IMPACT OF URBANIZATION ON WATER YIELD, FLOOD PEAKS, SEDIMENT YIELD, AND WATER QUALITY IN THE BERKELEY HILLS, CALIFORNIA

by

JOE R. McBRIDE

Department of Forestry and Conservation
University of California, Berkeley

CALIFORNIA WATER RESOURCES CENTER
University of California   Davis, California

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ABSTRACT

The objective of this project was to determine the impact of urbanization on the hydrologic characteristics of watersheds in the Berkeley Hills of central California. The initial approach was to calibrate three stream gaging station prior to the development of one watershed above one of these stations and to follow changes in hydrologic characteristics during and subsequent to development. Economic and political developments in 1974 and 1975 prevented the developer from building on the principal watershed. A summary of data on annual water yield, characteristics of flood peaks, sediment yield, and water quality for the three non-urban watersheds is presented.

A subproject completed during the study compared periodicity of streamflow in previously urbanized and non-urbanized watersheds in the Berkeley Hills. Two daily discharge peaks which lagged 1.5 hours behind two daily peaks in lawn irrigation were observed. Peak daily streamflow on the urbanized watershed was 10 times that of a similar non-urbanized watershed. The stream from the urbanized watershed flowed continuously throughout the year while the stream from the non-urbanized watershed ceased flowing from late July until mid-October.

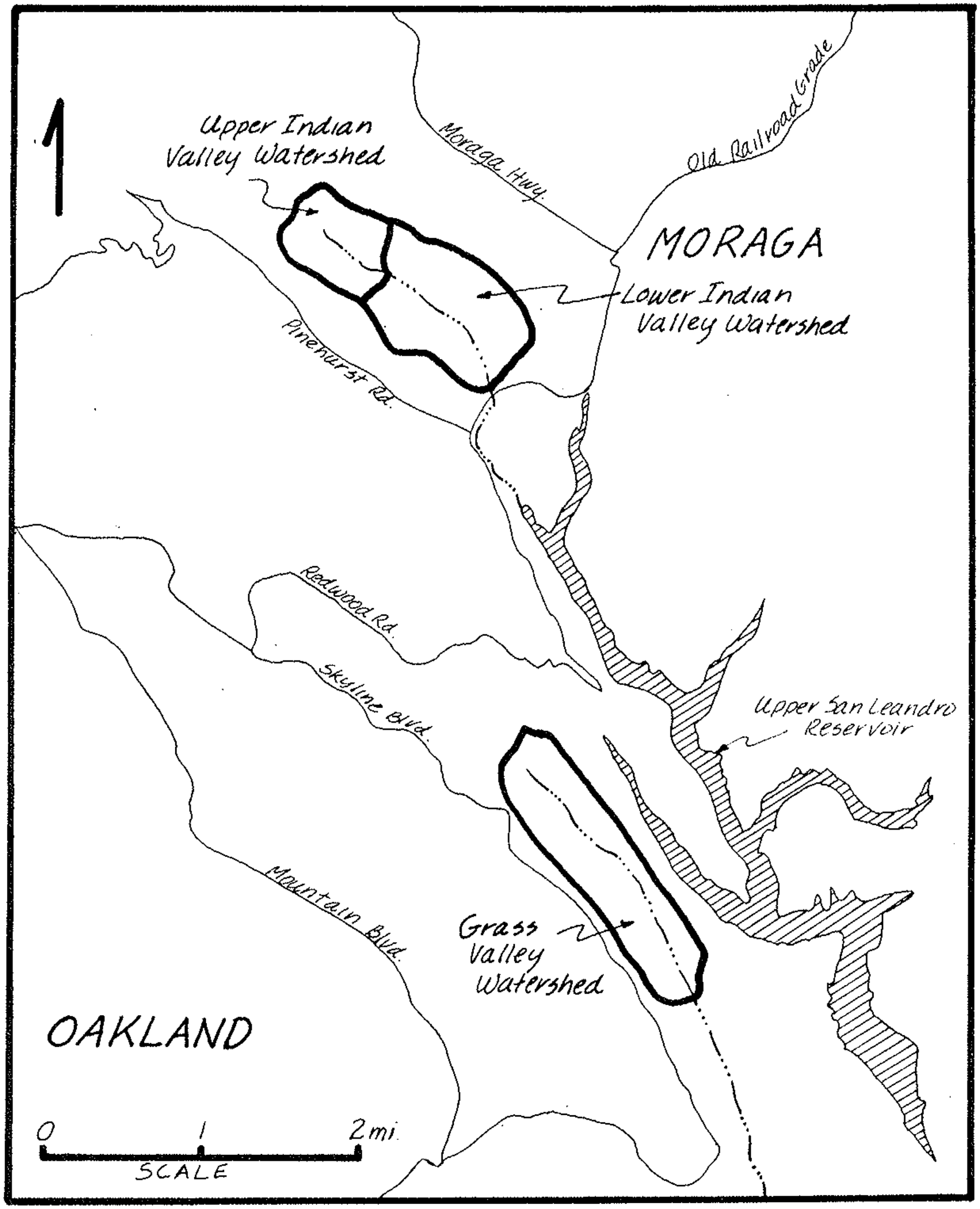


Fig. 1. Location of Indian Valley and Grass Valley Watershed

Introduction

A study of the impact of urbanization on the hydrologic characteristics of watersheds in the Berkeley Hills of central California was initiated in 1973. The intent of this project was to develop models to predict changes in annual discharge, flood peak, sediment load, and water quality that would result from urbanization. The initial approach was to select a watershed which was scheduled for development, calibrate streamflow characteristics for this watershed with two undeveloped watersheds prior to development, and use the calibrations to measure changes following urbanization. The data produced would be used to test the predictive models.

The study did not achieve its objective by the end of the period funding by the Office of Water Resources Research because development of the principal watershed did not procede on schedule. The overall study is being continued with support from other agencies. The purpose of this report is to summarize the progress of the study during the period of funding by the Office of Water Resources Research. The baseline data collected during this period will be used for comparison with streamflow collected after urbanization occurs.

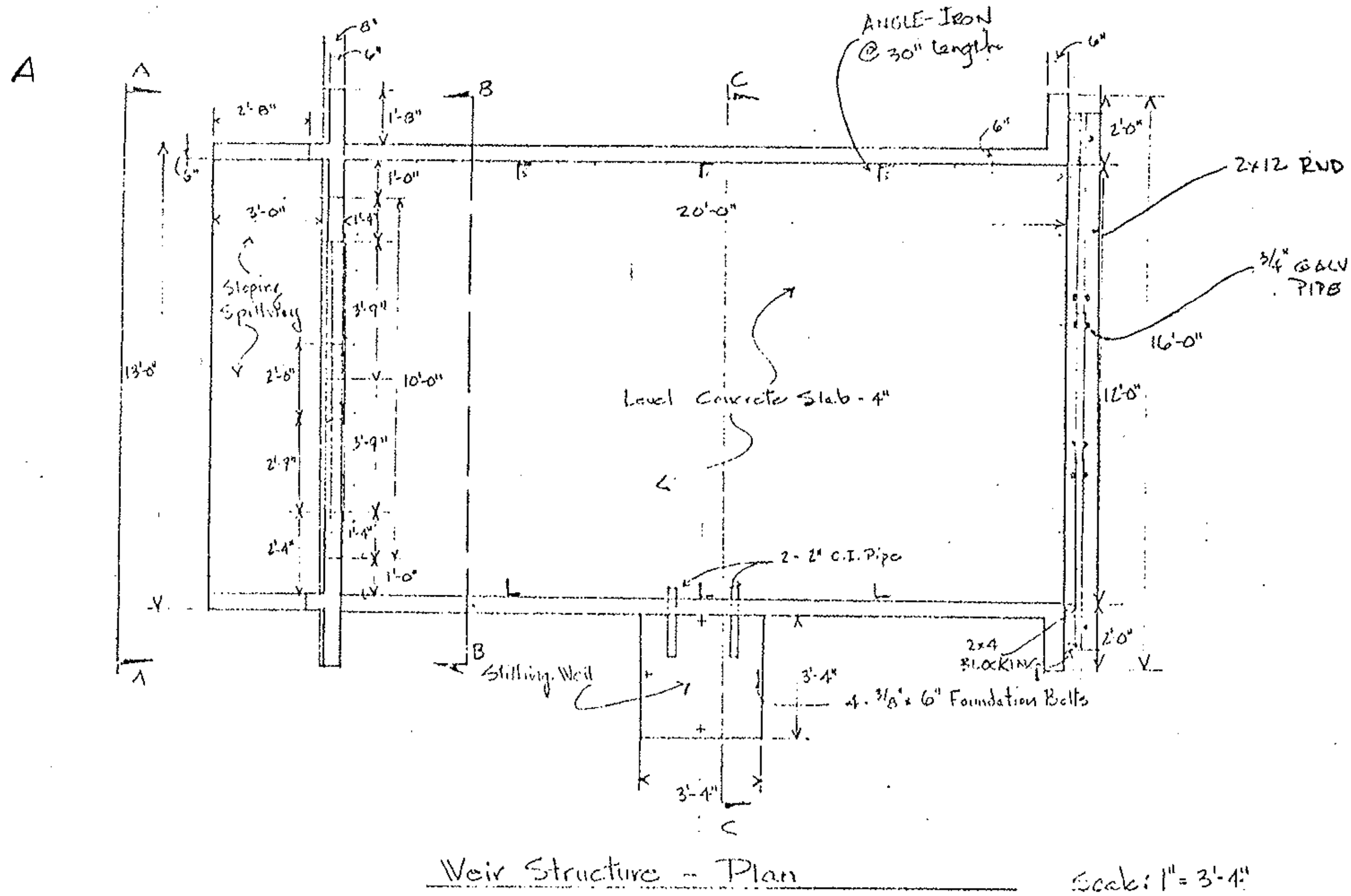
Study Site

The principal study site selected for this project was the Indian Valley watershed near Moraga, California (Fig.1). This 665 acre watershed is typical of many watersheds in the East Bay area. The owner of the lower two thirds of the watershed was in the process of planning a development for his property when the project was initiated in 1973. Construction of the development was to begin in the spring of 1975. The upper one third of the Indian Valley watershed (224 acres) was owned by another individual who was not planning to develop his property. This upper portion of the watershed provided a control to be used in the calibration of the lower portion of the same watershed. A second watershed, known as Grass Valley and located in Redwood Regional Park (Fig.1), was selected as a second control. This 550 acre watershed shared common geologic, edaphic, topographic, and vegetative characteristics with the Indian Valley watershed. Details of the physical and biological features of these watersheds are summarized by Rademacher (1973).

Stream Gaging Stations

Selection of stream gaging sites was governed primarily by project objectives and, to a lesser degree, by the constraints of terrain and channel geometry.

Streamflow in the San Francisco Bay area is highly variable both season to season and throughout the year as is typical of mediterranean climates. For purposes of calibration between watersheds, research objectives were oriented toward measurement of low (base) to moderately high flows (Q2). Changes within this regime, particularly those of moderate flow, are of greater significance to water budget formulation than the more infrequent peak discharges. Flood flows of recurrence interval higher than 2 years are, of course, physically more difficult to accurately measure in weir structures by water level recorders. In addition, alternate methods of analysis are available for these less frequent peak flows.



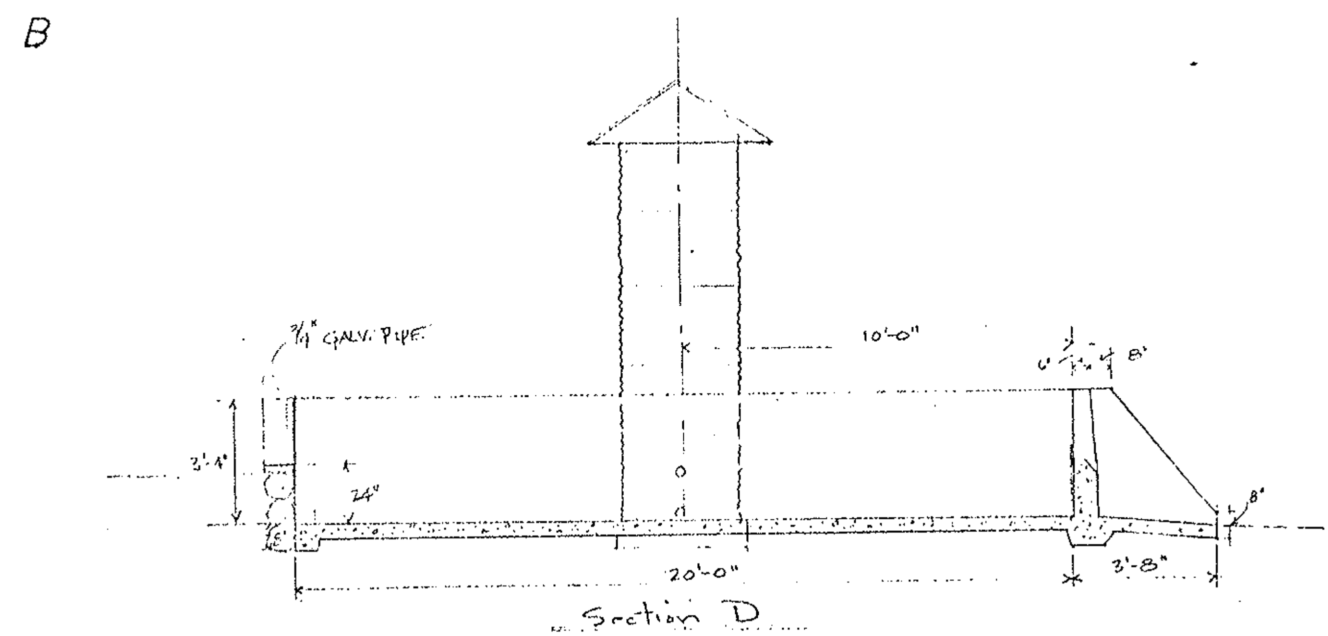


Fig. 2 Stream Gaging Station
a. Station plan and section indentification
b. Longitudinal - section

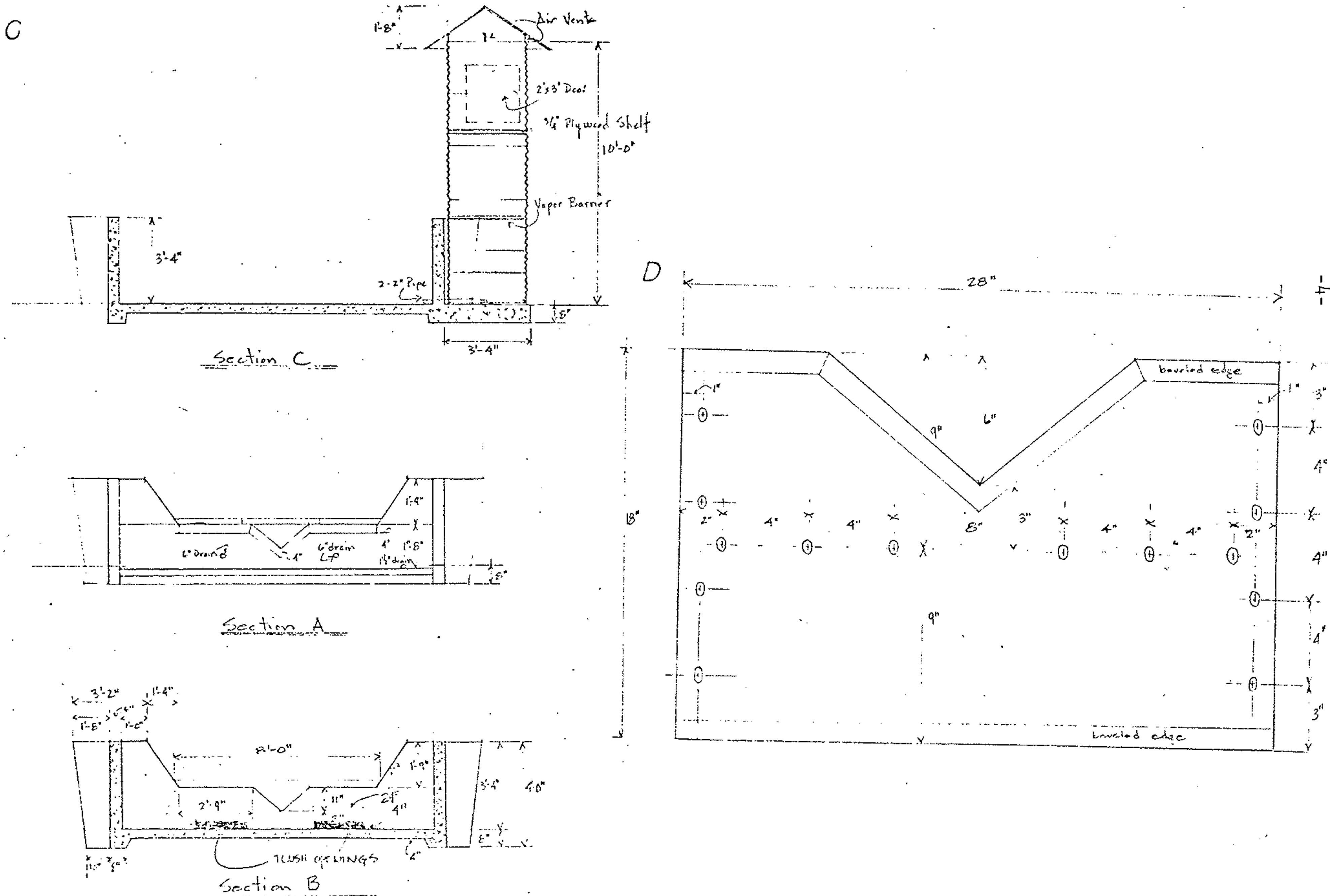


Fig. 2. Stream Gaging Station
c. cross-sections
d. detail of compound blade segment of weir

The measurement of sediment yield was confined to bed load volume and size determination as trapped by the stream gaging headwall after each storm event. These measures are relative indice between control points and represent at most ± 80% of this total bed load material. Because of the need to accurately measure all but the more extreme and infrequent runoff peaks, control points were established which had, 1) high vertical banks, 2) relatively straight reaches, and 3) with channel gradient breaks or changes in slope. These features provided the physical control necessary for the construction of gaging devices. Considerations of impermeability of substrate or bedrock material for total flow measurement was not a factor because of the geologic structures within the watersheds.

At each of the three chosen control points, stream gaging structures were constructed at grade to influence as little as possible the existing surface flow regime. Each structure consisting basically of weir headwall, stilling pool and well housing for the water stage recorder. The channel structures were constructed of reinforced concrete designed to withstand extreme flood flows as diagrammed in Figure 2. All gaging stations were designed and constructed to the same specifications of critical dimensions for flow measurements. This allowed consistance in field calibration and direct comparison of both chart records and hydrograph of individual storm events.

The decision to utilize weirs rather than flumes was based on two assumptions; 1) weirs, if properly maintained are more accurate than flumes in measuring flowing water and 2) sediment laden flows would be heavy only during extreme events. The latter assumption was to prove inaccurate as all three watershed areas, regardless of land-use activity, produced high sediment yield even in moderate prolonged storm events, which are typical for this geographic area.

Because of the desirability of more accurately measuring periods of low flow during late spring and early summer, two weir devises were designed and build in the form of a compound weir structure. These weirs were fabricated of stainless steel and are thin plate, sharp-crested blades. Figure 2 contains a detail of the central segment of the compound weir which is easily reversible in its position on the headwall. The straight blade edge is a segment of a modified Cipolletti 8 foot trapezoidal weir. The notched blade edge contained the 6 inch 120° V-notch weir and is a complete unit when mounted on the headwall.

The modified 8 foot Cipolletti weir was capable of accurately measuring flows from 0.50 to 100.6 cfs or 75% of the total flow time. Low flows below 0.75 cfs, which accounted for approximately 25% of the flow time were more accurately measured by the 120° V-notch weir. On the average, the notched weir was put into operation in the first part of May when maximum diurnal flows fell below 0.78 cfs and continued in operation until mid-July when continuous surface flow ceased. The rating curves for these two weirs are shown on Figure 4.

The stilling pool required both for the V-notch weir and to trap bed load sediment consisted essentially of a 20 foot open-ended concrete box 3.5 feet high with a smooth textured, flat concrete floor. Baffle screens were used toward the rear (upstream) portion of the stilling pool to collect floating debris and regulate the current. A 3 foot splash ramp was constructed on the downstream side of the headwall for energy dissipation.

The stilling well and recorder housing was centered 12 feet upstream from the weir blade, adjacent to the stilling pool. Stevens Model 71A continuous chart recorders were used in all installations. Regular calibration checks were

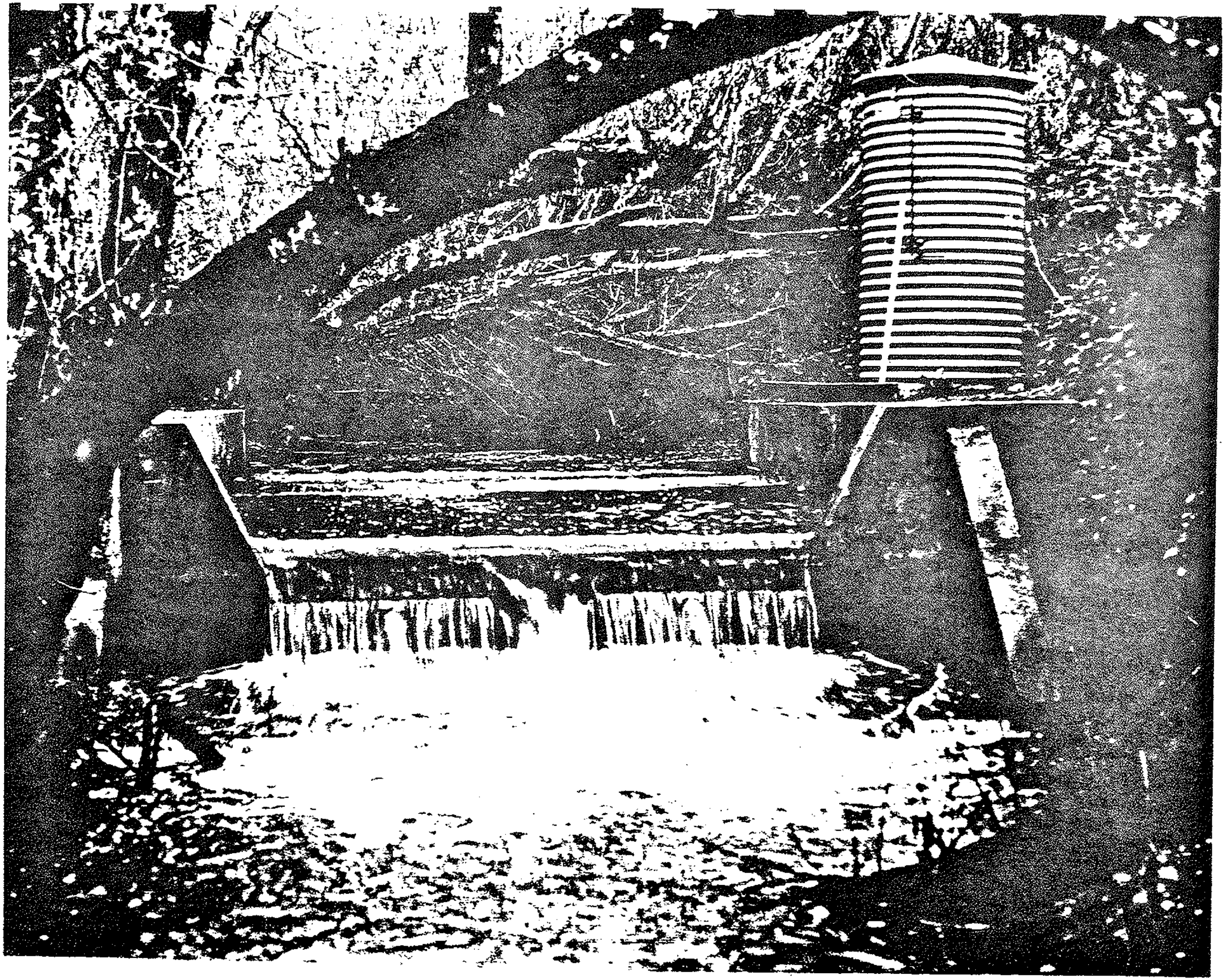
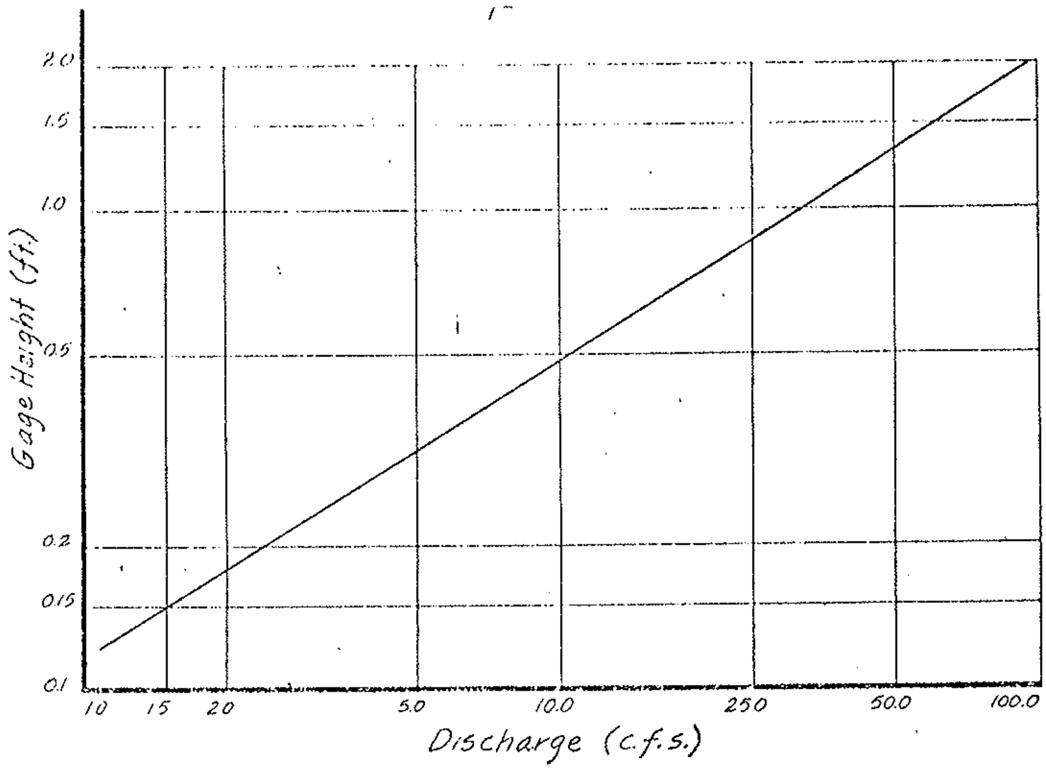


Figure 3. Photograph of Gaging Station in Operation

A



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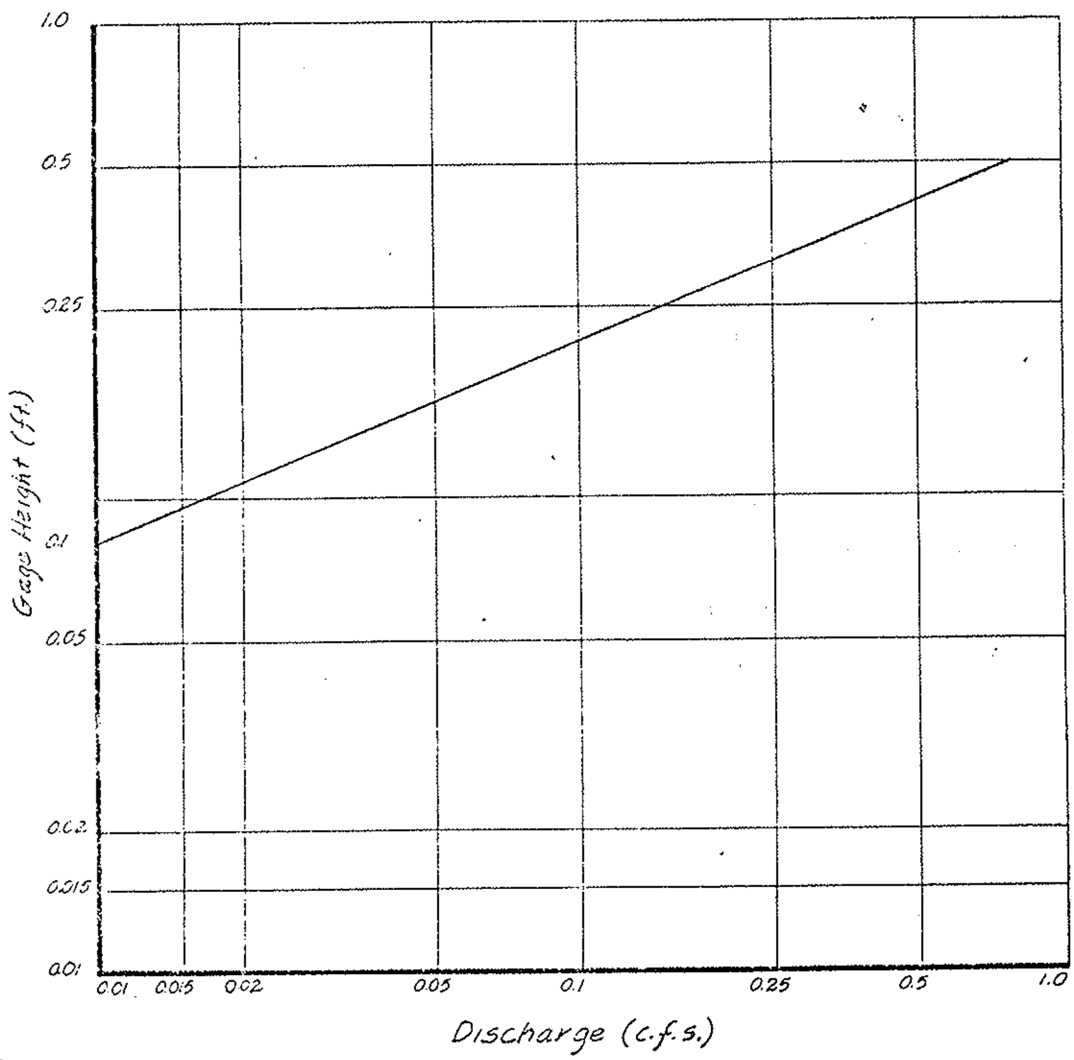
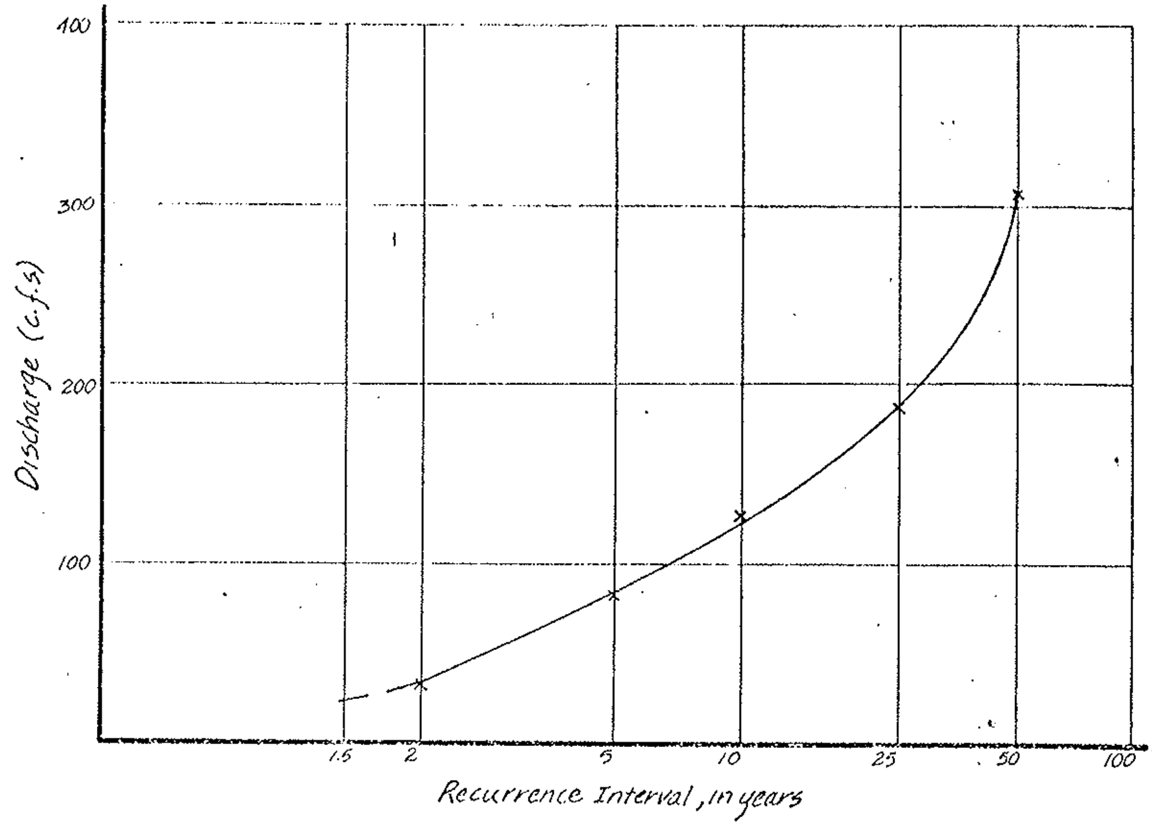


Figure 4. Rating Curves
a. eight-foot modified trapequidal weir
b. six-inch 120° V-notch weir

B



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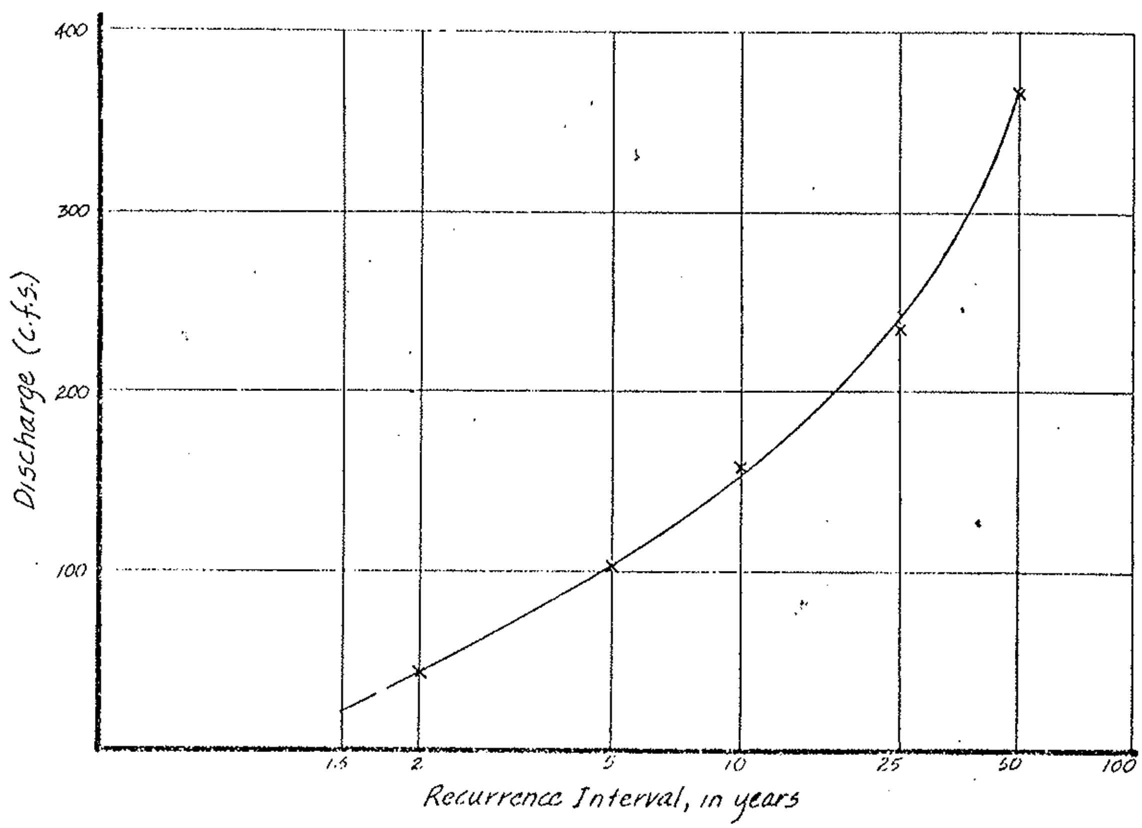
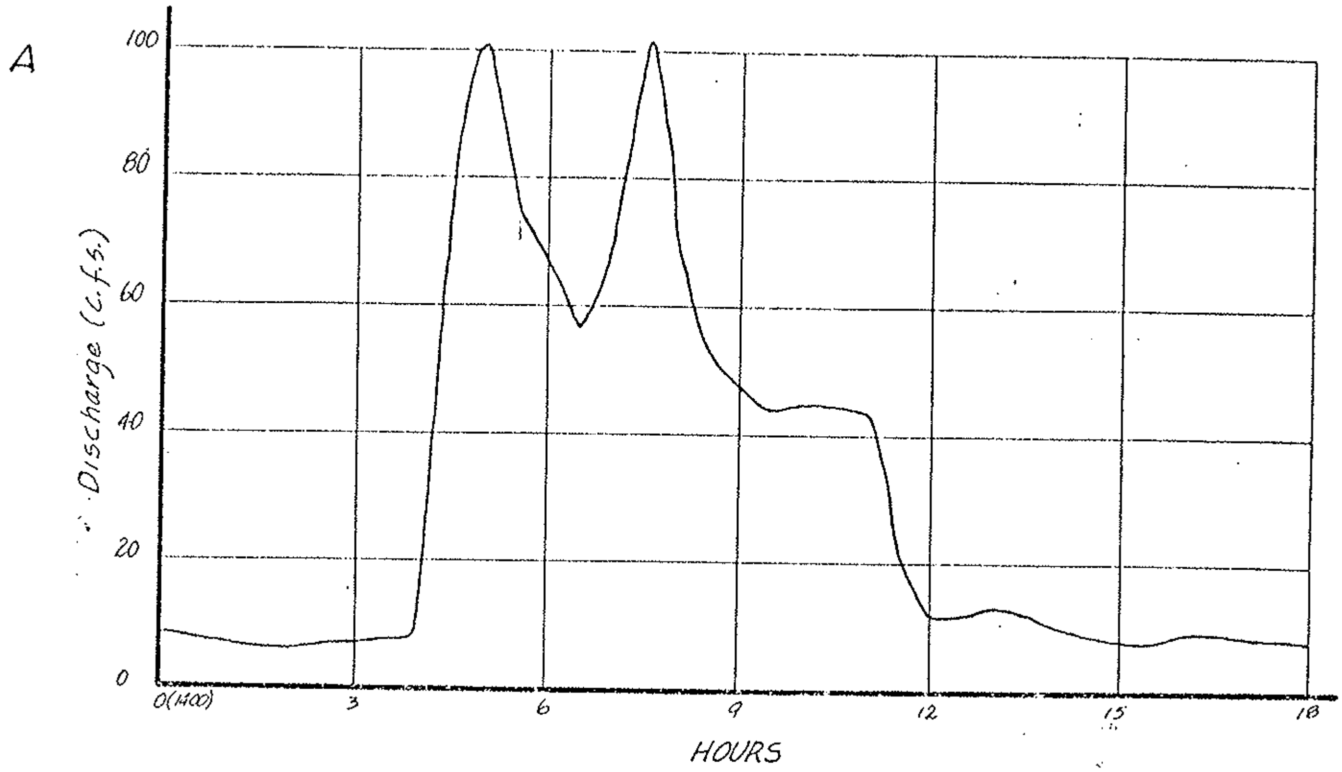


Figure 5. Flood frequency Analysis Curves
a. Indian Valley Creek
b. Grass Valley Creek



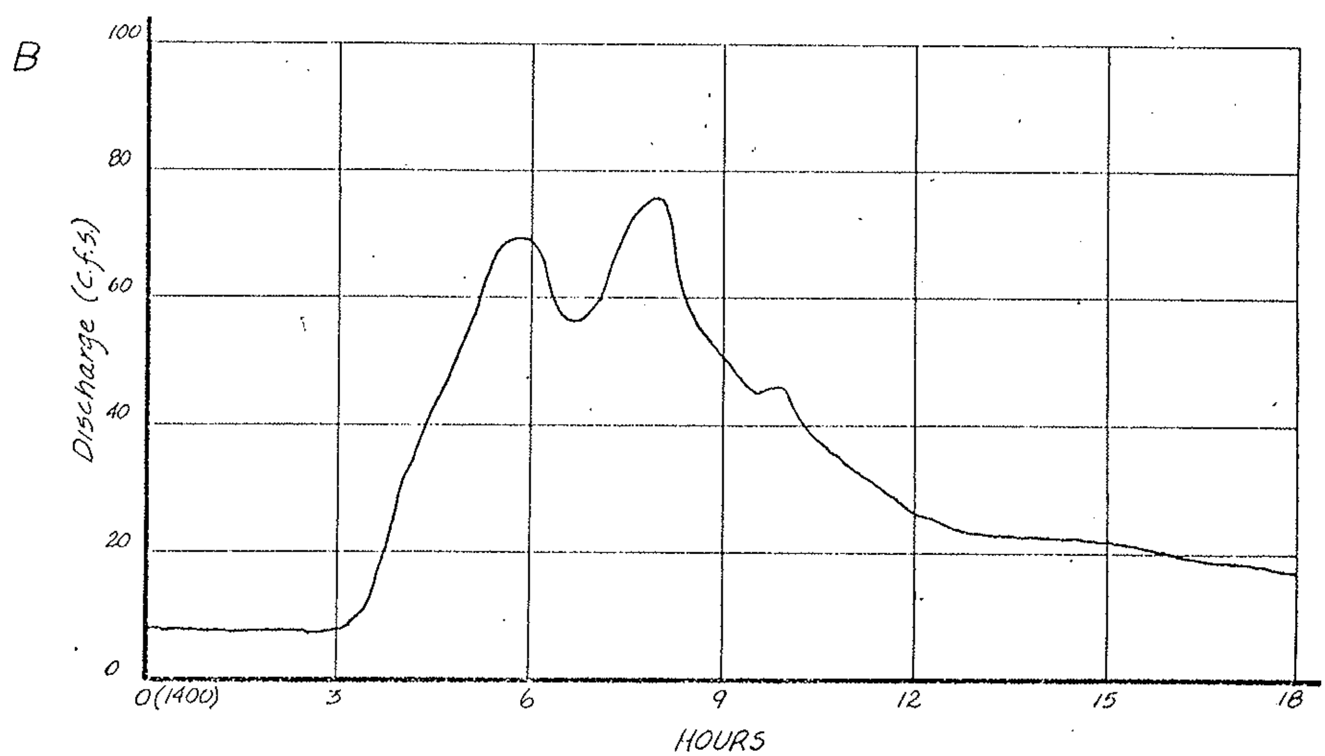


Figure 6. Storm Hydrographs for event of March 1, 1974
a. Indian Valley Creek
b. Grass Valley Creek

made on stage height and clock time. Figure 3 shows the lower Indian Valley stream gaging station in operation with a low flow (approximately 10 cfs) in early spring 1975.

After the first season of measurement, it became apparent that heavy sediment discharges especially bed loads were both an interference with flow measurements as well as a problem of measurement and removal. Release of trapped sediment was made by manually removing it from the stilling pool after major storm events. This involved both flushing material out through the headwall drains and shoveling material over the blade by hand. The time and labor required to physically keep a gaging station operative during periods of heavy runoff became an increasing problem.

To study the problem of sediment deposition and develop a system for more efficient removal, a 1/6 scale model was constructed of the stream reach at the gaging station. Sediment material from Indian Valley Creek was used in the model, although gravel over 3/4" was removed. In addition, the scaled length of the stilling pool was doubled (1/3 actual length) to analyze the pattern of deposition and movement under simulated flow regimes.

The studies indicated that by temporary storage of 1.3 feet of head behind movable wooden dam panels and the construction of drain ducts in the headwall, most amounts and types of sediment could be flushed from the stilling pool in less than 3 hours. The elements of the sediment flushing system are noted on Figure 2.

Annual Discharge

The annual discharge from the Indian Valley watershed during the 1973-74 hydrologic year was 563.5 acre feet. The discharge from the Grass Valley watershed amounted to 763.2 acre feet for the same period. Rainfall during the 1973-74 amounted to 35.5 inches in the study area. The larger annual discharge recorded in Grass Valley is related to its somewhat steeper average slope.

Monthly discharge for each watershed is shown in Table 1. A comparison of discharge from the watersheds in the months of May, June, and July shows how much more rapidly streamflow in Grass Valley Creek is terminated once precipitation stops. This is due in part to the slightly steeper topography in Grass Valley and the occurrence of more permeable parent materials.

The discharge shown for February appears to be low in relation to the total monthly precipitation. Precipitation occurred on February 1,12,16,18,19,21,26, and 28 during 1974. The storm on the 28th contributed 45 percent of the months' precipitation. Much of the runoff from this storm contributed to the discharge shown for the month of March.

Flood Peak

Flood frequency analysis for the two watersheds was made using the multiple regression equations developed by Rantz (1971). The probable recurrence intervals for selected peak discharges are plotted in Figure 5 for Indian Valley and Grass Valley creeks; both areas are unurbanized and unsewered.

Preliminary analysis of stream flow records indicate that Q values at more frequent recurrence intervals (low R.I. values) are apparently higher than those calculated by frequency analysis methods. For example Figure 6 shows the hydrographs for the runoff event which produced the annual flood event for 1974. Plotting Q values from Figure 5, indicates that this peak discharge should have

Table 1. Monthly discharge from Indian and Grass Valleys, 1973-74

Discharge (Acre-feet)

Month	Indian Valley	Grass Valley	Precipitation
October	0	0	0
November	34.4	26.2*	5.9
December	94.0	153.7	7.1
January	119.0	178.7	3.9
February	45.8	35.4	4.4
March	154.4	213.3	8.7
April	90.2	152.9	3.9
May	17.1	2.9	0
June	7.2	0.1	0
July	1.4	0	0
August	0	0	0
September	0	0	0
TOTAL	563.5	763.2	35.5

* Discharge for November estimated since streamflow measurement were not initiated until December on the Grass Valley watershed.

Table 2. Average particle size distribution of sediments collected from the stilling ponds of the Indian and Grass Valley stream gaging stations.

Average Particle Size Distribution (%)

Texture Class	Indian Valley	Grass Valley
Sand	90	77
Silt	8	19
Clay	2	14

Table 3. Chemical composition of Indian and Grass Valley Creeks during and between flood peaks

Creek	Character of Flow	Turbidity (F.T.U.)	Dissolved Oxygen (ppm)	pH	Nitrate (mg/l)	Phosphate (mg/l)	Iron (mg/l)	Chlorine (mg/l)	Sodium Chloride (mg/l)	Silica (mg/l)	Hardness ($CaCO_3$ mg/l)
Indian Valley	Between Peaks	39	11	8.2	1.32	2.1	0.05	16	29	2.6	154
	Peak flow	1100	11	8.5	1.76	2.4	0.60	10	16	3.5	60
Grass Valley	Between Peaks	24	13	7.9	1.41	1.7	0.25	18	33	2.4	106
		2500	10	7.8	3.50	1.6	1.50	10	16	4.0	40

a recurrence interval of 4 to 5 years. Precipitation records, channel geometry and field evidence suggest, however, that flows of this magnitude are of more frequent ocurrence. Flood peak values from 1974 and 1975, although of limited duration, tend to support this finding. The factors contributing to this difference in expected peak flows have been beyond the scope of this project.

Sediment Load

Sediment load measurements were initiated during the 1974-75 hydrologic year. The thickness of the sediment deposited in the stilling poin was measured at 16 equally spaced grid points once a week. The sediment was removed from the stilling pond after each measurement. Particle size distribution was determined for samples of the sediment using the hydrometer method.

The total volume of sediment deposited in the Indian Valley stilling pond amounted to 1353.2 cubic feet while 1410.2 cubic feet of material was deposited in the Grass Valley stilling pond. A summary of particle size distribution is shown in Table 2.

Water Quality

An estimate of water quality can be based on the chemical composition of the stream water. Several chemical elements, ions, compounds, were measured along with water turbidity on a monthly basis during the 1974-75 hydrologic year. Measurements were taken both during and between flood peaks (Table 3).

Other Studies

Soil infiltration rates were measured for several soil types occurring in Indian Valley. Rainfall interception was measured in the oak woodland and baccharis brushland vegetation types in Indian Valley. Further studies are planned to extend infiltration and interception measurements to remaining soil and vegetation types. This will provide data for constructing various watershed models.

Comparisons between previously urbanized and non-urbanized watersheds were made to measure the effect of urbanization on the periodicity of streamflow and water quality (McBride, 1975).

Streams coming out of urbanized watersheds exhibited two daily peaks in discharge (Figure 7). These peaks lagged 1.5 hours behind the two daily peaks in lawn irrigation for a 168 acre watershed. The average daily peak flow of water from an urbanized watershed was 10 times greater than that of a non-urbanized watershed of similar size. Streamflow continued throughout the year on the urbanized watershed while on the non-urbanized watershed streamflow ceased from the last week of July until mid October.

Results from water quality measurements on urban and non-urban streams indicate very little difference in PH, turbidity, nitrate, or iron. Total phosphate and water hardness ($CaCO_3$) are higher in the non-urbanized streams while chlorine levels are higher in the urbanized streams.

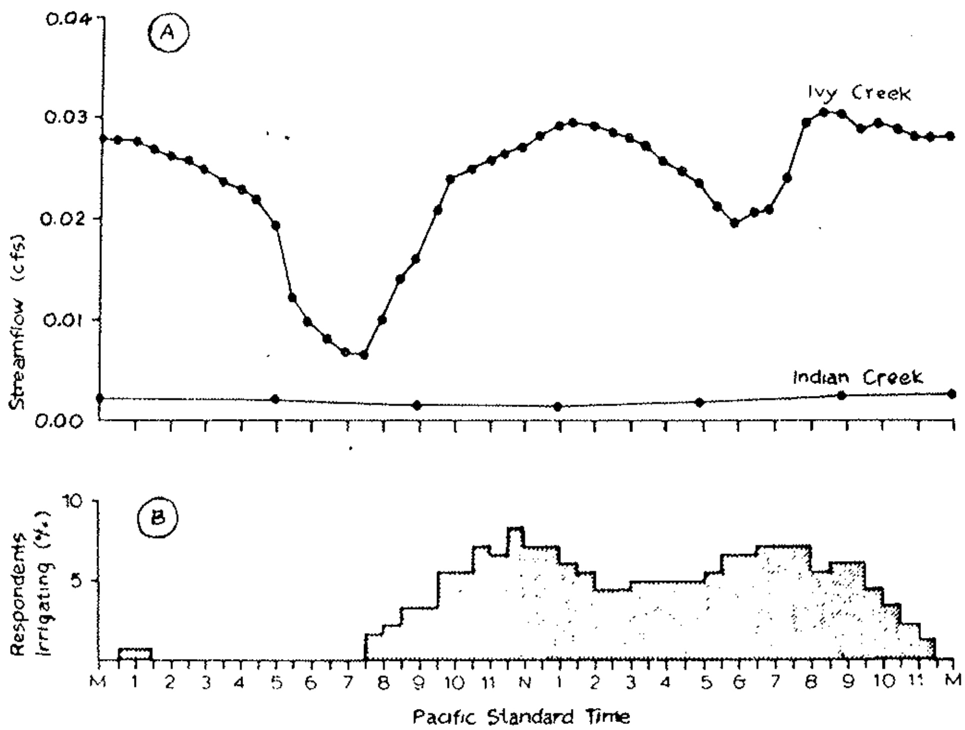


Fig. 7. Streamflow (A) and timing of irrigation (B) in Ivy Creek (urbanized watershed) and Indian Creek (non-urbanized watershed).

Summary:

Baseline data has been recorded for undeveloped watersheds in the Berkeley Hills. These data includes annual discharge, flood peak, sediment load, and water quality. The streamflow data was collected at specially designed gaging stations which provided the versatility necessary for measuring wide the variations in streamflows encountered in ephemeral streams. The data will be used to measure impact of urbanization once the principal watershed is developed.

Publications:

McBride, J. 1975. Urbanization and Streamflow in the Berkeley Hills. Calif. Agric. 29(4):6-7.

Rademacher, K. A. 1973. Evolution of the Landscape in the Flicker Ridge Area, Contra Costa County, California: A Physical Geography. M.A. Thesis, Dept. Geog. Univ. Calif., Berkeley, CA. 115 p.

Literature Cited:

Rademacher, K. A. 1973. Evolution of the Landscape in the Flicker Ridge Area, Contra Costa County, California: A Physical Geography. M.A. Thesis, Dept. Geog. Univ. Calif., Berkeley, CA. 115 p.

McBride, J. 1975. Urbanization and Streamflow in the Berkeley Hills. Calif. Agric. 29(4)6-7.

Rantz, S.E. 1971. Suggested Criteria for Hydrologic Design of Storm-Drainage Facilities in the San Francisco Bay Region, CA. Open File Report. U.S. G.S. in cooperation with H.U.D. Menlo Park, CA.