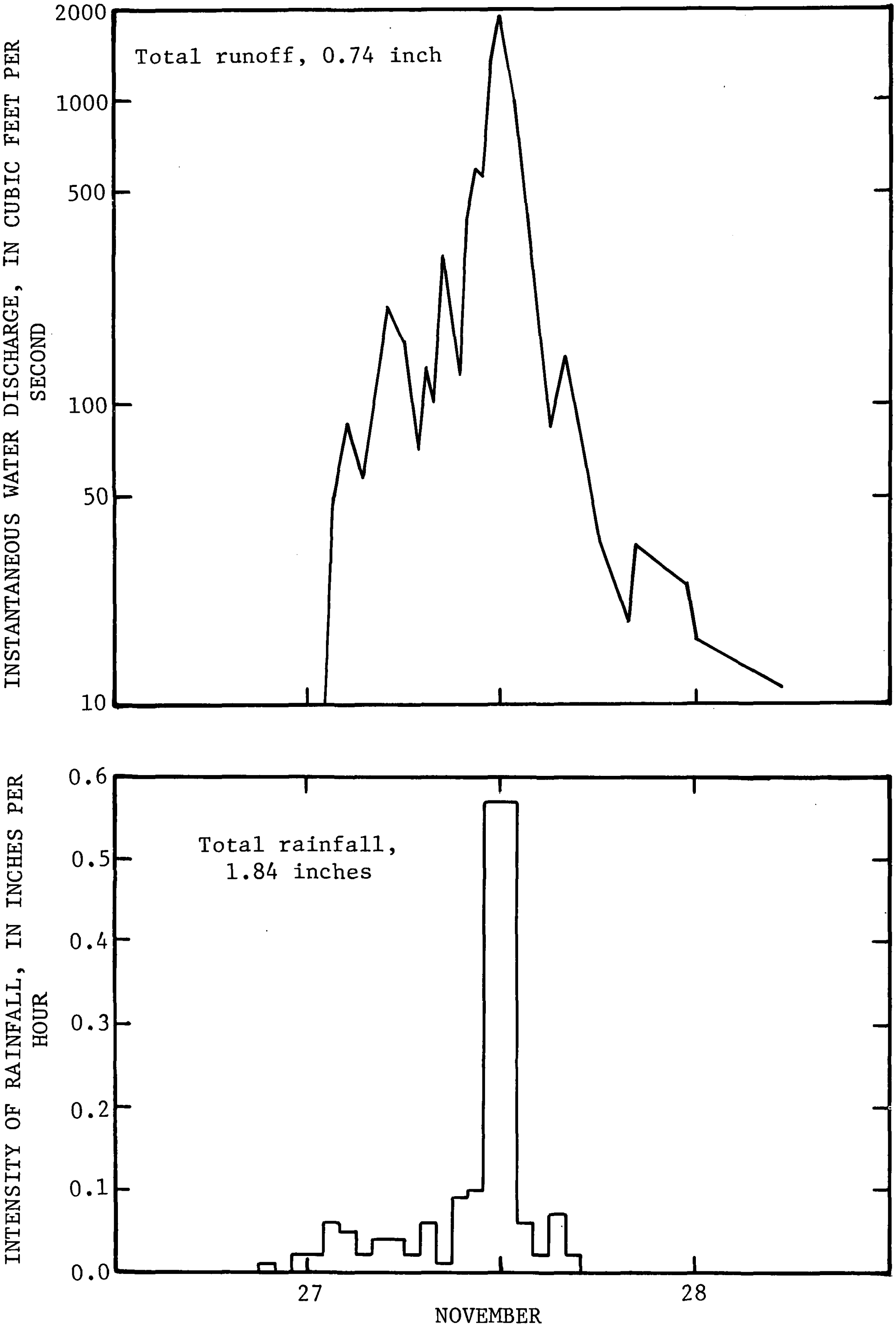


FIGURE 10.--Water discharge at Colma Creek gaging station and rainfall at San Francisco Airport during the storm of November 27-28, 1970.

The quantity and distribution of streamflow during the 1964-71 water years are probably not representative of long-term conditions because of the extensive amount of urban development in recent years and because rainfall in that period was about 9 percent more than normal (table 2). Possible changes in storm runoff characteristics between the 1964 and 1971 water years were investigated by comparing storm runoff at the Colma Creek gaging station with rainfall at the San Francisco Airport. The analysis of rainfall-runoff characteristics was limited to storms with more than 0.4 inch of rainfall to minimize the runoff quantities unrelated to rainfall, such as irrigation return flow from urban and agricultural areas. Individual data points and an average curve of the relation of rainfall to runoff for 72 selected storms between November 1963 and November 1970 are shown in figure 11. Data points for the early years of the study (1964-66) are generally below the average curve (1964-71) and points for the later years (1969-71) are generally above the curve, suggesting that a larger percentage of storm rainfall was discharged as runoff in the latter period. Whether or not this increased runoff is due to the addition of impervious area during urbanization is unclear, because the variability of the storm runoff-rainfall relation (the scatter of data points around the average curve) is large and the data available for analysis are small.

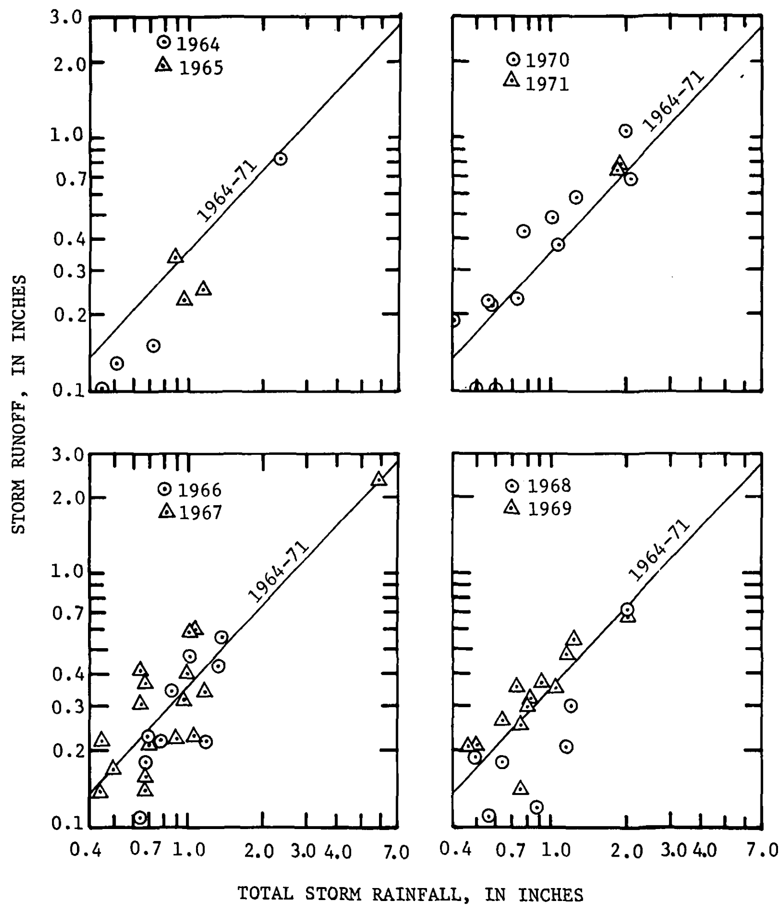


FIGURE 11.--Relation of storm runoff of Colma Creek at South San Francisco to storm rainfall at San Francisco Airport for 72 selected storms between 1964 and 1971.

Hydrologic data for the Colma Creek gaging station and the San Francisco Airport (table 5) indicate that the fraction of rainfall discharged as runoff during storm seasons increased significantly from 1964 to 1971. Comparison of two storm seasons with nearly identical rainfall (1966 and 1971) indicates that storm runoff was about 30 percent larger during the latter season.

TABLE 5.--*Rainfall, runoff, and land use during November to March storm seasons, 1964-71*

Water year	Rainfall (inches)	Runoff (inches)	Ratio of runoff to rainfall	Land use (percent)[1]			
				Open space	Urban	Agriculture	Construction
1964	10.44	2.58	0.25	--	[2]34	--	--
1965	15.78	5.28	.33	--	--	--	--
1966	16.89	5.38	.32	--	--	--	--
1967	24.31	9.52	.39	42	38	5	15
1968	14.51	5.10	.35	--	--	--	--
1969	25.84	11.24	.43	41	40	5	14
1970	17.01	7.58	.45	42	46	4	8
1971	16.83	7.30	.43	--	--	--	--

[1]Upstream from Colma Creek gaging station.
[2]Interpolated from land-use data determined for 1956 and 1967.

Possible trends in peak flow were investigated using graphical techniques similar to those used for storm runoff and rainfall. Peak flows shown in figure 12 were selected from the 72 storms used for the analysis of storm runoff. Each peak flow was selected on the basis of (1) the rainfall that occurred during the 2 hours prior to the peak flow totalled more than 0.1 inch and (2) antecedent flows (minimum discharge prior to 2-hour rainfall) were less than 25 percent of peak flows. Examination of data in figure 12 indicates little, if any, change in the relation between peak flow and rainfall from 1965 to 1971. The maximum peak flow which occurred in 1964 was considerably lower than would be indicated by the average curve for the study period (1964-71). This peak may be atypical because of generally deficient rainfall during 1964. Peak flows for other years are widely distributed around the average curve. A large part of the variability between peak flow and rainfall may be due to the unusual physical characteristics of the Colma Creek basin. Debris basins, for example, retard storm runoff and reduce peak flows. Flooding at various locations upstream from the gaging station would tend to attenuate peak flows, because water circulating through urban areas would move at a slower rate than water moving in stream channels.

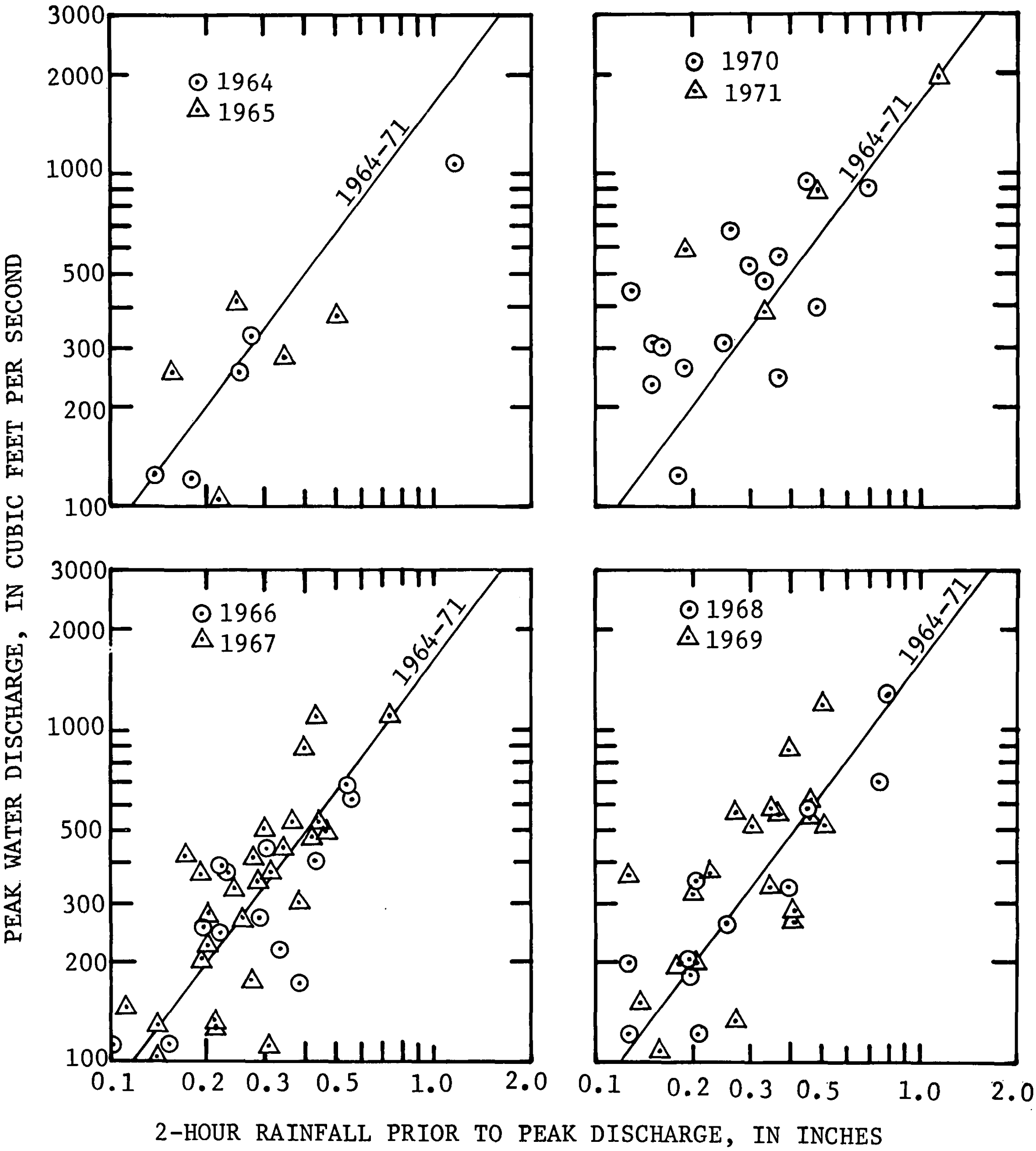


FIGURE 12.--Relation of peak water discharge of Colma Creek at South San Francisco to storm rainfall at San Francisco Airport for 72 selected storms between 1964 and 1971.

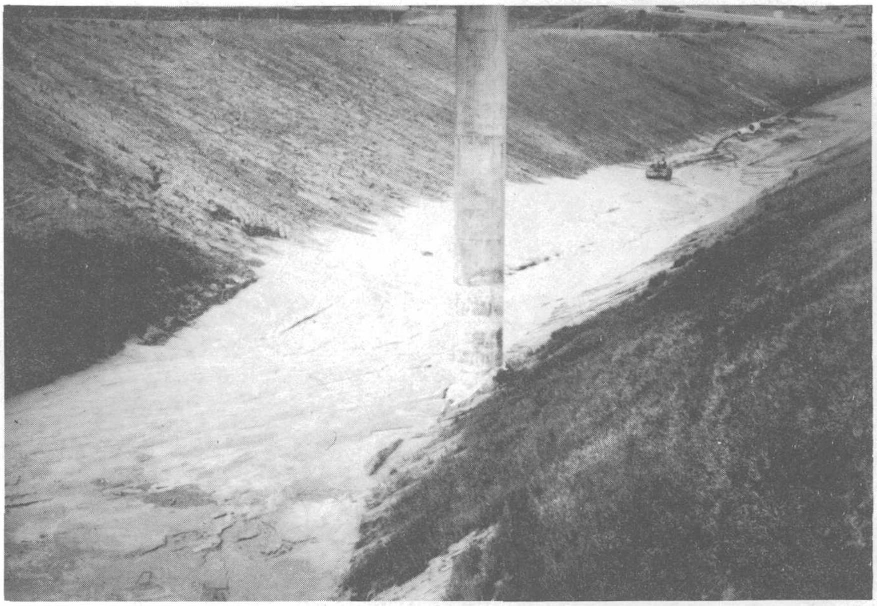
SEDIMENT DISCHARGE

Sediment Sources and Transport

The major source of sediment in the Colma Creek basin is the western highlands where large areas of readily erosible soils are exposed (fig. 13). The quantity of sediment transported from these areas is extremely variable and depends considerably on the amount and intensity of rainfall, magnitude of soil disturbance, time after initial surface disturbance, soil type, and land slope. Large quantities of sediment are transported from areas where land surfaces are under cultivation or excavation and small quantities are transported from areas covered by vegetation or impervious structures.

Suspended-Sediment Discharge

Suspended-sediment data were collected at many sites in the Colma Creek basin subsequent to March 1965. These data range from a few samples at miscellaneous sites to many samples per year at streamflow-measurement stations (fig. 2). Sampling frequency at each site was based on, among other considerations, the number of samples required to determine the average concentration and particle-size distribution of sediment transported by the stream during a specified period of time, as a day, a storm, or a year. Samples of suspended sediment were collected with depth-integrating samplers and by procedures described in Report 14 of the U.S. Inter-Agency Committee on Water Resources, Subcommittee on Sedimentation (1963).



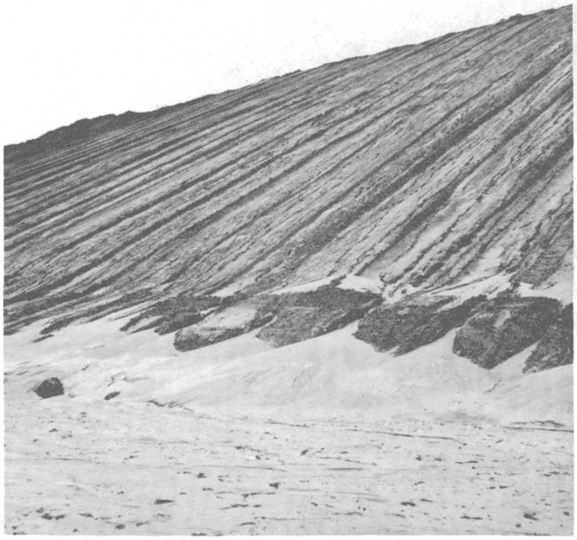


FIGURE 13.--Erosion and deposition in active construction areas. Reduced erosion from slopes recently planted with grass is indicated in upper photograph.

Annual records of suspended-sediment discharge were computed for two stations: Colma Creek at South San Francisco and Spruce Branch at South San Francisco. Sediment discharge at the Colma Creek gaging station is representative of the quantity of sediment transported from about 65 percent of the basin. The station is downstream from most areas under active urban development. However, sediment discharges reported for Colma Creek (table 6) include only the quantity of sediment transported past the site and do not account for sediment deposited in upstream areas or trapped in upstream debris basins. The amount of sediment trapped in the debris basins is discussed in a later section of this report.

TABLE 6.--*Water and sediment discharge of Colma Creek and Spruce Branch at South San Francisco*

Streamflow and sediment station	Drainage area (sq mi)	Water year (Oct. 1 to Sept.30)	Water discharge		Suspended sediment					
					Total		Sand		Maximum day (tons)	
			Annual (cfs-days)	Maximum day (cfs)	Discharge (tons)	Mean concentration (mg/l)	Discharge (tons)	Mean concentration (mg/l)	Total	Sand
Colma Creek at South San Francisco	10.8	1966	1,700	160	32,100	6,990	[1]11,800	2,570	5,790	[1]2,480
		1967	3,640	462	122,000	12,400	[1]60,800	6,190	27,000	[1]14,800
		1968	1,920	198	35,700	6,890	18,800	3,630	7,890	4,810
		1969	3,890	162	65,100	6,200	34,200	3,260	4,290	2,610
		1970	2,900	205	24,900	3,180	14,300	1,830	5,560	3,590
Spruce Branch at South San Francisco	1.68	1966	416	43	4,760	4,240	2,220	1,980	854	523
		1967	740	113	9,800	4,900	5,580	2,790	2,300	1,400
		1968	364	60	[3]39,300	[3]40,000	-	-	-	-
	[2].70	1969	304	13	[3]27,000	[3]32,900	-	-	-	-

[1]Revised from Knott (1969).
[2]Drainage area reduced by upstream diversion.
[3]Result of highway construction, real estate development, and ineffective debris basin.

A daily-record station on Spruce Branch was established in 1965 downstream from a fully urbanized area considered representative of the future conditions in the Colma Creek basin. Sediment discharges at this station (table 6) were small during 1966 and 1967 but increased sharply in the 1968 and 1969 water years when a small debris basin, filled to capacity, was later breached by heavy rains. Sediment yields in 1968 and 1969 were augmented by increased construction activity in other parts of the Spruce Branch drainage. The Spruce Branch station was discontinued after the 1969 water year because sediment discharges were no longer representative of a stable urban basin as a result of the construction activity.

Sediment data reported for Colma Creek and Spruce Branch gaging stations (table 6) are "suspended-sediment discharges" and do not include bedload discharge. The quantity of material transported near the streambed, however, constitutes a small part of the total sediment discharge at the Colma Creek station because stream velocities and turbulence during medium and high flows keep nearly all of the transported sediment in suspension. Suspended-sediment discharges reported for Spruce Branch probably were equivalent to total sediment discharge prior to 1968. Later records for Spruce Branch, however, represent a smaller fraction of the total sediment discharge because flow characteristics at the station were altered by sediment deposition. Data collected at these two sites have been published annually in the U.S. Geological Survey series, "Water Resources Data for California."

Relation Between Suspended-Sediment Discharge and Water Discharge

Sediment discharge passing the Colma Creek gaging station is related to water discharge and concentration of suspended sediment. This relation is given by the equation

$$Q_s = KC_sQ_w$$

where Q_s is the sediment discharge, in tons per day,
K is a constant (equivalent to 0.0027 for sediment having a specific gravity of 2.65),
C_s is the concentration of suspended sediment, in milligrams per liter, and
Q_w is the water discharge, in cubic feet per second.

The relation between sediment and water discharge, referred to as a sediment-transport curve, is commonly expressed in graphical form as an average curve on logarithmic paper.

Sediment-transport curves for 1966-70 (figs. 14-15) indicate that sediment discharge during streamflows larger than 100 cfs was relatively unchanged between 1966 and 1969. The curve for 1970, however, shows a large decrease in the rate of sediment discharge for all flows.

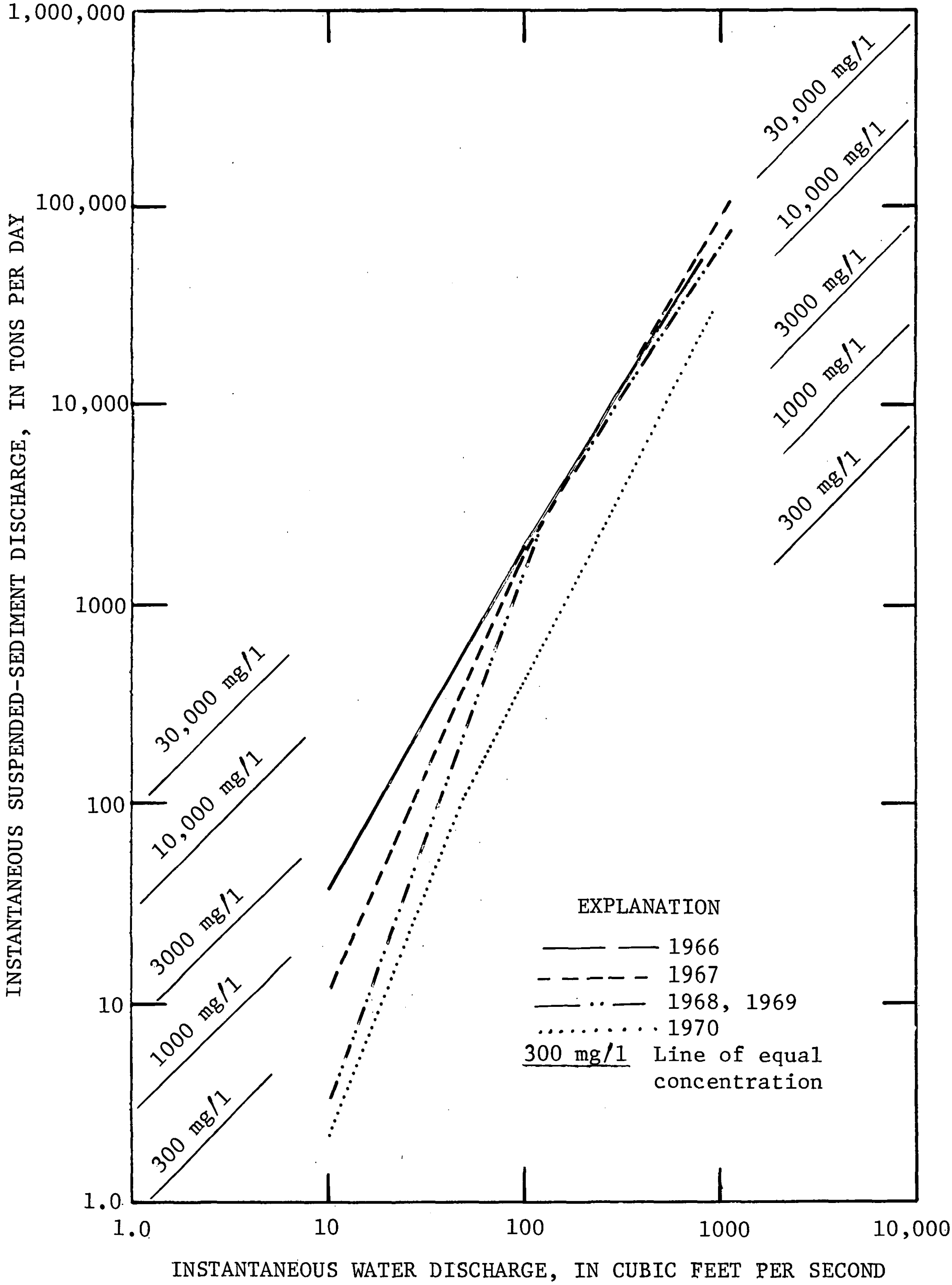


FIGURE 14.--Relation of suspended-sediment discharge to water discharge, Colma Creek at South San Francisco, 1966-70 water years.

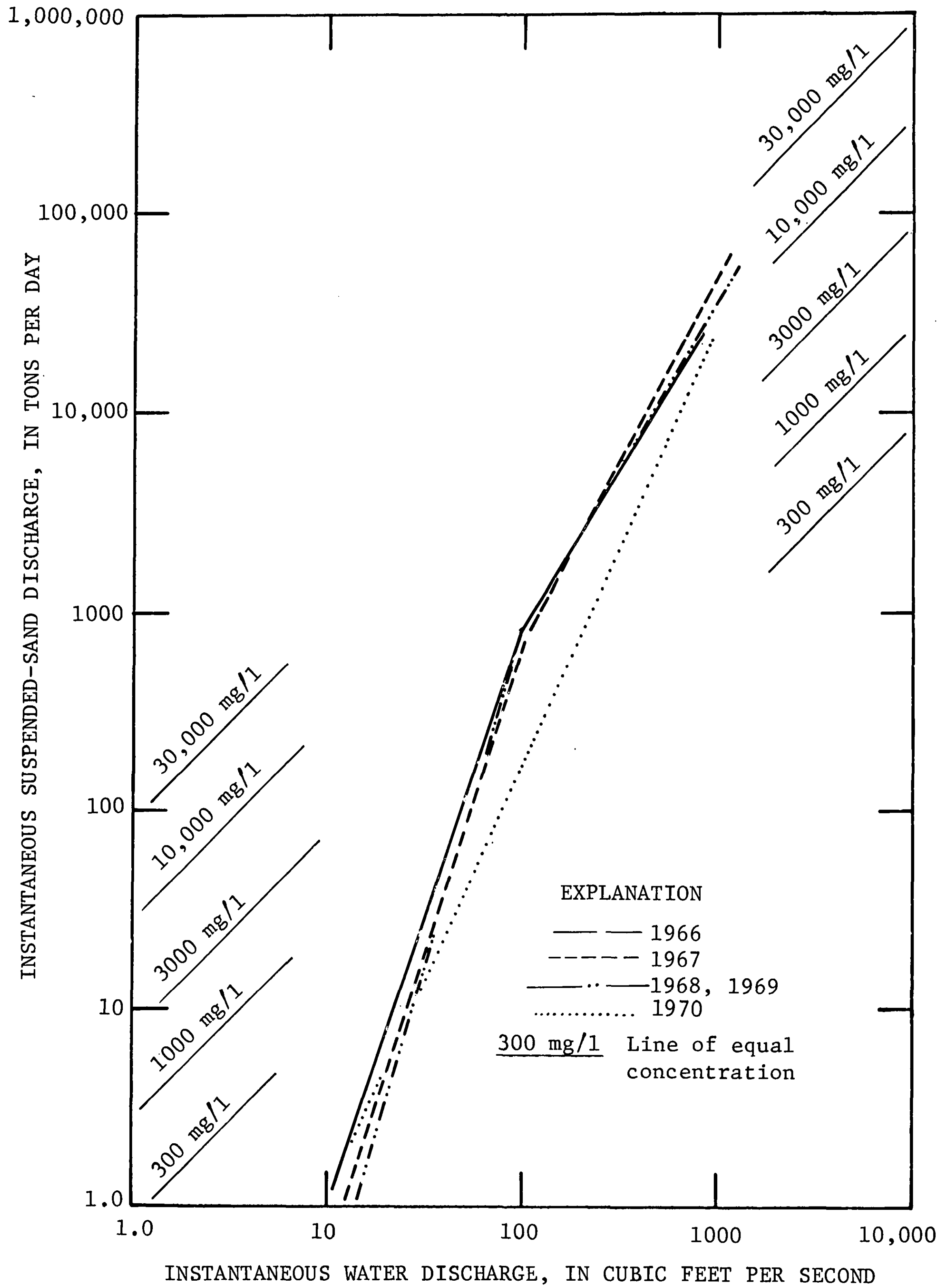


FIGURE 15.--Relation of suspended-sand discharge to water discharge, Colma Creek at South San Francisco, 1966-70 water years.

The decrease in sediment discharge relative to water discharge between 1969 and 1970 may be because of the additional runoff caused by the impervious surfaces in the newly constructed urban areas, or because of the large decrease in construction during the period. The increased runoff is assumed to be of minor significance because little change occurred in the ratio of runoff to rainfall (table 5). The large decrease in construction between 1969 and 1970, therefore, is assumed to be the primary cause for the decrease in sediment discharge relative to water discharge.

Sediment-water discharge relations for Spruce Branch were unstable because of frequent major changes in the size of sediment source areas and because of intermittent urban development. Sediment yields in 1966 and 1967 probably were not representative of a stable urban area because about 6 percent of the basin was under development. Sediment yields in 1968 and 1969 are indicative of unusual conditions where increased construction activity coincided with intermittent discharges of sediment from an ineffective debris basin. When the debris basin is repaired, the sediment yields probably will return to the 1966-67 level.

Sediment Trapped in Debris Basins

A significant part of the sediment eroded from areas under development is trapped in debris basins (fig. 2) upstream from the Colma Creek gaging station. Most of this sediment is deposited in a debris basin on the North Fork of Twelvemile Creek. Reconnaissance surveys were made of this debris basin and a debris basin on Colma Creek near Colma (Collins Avenue) to determine the amount of sediment trapped upstream from the gage. The debris basins were surveyed before and after the 1969 storm season (1969 water year) by the San Mateo County personnel.

The surveys were made by transit-stadia traverse along a series of sediment ranges established at predetermined intervals. The volume of sediment deposited during the 1969 water year was computed by a prismoidal method (Eakin and Brown, 1939, p. 158-159).

Samples of deposited sediment were obtained during the second survey at several ranges using a piston-type U.S. BMH-53 bed-material sampler (Inter-Agency Committee on Water Resources, 1963). Samples obtained with the sampler were representative of the top 8 inches of deposited sediment. Sediment samples collected from both debris basins were analyzed for specific weight and particle-size distribution for conversion of sediment volume to weight units. This conversion was necessary to compare the amount of sediment trapped in the debris basins with concurrent sediment-discharge data of Colma Creek. A representative specific weight for each debris basin was determined by weighting each sample according to sediment volumes between ranges.

Sediment contributed to the debris basin on the North Fork of Twelvemile Creek (fig. 16) is eroded from an 0.43-square mile area under development for residential homes. An inspection of the debris basin after the 1969 storm season indicated that nearly 100 percent of the sand-size or coarser material was probably trapped behind an earth dike surrounding the outlet structure. Deposits of finer material at elevations near the top of the dike suggested ponding during large storm events and that some outflow of silt- and clay-size material occurs. During the 1969 water year, 10,600 cubic yards of sediment were deposited, consisting of 59 percent sand (0.062-2.0 mm) and 41 percent silt-clay (<0.062 mm). Based on these percentages the average specific weight of deposited sediment is 86 pounds per cubic foot. The debris basin therefore prevented 12,300 tons of sediment from reaching the Colma Creek gaging station in 1969.

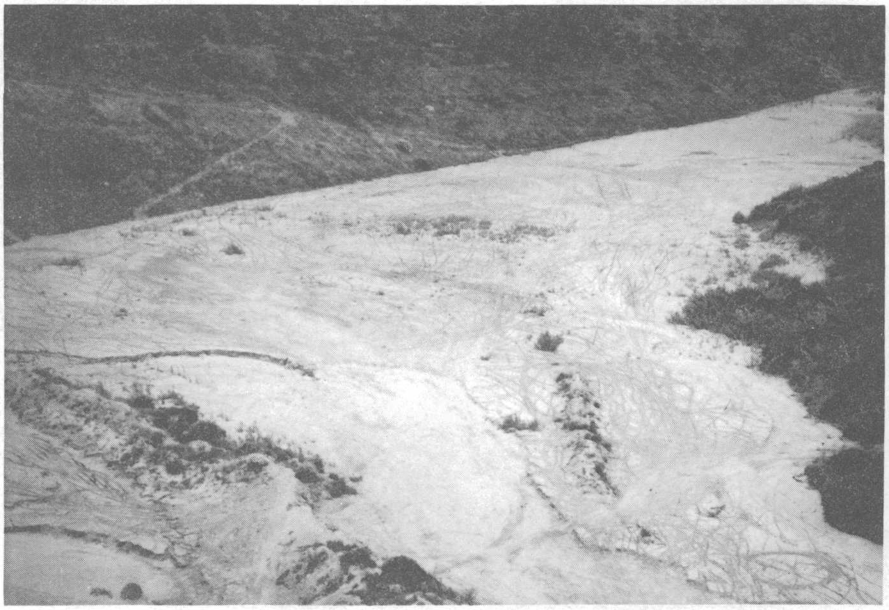


FIGURE 16.--Views of debris basins on the North Fork of Twelvemile Creek and Colma Creek near Collins Avenue. In 1969, these two facilities trapped about 17,000 tons of sediment eroded from upstream construction areas.

The debris basin on Colma Creek adjacent to Collins Avenue at Colma (figs. 2 and 16) was constructed prior to 1964. The capacity of the basin (about 3,300 cubic yards) is small relative to the upstream drainage area (1.27 sq mi) and generally is filled before the end of the average storm season. The basin is dredged about once a year.

Sediment deposited in the debris basin in 1969 consisted of 2 percent silt-clay (<0.062 mm), 95 percent sand (0.062-2.0 mm), and 3 percent fine to coarse gravel (2.0-32.0 mm). The deposits remaining at the end of the 1969 water year were probably the result of considerable sorting. Storm flows passing through the basin, after it was filled, caused the fraction of particles coarser than sand to increase and, consequently, the fraction of particles finer than sand decreased.

During 1969, the debris basin trapped a total of 3,300 cubic yards or 4,590 tons. The specific weight of deposited material was 102 pounds per cubic foot.

Although many debris basins, other than the ones surveyed, have been constructed in the Colma Creek basin, they are small in capacity and have generally been used for short periods. When construction in upstream areas is completed, they are generally abandoned and the basin area developed for urban use. The number of debris basins being used in any one year is unknown but probably ranges from five to 10.

Sediment deposits in these basins are probably similar to those found at Collins Avenue, in that the deposits are mostly sand or coarser material. Each of two samples obtained from one of the basins (Sutton Avenue) contained 94 percent sand and 6 percent silt and clay. Specific weights of the samples were 102 and 107 pounds per cubic foot.

The estimated sediment collectively trapped by these small debris basins ranges from 500 tons in an average runoff year to 1,500 tons in a large runoff year.

Total Sediment Yield at Colma Creek Gaging Station (1966-70)

Total sediment yield at the Colma Creek gaging station for the 1969 water year was determined by combining the sediment deposited in upstream debris basins with the sediment passing the gaging station on the assumption that all sediment so trapped would normally be conveyed through the channel system to the gaging station. Sediment yield for the 1966-68 and 1970 water years (table 7) was estimated on the basis of the relation between sediment trapped in the debris basins in 1969 and sediment passing the gaging station in 1969. It was estimated that the North Fork Twelvemile Creek debris basin trapped about 90 percent of the total sediment inflow including 100 percent of the sand inflow.

The debris basins trap a larger percentage of sand than silt or clay. The sand passing the gaging station ranged from 55 percent of the total sand yield in 1966, an average year, to 75 percent in 1967, a wet year. The silt-clay passing the gaging station ranged from 79 to 86 percent of the total silt-clay yield.

TABLE 7.--*Total sediment yield of the basin upstream from the Colma Creek gaging station including sediment trapped in upstream debris basin, 1966-70*

Water year (Oct. 1 to Sept. 30)	Annual sediment yield					
	Total		Sand		Silt-clay	
	Tons	Tons per sq mi	Tons	Tons per sq mi	Tons	Tons per sq mi
1966	45,300	4,190	21,600	2,000	23,700	2,190
1967	153,000	14,200	81,300	7,530	71,300	6,600
1968	47,500	4,400	27,700	2,560	19,800	1,830
1969	82,500	7,640	46,500	4,310	36,000	3,330
1970	36,800	3,410	23,300	2,160	13,500	1,250

Sediment Yield from Areas of Dissimilar Land Use (1969-70)

Selection of Index Stations

In 1968, when sediment discharge at the Spruce Branch gaging station increased sharply relative to the Colma Creek station, a reconnaissance was made to select additional sampling sites to establish an index of sediment yield for various types of land use. Four general types of land use were prevalent in the study area that could reasonably be associated with sediment yield. These land-use types are:

1. Open-space areas where soils were protected by native or reestablished vegetation, parks, and cemeteries.

2. Urban areas which include residential, commercial, and industrial communities. The urban areas were not subdivided into lawns and impervious areas. Comparison of aerial photographs of the urban areas in the Colma Creek basin with photographs of the Permanente Creek basin (Harris and Rantz, 1964, p. B11) in Santa Clara County indicates that in the Colma Creek basin lawns and impervious areas may be about 75 and 23 percent, respectively, and that about 2 percent of the urban area includes small areas of exposed soil, such as gardens, unprotected slopes, and land under development.

3. Agricultural areas where soils have been under cultivation for many years. Areas of older exposed soil where vegetation has not been reestablished were included in this category.

4. Construction areas including freshly excavated areas and areas that had been exposed for as much as several years. Agricultural and construction areas are sometimes combined and are referred to in this report as exposed-soil areas because each is characterized by soil disturbance and(or) lack of vegetal cover.

Five index stations (table 8 and fig. 17) were selected ranging from a relatively undisturbed rural basin to a rapidly developing basin where soils were exposed over more than 40 percent of the area.

Sediment samples and water discharge data at index stations were obtained at outfalls or culverts where sediment concentration could be determined throughout the total flow depth. Sediment discharges thus determined are representative of the total quantity of sediment passing each station.

TABLE 8.--*Drainage area and land use of sediment yield-index stations in the Colma Creek basin (1969-70)*

Index station	No.	Water year (Oct. 1 to Sept. 30)	Drainage area (sq mi)	Land use (percent of drainage area)			
				Open space	Urban	Agriculture	Construction
Guadalupe Canyon	1	1969	0.73	95	4	1	0
		1970		95	4	1	0
B Street	1-2	1969	1.50	70	23	7	0
		1970		70	24	6	0
Hickey Boulevard	3	1969	1.15	15	43	0	42
		1970		24	53	0	23
Colma Creek gaging station	4	1969	10.8	41	40	5	14
		1970		42	46	4	8
Avalon	5	1969	.33	13	67	0	20
		1970		-	-	-	-

Runoff and Sediment Concentration at Index Stations

Runoff and sediment-concentration data were collected simultaneously at index stations during seven storms in 1969 and 1970. Data collected during only four storms, however, were sufficient to construct a continuous record of runoff and sediment concentration throughout antecedent flow, peak flow, and subsequent recession flow. Data collected during the other three storms, representative of recession flow only, were not used in this report.

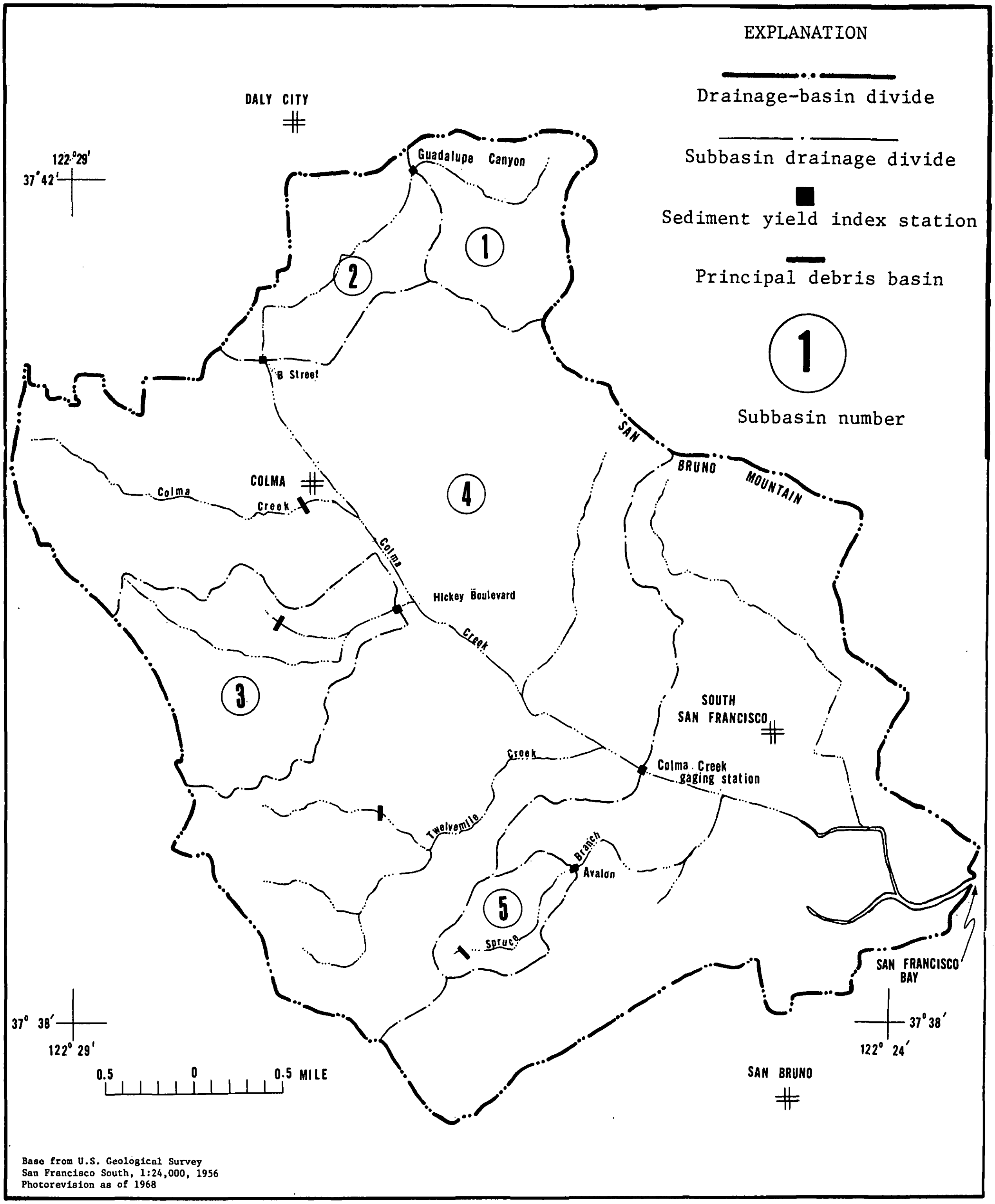


FIGURE 17.--Sediment yield-index stations in the Colma Creek basin.

The sampled storms included typical small and large storms that produced multiple peak flows. Streamflow receded rapidly after each peak flow, but did not approach antecedent flow magnitudes until several hours after rainfall had ceased. Data were collected continuously through storms for periods ranging from 4 to 8 hours. Runoff and sediment-concentration data for selected periods of simultaneous storm runoff are given in table 9.

TABLE 9.--*Runoff and sediment concentration at index stations in the Colma Creek basin (1969-70)*

Index station	Storm date and size	Drainage area (sq mi)	Peak flow (cfs)	Runoff		Peak concentration (milligrams per liter)			Average concentration (milligrams per liter)		
				Acre-feet	Acre-feet per sq mi	Total	Sand	Silt-clay	Total	Sand	Silt-clay
Guadalupe Canyon[1]	Jan. 20, 1969	0.73	-	-	-	-	-	-	-	-	-
B Street	(moderate)	1.50	15	2.5	1.7	8,160	7,900	260	2,580	2,450	133
Hickey Boulevard		1.15	101	11	9.6	31,600	19,000	12,600	7,220	3,710	3,510
Avalon		.33	32	2.4	7.3	401,000	270,000	131,000	61,300	35,200	26,100
Colma Creek gaging station		10.8	318	50	4.6	24,700	15,000	9,700	8,820	4,130	4,690
Guadalupe Canyon	Feb. 11, 1969	.73	10	2.2	3.0	7,900	5,200	2,700	2,000	1,330	674
B Street	(large)	1.50	26	5.6	3.7	24,600	23,000	1,560	9,550	9,040	509
Hickey Boulevard		1.15	172	26	23	27,900	14,900	13,000	8,860	5,220	3,640
Colma Creek gaging station		10.8	550	69	6.4	24,700	12,700	12,000	10,700	5,410	5,310
Guadalupe Canyon	Jan. 23, 1970	.73	5.8	1.7	2.3	106	69	37	78	47	31
B Street	(small)	1.50	6.3	1.8	1.2	176	114	62	125	85	40
Hickey Boulevard		1.15	4.5	1.0	.87	1,270	180	1,090	415	20	395
Colma Creek gaging station		10.8	40	8.9	.82	500	230	270	134	41	93
Guadalupe Canyon	Feb. 16, 1970	.73	6.4	2.4	3.3	18,000	15,000	3,000	1,370	660	708
B Street	(moderate)	1.50	35	7.0	4.7	14,500	13,300	1,220	2,050	1,790	263
Hickey Boulevard		1.15	65	11	9.6	12,800	5,200	7,600	2,750	1,330	1,420
Colma Creek gaging station		10.8	312	85	7.9	10,900	6,400	4,500	2,110	980	1,130

[1]Data insufficient to construct a continuous record of storm runoff or sediment concentration.

Runoff sampled at Guadalupe Canyon and B Street index stations is representative of hydrologic conditions existing near San Bruno Mountain and in the eastern part of the Colma Creek basin. Runoff at these stations during moderate to large storms was generally less, per square mile, than runoff at the Colma Creek gaging station. In this area rainfall was less than the basin average (table 3). A large part of the tributary area is covered by vegetation which retards runoff and probably causes high infiltration rates.

Runoff at west-side stations was generally more than twice as large per square mile, as runoff at east-side stations and was always larger than runoff at the gaging station. The larger runoff is attributed to the larger rainfall in the west side of the basin and to the increased runoff-rainfall ratio in the urbanized sections.

Sediment concentration was least at the Guadalupe Canyon station where only about 4 percent of the upstream area had been developed for roadways (listed as urban in table 8). Most of the sediment sampled at this station was eroded from undeveloped areas; but some sediment, especially sand, probably came from road cuts where the soils were unprotected by vegetation.

Sediment concentration data at the B Street station include sediment from the undeveloped area in Guadalupe Canyon, an established urban area, and from an agricultural area at the mouth of Guadalupe Canyon. Sediment concentrations, during larger storms, change significantly as the stream passes from Guadalupe Canyon to the B Street station. Although the average total sediment concentration increases at the downstream site, the largest changes occur in the sand-size fraction (table 9). Sand concentration increases from Guadalupe Canyon to B Street by 200 to 600 percent, whereas silt-clay concentration decreases by 20 to 60 percent. Increased sand concentration probably is related to the increased percentage of exposed soil (cultivated lands) between Guadalupe Canyon and B Street and to the larger sand yield from the urban area. The reason for a decrease in silt-clay concentration is not clear. However, possibly silt and clay, being finer in particle size and more easily eroded, were eroded from urban and agricultural areas at a faster rate after development, or perhaps the exposed soils were originally deficient in silt and clay. Silt-clay yield from the urban area upstream from B Street is probably lower than the yield from undeveloped areas.

Sediment-concentration data at Hickey Boulevard include sediment eroded from established urban areas, several cemetaries, and large areas that were under construction from 1967 through 1970. Total concentration at Hickey Boulevard was generally somewhat larger than at B Street but was reduced considerably by dilution of flow from urban areas. Sand and silt-clay concentrations at Hickey Boulevard were generally equal in magnitude except during the small storm of January 23, 1970, when silt-clay concentration was much larger.

Sediment concentration observed at the Avalon station was larger than concentration observed at any of the other index stations during 1969-70 and peak concentrations were the largest ever observed in the Colma Creek basin. Part of the sediment was derived from a small debris basin which had previously been filled to capacity, thus allowing sediment from construction areas to flow directly into the stream. It was also probable that sediment deposited in the debris basin during previous storms was washed out during January 20, 1969, and was not representative, therefore, of normal flow. Sediment sampling at the Avalon station was largely discontinued after the first visit, because it was assumed that sediment discharge data would not be uniform during successive storms.

Sediment Discharge at Index Stations

Sediment discharges at index stations in the Colma Creek basin during four storms in 1969-70 are given in table 10. These discharges were computed from continuous streamflow and sediment-concentration data.

A comparison of sediment discharges in table 10 indicates that the least amount of sediment was transported from the area upstream from the Guadalupe Canyon station where the percentage of urban and exposed-soil areas was smallest (table 8). Sediment discharge at the Guadalupe Canyon station constituted a minor percentage of sediment discharge passing the Colma Creek gaging station (less than 1 percent).

Sediment discharge increased significantly from Guadalupe Canyon to B Street as a result of a large increase in the percentage of agricultural areas. Almost all of the increased discharge was composed of sand-sized particles. Silt-clay discharge increased only in proportion to the increase in drainage area. Sediment discharge at B Street is about 2 to 7 percent of the quantity of sediment passing the Colma Creek gaging station.

TABLE 10.--*Sediment discharge at index stations in the Colma Creek basin (1969-70)*

Index station	Storm date and size	Drainage area (sq mi)	Sediment discharge					
			Total		Sand		Silt and clay	
			Tons	Tons per sq mi	Tons	Tons per sq mi	Tons	Tons per sq mi
Guadalupe Canyon	Jan. 20, 1969	0.73	-	-	-	-	-	-
B Street	(moderate,	1.50	13	8.7	12	8.0	0.57	0.38
Hickey Boulevard	5 hours)	1.15	172	150	90	78	82	71
Colma Creek gaging station[1]		10.8	663	61	332	31	331	31
Avalon		.33	420	1,270	265	803	155	470
Guadalupe Canyon	Feb. 11, 1969	.73	6.6	9.0	4.7	6.4	1.9	2.6
B Street	(large,	1.50	65	43	61	41	4.1	2.7
Hickey Boulevard	4 hours)	1.15	373	324	219	190	154	134
Colma Creek gaging station[1]		10.8	1,450	134	751	70	701	65
Guadalupe Canyon	Jan. 23, 1970	.73	.17	.23	.10	.14	.07	.10
B Street	(small,	1.50	.34	.23	.23	.15	.11	.07
Hickey Boulevard	2 hours)	1.15	.72	.63	.04	.03	.68	.59
Colma Creek gaging station[1]		10.8	1.9	.18	.58	.05	1.3	.12
Guadalupe Canyon	Feb. 16, 1970	.73	4.1	5.6	1.9	2.6	2.2	3.0
B Street	(moderate,	1.50	28	19	25	17	3.2	2.1
Hickey Boulevard	7 hours)	1.15	70	61	35	30	35	30
Colma Creek gaging station[1]		10.8	378	35	187	17	191	18

[1]Colma Creek data not adjusted for sediment deposited in upstream debris basins.

The largest sediment discharge in the area upstream from the gaging station was observed at Hickey Boulevard. The area upstream from Hickey Boulevard is a major source of sediment in the basin. Although it is only 11 percent of the drainage area, it yielded 26 percent of sediment passing the gaging station in 1969. The percentage was reduced to 19 percent in 1970 because of large scale conversion of construction areas to urban areas. West-side basins adjacent to Hickey Boulevard, where development patterns are similar, probably supply most of the sediment which passes the gaging station.

Estimated Sediment Yields for Various Types of Land Use

Open-space areas.--Sediment-yield data at the Guadalupe Canyon index station are assumed to be representative of average sediment yield from open-space areas in the Colma Creek basin where soils are covered by vegetation. These yields are probably slightly larger than yields from cemetery or park lands where soils are well protected by dense grass cover and are less than yields from undeveloped grasslands in the western basin where vegetation is less dense.

Exposed-soil areas.--When land covered with forest or brush is developed for agricultural or urban use, surface vegetation is removed and original soil or subsoil is exposed to erosion. Sediment yield often increases during the early stages of development and the amount of increase is often related to the amount of land exposed (Guy and Ferguson, 1962).

Regression equations defining the relation between sediment yield and percentage exposed soil within the various subbasins (table 11) upstream from Colma Creek gage were computed by the least squares method. Sediment yield data at the gaging station were adjusted to include the probable quantity of sediment trapped in debris basins during the monitored storm events. It was also assumed that minor aggradation and degradation occurred in the channel system since most of the stream channels upstream from the gaging station are lined with stable material such as masonry or concrete. The general equation for the regression equations is

$$Q_s = A + BP$$

where Q_s = the silt-clay or sand yield, in tons per square mile,

P = the total percentage of exposed soil, and

A and B = numerical constants.

TABLE 11.--*Sediment yields in the Colma Creek basin*

Subbasin Number	Subbasin Area	Storm date and size	Drainage area (sq mi)	Percentage of exposed soil: Agriculture	Percentage of exposed soil: Construction	Sand yield (tons per sq mi)	Silt-clay yield (tons per sq mi)
1-2	Upstream from B Street	Jan. 20, 1969	1.50	7	0	8.0	0.38
3	Upstream from Hickey Boulevard	(moderate)	1.15	0	42	78	71
4	Between B Street, Hickey Boulevard, and Colma Creek gaging station		8.15	5	13	[1]42	[2]37
5	Upstream from Avalon		.33	0	20	800	470
1	Upstream from Guadalupe Canyon	Feb. 11, 1969	.73	1	0	6.4	2.6
2	Between Guadalupe Canyon and B Street	(large)	.77	12	0	73	2.9
3	Upstream from Hickey Boulevard		1.15	0	42	190	134
4	Between B Street, Hickey Boulevard, and Colma Creek gaging station		8.15	5	13	[1]88	[2]80
1	Upstream from Guadalupe Canyon	Jan. 23, 1970	.73	1	0	.14	.10
2	Between Guadalupe Canyon and B Street	(small)	.77	12	0	.17	.05
3	Upstream from Hickey Boulevard		1.15	0	23	.03	.59
4	Between B Street, Hickey Boulevard, and Colma Creek gaging station		8.15	4	7	[1].08	[2].10
1	Upstream from Guadalupe Canyon	Feb. 16, 1970	.73	1	0	2.6	3.0
2	Between Guadalupe Canyon and B Street	(moderate)	.77	12	0	30	1.3
3	Upstream from Hickey Boulevard		1.15	0	23	30	30
4	Between B Street, Hickey Boulevard, and Colma Creek gaging station		8.15	4	7	[1]30	[2]25

[1]Yield adjusted for sand deposited in upstream debris basins.
[2]Yield adjusted for silt-clay deposited in upstream debris basins.

A statistical fit using the least squares method was chosen arbitrarily to avoid any subjective bias and to measure the probable accuracy of sediment yields estimated for areas containing a large percentage (50-100) of exposed soil. Accuracy was measured by the standard error, in tons per square mile. However, in some instances, the computed yield based on the equation is negative where the percentage of exposed soil was small (0-5 percent). Therefore, the regression curves in figures 18-20 are not considered valid where indicated sediment yields are smaller than the standard error.

Regression data for the small storm of January 23, 1970 (fig. 18), indicate that silt-clay yields increased and sand yields decreased with increases in the percentage of exposed-soil area. The amount of sand transported during a small storm, however, may be influenced, to a significant degree, by factors which have small effects on silt-clay material, such as irregularities in land surface and hydraulic characteristics of stream channels. The relation between sediment yield and exposed soil is considered poor, because during small storms environmental factors probably affect sediment yield more than exposed-soil area.

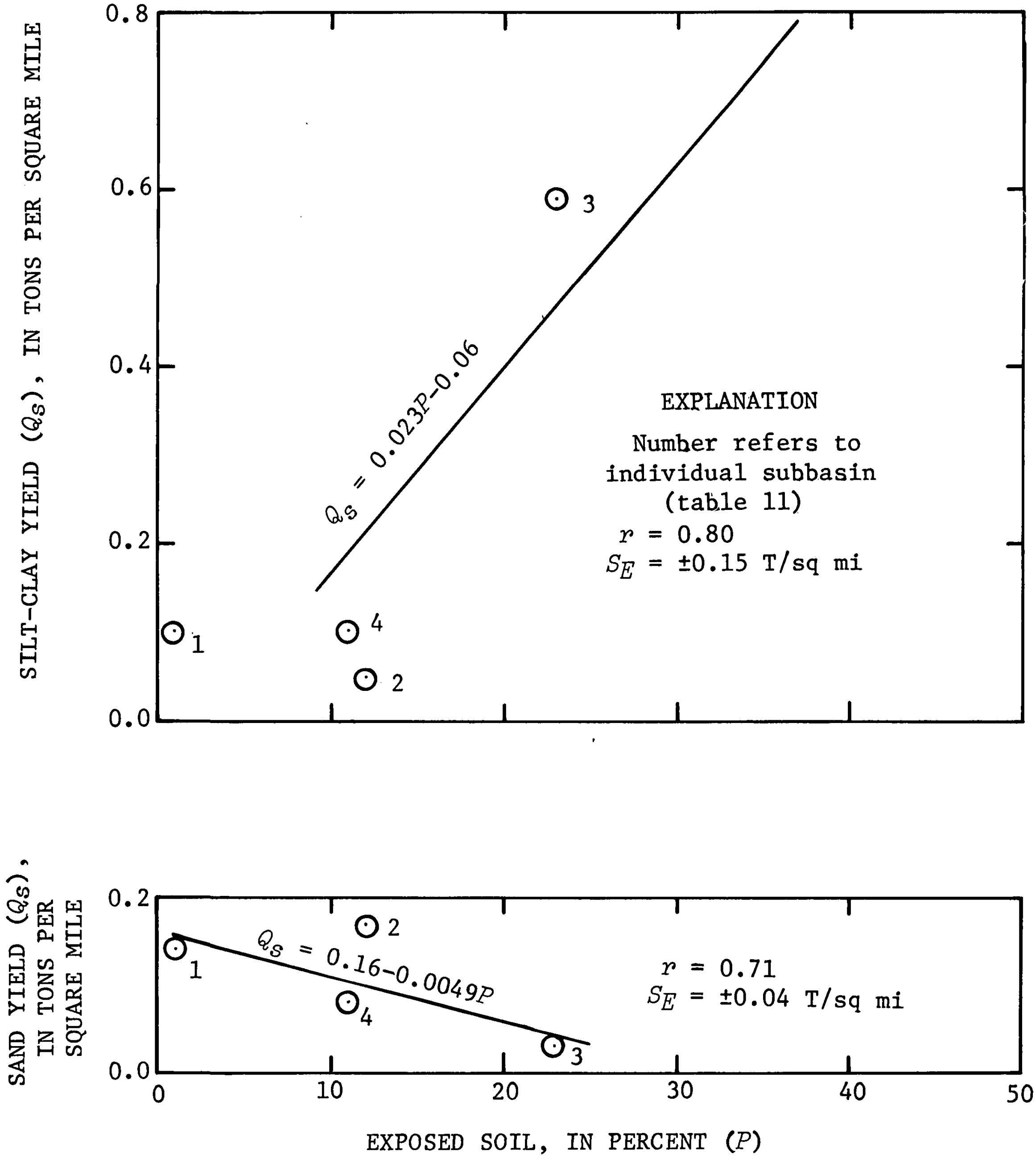


FIGURE 18.--Relation of sediment yield (during a small storm on January 23, 1970) to exposed soil in subbasins in the Colma Creek basin.

Figure 19 shows the relation of sediment yield to exposed soil for two moderate storm events where rainfall and runoff characteristics were comparable. Substantial reductions in sediment yield were observed for two of the subbasins (designated in fig. 19 as 3 and 4) between 1969 and 1970. These reductions resulted when a large part of the exposed-soil areas were converted to urban use or reestablished with vegetation. Data for both storms (fig. 19) show a general trend for an increase in sediment yield with increased exposed soil A considerable variation exists, however, in the distribution of points relative to the average regression line. Data points for construction areas generally lie above the regression line and data points for agricultural areas generally fall below the line.

Figure 20 shows the relation of sediment yield to exposed soil for the large storm of February 11, 1969. Regression data for this storm have better correlation coefficients (0.93 to 0.99) than data for small or moderate storms.

Silt-clay yields from the area between the Guadalupe Canyon and B Street stations were exceptionally low during each of the monitored storm events. A subsequent inspection of this area indicated that silt-clay material was extremely low in the agricultural soils. A single sample of agricultural soil contained 2 percent silt-clay, 97 percent sand, and 1 percent granules. Although one sample is not considered representative of the entire area, it does indicate that areas deficient in silt- and clay-size sediment exist upstream from the B Street station. Visits to other agricultural areas in the Colma Creek basin indicated that silt-clay material was much more prevalent than in the area upstream from B Street. The composition of cultivated soils throughout the basin was estimated to be about 70 percent sand and 30 percent silt-clay.

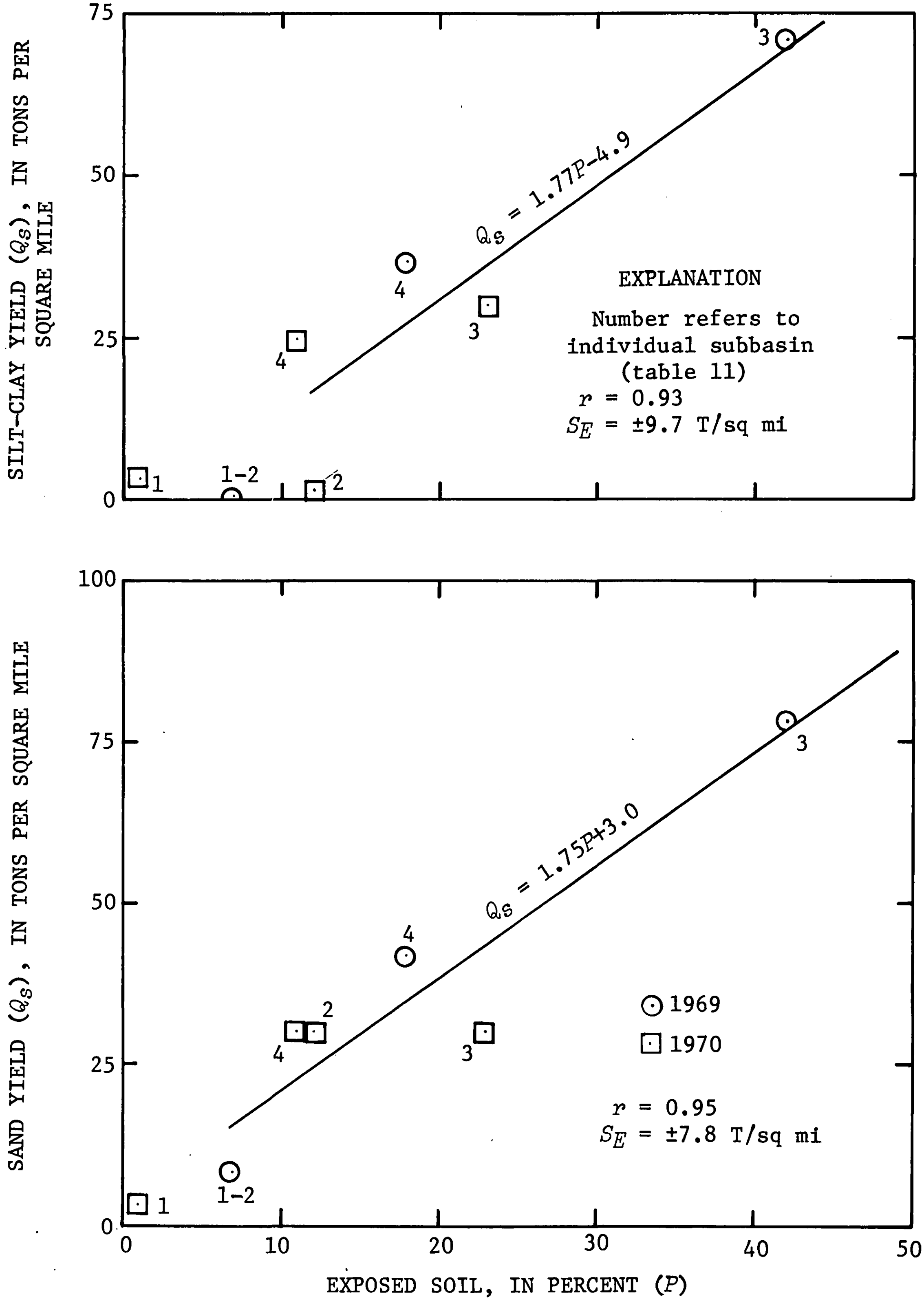


FIGURE 19.--Relation of sediment yield (during moderate storms of January 20, 1969, and February 16, 1970) to exposed soil in subbasins in the Colma Creek basin.

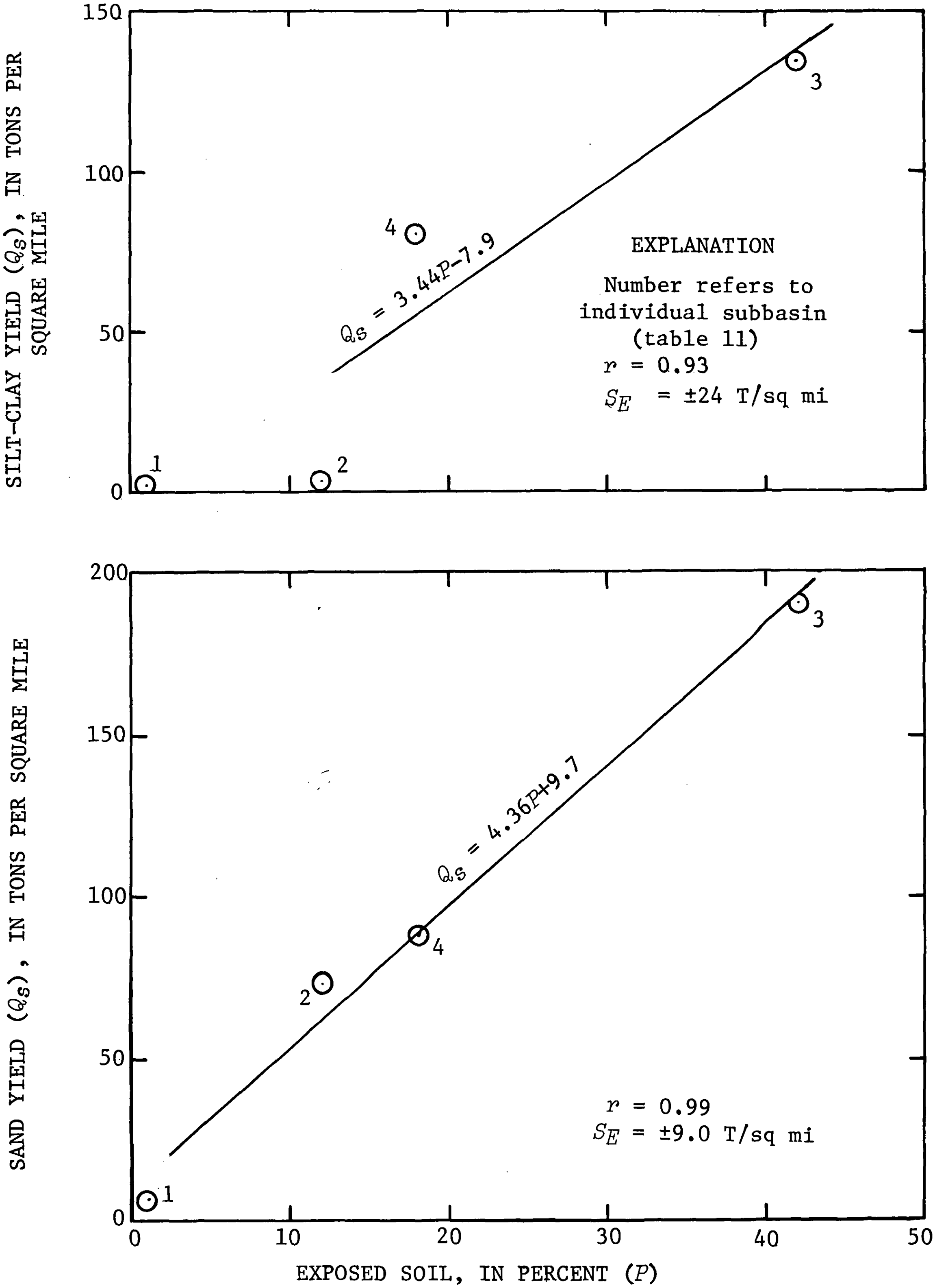


FIGURE 20.--Relation of sediment yield (during a large storm on February 11, 1969) to exposed soil in subbasins in the Colma Creek basin.

The quantity of sand (tons per square mile) transported from construction and agricultural areas (table 12) during moderate and large storms was computed from regression equations (extrapolated to 100 percent exposed soil). Silt-clay yields shown for agricultural areas in table 12, however, were adjusted to one-half of the computed value, because the silt-clay discharge observed from agricultural lands (upstream from the B Street index station) were substantially less than those computed from the regression equation.

TABLE 12.--*Estimated sediment yield for various types of land use in Colma Creek basin (1969-70)*

Storm size	Land use	Sediment yield					
		Total		Sand		Silt-clay	
		Tons per sq mi	Index[1]	Tons per sq mi	Index[1]	Tons per sq mi	Index[1]
Moderate	Open space	4.3	1.0	2.6	1.0	1.7	1.0
	Urban	10	2.3	5.6	2.2	4.7	2.8
	Agriculture	270	63	180	69	90	53
	Construction	350	81	180	69	170	100
Large	Open space	9.0	1.0	6.4	1.0	2.6	1.0
	Urban	23	2.6	14	2.2	8.7	3.3
	Agriculture	620	69	450	70	170	65
	Construction	790	88	450	70	340	130

[1]Sediment yield index for open-space areas expressed as unity.

Urban areas.--The quantity of sediment derived from established urban areas in the Colma Creek basin was small compared to that of exposed-soil areas. Observations of gutter flow during storm events indicated that sediment concentrations were low (100-200 milligrams per liter) and that most of the sediment appeared to be sand-size material washed from roadways. Residential areas seemed to be reasonably free of litter, although a significant quantity of urban debris such as toys, brush clippings, cans, and lumber was observed at index stations downstream from urban areas. Some of the urban debris was relatively large in size and could not be sampled with available equipment. This debris was not included as part of reported sediment yields.

Sediment yields, representative of urban areas, could not be determined accurately by direct measurement, because some mixing of runoff from exposed-soil areas was encountered at each sampling site. Sediment yields for typical urban areas in the basin were estimated for an average land-use composition of 75 percent open land, 23 percent impervious surface, and 2 percent exposed soil. The fraction of the basin covered by impervious surfaces was assumed to contribute no sediment.

Annual Sediment Yield

The annual quantity of sediment transported from various land-use areas (table 13) was computed by prorating the annual sediment yields at the Colma Creek gaging station during 1969 and 1970 on the basis of sediment yield indexes characteristic of moderate to large storms and the distribution of land use upstream from the gaging station. Because index data were comparable for different storm sizes, a series of composite sediment-yield indexes were assigned for average sediment-transport conditions:

Land use	Sediment transported	Sediment yield index
Open space	Sand	1.0
Urban	Sand	2.2
Agriculture	Sand	70
Construction	Sand	70
Open space	Silt-clay	1.0
Urban	Silt-clay	3.0
Agriculture	Silt-clay	60
Construction	Silt-clay	120
Open space	Total	1.0
Urban	Total	2.4
Agriculture	Total	65
Construction	Total	85

TABLE 13.--*Annual sediment yields from different land-use areas upstream from the Colma Creek gaging station*

Year	Land use		Sediment yield					
			Total		Sand		Silt-clay	
	Type	Percent	Tons	Tons per sq mi	Tons	Tons per sq mi	Tons	Tons per sq mi
1969	Open space	41	2,000	452	1,310	296	689	156
	Urban	40	4,820	1,120	2,800	648	2,020	468
	Agriculture	5	16,190	30,000	11,150	20,600	5,040	9,330
	Construction	14	59,470	39,300	31,230	20,600	28,240	18,700
	Total[1]	100	82,500	7,640	46,500	4,310	36,000	3,330
1970	Open space	42	1,410	311	995	219	411	91
	Urban	46	3,750	755	2,400	483	1,350	272
	Agriculture	4	8,990	20,800	6,640	15,400	2,350	5,440
	Construction	8	22,660	26,200	13,270	15,400	9,390	10,900
	Total[1]	100	36,800	3,410	23,300	2,160	13,500	1,250

[1]Computed from table 7.

Annual yields from land-use areas were computed from the equation:

$$Y_{(o,u,a,c)} = \frac{XI_{(o,u,a,c)}P_{(o,u,a,c)}}{I_oP_o+I_uP_u+I_aP_a+I_cP_c}$$

where Y = the annual sediment yield from a specific land-use area, in tons,
X = the annual yield at the Colma Creek gaging station, in tons,
I = the sediment yield index, and
P = the percentage of a specific land use upstream from the gaging station.

The subscripts o, u, a, and c refer to the type of land use (open space, urban, agriculture, or construction). These annual yields are given in table 13.

Construction areas, representative of 14 percent of the basin, contributed 59,000 tons or 72 percent of the sediment transported from areas upstream from the Colma Creek gaging station in 1969. About 17,000 tons of sediment transported from these areas were trapped in debris basins. Agricultural areas contributed 16,000 tons of sediment (20 percent), none of which was deposited in debris basins. Urban and open-space areas, representative of 81 percent of the basin, contributed 6,800 tons of sediment or about 8 percent of the total sediment yield.

In 1970, sediment yield from all areas was less than in 1969 because of reduced storm activity. Construction areas contributed 23,000 tons of sediment, of which about 12,000 tons was trapped in debris basins. Of the remaining sediment yield upstream from the Colma Creek gaging station, agricultural, urban, and open-space areas contributed 9,000, 3,800, and 1,400 tons, respectively.

Comparison of Estimated Annual Sediment Yields from Open-Space Areas with Sediment Yields from Selected Bay Area Streams

The validity of sediment-yield estimates from open-space areas in the Colma Creek basin was tested by comparing sediment yields for 1967, 1969, and 1970 (years when land-use percentages were determined) with concurrent data for sediment stations on streams in the San Francisco Bay area which are relatively undeveloped (table 14). Estimated sediment yields fall within the range of yields for other bay area streams, but large variations in runoff suggest that rainfall characteristics are quite different and that storm events may not be related. It is assumed that estimated yields are reasonable.

TABLE 14.--*Comparison of sediment yield from open-space areas in the Colma Creek basin with sediment yields from selected bay area streams*

Year	Sediment station	Drainage area (sq mi)	Runoff (acre-feet per sq mi)	Sediment yield (tons per sq mi)
1967	Uvas Creek above Uvas Reservoir, near Morgan Hill	21	1,020	2,290
	Coyote Creek near Gilroy	109	320	721
	Arroyo Valle near Livermore	147	155	1,000
	Alameda Creek near Niles	633	112	[1]454
	Open-space areas in Colma Creek basin	4.6	[2]669	780
1969	Uvas Creek above Uvas Reservoir, near Morgan Hill	21	1,820	1,140
	Coyote Creek near Gilroy	109	868	1,540
	Alameda Creek near Niles	633	174	[1]256
	Open-space areas in Colma Creek basin	4.4	[2]714	452
1970	Uvas Creek above Uvas Reservoir, near Morgan Hill	21	1,020	580
	Coyote Creek near Gilroy	109	328	179
	Alameda Creek near Niles	633	91.8	[1]137
	Open-space areas in Colma Creek basin	4.6	[2]532	311

[1]Yield reduced by reservoirs.
[2]Runoff per square mile at Colma Creek gaging station.

Prediction of Future Sediment Yields

An estimate of the quantity of sediment transported by Colma Creek when the basin is completely urbanized is of considerable importance in the planning of future dredging programs and in the design of flood-control facilities. For example, if insufficient storage is provided in stream channels for the deposition of sediment, particularly in low areas near San Francisco Bay, the capacity of Colma Creek to transport floodflows within the designed channels would be reduced and periodic flooding could occur. A knowledge of the quantity of sediment transported during average storm periods is needed also to estimate future average maintenance costs.

Future sediment yields for the Colma Creek basin were estimated by (1) determining sediment yields, characteristic of different land-use types for various periods in a year of average rainfall (table 15) and in a year of extremely high rainfall (table 16), and (2) applying these yields to future land-use distributions to determine the quantity of sediment that would be transported during similar storm events if the basin were fully urbanized. Sediment yields, in weight units, were converted to volume using the relation proposed by Lara and Pemberton (1965) for riverbed sediment and unit weight coefficients of 60, 73, and 97 pounds per cubic foot for clay, silt, and sand, respectively. These coefficients were compiled from 187 samples collected in 21 reservoirs in the United States. A composite unit weight coefficient of 66 pounds per cubic foot was used for silt-clay yields.

TABLE 15.--*Sediment yields for different types of land use during a year of average rainfall (1970)*

Period	Rainfall at San Francisco Airport (inches)	Land use	Sediment yield[1] Total	Sand	Silt-clay	Total	Sand	Silt-clay
			(Tons per sq mi)			(Cubic yards per sq mi)		
Daily maximum	2.09	Open space	72	55	17	61	42	19
		Urban	170	120	50	150	93	56
		Agriculture	4,900	3,900	1,000	4,100	3,000	1,100
		Construction	5,900	3,900	2,000	5,200	3,000	2,200
Daily mean for storm season (November-to March)	.13	Open space	1.8	1.3	.5	1.6	1.0	.6
		Urban	4.5	2.9	1.6	4.0	2.2	1.8
		Agriculture	130	94	32	110	72	36
		Construction	160	94	65	150	72	73
Weekly maximum	4.07	Open space	100	77	28	90	59	31
		Urban	250	170	84	220	130	94
		Agriculture	7,100	5,400	1,700	6,000	4,100	1,900
		Construction	8,800	5,400	3,400	7,900	4,100	3,800
Monthly maximum	8.33	Open space	150	110	44	140	87	49
		Urban	380	250	130	350	190	150
		Agriculture	11,000	8,000	2,700	9,100	6,100	3,000
		Construction	13,000	8,000	5,300	12,000	6,100	5,900
Year	19.56	Open space	310	220	91	270	170	100
		Urban	760	480	270	680	370	310
		Agriculture	21,000	15,000	5,400	18,000	12,000	6,100
		Construction	26,000	15,000	11,000	24,000	12,000	12,000

[1]Based on sediment yield indexes and percentage of land use upstream from Colma Creek gaging station in 1970 (open space, 42 percent; urban, 46 percent; agriculture, 4 percent; construction, 8 percent).

TABLE 16.--*Sediment yields for different types of land use during a year of extremely high rainfall (1967)*

Period	Rainfall at San Francisco Airport (inches)	Land use	Sediment yield[1] Total	Sand	Silt-clay	Total	Sand	Silt-clay
			(Tons per sq mi)			(Cubic yards per sq mi)		
Daily maximum	4.07	Open space	180	120	58	160	92	65
		Urban	430	260	170	400	200	200
		Agriculture	12,000	8,400	3,500	10,000	6,400	3,900
		Construction	15,000	8,400	7,000	14,000	6,400	7,800
Daily mean for storm season (Nov.-Mar.)	.16	Open space	4.4	2.8	1.6	4.0	2.2	1.8
		Urban	11	6.2	4.9	10	4.7	5.5
		Agriculture	300	200	98	260	150	110
		Construction	400	200	200	370	150	220
Weekly maximum	7.58	Open space	280	190	95	250	140	110
		Urban	710	420	290	640	320	320
		Agriculture	19,000	13,000	5,700	16,000	10,000	6,400
		Construction	24,000	13,000	11,000	23,000	10,000	13,000
Monthly maximum	10.43	Open space	380	250	130	340	190	150
		Urban	940	550	390	860	420	440
		Agriculture	26,000	18,000	7,800	22,000	13,000	8,800
		Construction	34,000	18,000	16,000	31,000	13,000	18,000
Yearly	30.75	Open space	780	490	290	710	380	330
		Urban	2,000	1,100	880	1,800	830	990
		Agriculture	53,000	35,000	18,000	46,000	26,000	20,000
		Construction	70,000	35,000	35,000	66,000	26,000	40,000

[1]Based on sediment yield indexes and percentage of land use upstream from Colma Creek gaging station in 1967 (open space, 42 percent; urban, 38 percent; agriculture, 5 percent; construction, 15 percent).

Data given in tables 15 and 16 can be used to estimate the quantity of sediment transported during various periods if the distribution of land use in the basin is known or assumed. Sediment yield for a particular area is computed by the equation:

$$Y = \frac{A}{100}(P_oY_o+P_uY_u+P_aY_a+P_cY_c)$$

where Y = sediment yield during a specified period, in tons or cubic yards,
A = drainage area, in square miles,
P_o = percentage of the area covered by a particular type of land use, and
Y_o = appropriate sediment yield for a specific land use given in table 15 or 16, in tons, or cubic yards, per square mile per period.

o, u, a, c are subscripts referring to the particular land use. For example, during 1970 the distribution of land use in the entire Colma Creek basin was 37 percent open space, 54 percent urban, 3 percent agriculture, and 6 percent construction. Sediment yield (in tons) during an average year would be:

$$Y_{\text{average annual}} = \frac{16.3}{100}(37\text{x}310+54\text{x}760+3\text{x}21{,}000+6\text{x}26{,}000) = 44{,}000 \text{ tons}$$

and the maximum annual sediment yield would be:

$$Y_{\text{maximum annual}} = \frac{16.3}{100}(37\text{x}780+54\text{x}2{,}000+3\text{x}53{,}000+6\text{x}70{,}000) = 120{,}000 \text{ tons}$$

The foregoing example is only one of many possible combinations of land use which may be representative of the Colma Creek basin from the present (1970) to complete urbanization. Because many combinations of final land use are possible, sediment yields for various periods were computed for two hypothetical combinations of land use that include a range of solutions.

The first combination, representative of complete urbanization (table 17), is based on the assumption that eventually 65 percent of the basin will be urbanized and that 35 percent of the basin will be utilized as open space. No large areas of exposed soil will exist. Annual sediment yields for the Colma Creek basin under these conditions will probably range from 9,700 to 25,000 tons (8,800 to 23,000 cubic yards). Sand yield, the type of sediment most likely to deposit in stream channels, will range from 6,300 to 14,000 tons per year. The silt-clay yield, which will largely be transported into San Francisco Bay (Knott, 1969), will range from 3,400 to 11,000 tons per year. A large fraction of the annual sediment yield will be transported in relatively short periods during extreme storm events. The maximum quantity of sediment transported during daily, weekly, and monthly periods will account for about 25, 35, and 50 percent of the annual yield.

TABLE 17.--*Sediment yields for selected time intervals in the Colma Creek basin after development assuming complete urbanization (65 percent urban and 35 percent open space)*

Storm activity during year	Time interval	Sediment yield					
		Total	Sand	Silt-clay	Total	Sand	Silt-clay
		(Tons)			(Cubic yards)		
Average	Daily maximum	2,200	1,600	630	1,900	1,200	700
	Daily average[1]	58	38	20	51	29	22
	Weekly maximum	3,200	2,200	1,000	2,900	1,700	1,200
	Monthly maximum	4,900	3,300	1,600	4,400	2,500	1,900
	Year	9,700	6,300	3,400	8,800	4,900	3,900
Extremely wet	Daily maximum	5,500	3,400	2,100	5,100	2,600	2,500
	Daily average[1]	140	82	61	130	62	69
	Weekly maximum	9,100	5,500	3,600	8,200	4,200	4,000
	Monthly maximum	12,000	7,300	4,900	10,000	5,500	5,000
	Year	25,000	14,000	11,000	23,000	11,000	12,000

[1]During storm season (November through March).

A second possible combination of land use is based on the assumption that the basin will be completely urbanized except for the agricultural areas existing in 1970 (table 18). The basin will consist of 62 percent urbanized area, 35 percent open space, and 3 percent agriculture (cultivated land) or exposed soil. The annual quantity of sediment transported will range from 19,000 tons in an average year to 50,000 tons in an extremely wet year. The large difference in sediment yield between land-use combinations in tables 17 and 18 indicates that the total yield of the Colma Creek basin is extremely sensitive to small percentages of exposed-soil area (agriculture and construction).

TABLE 18.--*Sediment yields for selected time intervals in the Colma Creek basin after development, assuming 62 percent urban, 35 percent open space, and 3 percent agriculture*

Storm activity during year	Time interval	Sediment yield					
		Total	Sand	Silt-clay	Total	Sand	Silt-clay
		(Tons)			(Cubic yards)		
Average	Daily maximum	4,500	3,400	1,100	3,800	2,600	1,200
	Daily average[1]	120	83	35	100	63	39
	Weekly maximum	6,600	4,800	1,800	5,800	3,700	2,100
	Monthly maximum	10,000	7,100	2,900	8,700	5,400	3,300
	Year	19,000	13,000	5,900	18,000	11,000	6,700
Extremely wet	Daily maximum	11,000	7,400	3,800	10,000	5,700	4,300
	Daily average[1]	290	180	110	250	130	120
	Weekly maximum	18,000	12,000	6,300	16,000	8,900	7,000
	Monthly maximum	24,000	16,000	8,500	22,000	12,000	9,600
	Year	50,000	31,000	19,000	45,000	23,000	22,000

[1]During storm season (November through March).

SUMMARY AND CONCLUSIONS

In recent decades, urbanization has exerted an increasing impact on the hydrologic system of the Colma Creek basin and, inevitably, certain changes in the system have occurred. As of 1970, 54 percent of the entire basin was urbanized and 6 percent was under construction. This report describes some of the changes in water and sediment discharge that coincided with a period of major urban expansion (1964-71). Relations between sediment yield and land use that occurred in 1969 and 1970 are evaluated and used to estimate future sediment yields for the basin when it becomes completely urbanized.

Storm runoff characteristics of Colma Creek at South San Francisco probably changed during the study period (table 5). Also, analysis of rainfall and runoff data for 72 storm events indicated that a larger fraction of rainfall was discharged as runoff, probably because of urbanization, although an increase in peak flow relative to antecedent rainfall was not detectable between 1964 and 1971. Streamflow data, obtained simultaneously at several tributary sites within the basin, indicated that storm runoff from highly urbanized or developing areas was generally more than twice that of undeveloped areas.

The relation between suspended-sediment and water discharge of Colma Creek at South San Francisco was relatively uniform from 1966 to 1969. In 1970, however, the rate decreased sharply in response to reductions in upstream construction activity. A significant quantity of sediment transported from upstream areas is deposited in various debris basins. Data obtained from surveys of the largest debris basins suggested that these facilities trap from 25 to 45 percent of the annual sand yield and from 14 to 21 percent of the annual silt-clay yield. Total-sediment yield upstream from the Colma Creek gaging station ranged from 3,400 to 14,000 tons per square mile during 1966-70.

Sediment discharge rates of Spruce Branch at South San Francisco were relatively stable in 1966-67, but increased sharply in 1968 and 1969 owing to increased construction activity and to sediment losses from a debris basin which was breached several times during large storms. Annual suspended-sediment yield upstream from the Spruce Branch gaging station ranged from 2,800 to 39,000 tons per square mile during the period 1966-69.

The quantity of sediment derived from different source areas in the basin is extremely variable. Most of the variability is related to land use. Sediment yields from construction and agricultural areas are 85 to 65 times greater than yields from undeveloped or open-space areas. Yields from agricultural areas, however, are probably representative of maximum rates, because sediment movement generally occurs during the winter season when vegetal cover is at a minimum and because land slopes are large (5-15 percent).

Future sediment yields of the Colma Creek basin will undoubtedly be lower than yields observed during the study period when construction activity was high. If the basin becomes completely urbanized (65 percent urban and 35 percent open space), it is probable that sediment yields for the entire basin will range from 9,700 tons in a year of average rainfall to 25,000 tons in a year of extremely high rainfall. Sediment yields for average or extremely high rainfall periods, for conditions less than complete urbanization, can be estimated from equations based on sediment-yield indexes for various types of land use and the percentage of land use.

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SEDIMENT YIELDS IN COLMA CREEK BASIN AFFECTED BY URBAN DEVELOPMENT

Greatly accelerated erosion and sedimentation have resulted from conversion of a typical small watershed from its original state to urban development, according to a recently released report by the U. S. Geological Survey, Department of the Interior. Such accelerated sedimentation clogs storm drains, causes increased flooding, and generally detracts from the quality of the environment. The study of the Colma Creek basin in northern San Mateo County indicates that sediment yields in areas under construction increased as much as 85 times the rate under natural conditions. Now that urbanization of the basin is largely complete, sediment yields are expected to decline substantially in the next decade (1971-80).

The 8-year study documents changes in water and sediment discharge that occurred during a period of major urban expansion (1964-1971) and provides a projection of what the sediment yield will be when the basin is fully urbanized. Sediment yield represents the amount of material that has eroded from the landscape and moved into the nearby waterways.

"Any changes in the landscape can have some effect on the natural processes", said J. M. Knott, hydrologist with the Geological Survey and author the report, "and erosion, sedimentation and flood levels can be especially susceptible to such changes. We've used standard measurements on the streams in the basin to give us an objective look at the problem."

"The total yield of the Colma Creek basin is extremely sensitive to small percentages of exposed soil area, such as construction and crop areas," said Knott. In 1967, an extremely wet year when construction activity was high, the sediment yield at the Colma Creek gaging station was 14,000 tons per square mile compared to sediment yields of 450 to 2,300 tons per square mile for several streams that drain undeveloped areas in the bay region.

Colma Creek drains a 16.3 square mile area on the east side of the San Francisco Peninsula. The area is bounded by San Bruno Mountain on the north, and by Skyline Ridge on the southwest. In 1946 about 85 per cent of this area was in open space, but by 1970 54 per cent was urbanized, 6 per cent was under construction, 37 per cent was in open space, and 3 per cent was used for agriculture. During the later part of this decade, land use is expected to stabilize, with 62 per cent urban, 35 per cent open space, and 3 per cent agricultural.

Because only part of the basin was urbanized, it was possible to compare the amount of sediment being eroded from areas of contrasting land use. Knott found that urbanized areas produced about twice the sediment yield as undeveloped ("open space") areas, agricultural areas produced 65 times as much, and areas under construction produced 85 times as much sediment yield as open-space lands. In 1970 the total sediment yield for the basin decreased significantly in response to reduced construction activity.

When the basin becomes completely urbanized (65 per cent urban and 35 per cent open space), it is probable that annual sediment yields will range from 600 tons per square mile in a year of average rainfall, to 1,500 tons per square mile in a year of extremely high rainfall.

Storm runoff increased between 1964 and 1970 by about 30 per cent. This is a common effect of urbanization--as the ground is covered by paving and rooftops, less rainfall is allowed to seep into the earth. However, no significant change in peak flow or flood height was detected near the mouth of the stream over the time span, probably because the installation of debris basins allowed some storm waters to be captured upstream and released gradually.

"Colma Creek is extremely sensitive to small amounts of rainfall," said Knott. "Moderate runoff generally results from a rainfall of less than one-tenth inch per hour."

Knott found it useful to compare storm runoff data for contrasting land uses. "During several moderate to large storms, runoff from urbanized areas unaffected by debris basins ranged from 2 to 7 times the amount of runoff from undeveloped areas," he said. This produced peak flows in the streams that were 3 to 11 times higher from urban areas than for streams draining undeveloped areas.

"Since the early development of the basin, the frequency of flooding along Colma Creek has increased," said Knott. "Large quantities of sediment have been eroded from the highlands and deposited along flat reaches of the stream channels. Sandy sediment fills the streams channels early in the storm season and extensive dredging is required to prevent subsequent flooding." The smaller clay particles, perhaps one-half of the total sediment yield, are carried on out into San Francisco Bay.

The 54-page report, prepared in cooperation with the County of San Mateo, is titled, "Effects of Urbanization on Sedimentation and Floodflows in Colma Creek basin, California." It is being distributed by the San Francisco Bay Region Environment and Resources Planning Study, and may be obtained from:

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