Effect of Urban Growth on Streamflow Regimen of Permanente Creek Santa Clara County California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1591-B

Prepared in cooperation with the California Department of Water Resources

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By E. E. HARRIS *and* S. E. RANTZ

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EFFECT OF URBAN GROWTH ON STREAMFLOW REGIMEN OF PERMANENTE CREEK, SANTA CLARA COUNTY CALIFORNIA

By E. E. Harris and S. E. Rantz

ABSTRACT

This report presents the results of an investigation of the effect of urban growth on the streamflow regimen of Permanente Creek in Mountain View, Santa Clara County, Calif. The data available did not permit a complete study of all hydrologic aspects, but there is conclusive evidence that the volume of storm runoff produced by rainfall on the valley floor has increased substantially as a result of urbanization. In 1945, storm runoff from the 5.12-square mile project area was insufficient to balance channel losses, and the streamflow entering the project area in the Permanente Creek channel was greater than that leaving the area. If, however, total outflow from the project area is considered to be the sum of the streamflow leaving the area plus channel seepage in the area, the ratio of total outflow to inflow was 1.18. By 1958, storm runoff from the project area was far in excess of channel losses and the ratio of total outflow to inflow was 1.70. This increase in outflow is attributed to the fact that urban development during the period 1945 to 1958 increased the extent of impervious surface in the project area from about 4 percent to 19 percent.

The effect of urban growth in other basins in Santa Clara County should be investigated before any attempt is made to project the quantitative results of this study to other areas in the county.

INTRODUCTION

PURPOSE AND SCOPE

Santa Clara Valley has experienced a tremendous increase in population in the last twenty years, and particularly in the last decade. As with all rapidly growing communities, its water problems have grown accordingly. In recognition of this growth, county and independent water agencies were organized to deal with the increasing problems of pollution, flood control, water conservation, and the development of distribution systems for the increased domestic and commercial demands. Because much of the land that was predominantly agricultrual has been converted to residential and commercial use, there has been an increase in impervious surface area; one of the prime concerns of the water agencies has been the impact of this urban growth on the natural recharge of ground water and on the adequacy of storm-drainage facilities. There is reason for concern. Studies in other parts of the country have shown that an increase in intensity and volume of storm runoff generally accompanies an increase in urban growth (Savini and Kammerer, 1961). The availability of streamflow data for the Permanente Creek basin in the northwestern part of Santa Clara Valley affords an opportunity to study one facet of the effect of urbanization in the valley, namely, the resulting change in volume of storm runoff.

The Santa Clara Valley Water Conservation District, in connection with the development and management of water resources in the valley, installed three gaging stations in the Permanente Creek basin in 1939. Two of the stations, one on Permanente Creek and the other on Magdalena Creek, a tributary, are located at sites where the streams enter the valley. (See figs. 1 and 2.) That part of the basin upstream from these gaging stations (Nos. 32 and 33) is referred to in this report as the index area. The downstream gaging station (No. 34) on Permanente Creek at the California Street bridge in the city of Mountain View is 1 mile downstream from the mouth of Magdalena Creek. That part of the basin downstream from the index area and upstream from station 34 is referred to in this report as the project area. The Santa Clara Valley Water Conservation District established the three gaging stations to obtain a measure of the water recharging the underlying ground-water basin through the streambed in the project area. Stations 32 and 33 measure the streamflow entering the project area; station 34 measures the streamflow leaving the project area. No measurement of the sediment load of the streams has ever been made.

The index area, occupying 10.9 square miles, was predominantly rural in 1939, and has since experienced little change in land use. The project area, occupying 5.12 square miles, has become almost completely urbanized since 1939. This report describes the effect of this urban growth on the volume of storm runoff produced by rainfall in the project area. For reasons that are discussed later in the report, the study period covered the years 1945–58.

ACKNOWLEDGMENTS

The study described in this report was made under a cooperative agreement between the U.S. Geological Survey and the California Department of Water Resources. The report was prepared under the general supervision of Walter Hofmann, district engineer of the Surface Water Branch of the Geological Survey.

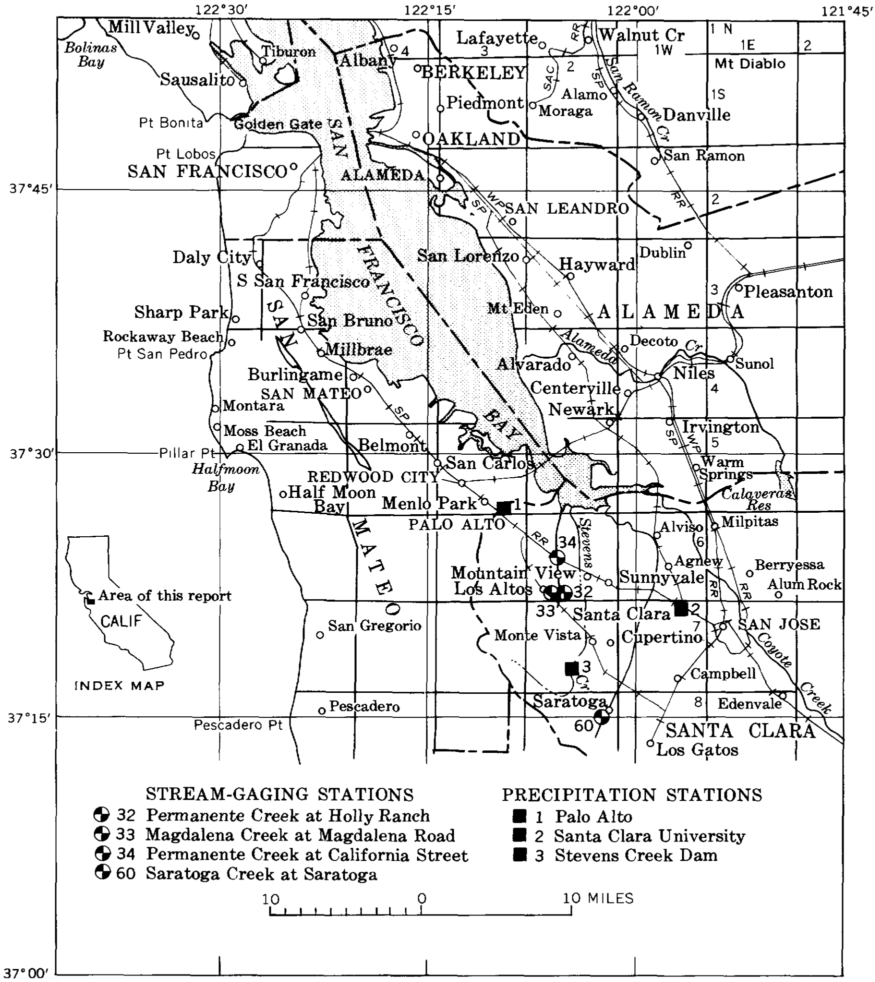

FIGURE 1.—Index map of southern San Francisco Bay area.

The cooperation of the Santa Clara Valley Water Conservation District in furnishing the streamflow and ground-water data used in this study is gratefully acknowledged.

DESCRIPTION OF BASIN

Permanente Creek heads in the Santa Cruz Mountains of west-central California and in its upper course flows eastward in accordance with the drainage pattern of streams in the San Andreas Rift zone. The creek then turns north and flows through the Santa Clara Valley into the south end of San Francisco Bay. Maximum altitude in the Permanente Creek basin in on Black Mountain, which rises to 2,810

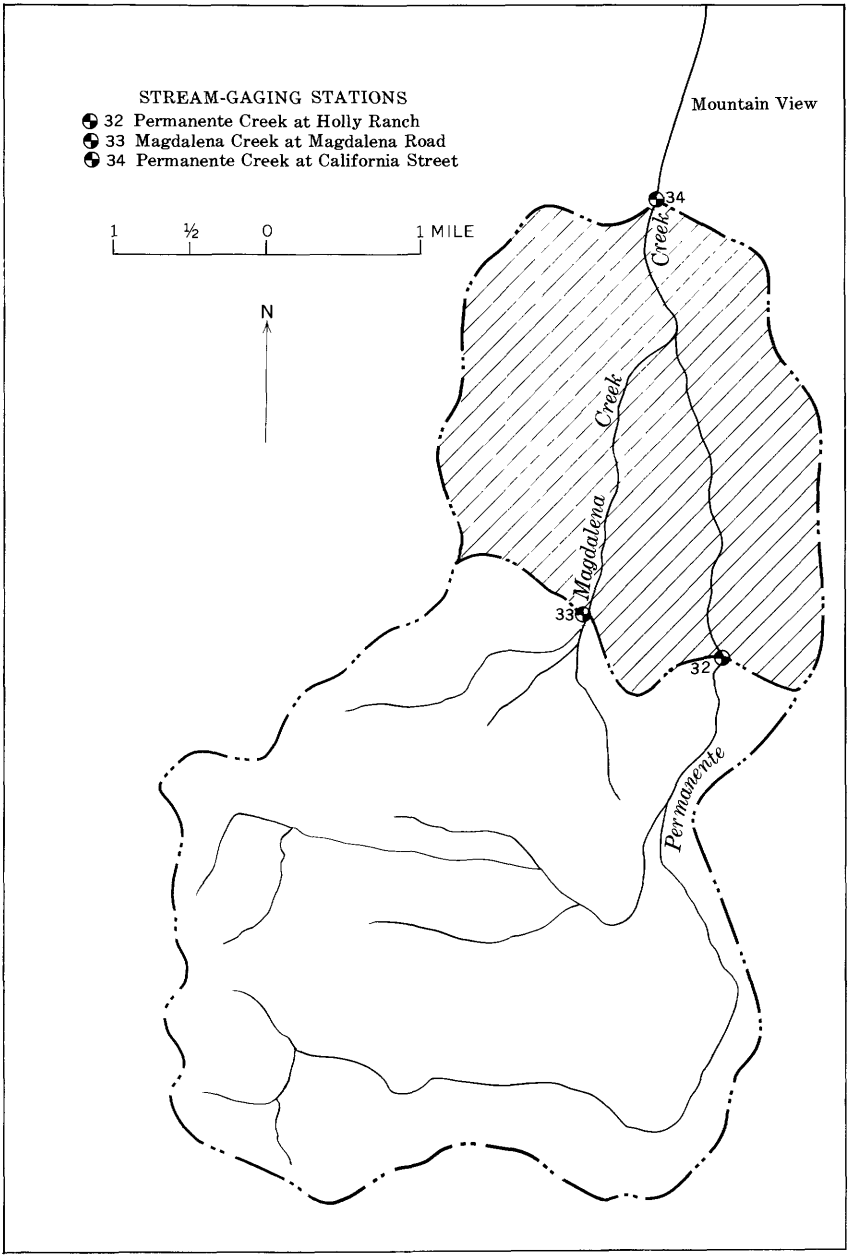

FIGURE 2.—Map of the Permanente Creek basin showing location of gaging stations. Project area shaded Base from Palo Alto quandrangle (1948).

feet. Magdalena Creek is a left-bank tributary that heads in the foothills of the Santa Cruz Mountains and flows into Permanente Creek on the valley floor in the city of Mountain View. Maximum altitude in the Magdalena Creek basin is 1,148 feet. The terrain in the upper basin is mountainous and the bed slope is steep. In the first 4.4 miles the stream falls 1,540 feet for an average gradient of 355 feet per mile. The slope decreases on the valley floor to 55 feet per mile and becomes very flat near the mouth. The total drainage area of Permanente Creek is 17.5 square miles.

The upper part of the basin is underlain by bedrock consisting principally of consolidated sedimentary rocks but which includes minor areas of metamorphic and igneous rock. Overlying this consolidated bedrock is the Santa Clara Formation, which consists of semiconsolidated conglomerate, sandstone, siltstone, and claystone. The conglomerate and sandstone are poorly sorted and have a fine-grained matrix; thus, the formation has a low permeability and yields only small to moderate quantities of water to wells. Within the valley proper, unconsolidated alluvial and bay deposits of clay, sand, and gravel overlie the Santa Clara Formation and form the valley floor. As shown by well logs, the alluvial and bay deposits attain a thickness of 1,000 feet or more in the valley trough. However, the lower parts of these wells may be in the Santa Clara Formation, which to date has not been differentiated from the overlying unconsolidated alluvium in drill holes (Poland and Green, 1962, p. 2).

HYDROLOGY OF BASIN

PRECIPITATION

The Santa Clara Valley lies within the path of storms which periodically sweep inland from the North Pacific during winter months. Rainfall resulting from these storms ranges from moderate to heavy, and direct precipitation provides a substantial part of the water supply of the area. More than 80 percent of the seasonal precipitation in the Santa Clara Valley occurs during the 5 months from November through March. The remaining months of the year are correspondingly dry, and only traces of rainfall occur in July and August (California State Water Resources Board, 1955, p. 23, 26).

There are no precipitation stations within the Permanente Creek basin, but stations are operated nearby at Palo Alto, Santa Clara University, and Stevens Creek Dam (fig. 1). The first two stations are part of the climatological network of the U.S. Weather Bureau; the precipitation station at Stevens Creek Dam is operated by the Santa Clara Valley Water Conservation District. Because virtually all the precipitation in the basin occurs during general storms that cover large areas, records for any one of the precipitation stations were considered adequate for use as an index of runoff. The Palo Alto station was chosen for this purpose, primarily because it is equipped with a recording rain gage and therefore provides a convenient record of the calendar dates on which rainfall occurred.

The Palo Alto station is now 5 miles northwest of Mountain View at an altitude of 23 feet, but prior to 1953 the station was 6 miles northwest of Mountain View at an altitude of 54 feet. A double mass-curve comparison of annual precipitation recorded at Palo Alto and at Santa Clara University indicated that there is virtually no inconsistency in the precipitation catch at the two Palo Alto sites. Double mass-curve analysis is discussed in some detail on p. 17.

GROUND WATER

The effect of urban growth on ground-water recharge in the project area was not studied. The numerous, roughly parallel streams of the Santa Clara Valley form one large coalescing alluvial fan, and it is therefore not practicable to attempt to isolate the effect of a change in land use in a single small stream basin. The ground-water aquifer is artificially recharged throughout the valley, but heavy pumping has kept the water table low, and Permanente Creek loses water through channel seepage as it flows through the valley. Records of the elevation of the ground water table obtained at four wells in the basin indicate the water table to be 150 to 300 feet below ground elevation in the project area. Inspection of the streamflow records gives no indication of any general alteration of the influent characteristics of the stream channel during the period studied.

SURFACE WATER

The upstream reaches of Permanente and Magdalena Creeks traverse a fairly impermeable mountainous area but have some flow all year except during dry years. After leaving the mountains, the streams become influent in the loosely consolidated alluvial material of the valley and lose water through the permeable streambed. The creeks flow in the valley only during and shortly after winter storm periods.

The streamflow records for the three gaging stations in the Permanente Creek basin (fig. 2) were reviewed and daily discharge hydrographs were compared. Examination of the rating curves for these alluvial channels showed that the ratings are not precisely defined at extreme high-water stages, and therefore no detailed study of instantaneous peak flows was made. The rating curves are sufficiently well defined, however, to permit a study of the volume of flood runoff, the bulk of which occurs at medium high stages.

All three stream-gaging stations were established in 1939 when the

Santa Clara Valley Water Conservation District installed staff gages that were read twice daily. In March 1944, station 34, where runoff from the project area is measured, was equipped with a recording gage, and in April 1945 recording gages were installed at stations 32 and 33, where runoff from the index area is measured. Because the runoff records became more reliable after installation of the recording gages, a test was made to determine if the Permanente Creek records prior to April 1945 were reasonably consistent with those obtained after that date. Double mass-curve analysis was used in the test.

A double mass curve is constructed by plotting cumulative totals of the variable being tested against cumulative totals of a second, or reference, variable, a common period of time being used for both. A change in slope of a line fitted to the plotted points indicates and dates a change in trend of the relation between variables. As a prerequisite to the use of double mass-curve analysis, there must be a simple ratio between the variables that are plotted. Thus, if y is the variable being investigated and x is the reference variable, the relation of y to x must take one of the three following forms:

$$\frac{y}{x}=m;\ \frac{y}{x-a}=m;\ \frac{y-b}{x}=m.$$

These equations are obtained by fitting a straight line to a simple plot of the two variables, and in each equation m is the slope of the line. If the line passes through the point of origin of the graph, we have the first equation, $\frac{y}{x}=m$. If the line does not pass through the origin, there will be an x intercept at a and a y intercept at b, and either of the two remaining equations will apply. It is particularly important that the intercept, if any, be used in the double mass plot if a series of dry years precedes or follows a series of wet years. Failure to use the intercept under these circumstances will result in a break in slope of the double mass curve at the year marking the end of the wet or dry period, even when there has been no actual change in trend of the relation between variables. It is also true that in double mass-curve analysis results obtained are usually better when both x and y are either streamflow records or precipitation records than when one variable is streamflow and the other precipitation—a logical result of the fact that correlations of streamflow versus streamflow or precipitation versus precipitation are usually closer and more nearly linear than are correlations of streamflow versus precipitation.

Because streamflow comparisons are invariably more satisfactory than rainfall-runoff comparisons, a nearby unregulated stream having a sufficiently long discharge record was sought for double mass-curve comparison with Permanente Creek. Only Saratoga Creek met these

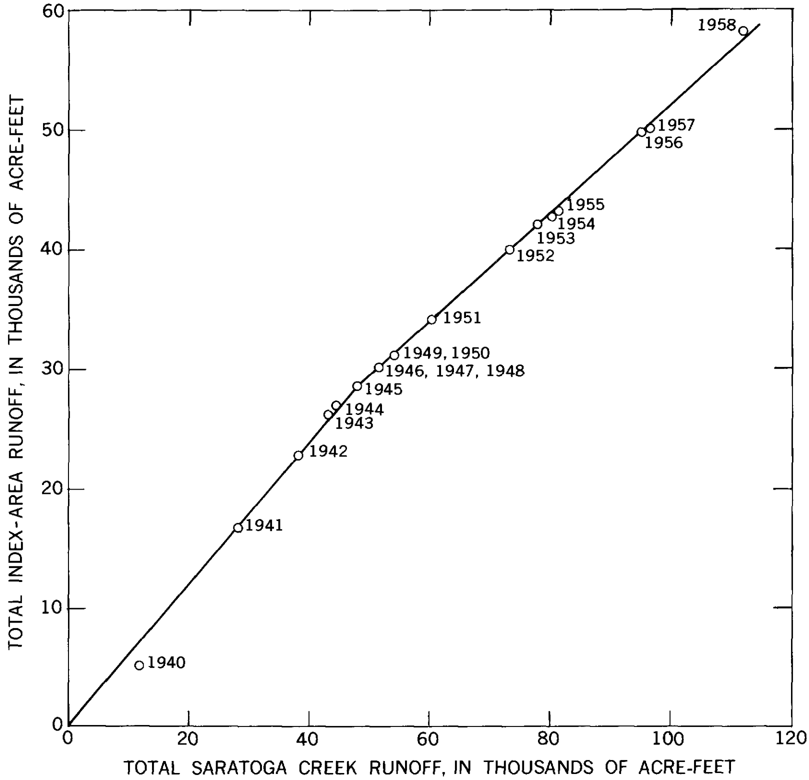

FIGURE 3.—Double mass curve of cumulative total annual runoff for index area (stations 32 and 33) and Saratoga Creek (minus 1,800 acre-ft), 1940–58.

qualifications concerning proximity, nonregulation, and length of record. Actually there is a diversion for municipal supply upstream from the Geological Survey gaging station on Saratoga Creek near Saratoga (station 60, fig. 1), but a record of monthly diversions is available. Table 1 lists annual runoff for the gaging stations in the Permanente and Saratoga Creek basins. Column 4 of the table is the combined runoff at stations 32 and 33, or the runoff from the index area; column 6 is the combined gaged runoff at station 60 and the upstream diversion for municipal supply, or the natural runoff of Saratoga Creek. Figure 3 is a double mass plot of cumulative annual runoff from the index area (column 7) and cumulative annual natural runoff of Saratoga Creek minus 1,800 acre-feet (column 8). The 1,800 acre-feet subtracted from each annual value of Saratoga Creek runoff is the constant needed to transform the relation between variables to a simple ratio. In other words, the runoff relation has the form:

Annual index area runoff $= m$ (annual Saratoga Creek runoff $-1{,}800$).

TABLE 1.—*Annual runoff, in acre-feet, in Permanente and Saratoga Creek basins*

Water year	Index area runoff			Project-area outflow	Saratoga creek natural runoff	Cumulative totals	
	Station 32	Station 33	Total	Station 34	Station 60	Stations 32 and 33	Station 60 minus 1,800
1	2	3	4	5	6	7	8
1940	4,170	1,122	5,290	3,950	13,240	5,290	11,440
1941	8,802	2,600	11,400	9,040	18,450	16,690	28,090
1942	5,159	1,000	6,160	4,880	12,100	22,850	38,390
1943	3,117	431	3,550	3,270	7,040	26,400	43,630
1944	516	63	579	589	3,060	26,980	44,890
1945	1,714	119	1,830	1,540	4,930	28,810	48,020
1946	1,039	141	1,180	486	5,210	29,990	51,430
1947	282	1	283	38	1,810	30,280	51,440
1948	70	0	70	0	1,970	30,350	51,610
1949	600	123	723	328	4,190	31,070	54,000
1950	305	49	354	55	1,990	31,420	54,190
1951	2,600	297	2,900	1,940	7,910	34,320	60,300
1952	4,353	1,174	5,530	4,740	14,870	39,850	73,370
1953	2,028	403	2,430	1,480	6,290	42,280	77,860
1954	498	116	614	120	4,000	42,890	80,060
1955	236	153	389	171	3,190	43,280	81,450
1956	5,000	1,488	6,490	8,320	15,480	49,770	95,130
1957	371	147	518	384	2,850	50,290	96,180
1958	6,279	1,825	8,100	10,830	17,560	58,390	111,940

The break in slope of the curve on figure 3 at the year 1945 shows that the records prior to that year are not consistent with later records. The relative slopes of the two lines indicate that the annual discharges computed during the earlier period may be about 30 percent high. A similar conclusion was reached when the annual combined runoff for stations 32 and 33 was compared in a double mass-curve analysis with annual precipitation at Palo Alto. This type of analysis could not be repeated to test the early records for station 34 because, as is shown below, changes in land use caused changes in the runoff regimen of the project area.

The lack of consistency in the streamflow records for the index area before and after the installation of water-stage recorders is attributed to the quality of the early records of storm runoff. To eliminate any distortion that might be introduced by the use of the earlier records, the period prior to April 1945 was not used in this study The latest runoff records for Permanente Creek available for analysis were those for 1958, and the study period accordingly terminated at that date.

URBAN GROWTH IN THE PROJECT AREA

Three sets of aerial photographs of the project area are available. Fortunately for this study, they were obtained at three different stages of urban development: 1948, 1953, and 1960. The 1948 photograph is shown on figure 4, the 1960 photograph on figure 5. These pictures

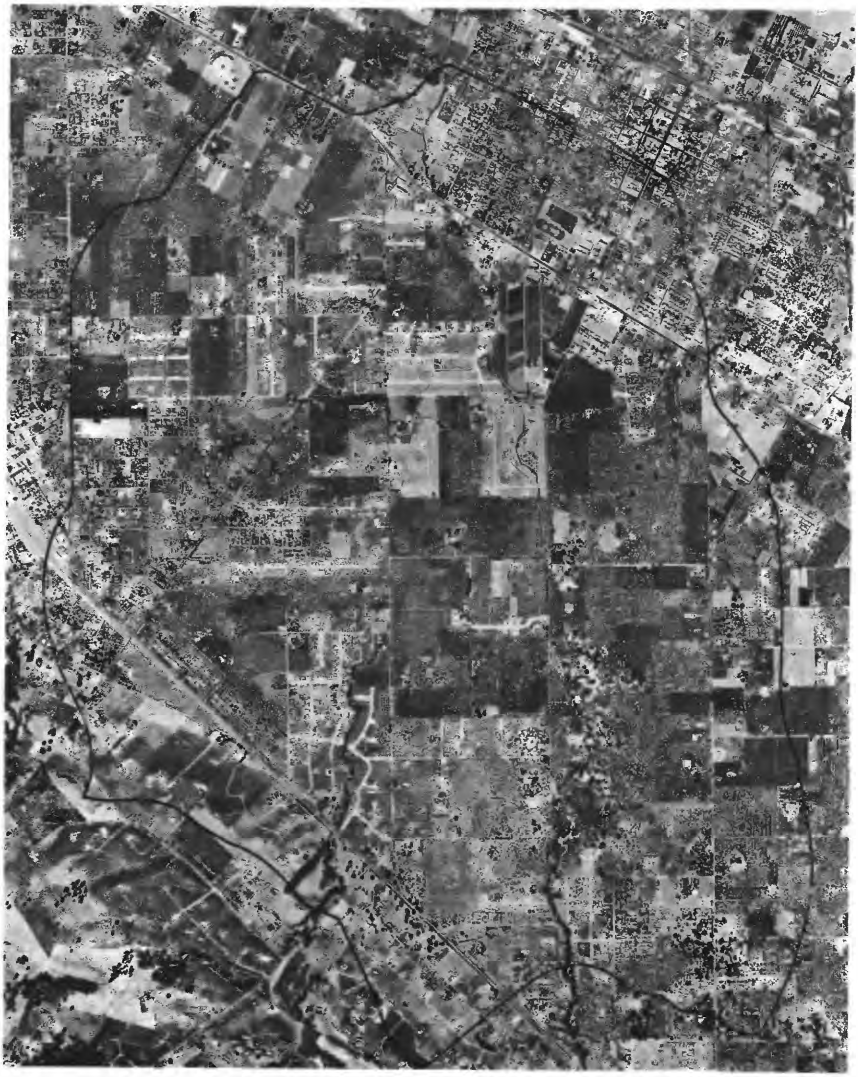

FIGURE 4.—Aerial photograph of project area in 1948.

illustrate strikingly the change in land use, from orchard to urban, that occurred during those 12 years. The major element in the urban growth has been the construction of residential-tract homes. A computation of random samples indicated that each home represents an impervious area of 4,000 square feet. This area includes the house, driveway, patio, sidewalks, and the lot frontage to the center of the street. Paved areas in shopping centers, school playgrounds, and other thoroughfares were estimated also. These unit figures were

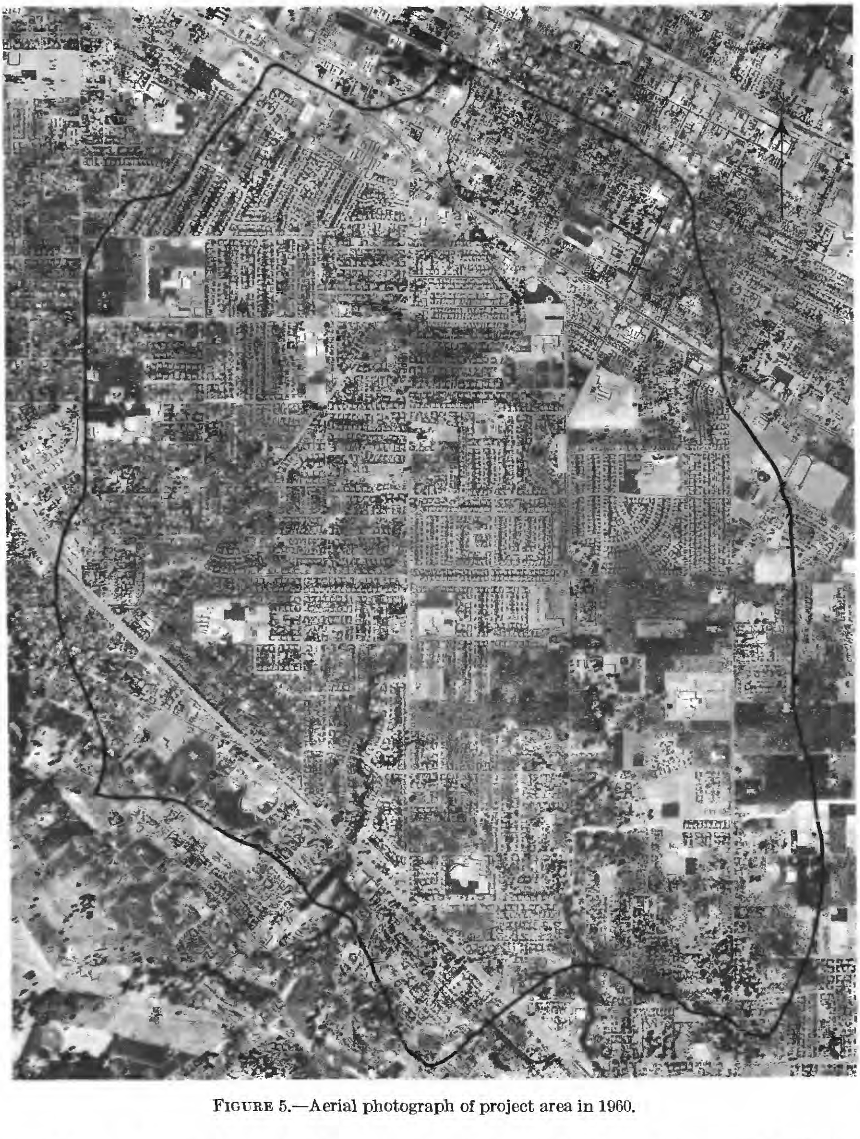

FIGURE 5.—Aerial photograph of project area in 1960.

used as a base, and the houses were counted from the aerial photographs and the total impervious area computed. The degree of urbanization can be expressed numerically as the percentage of the total project area that has been made impervious. The index area has had no appreciable change in impervious area, but the impervious part of the project area has increased from 5.7 percent in 1948 to 19.1 percent in 1960. (See table 2.) Although no aerial photographs prior to 1948 are available, it is estimated that the impervious part of the project area was about 4 percent in 1945 when the study period started. The increase in urban development was greatest in 1955 and 1956, and approximately 19 percent of the project area was impervious by the close of 1958, the end of the study period.

TABLE 2.—*Percent of index and project areas impervious, as computed from aerial photographs*

Year	Index area (percent)	Project area (percent)
1948	0. 7	5. 7
1953	1. 1	11. 8
1960	2. 0	19. 1

Accompanying the increase in urbanization was the usual construction of storm drainage facilities which undoubtedly influenced the magnitude of peak discharges from the project area. There was no basic change, however, in the drainage pattern during the study period, 1945–58. There is now (1964) a flood diversion channel from Permanente Creek to Stevens Creek, but it was constructed in 1960, after the close of the study period.

In the upper part of the basin, or index area, the only major development is the Permanente Cement Co. plant, which has been in operation since 1939, the year that streamflow records were first collected in the area.

EFFECT OF URBAN GROWTH

To study the time trend of the effect of urban growth on runoff characteristics, the precipitation and runoff records were inspected to obtain storm periods that were accompanied by appreciable runoff. An analysis of the change in annual volume of runoff was considered but was rejected because of the complicating effect of return flow from irrigation and because channel losses in Permanente Creek obscure the effect of light rainfall in producing runoff from the project area. To avoid these complications the analysis was therefore restricted to storm periods during which there was significant runoff. As mentioned earlier, the streams in the project area carry little flow, or may be dry, between storms. Storm runoff and rainfall was therefore considered to have started on the day on which an appreciable stream rise began. Because the response of runoff to storm rainfall is very rapid and because the project area is small, storm runoff was considered to have ended 3 days after the rains ceased. The use of runoff as an indication of storm periods minimizes, to a degree, the effect of antecedent soil-moisture conditions on the rainfall-runoff relation for the basin, because soil-moisture deficiencies would be at least partly satisfied before storm runoff began.

Table 3 shows values of runoff for the Permanente Creek basin and precipitation at Palo Alto for storm periods during the years 1945–58. Column 1 of the table lists the days of storm rainfall. Where individual rain periods were separated by less than 3 rainless days, the individual rain periods were grouped together in column 1 as a single long storm period. Columns 2–4 are self-explanatory. Column 5, the duration of storm runoff, is equal to the number of rainy days indicated by column 1 plus 3 days, as explained in the preceding paragraph. Accurate determination of channel seepage rates from an inspection of the records is exceedingly difficult, but study of the records does indicate that a daily seepage rate of 10 acre-feet is of the proper order of magnitude for those days when the entire width of the streambed was submerged. Accordingly, the volume of channel seepage (column 6) is obtained by multiplying the storm duration (column 5) by 10. Column 8 is the gaged outflow from the project area. Column 7, representing local runoff from the project area, is obtained by subtracting column 4 from the sum of columns 6 and 8. For two storm periods this subtraction resulted in small negative values of local runoff. This result was attributed to inaccuracies in the data, and the local runoff was called zero for the two periods. Column 9 lists the precipitation at Palo Alto for the days shown in column 1.

The data from table 3 were used in a double mass-curve analysis to determine the effect of urban growth on the volume of storm runoff from the project area. The first relation tested for a time trend was that of storm runoff from the index area (combined flow of stations 32 and 33) and storm runoff leaving the project area. Inspection of columns 4, 6, 7, and 8 of table 3 shows that in the early years local storm runoff from the project area was insufficient to balance channel losses and that the streamflow entering the project area in the Permanente Creek channel was greater than that leaving the area. However, the total storm runoff leaving the project area is actually the sum of the gaged streamflow at station 34 and the estimated channel seepage in the area. Furthermore, it was found that when channel seepage was included in the outflow from the project area, the relation of total project-area outflow to index-area storm runoff was a simple ratio. Accordingly, estimates of channel seepage were considered in constructing the upper double mass curve of figure 6.

The upper double mass curve on figure 6 relates project-area storm outflow plus channel seepage (column 11, table 3) to index-area storm runoff (column 10). A sharp break in the curve appears in 1955, the year that urban development greatly increased. Prior to 1955, the ratio of storm outflow plus channel seepage to index area

TABLE 3.—*Storm runoff in Permanente Creek basin and storm precipitation at Palo Alto, 1945–58*

Storm period	Runoff from index area (acre-feet)			Duration of storm runoff (days)	Channel seepage in project area (acre-feet)	Local runoff from project area (acre-feet)	Outflow from project area, station 34 (acre-feet)	Precipitation at Palo Alto (inches)	Cumulative totals			
	Station 32	Station 33	Total						Index-area runoff (acre-feet)	Project-area outflow plus channel seepage (acre-feet)	Precipitation at Palo Alto minus 0.5 inch (inches)	Local runoff from project area (acre-feet)
1	2	3	4	5	6	7	8	9	10	11	12	13
Dec. 27, 1945	99	22	121	4	40	10	91	0.72	121	131	0.22	10
Mar. 10–11, 1949	196	77	273	5	50	31	254	.66	394	435	.38	41
Mar. 19–22, 1949	91	8	99	7	70	11	40	1.15	493	545	1.03	52
Feb. 4–5, 1950	44	38	82	5	50	18	50	1.48	575	645	2.01	70
Nov. 18–20, 1950	214	81	295	6	60	47	282	4.13	870	987	5.64	117
Dec. 2–8, 1950	464	69	533	10	100	69	502	5.05	1,403	1,589	10.19	186
Dec. 13–14, 1950	173	4	177	5	50	0	109	.62	1,580	1,748	10.31	186
Dec. 1–5, 1951	153	52	205	8	80	59	184	4.52	1,785	2,012	14.33	245
Dec. 28–30, 1951	79	71	150	6	60	144	234	2.36	1,935	2,306	16.19	389
Jan. 6–7, 1952	131	60	191	5	50	22	163	1.50	2,126	2,519	17.19	411
Jan. 11–16, 1952	901	506	1,407	9	90	302	1,619	3.67	3,533	4,228	20.36	713
Mar. 14–19, 1952	676	188	864	9	90	125	899	2.50	4,397	5,217	22.36	838
Dec. 5–7, 1952	145	48	193	6	60	34	167	2.93	4,590	5,444	24.79	872
Dec. 26–30, 1952	280	91	371	8	80	157	448	2.13	4,961	5,972	26.42	1,029
Jan. 5–8, 1953	226	67	293	7	70	0	212	1.18	5,254	6,254	27.10	1,029
Dec. 18, 1955–Jan. 28, 1956	2,825	1,234	4,059	45	450	2,683	6,292	15.47	9,313	12,996	42.07	3,712
Feb. 19–29, 1956	484	99	583	14	140	376	819	1.28	9,896	13,955	42.85	4,088
Feb. 21–28, 1957	123	65	188	11	110	93	171	2.65	10,084	14,236	45.00	4,181
Jan. 23–26, 1958	71	52	123	7	70	145	198	2.08	10,207	14,504	46.58	4,326
Feb. 2, 1958	194	177	371	4	40	207	538	1.08	10,578	15,082	47.16	4,533
Feb. 18–19, 1958	335	153	488	5	50	657	1,095	1.58	11,066	16,227	48.24	5,190
Feb. 24–25, 1958	371	135	506	5	50	389	845	1.37	11,572	17,122	49.11	5,579
Mar. 14–16, 1958	282	137	419	6	60	260	619	1.61	11,991	17,801	50.22	5,839
Mar. 20–Apr. 7, 1958	2,632	899	3,531	22	220	2,013	5,324	7.49	15,522	23,345	57.21	7,852

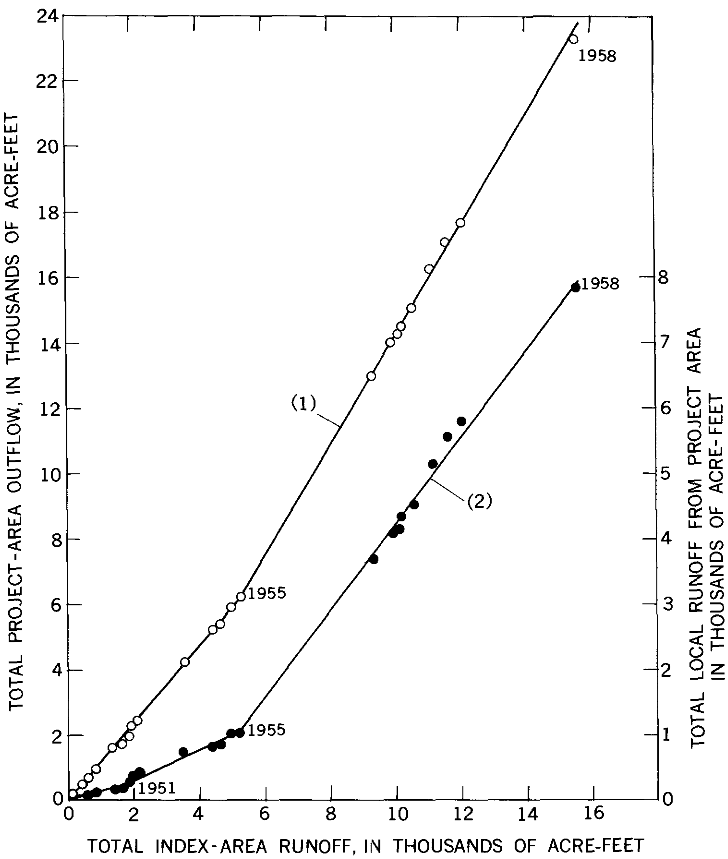

FIGURE 6.—Double mass curve of storm runoff from the index area (Sta. 32 and 33) versus cumulative totals of: (1) storm outflow plus channel seepage from the project area and (2) local storm runoff from the project area, 1945–58.

runoff was 1.18. From 1955 to 1958, the period of maximum urban growth, this ratio was 1.70, an increase of 44 percent. This increase in outflow is attributed to the increase in the extent of impervious surface that resulted from urbanization of the project area. It is not to be inferred from the outflow-inflow ratio of 1.70 for storm periods that the 5.12-square-mile project area is now more productive of runoff, on a unit area basis, than is the 10.9-square-mile index area. Precipitation that infiltrates in the index area continues to feed the perennial streams there long after rainfall has ceased, and storm-period runoff from the index area therefore represents only a part of the streamflow attributable to the rain. On the other hand, in the project area there is little runoff after the end of a storm, and storm-period runoff from the project area represents almost all the streamflow attributable to the rain. The data in table 1 (columns 4 and 5) show that the index area is more productive of runoff than the project area.

The lower double mass curve on figure 6 relates local storm runoff from the project area (column 13, table 3) to index-area storm runoff (column 10). Again, a sharp break in the curve appears in 1955. It is seen, too, that a lesser change in trend of the relation occurred in 1951. After 1951, local storm runoff exceeded channel losses in most, though not all, years until the end of the study period.

As mentioned earlier, precipitation-runoff relations are generally not as satisfactory as simple runoff relations in studying trends in runoff, particularly when short time intervals such as storm periods are considered, because volume of precipitation is not the only factor that affects the runoff; rainfall intensity and antecedent soil-moisture conditions must also be considered. Despite these complicating factors, a double-mass curve was constructed (fig. 7) relating local storm runoff from the project area to storm precipitation totals at Palo Alto. In computing cumulative precipitation values for this graph (column 12, table 3), 0.5 inch of rainfall was subtracted from each storm volume in order to transform the rainfall-runoff relation to a simple ratio. This subtraction is equivalent to saying that 0.5 inch of rain in each storm fails to contribute to storm runoff. The graph on figure 7 is less satisfactory than those on figure 6, but it too shows changes in trend in 1951 and 1955.

SUMMARY

The streamflow records available for the Permanente Creek basin do not permit a complete study of the effect of urban growth on streamflow regimen, and this investigation was therefore limited to a study of trends in the volume of storm runoff produced by rainfall on the valley floor. It was found that a substantial increase in volume of storm runoff coincided with the period of major urban development. As a result of the increase in impervious surface in the project area from about 4 percent of the total area in 1945 to 19 percent in 1958, the ratio of outflow from the area (including channel seepage) to inflow increased from 1.18 to 1.70. The effect of urban growth in other basins in Santa Clara County should be investigated before any attempt is made to project the quantitative results of this study to other areas in the county.

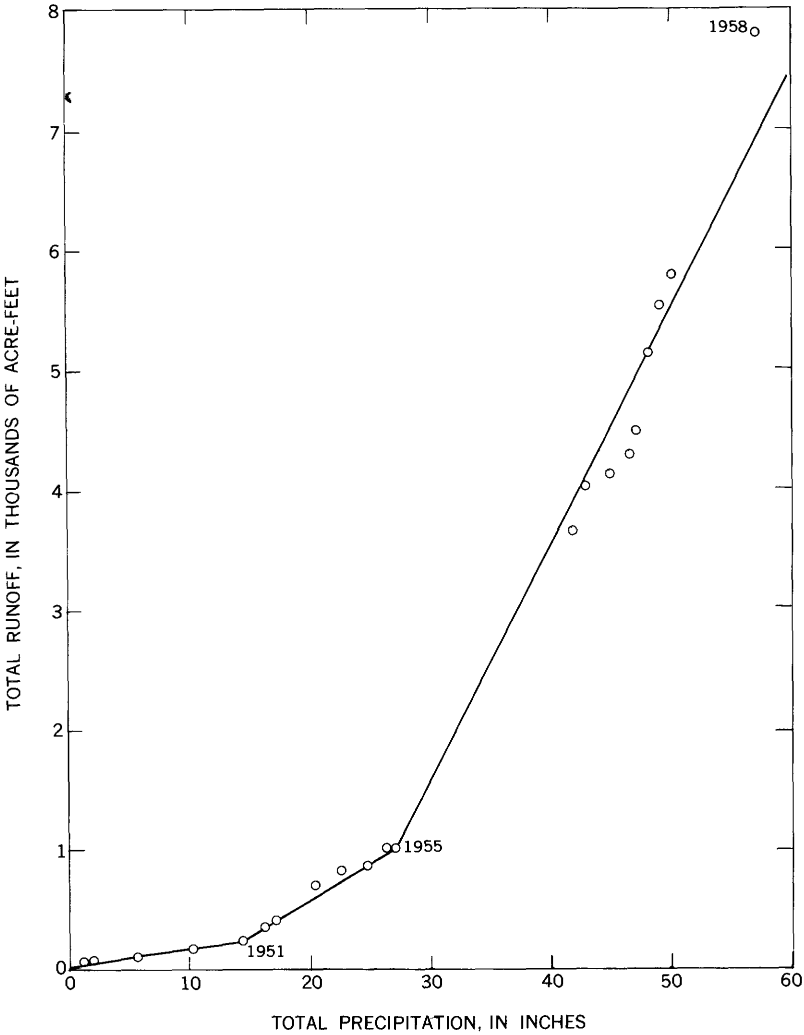

FIGURE 7.—Double mass curve of cumulative total storm precipitation (at Palo Alto, minus 0.5 inch) and cumulative total local storm runoff from the project area, 1945–58.

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