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Master Drainage and Sediment Control Plan

Lagunitas and Walker Creek Watersheds

Marin County Soil Conservation Service

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June 30, 1965

The Board of Directors
Marin County Soil Conservation District
Point Reyes Station, California

Gentlemen:

We are transmitting herewith our report which provides a master drainage and sediment control plan for the Lagunitas and Walker Creek watersheds.

This report has been prepared with the assistance of Soil Mechanics and Foundation Engineers, Inc., of Sunnyvale, California, who furnished the sediment control investigation. They prepared Chapter 5 and related exhibits. Mr. Thomas E. Wales, Consulting Civil Engineer of Palo Alto, California, acted as a special consultant to the District and in this capacity reviewed the report and the recommendations.

In addition to the project staff and the consultants noted above, valuable information was furnished to this study by many other individuals and agencies: Mr. Mogens Ring, Associate Civil Engineer, Public Works Flood Control, County of Marin; Mr. David W. Dresbach, Program Coordinator, Division of Soil Conservation, State of California Resources Agency; Soil Conservation Service, U. S. Department of Agriculture; Marin Municipal Water District; North Marin Water District; Department of Water Resources, State of California; Point Reyes National Seashore Park Service. We are very appreciative of the help given by these collaborators.

This work was made possible by funds granted to the Marin County Soil Conservation District by the State of California Soil Conservation Commission and the County of Marin.

It has been a privilege to work with the Board on this report and our firm is willing to assist in any possible way in the future development of the program presented herein.



Sincerely yours,

GEORGE S. NOLTE CONSULTING
CIVIL ENGINEERS, INC.

George S. Nolte, President

SUNNYVALE

SAN RAFAEL
SACRAMENTO

WALNUT CREEK
SAN FRANCISCO

SALINAS

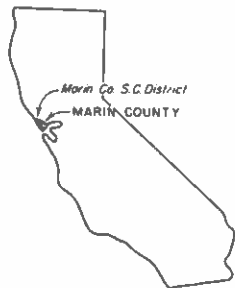
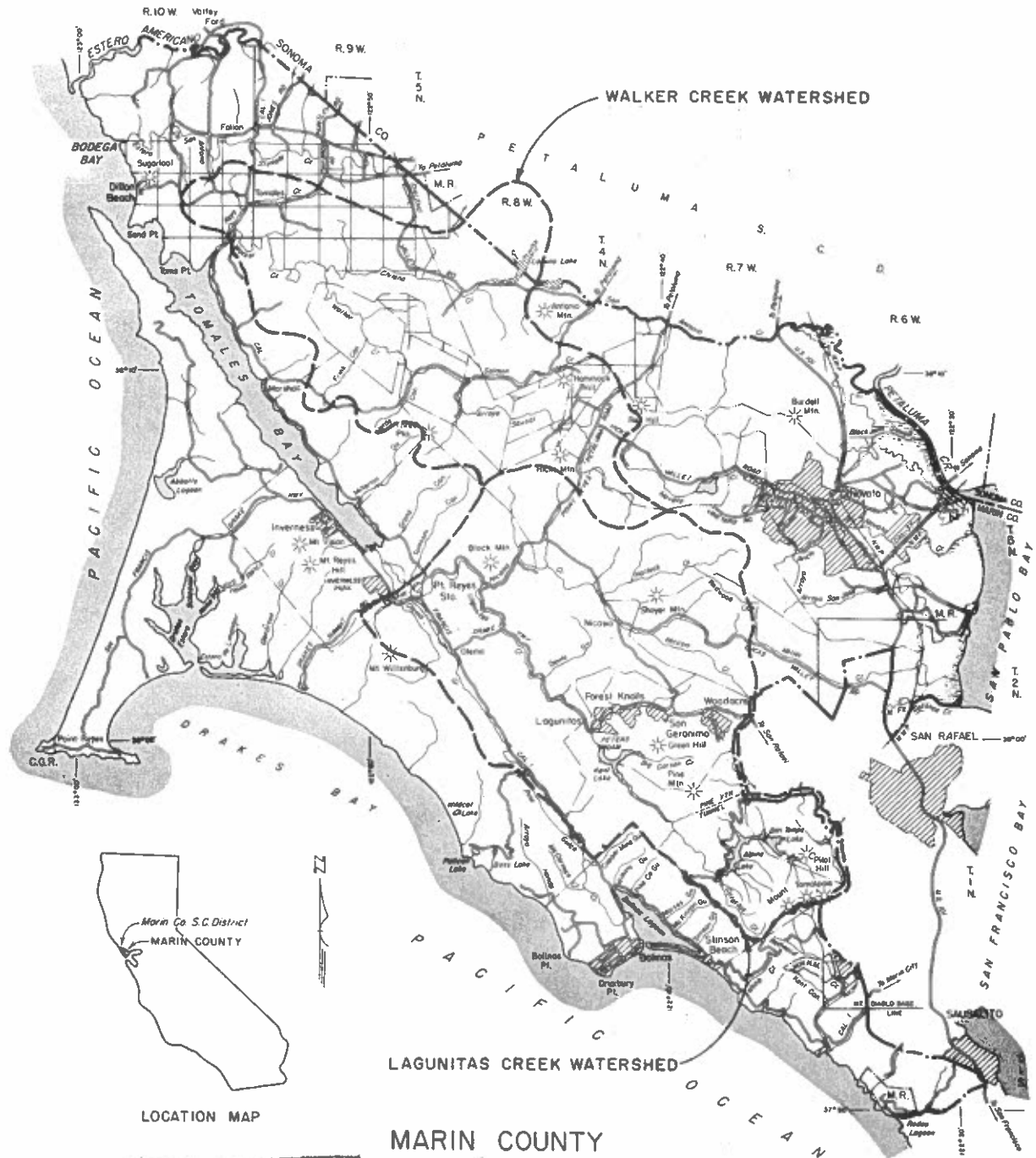
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Master Drainage and Sediment Control Plan

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Marin County Soil Conservation Service

GOLD RIDGE S.C.D.



LOCATION MAP

PRO
POINT

MARIN COUNTY SOIL CONSERVATION DISTRICT MARIN COUNTY, CALIFORNIA

AUGUST 1959



Excluded Area

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE

PLATE 1-1

MARIN CO. S.C.D., (158) CAL. 7-P-19947-L

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INTRODUCTION

Hydrology is that branch of physical geography which is concerned with the origin, the distribution, the properties, of the waters of the earth. Each problem, or study, is unique in that it deals with a distinct set of physical conditions so variable and complex they must be reduced to mathematical equations or graphical correlations for purposes of problem solving.

Adequate basic data are essential to any science and hydrology is no exception. It is necessary to start with a mass of observed facts, analyze these facts statistically, and from this analysis establish the patterns which will govern design criteria for drainage facilities.

An uncomplicated stream rolling down a picturesque hillside into a quiet lagoon is thus translated into graphs, formulae, curves, and terminology which have little meaning for anyone but an engineer. An engineer who has made a special study of hydrology!

Because of the complexity of the subject, this first chapter contains the essence of the subsequent, more technical, chapters. Much of the accumulated data is illustrated on maps, graphs, and tables, which will be found in the Appendix, numbered according to the chapter in which they are discussed; Plate 4-5, for instance, relates

to Chapter 4; Table 3-1 relates to Chapter 3.

Recommendations which are an outcome of this study are very briefly stated on Page 1-8 and are expressed in greater detail in Chapter 8.

OBJECTIVES OF THE STUDY

The Marin County Soil Conservation District initiated this study of the Lagunitas and Walker Creek watersheds as a pilot effort to anticipate drainage needs as land use changes within the area. The West Marin Master Plan population projections to 1990 indicate a trend of urban development from the eastern side of the County, overflowing onto the watersheds. Additional changes are expected as Point Reyes is developed into a major recreational center. This study evaluates existing data gathering facilities, estimated peak flood flows, stream channels, and erosion and sedimentation. Criteria are established for the design of local urban drainage and major channel facilities. Suggestions are made for an appropriate agency structure to demonstrate leadership in drainage plans and administration of a program.

RAINFALL REGIME (CHAPTER 2)

Rainfall is the source and supply of storm water and an understanding of rainfall patterns is essential to drainage analysis. Recording rain gages, or the less informative standard rain gages, are used to supply daily rainfall records. A long period of record is required to establish accurate data and when it is necessary to use short-term rainfall records, they must be lengthened synthetically by correlation with records of other stations.

Such a correlation was made for purposes of developing intensity-duration-frequency curves for this study and we have recommended additional recording gages so sufficient data will be available for future drainage planning.

The intensity-duration-frequency (IDF) curves provide a coefficient which expresses the amount of some change or effect under variable conditions. The coefficient is used in the rational formula to determine peak flood flows within the drainage basin.

Rainfall characteristics of the study area are shown on Plate 2-1 and IDF curves are illustrated on graphs which will be found in the Appendix of this study.

REGIONAL STREAM STUDY (CHAPTER 3)

Streamflow records in the Tomales Bay drainage basins were insufficient to provide the data required to compute the peak rate of flow per unit area of watershed. To acquire the necessary data records of other coastal watersheds were used. This method of correlating data is based on the observed phenomena that hydrological relationships are uniform throughout a homogeneous region (in this instance, the coastal region). Index watersheds used are shown on Plate 3-1.

Concentration points, used to establish the period of time required for storm runoff to flow from the most remote point of a drainage area to a specific point, are shown on Plate 3-10 and peak flood flows for various concentrations points within the watersheds are tabulated in Table 3-1.

Formulae were developed for estimated peak flows, to be applied

in estimating drainage requirements under variable land use conditions. To restate this concept, the curves developed can be utilized to provide a means of estimating peak flow rate at any point in the basin with any amount of change in upstream land use.

CHANNEL PLANNING (CHAPTER 4)

The existing channels were evaluated by the use of U. S. Geological Survey maps, field surveys, and hydraulic computations. Fifty-five field cross sections were obtained by our survey crews at controlling sections and these appear on Plates 4-2 through 4-6, together with hydraulic information. Bridge and crossing structures are shown on the sections and the parts of these structures which can block the flow of water are shown within the closed straight lines.

"Level of protection" refers to the peak flow which can be contained by the channel or structure without flooding. The following levels of protection have been adopted by other agencies in the past and they are suggested for planning purposes in these watershed areas:

- Agricultural Lands, no levees - 10 year peak flow
- Agricultural Lands, levees constructed - 25 year peak flow
- Urban Areas, no levees - 25 year peak flow
- Urban Areas, levees constructed - 100 year peak flow

When more hydrographic information is obtained for these watersheds, a "project flood" level of protection could be adopted, which level may exceed the 100-year peak flow.

Channel capacities are considered in two parts: the area subject to tidal effect and the area upstream of the tidal effect. Walker Creek, Chileno Creek, Salmon Creek, Arroyo Sausal, Lagunitas Creek, Nicasio Creek, and San Geronimo Creek, are individually discussed

and because of the specific nature of these discussions, it is suggested that the reader refer directly to pages 4-6 through 4-10.

Design velocities for planning purposes are given in Table 4-3 for the various creek channels. Control of velocity is important to engineering planning in order to preclude the destruction of channel protective devices and other hydraulic structures, to control channel erosion and to minimize the deposition of solids from the flows. Velocities may be controlled by means of debris basins to retain bed load, stabilized channels of the proper grade and cross section, or by drop structures as necessary to maintain the grade.

Channel right-of-way widths are dependent upon the method chosen to contain the flood waters. Two methods considered are flood plain zoning and channel improvements. Proper maintenance of the improvements will preserve the quality of the original construction. The channels, therefore, should become the responsibility of a jurisdictional agency with authority to enforce policy and with financial capabilities.

GEOLOGY AND SEDIMENTATION (CHAPTER 5)

Soil Mechanics and Foundation Engineers, Inc. developed this study of geology and sedimentation. Basic data for sediment yield purposes was not available and the geology was developed to arrive at a rational basis for estimating sediment yield. This geology will provide basic information on which other investigations can be built. A soil survey has been recommended for this area in order that data will be available when full-scale drainage plans are required.

Geological conclusions as a result of this study are as follows:

1. The study area is made up predominantly of rocks and associated soils which are slightly to moderately erodible. The only appreciable quantities of easily erodible materials are in the alluvial deposits of the stream valleys and upland basins.
2. The Pleistocene and Recent geologic history suggest that the area has been relatively stable, subject primarily to gradual uplift and warping. Late Pleistocene sea level changes have had significant consequences. The recent history of Tomales Bay probably was initiated by a rise in sea level about 10,000 years ago.
3. Annual sediment yields for the Walker Creek and Lagunitas Creek watersheds are probably similar to, or slightly lower than, those of similar basins in the northern California coastal mountains. Arbitrary, but probably conservative, annual sediment yield values assigned to Walker Creek are 250 to 300 tons per square mile. The assigned values for Lagunitas Creek are 200 to 250 tons per square mile per year.
4. The problems of local gullying, bank erosion, channel silting and flooding should receive individual study and treatment as required. Individual and cooperative programs of conservation should be continued and encouraged. There are no major, widespread problems of erosion or sedimentation in either watershed at the present time.
5. Potential changes most likely to increase erosion in the Walker Creek and Lagunitas Creek watersheds are overgrazing and/or cultivation of the grasslands. In the Lagunitas Basin there is the added hazard of forest fires. Urbanization poses a potential problem in either area, but is probably more significant in the Lagunitas Creek basin because of the steepness of the land and the probability of greater hillside development.

6. Reservoirs in the Lagunitas Creek watershed probably have reduced by about one-half the amount of sediment contributed to the downstream basins. Within the study area, the only other major reduction in sediment yield likely to occur, would result from the construction of Walker Dam for water supply purposes. The need for the construction of basins specifically for sediment control could not be established solely on the basis of this study.

7. General programs of suspended sediment measurements, because of their expense, are not recommended at this time. Individual sediment studies may be warranted in connection with specific proposed stream control measures. A reasonable approximation of sediment yield in the Walker Creek area may be determined, at relatively low expense, by means of silting surveys of Nicasio Reservoir, since the tributary areas are quite similar.

PROGRAM ADMINISTRATION (CHAPTER 6)

Areas of urbanization in 1960, and projections for 1990, are shown on Plate 6-1. Leadership is necessary now for the consideration of anticipated drainage requirements with changing land use, development of plans for improvements, establishment of a financial structure to make assessments, accumulate monies, and make disbursements. Urban development will enlarge the tax base and developers of new areas could be assessed to provide for drainage improvements necessitated by increased peak flood flows. Some examples of existing flood control districts are reviewed in this chapter.

Planning for flood control and changing land use should consider the possibility of population growth greater than has been predicted.

DESIGN CRITERIA FOR DRAINAGE FACILITIES (CHAPTER 7)

In this chapter the information developed in this study is related to drainage needs for the area. Urban drainage design elements are presented in a condensed form.

RECOMMENDATIONS (CHAPTER 8)

1. Recording rain gages should be installed at Woodacre, Point Reyes Station and Tomales.
2. A stream gage should be installed on Lagunitas Creek.
3. The deactivated stream gage on Walker Creek should be returned to operation.
4. Hydrologic information should be collected and published regularly as a cooperative effort with other agencies.
5. Channel improvements should be considered for the more troublesome locations.
6. A soil survey of this area should be completed.
7. Erosion control policies should be established and practiced in all construction work.
8. The cooperative soil conservation program should be continued.
9. The development of the Walker Creek Dam project should be encouraged from a sediment control viewpoint.
10. The urban drainage facilities design criteria, proposed in Chapter 7, should be adopted.
11. Consideration should be given to the choice of an appropriate agency or authority to assume responsibility for implementing a flood control program.

GENERAL

Rainfall is the source and supply of storm water, and an understanding of rainfall patterns is essential to drainage analysis. Recording rain gages, or the less informative standard rain gages, are used to supply daily rainfall records which are essential to the establishment of rainfall patterns. A long period of record is required to establish accurate data since short-term records may reflect a sequence of either wet or dry years and may not be representative of long-term seasonal precipitation. When it is necessary to use short-term rainfall records, it is advisable to lengthen them synthetically by correlating them with records of stations for which long-term means have been established.

At this time, rain gages within the area are insufficient in number and do not provide as much data as is desirable for hydrologic planning. The existing rain gages, both standard and recording, are shown on Plate 2-1, in the Appendix of this report. We have recommended that three additional recording gages be established at Woodacre, Point Reyes Station, and Tomales.

For purposes of this study we established mean seasonal precipitations for rain gages in the study area by correlating their short

term average rainfalls with the longer record available at the Kentfield rain gage.

MEAN SEASONAL PRECIPITATION

The rainfall pattern is determined from the mean seasonal precipitation, which is the average of twelve-month rainfalls at a given location. Seasons are conventionally measured from July 1 through the following June.

In the Tomales Bay drainage basins, mean seasonal rainfall varies from 23 inches at the upper end of Chileno Creek to about 53 inches in the vicinity of Kent Lake. A summary of the rainfall data accumulated from the rain gages in the study area and correlated with the rain gage at Kentfield, is shown in graph form on Plate 2-2.

The isohyets, or lines, which appear on Plate 2-1, represent equal mean seasonal precipitation. Values of the isohyets¹, indicated in inches on the map, were compared with data from the individual rain gages within the study area. General agreement between the point values permitted use of the isohyetal map without modification.

INTENSITY-DURATION-FREQUENCY OF RAINFALL

Development of a rational design for local drainage facilities was based on IDF curves which relate the average intensity of rainfall to storm duration and frequency of occurrence.

¹These lines are based on an isohyetal map by the U. S. Army Engineer District, Corps of Engineers, San Francisco, California. The base period for the isohyets is July 1906 to July 1956.

Several sources of data³ were examined in preparing IDF curves for the Lagunitas and Walker Creek watersheds. The fifteen-year record of hourly rainfall readings at Novato 8WNW provided the best available data for defining representative intensity-duration-frequency curves. These curves, shown on Plate 2-3 and used as the basis for the rational design², were derived from maximum rainfall depth at Novato 8WNW for durations of 1, 6, 12 and 24 hours. Due to the short period of record at this station it was necessary to adjust some of the computed points to the typical IDF curve shape, using more general data.⁴

The resultant IDF curves plot as straight lines on log-log paper and have the general equation: $i = \frac{A}{t^n}$

where: i is the average rainfall intensity in inches per hour
 A is a constant dependent on the frequency of occurrence
 t is the duration of rainfall, in minutes
 n is an exponent reflecting the rate of change of rainfall intensity with respect to rainfall duration; physically, it is the slope of the intensity-duration curve when plotted on log-log paper

²Q = CIA

³Technical Paper No. 25, published by the U. S. Weather Bureau, contains IDF curves for Mt. Tamalpais and Point Reyes (Lighthouse). Due to their extreme locations, neither of these stations was considered representative of storm rainfall characteristics of the Lagunitas and Walker Creek watersheds. Data presented in Technical Papers No. 28 and No. 40 yield generalized IDF curves for the West Marin County area, but are too general to reflect the significant rainfall intensity variation within the study area.

Marin Municipal Water District, operator of the gages at Nicasio and Kent Lake, made available the records from 1959 to 1964. These records are too short to support independent development of IDF curves but contain a sufficient number of large storms to permit comparison of rainfall characteristics between these stations and Novato 8WNW for selected isolated storm events.

⁴U. S. Weather Bureau Technical Paper No. 40.

2-4 . Intensity-Duration-Frequency of Rainfall

The value of the exponent, n , was determined by measuring the slope of the parallel plotted IDF curves and was found to be 0.55. The typical range of values of this exponent is very small and it can be assumed to remain constant throughout an area of the size of the Tomales Bay drainage basins.

The value of A for each frequency was determined by solution of the intensity formula, using the intensity values and corresponding durations taken from the plotted curves. The completed intensity equations for various frequencies of occurrence at Novato 8 WNW are tabulated on Plate 2-3.

MODIFICATION OF INTENSITIES FOR ANY LOCATION IN THE WATERSHED

In addition to the recording gage at Novato 8 WNW, there are two other recording rain gages at Nicasio and at Kent Lake. Marin Municipal Water District, the operator of these gages, made available the records from 1959 to 1964. The records are too short to support the independent development of IDF curves, but they contain a sufficient number of large storms to permit comparison of rainfall characteristics between these stations and Novato 8 WNW for selected isolated storm events.

Preliminary comparison of the rainfall of individual storms indicated that the intensities at Nicasio and Kent Lake were appreciably higher than corresponding intensities at Novato 8 WNW. The ratio between rainfall intensities at Nicasio and those at Novato 8 WNW was found to be very nearly equal to the ratio of their respective mean seasonal precipitations. At Kent Lake the adjustment on the basis of mean seasonal precipitations resulted in computed intensities about fifteen to twenty percent higher than those observed. Thus, the ratio between rainfall intensities at Kent Lake and those at Novato 8 WNW was

determined to be 0.85 times the ratio of their respective mean seasonal precipitations.

On the basis of these observations, it was decided to define the rainfall intensity-frequency relationship for any point in the Lagunitas and Walker Creek watersheds by a general equation of the form: $i = \frac{kA}{t^n}$ where A and n are the same as those determined for Novato 8 WNW.

The value of the adjustment factor k is based on the ratio between the mean seasonal precipitation at the point under consideration and that at Novato 8WNW, with modification in the vicinity of Kent Lake to reflect the non-applicability of the straight MSP ratio in that area. In areas where the MSP ratio was less than unity, the adjustment factor k was assumed to be 1.0. The map on Plate 2-4 shows the variation of k throughout the study area and permits the simple determination of IDF curves for any point in the study watersheds. The regions between the lines on this map represent zones of equal values of k.

GENERAL

Streamflow records in the Tomales Bay drainage basins are extremely limited. Of three stream gages reported in the publications of the U. S. Geological Survey, only one has sufficient record to provide a basis for the determination of flood-frequency values. This gage, now discontinued, was located on Arroyo Nicasio near Point Reyes Station. Its period of record began in 1953 and was terminated in 1960 with the construction of Nicasio Dam. The remaining watersheds in the Tomales Bay drainage basins are ungaged and their flood-frequency values must be estimated on the basis of the best available data and applicable hydrological techniques.

HYDROLOGICALLY HOMOGENEOUS COASTAL REGIONS

The Regional Stream Study has been selected as the method to be used in estimating the flood-frequency relationships of the ungaged watersheds in the Tomales Bay drainage basins. This method is based on the observed phenomenon that, for a particular frequency of occurrence, the peak rate of flow per unit area of watershed is a function of the size of the watershed, and that this relationship is uniform throughout a hydrologically homogeneous region.

The U. S. Geological Survey, in a Regional Stream Study,¹ found that the magnitude of the mean annual flood for any stream with an entirely coastal watershed is related to the size of the tributary drainage area, and that this relationship is not materially affected by relatively large variations in mean annual precipitation. The results of this study also indicate that the slope of the dimensionless flood-frequency curve is essentially constant within a hydrologically homogeneous coastal region.

These observations lead to the conclusion that unmeasured peak rates of flow may be estimated from the measurable watershed area by means of an equation relating flood peak, flood frequency, and watershed area. Such an equation may be written: $Q_p = KA^n$

where: Q_p is the peak rate of flow in cubic feet per second
 K is a constant for any given frequency of occurrence
 A is the area, in square miles, of the tributary watershed
 n is a constant for any hydrologically homogeneous region.

INDEX WATERSHEDS

Values of K and n are determined from the correlation of flood-frequency curves for index watersheds in the same hydrologic region as the ungaged watersheds for which flood-frequency values are to be estimated. The index watersheds must be gaged and must have a sufficiently long period of gage record to provide a basis for the determination of flood-frequency values. It is important that these gage records be unaffected by any upstream regulation or diversion of flows.

Plate 3-1 shows the locations of stream gages in coastal watersheds for which published records are available. Pertinent gage information

¹"Surface-Water Hydrology of Coastal Basins of Northern California."

such as name, tributary drainage area, and period of record, is tabulated in the block at the lower left-hand corner.

All of those watersheds having a period of gage record in excess of seven years were selected as index watersheds for use in determining regional average flood-frequency parameters, with the exception of the Gualala River. The flow records for the Gualala River watershed did not yield a flood-frequency curve of sufficient certainty to warrant its use in regional correlations.

INDEX FLOOD-FREQUENCY CURVES

Flood-frequency curves were prepared for each of the index watersheds. The frequency formula used is: $T_r = (N+1)/M$

where: T_r is the recurrence interval in years for a flood of relative magnitude M , arranged in decreasing order of magnitude, and

N is the effective period of record in years.

Sample index flood-frequency curves are shown on Plates 3-2 through 3-5. They were drawn on arithmetic probability paper to take advantage of the tendency of such curves to approximate straight lines on this type of graph.

The plotted points for the Noyo and Navarro Rivers conformed very well with computed flood-frequency curves based on the regional averages for Sub-region 1 of the Northern California Coastal Basins Regional Stream Study. The flood frequency curves for Arroyo Nicasio and the more southerly watersheds tended to be steeper, indicating more variable runoff and a greater difference in severity between storms that produce minor floods and those that produce major floods.

CORRELATION OF INDEX MEAN ANNUAL FLOOD FLOWS TO WATERSHED AREA

The flood-frequency curves for the index watersheds were correlated by plotting the mean annual flood peaks² against tributary watershed areas. The plotted points are shown on Plate 3-6. The regional average mean annual flood peak vs. watershed area curve for Sub-region 1 of the Northern California Coastal Basins Regional Stream Study, was drawn on the same graph. It was observed that the plotted points and the curve agreed very well. While the gage record for Arroyo Nicasio indicated a slightly greater mean annual flood than that indicated by the regional average, it was felt that the short record for Arroyo Nicasio did not justify modification of the regional average curve.

The conclusion of the U. S. Geological Survey, that no correlation is apparent between the mean annual peak flood and the mean annual precipitation, was considered for our index watersheds. Our investigation verifies this conclusion for our index watersheds.

The equation of the selected mean annual flood peak vs. tributary watershed area curve is $Q_p = 130 A^{0.91}$. Similar regional analyses yielded equations for mean annual average flows for selected durations. Mean annual flood discharge-drainage area relationships for the Tomales Bay drainage basins are shown graphically on Plate 3-7. The corresponding discharge formulae are tabulated below:

<u>Flood Event, 2.33-Year Recurrence Interval</u>	<u>Formula</u>
Peak Flood Flows	$Q_p = 130 A^{0.91}$
Mean Flows - Maximum Day	$Q_m = 67 A^{0.91}$
Mean Flows - Maximum 30 days	$Q_m = 12 A^{0.91}$
Mean Flows - Maximum 120 days	$Q_m = 5.3 A^{0.91}$

where: Q_p = peak flow in CFS
 Q_m = mean flow in CFS over the specified duration
 A = tributary watershed area in sq. mi.

²2.33 year recurrence interval.

DIMENSIONLESS FLOOD-FREQUENCY CURVE

Flow rates for floods occurring less frequently than the mean annual event are determined from a dimensionless flood-frequency curve. This curve expresses the magnitude of the flood event for any frequency of occurrence as a ratio to the magnitude of the mean annual flood event. From the gaged series flood-frequency curve for Arroyo Nicasio, it was determined that the magnitude of the 100-year flood event was approximately 3.5 times as great as the magnitude of the mean annual flood event. This and other flood-frequency ratios are tabulated below:

<u>Recurrence Interval</u>	<u>Ratio to Mean Annual Event</u>
10 years	2.0
25 years	2.6
50 years	3.1
100 years	3.5

The dimensionless flood-frequency curve is shown graphically on Plate 3-8. It can be used to determine the magnitude of infrequent floods for all durations of flow.

SAMPLE DETERMINATION OF PEAK FLOOD DISCHARGE

To determine the peak rate of flood discharge for any ungaged watershed in the Tomales Bay drainage basins for any frequency of occurrence, it is necessary only to enter the mean annual discharge-tributary drainage area curve with the size of the drainage area and determine the mean annual flood peak, multiplying the mean annual value by appropriate ratio for the desired frequency of occurrence to determine the flood peak for that frequency.

If, for example, it were desired to determine the 10-year peak flood flow for Walker Creek at Camp Tomales, the procedure would be:

1. Determine the size, in square miles of the tributary watershed.

From Table 3-1, this is seen to be 73.1 square miles.

2. Determine the magnitude of the mean annual flood peak for the watershed.

Enter the graph of Plate 3-7 with a drainage area of 73.1 sq. mi. and read a mean annual peak flood of 6,700 CFS.

3. Determine the magnitude of the flood peak for the desired frequency of occurrence by multiplying the mean annual flood peak by the appropriate peak ratio from the dimensionless flood-frequency curve.

From the dimensionless flood-frequency curve of Plate 3-8 it is seen that the ratio between the 10-year flood peak and the mean annual flood peak is 2.0. Multiplying 6,700 CFS by 2.0 gives a 10-year flood peak of 13,400 CFS.

Thus, the 10-year peak flood flow in Walker Creek at Camp Tomales has been found to be 13,400 CFS.

PEAK FLOOD DISCHARGE IN REGULATED WATERSHEDS

The development of techniques for estimating peak flood flows in the ungaged streams of the Tomales Bay drainage basins has thus far been based on the assumption of natural, unregulated watersheds. A special case exists on lower Nicasio and Lagunitas Creeks, where most of the tributary watershed of each creek lies upstream of a large dam and reservoir. The rate of outflow from such reservoirs is seldom equal to the rate of inflow, and the determination of peak flood flows downstream from these dams must reflect the impact of flow regulation.

Nicasio Dam and Peters Dam were not designed for any flood control effect and thus do not have any capacity reserved for the containment of flood flows. Analysis of the past operation of these

reservoirs indicates that they have been full and spilling in nearly every year of operation, and it is safe to assume that they will be full at the time a flood peak from upstream hits the reservoir.

To evaluate the effect of these reservoirs on peak flood flows, inflow hydrographs for the upstream watersheds were developed and routed through the reservoirs. The inflow hydrographs were based on the dimensionless hydrographs³. Peak flow rates were determined by the techniques described previously in this report. A graphical routing procedure was used to determine the outflow hydrographs.

Typical inflow and outflow hydrographs for Nicasio Dam are shown on Plate 3-9. Inflow hydrographs representing several different storm durations were routed through the reservoirs. The resulting outflow hydrographs had peak flow rates ranging from 35 percent to 70 percent of the corresponding inflow hydrograph peaks. The smaller outflow peaks corresponded to the shorter duration storms. The longest duration storms examined produced outflow peaks of approximately 70 percent of the corresponding inflow peaks. This 30 percent reduction in flood peaks was taken to be the effect of flow regulation by the dams on the flood peaks of their upstream watersheds.

Since flood peaks are estimated by the formula, $Q_p = KA^{0.91}$, a 30 percent reduction in Q_p can also be expressed as a proportional reduction in effective tributary watershed area. If the outflow Q_p is equal to 70 percent of the inflow Q_p , then the effective watershed area to the 0.91 power is equal to 70 percent of the actual watershed area to the 0.91 power. This may be written:

$$\frac{(A \text{ effective})^{0.91}}{A \text{ actual}} = 0.70$$

³ rainfall distribution curve B, hydrograph family No. 3

3-8 . Regional Stream Study

The equation may be solved to yield:

$$\frac{A_{\text{effective}}}{A_{\text{actual}}} = (0.70)^{1/0.91} = (0.70)^{1.11} = 0.68$$

For the purposes of estimating peak flows in channels downstream from Nicasio or Peters Dams, the effective watershed area above a dam will be taken as 68 percent of the actual area. A sample calculation is given below to demonstrate the use of this modification for regulated watersheds:

It is desired to estimate the 25-year peak flood flow in Lagunitas Creek immediately above its confluence with Nicasio Creek:

- . Reference to Plate 3-10 and Table 3-1 shows that the total tributary watershed area at that point is 42.6 square miles (point L-4 with the Nicasio Creek drainage area subtracted).

- . The tributary area above Peters Dam is shown in Table 3-1 (point L-11) as 21.5 square miles.

- . The effective watershed area at the desired point is $0.68 \times 21.5 + (42.6 - 21.5) = 14.6 + 21.1 = 35.7$ square miles.

- . The mean annual peak flow for a watershed of 35.7 square miles is read from Plate 3-7 as 3,400 CFS.

- . The ratio of the 25-year flood to the mean annual flood, from Plate 3-8, is 2.6.

Thus, the 25-year flood peak in Lagunitas Creek immediately above its confluence with Nicasio Creek is $2.6 \times 3,400 \text{ CFS} = 8,840 \text{ CFS}$. This flow rate reflects the regulation of Peters Dam on discharges from its tributary watershed

If there were no dams in this watershed, the unregulated peak flow would be 10,400 CFS.

ESTIMATED PEAK FLOWS

Estimated peak flood flows for events with recurrence intervals⁴ of 2.33 years, 10 years, and 100 years are given in Table 3-1 for selected concentration points, without consideration to the influence of urbanization. The location of the concentration points is shown on Plate 3-10. The effective tributary areas from Plate 3-6 are used to obtain the 2.33 year peak flood flow and the total area is reduced to effective area for those creeks having reservoir regulation. The 10 year and 100 year peak flood flows are then obtained by using the proper multiplier from Plate 3-8, and multiplying the 2.33 year peak flood flow values.

Peak flood flows shown in Table 3-1 reflect the existing conditions in the watershed. Urbanization of any magnitude will result in greater peak flood flows due to increased impervious surface factor (K), and in the variable channel improvement factor (C). Peak flood flows can be determined, as an area urbanizes, by multiplying non-urban peak flood flows by these two factors:

$$\text{Urban } Q_{pk} = (C) (K) (\text{Non-Urban } Q_{pk})$$

The impervious surface factor has been evaluated on a rational approach, that of the relative increase in runoff coefficients. A value of 0.90 has been selected as the long-duration runoff coefficient for impervious surfaces, and a value of 0.65 was selected as the long-duration runoff coefficient for the pervious surface condition. The pervious runoff coefficient of 0.65 has been considered applicable to non-urban watersheds and is based upon Sacramento County basin precipitation and the corresponding storm runoff data. The impervious surface factor may be expressed for application to any given urban land use condition:

⁴ mean annual

$$X = \left[\left(\frac{\text{Impervious Surface Area}}{\text{Total Drainage Area}} \right)_{\text{Avg.}} (0.90 - 0.65) \right] + 0.65$$

$$K = (1.00 + X/0.65)$$

The ratio of impervious surface area to total drainage area, expressed as a percentage, as well as the resulting impervious surface factor, is shown in Table 3-2 for the three predominant land use conditions. The curve for each of these land use categories is plotted on Plate 3-12 with the (K) factor being a function of the percentage of the drainage area being urbanized.

If a section of the upstream channel is improved in some manner during the urbanization of an area, the peak flood flow will be increased by a channel improvement factor (C). The derivation of this factor has been based on a rational approach in the following manner.

The increase in peak flood flows, due to channel improvement, is assumed proportional to the increase in average rainfall intensity (i) resulting from reduced concentration times. Plate 3-11 illustrates in a dimensionless manner the affect of urbanization on peak flood flow rates. It has been determined that $i = A/T^{0.55}$. If concentration times are assumed to be inversely proportional to average channel velocities (v), the ratio of average rainfall intensities can be expressed:

$$C = \left(\frac{i \text{ for } T \text{ improved}}{i \text{ for } T \text{ unimproved}} \right) = \left(\frac{(A)}{(A)} \right) \left(\frac{v \text{ improved}}{v \text{ unimproved}} \right)^{0.55}$$

where: $(A/A) = 1.0$

The increase in average channel velocity, from the unimproved to the improved condition, is assumed to be influenced by changes in the channel friction factor (n) and the hydraulic radius (R), in accordance with the Manning equation.

$$\left(\frac{v \text{ improved}}{v \text{ unimproved}} \right) = \left(\frac{n \text{ unimproved}}{n \text{ improved}} \right) \left(\frac{R \text{ improved}}{R \text{ unimproved}} \right)^{0.67}$$

The following average values can be used for the friction factor and hydraulic radius improvement. These values are based on field reconnaissance in other areas and are subject to revision by actual field conditions in the study area.

Average unimproved $n = 0.050$

Average improved $n = 0.025$

Average improvement in hydraulic radius: $\left(\frac{R \text{ improved}}{R \text{ unimproved}} \right) = 1.50$

Thus, if there is clearing only of the channel, without channel reshaping or improvement of the hydraulic radius, use this factor:

$$C_1 = \left(\frac{n \text{ unimproved}}{n \text{ improved}} \right)^{0.55} = \left(\frac{.050}{.025} \right)^{0.55} = 1.46$$

If the channel is improved by clearing and reshaping, then use this channel improvement factor:

$$C_2 = \left[\left(\frac{.050}{.025} \right) \left(\frac{R \text{ improved}}{R \text{ unimproved}} \right)^{0.67} \right]^{0.55} = 1.70$$

The factors are applicable where all of the channel system is improved, or will be improved, above a given point.

For those cases where only a portion of the upstream channel system is improved, these factors should be reduced by the ratio of improved upstream channel length to total upstream channel length:

$$C_1 = 1.00 + (0.46) (Li/Lt)$$

$$C_2 = 1.00 + (0.70) (Li/Lt)$$

The (Li/Lt) ratio should include all tributary and main channel drainage areas in excess of 160 acres.

The applicable channel improvement factor, a direct function of the percentage of upstream channel length which has been improved or will be improved, is shown on Plate 3-13.

As an illustration of the foregoing discussion, let us consider the influence of urbanization in the San Geronimo Valley on downstream peak flood flows:

Assume a 2.0 sq. mi. medium density development above Point G-5, with upstream channels cleared but not reshaped.

Assume that the length of cleared channels is directly proportionate to the percentage of the drainage area to be urbanized.

The results of this example are tabulated in Table 3-3

The only increase in flood flow volumes due to urbanization of tributary watersheds will result from increased impervious surfaces. Channel improvements will concentrate a given flood volume into a shorter duration of runoff, but should not affect the total volume of runoff.

In conclusion, significantly increased flow to the immediate downstream channel reaches will result where urban development constitutes a large portion of the total area tributary to such reaches. This effect decreases at points further downstream, with no attendant increase in urbanized area but with substantial increase in total tributary area.

When stream gage records of suitable duration are available, as recommended in this report, a quantitative analysis will be possible of the effects of urbanization for these watersheds.

Quantitative results of studies in other areas cannot be accurately correlated or projected to this study area because of differences

in urban development patterns, topography, and hydrological factors. However, a recent study by the U. S. Geological Survey, Effect of Urban Growth on Streamflow Regimen of Permanente Creek, Santa Clara County, California, provides a general illustration of what hydrological changes take place in a watershed when land use changes from cultivated and uncultivated land to urban development.

GENERAL

The existing major creek channels were evaluated as a part of this study and the results of our investigation are discussed in this chapter. The channels were evaluated by use of U. S. Geological Survey maps, field surveys, and hydraulic computations, and results are presented in terms of the present capacity of the channels. Channel widths required for various flows and suggested channel improvements were considered and the results of the investigation are graphically summarized on a series of plates, 4-1 through 4-10, and on Table 4-1 and 4-2.

METHODS USED TO EVALUATE CHANNEL CAPACITY

Fifty-five field cross sections were obtained by our survey crews at controlling sections. These sections were drawn, and the location and hydraulic information listed thereon. These sections were used as a basis for the evaluation of the existing channels.

The gradient or slope of each channel was determined from U.S.G.S. maps and from elevations for each surveyed channel section. The two slopes usually compared favorably, and the slope based on the field survey was generally used.

Each section was analyzed to obtain the depth of flow or stage for each rate of flow. The manning formula was used for these computations, using n values estimated by observation in the field from 0.040 to 0.070. The slope of the water surface was assumed to be equal to the channel slope in the vicinity of the section. In one or two locations, where special conditions existed, the water slope used was a modification of the channel slope, based on the available information. Increased depth of flow due to restrictions by drainage structures was not evaluated, except in the tidal areas.

The flow capacity of each channel section at bankfull depth was then determined. The ratio of bankfull flow capacity to the mean annual peak flow, 10-year peak flow, 25-year peak flow, and 100-year peak flow, was then calculated. The top width of the water surface was determined from the cross sections for each of the aforementioned peak flow frequencies. In areas where bankfull conditions were exceeded, assumptions had to be made in regard to topographic conditions, due to the fact that the top widths expected exceeded the cross section information available.

The last area of intensive evaluation was the tidal reaches of each stream. For various tidal heights and quantities of peak flow, the depth of flow or stage was computed within the areas subject to tidal influence.

The information derived from the foregoing evaluation is summarized on Table 4-1, Flow Conveyance Characteristics. The values of peak flow or discharge in cubic feet per second (CFS) are the values as presented in Table 3-1 in the Appendix. As explained in Chapter 3, these values of flow have been modified to reflect the flow regulation properties of the reservoirs, but the values have not been modified to reflect future urban development.

The channel areas subject to tidal influence are not shown on Table 4-1 but they are explained later in this chapter and on Plate 4-10.

EXPLANATION OF THE PLATES ON CHANNEL CAPACITY

Plates 4-1 through 4-9 present in graphic form the present channel characteristics and flow capacities. The boundaries of each major watershed are shown, and the remaining plates and discussion will group all the channels into the Lagunitas Creek group or the Walker Creek group.

Plate 4-1 is an index map of the locations of the channel sections, and the circle or hexagon, which enclose a section number, indicate whether the section is at a drainage structure or at a natural channel section.

Plates 4-2 through 4-6 illustrate channel sections that were surveyed for this report. Three additional sections that apply to the tidal area of Lagunitas Creek are shown on Plate 4-10. Applicable distances, horizontal and vertical, are shown on each section and the distances are in feet.

Elevations are based on mean sea level, and for some of the sections an established elevation control or bench mark was used. For other sections, where no bench mark elevation was available, the elevation was approximated from the U.S.G.S. maps. The lowest point in elevation in the section is normally the flow line of the section; this point is indicated by the symbol E_L .

The bridge and crossing structures are shown on the sections, and the parts of these structures which can block the flow of water are

shown within the closed straight lines. The hydraulic information used to evaluate each section is shown. The symbol that is comprised of an M and a number indicates the channel mile of the section. The channel miles were laid out on the U.S.G.S. maps, and the zero mile points were arbitrarily located near the mouth of the particular creek.

The information necessary to reestablish the channel miles is given on Plates 4-7, 4-8, and 4-9, under the stream profiles, and our computations on channel capacity are summarized on these plates. Each plate contains the same information for different sections of channel. The graph at the bottom of the page shows the channel profile and slope in percent, which is the rise in feet divided by the horizontal length in feet and multiplied by 100. This graph is based on the elevations as given on the U.S.G.S. maps. The next graph presents the cumulative drainage area with the zero point at the point of highest elevation in the watershed. The next graph shows the top width of the water surface for the 25-year peak flow and the 100-year peak flow, in relation to bankfull width. In the locations where the bankfull width is exceeded by the predicted flows, assumptions have been made in regard to topography which controls the top width as shown. The last graph presents the ratio of the mean annual, 10-year, 25-year, and 100-year peak flows to the existing channel capacity. The ratio of 1.0 indicates a bankfull condition and no flooding. Any ratios in excess of 1.0 indicate flooding.

LEVELS OF PROTECTION

In Chapter 3 the relationship was explained between the magnitude of peak flows and their average return in years. In this chapter

the return period of these peak flows is related to the level of protection that any channel can provide. The term "level of protection" refers to the peak flow which can be contained by the channel or structure without flooding. The following levels of protection have been adopted by other agencies in the past, and they are suggested for planning purposes in these watershed areas:

- Agricultural Lands, no levees - 10 year peak flow.
- Agricultural Lands, levees constructed - 25 year peak flow.
- Urban Areas, no levees - 25 year peak flow.
- Urban Areas, levees constructed - 100 year peak flow.

When more hydrographic information is obtained for these watersheds, a "project flood" level of protection could be adopted, which level of protection may exceed the 100-year peak flow presented in this report. The continuity of the level of protection throughout a channel with both agricultural and urban land use must be maintained. Chapter 7 lists the level of protection as it applies to local urban drainage facilities.

CHANNEL CAPACITIES

The discussion of channel capacities will be in two parts: the portion upstream of the area of tidal effect, and the area subject to tidal effect. It is important to remember that our information is based on the channel sections that we obtained, and the conditions found at each channel section apply only to that section. On Plates 4-7 through 4-9 we have connected our points of information from section to section with straight lines, to illustrate trends, but we are assuming uniformity between sections which is not usually true. The sections obtained were selected because it appeared that they controlled the flow regime of the channels. The worst conditions for our purposes occur at these sections.

WALKER CREEK. Flooding is not indicated on Walker Creek for Sections 8 through 13. Sections 6 and 7 indicate flooding for the 100-year peak flow only. Section 5 indicates flooding for the 10, 25, and 100-year peak flow, due to the restriction imposed on the water flow by the bridge structure. The area between Sections 4 and 5 is a virtually non-accessible reach of channel in a deep ravine. Because of the topography and geology of this reach of channel, it is our opinion that no flooding occurs until Channel Mile 3, which is just upstream of Section 4. This is approximately the beginning of the tidal affect on the creek storm flows.

The reach of channel subject to tidal affect on this creek is from about Channel Mile 3 to the bay. The main land use adjacent to the channel is by Camp Tomales and the State highway. Our analysis of this area is based on a computation of water surface using the channel sections shown on Plate 4-2. The topography was assumed to be continuous between the tidal sections that were surveyed. Based on these assumptions, the water surface elevations for the mean annual and the 10-year peak flow were computed. These peak flows were assumed to occur at the tidal elevation of the mean higher high water, as shown on Plate 4-12.

Plate 4-12 shows the average tidal cycle during the season of peak flow, which tidal cycle is considered to be the worst condition for our purposes in this report. Also listed on Plate 4-12 is the tidal elevation information as defined by the U. S. Coast and Geodetic Survey. This elevation information is used in this chapter and in Chapter 5, and it was necessary to transfer elevation base from the land surveys to the hydrographic surveys of the bay.

In San Francisco Bay it has been determined that the maximum water surface elevation exceeds the predicted water surface elevation due

to tidal action. This occurrence is due to wave action and other hydraulic occurrences which are not predictable. No allowance for this has been made here, and prior to any detailed studies involving these tidal areas, this phenomenon should be investigated. The investigation could be done by field measurement, which would involve the use of a portable recording tide gage placed near the area under consideration.

The water surface elevations that were computed (in feet) are as follows:

<u>Channel Mile</u>	<u>Mean Annual Peak Flow</u>	<u>10-Year Peak Flow</u>
0.0	2.6	2.6
0.7	7.0	8.0
1.8	7.5	9.5
2.2	9.2	11.0

Base of these elevations is mean sea level.

The elevations for other flows were not computed due to the assumptions involved regarding topography. The water surface elevations as shown are conservative, but more investigation of this problem should be done prior to any construction that can be damaged by flooding.

CHILENO CREEK. Chileno Creek is a tributary of Walker Creek which joins Walker Creek just upstream of Channel Mile 9. Sections 1, 3 and 5 indicate flooding due to the lack of waterway opening in the bridges at these sections. This flooding will either be to each side of the bridge (flooding the roadways) or over the top of the bridge. Section 4 can pass the mean annual peak flow within the banks, but all other flows spread out over the land. This is a typical type of occurrence in a valley of this sort, with the flat plain area available for flooding.

SALMON CREEK. Salmon Creek is a tributary of Walker Creek which joins Walker Creek at Channel Mile 16.8. In the area investigated, this creek shows no flooding potential for the flows considered.

ARROYO SAUSAL. Arroyo Sausal is a tributary of Walker Creek, and its confluence point is about one mile upstream of Salmon Creek. Our investigation of this creek indicates that no flooding potential exists at this time in the area adjacent to Walker Creek.

LAGUNITAS CREEK. The portion of this creek which is upstream of the tidal effect starts at Channel Mile 3, and it includes Sections 4 through 15. Sections 4, 5, and 6 indicate flooding above the elevation set by us as bankfull. The bankfull condition is not easily defined, but our definition for it is: "The limit of bankfull is at that point on either side of the channel where the land slope tends to become horizontal." Our field sections generally terminated just beyond the bankfull limit, but it is possible to have additional capacity above this limit.

Channel Section 7 appears to be adequate. Channel Sections 8 and 9 show some flooding for the 100 year peak flow. Channel Section 10 appears to be adequate. At Channel Section 11 an inadequate waterway opening in the bridge is causing a definite flood condition. Channel Section 12 does not pass the 100-year peak flow, and this is also a bridge problem. Channel Sections 13, 14 and 15 appear to be adequate.

The tidal influence on this creek extends from Tomales Bay to about Channel Mile 3, which is east and south of Point Reyes Station. This area is depicted on Plate 4-10, with a plan view, profiles of the water surfaces and levees, and typical channel sections. The water surface computations were performed in the same manner, and with the

same assumptions as described previously for Walker Creek, except that reasonable assumptions had to be made for the cross sections of the channel, as indicated on Plate 4-10. The reason for this is that the existing levee system will not contain the mean annual floods when the tide level is near higher high water.

Plate 4-10 suggests a flood control solution for a 10-year level of protection; however, the tidal elevation difficulty as discussed previously should be investigated before these suggestions are incorporated in any levee construction programs. It is suggested that the channel width be designed for the 100-year level of protection, and that the levees be constructed initially to the height required for the level of protection chosen. At a future date the levees could be extended in height without complete reconstruction.

NICASIO CREEK. Nicasio Creek is a tributary of Lagunitas Creek which joins Lagunitas Creek at about Channel Mile 6.5. Our investigation does not indicate any flooding in this creek from Nicasio Dam to Lagunitas Creek.

SAN GERONIMO CREEK. San Geronimo Creek is a tributary of Lagunitas Creek which joins it at Channel Mile 13.7 just below Peters Dam. This creek has a steeper profile than most of the other creeks, and its channel is capable of conveying the 100-year peak flow without flooding. The one exception to this is the man-made weir and fish ladder at Section 8. This weir will not pass the 10-year peak flow without some local flooding. The improvement of this condition would involve modifications to the weir and possibly some levees.

Nine culvert locations in this creek in the Woodacre area were investigated, and the culverts were rated. The culvert farthest

downstream has a contributory drainage area of one square mile, and all the other culverts have contributory drainage areas of less than one square mile. The farthest downstream culvert is adequate for the 10-year and 100-year peak flood flows as determined from Chapter 3. The smallest drainage area that can be analyzed by the methods of Chapter 3 is one square mile, and the 10-year peak flow is 265 CFS and the 100-year peak flow is 455 CFS. The other eight culverts in this area have capacities of 65 CFS to 145 CFS, and they are inadequate. These culverts also lack continuity of flow design, as many of the culverts can pass greater flows than the next culvert downstream.

These culverts should be analyzed by the methods of Chapter 7. The predicted 10-year peak flow, in accordance with Chapter 7, ranges from 320 CFS to 800 CFS, and this is an increase of almost three times over the flow predicted in Chapter 3. This illustrates the urban effect on an agricultural or natural watershed.

CHANNEL FLOW VELOCITIES

Velocity of storm water flows is an item of interest to engineers for two reasons: to limit the destruction of hydraulic structures, and to minimize the deposition of solids from the flows.

Recommended maximum velocities for any condition found in these watersheds is available in engineering references, and the velocity used should fit the particular circumstances. Typical maximum permissible velocities for earth channels are in a range of 2.50 to 6.00 feet per second, and for steel, timber, and concrete the range is 8 to 12 feet per second. Design velocities for planning purposes are given in Table 4-3 for the various creek channels.

In man-made structures, the minimum velocities based on peak flow volumes should be in the range of 3 feet per second. If these minimum velocities are not obtained, the channel can become filled with silt and costly maintenance work will be required.

The velocities as computed for the existing channels outside the areas of tidal effect are generally above the maximum permissible velocities discussed previously. Walker Creek's velocities range from 6 to 8 feet per second (FPS) except above Channel Mile 16, where velocities of 10 FPS and more exist.

The velocities for Chileno and Salmon Creeks vary at about 6 FPS, which will cause erosion in most sections of these streams. The range of velocities in Lagunitas Creek is from 4 to 9 FPS, with the average section velocity about 7 FPS. In San Geronimo Creek, the velocities range from 5 to 7 FPS. In all basins, velocities through structures are probably somewhat higher than indicated, and these velocities were not computed.

The methods employed to limit velocities in natural channel sections are determined by the existing natural conditions, the level of flood protection desired, and the financing available. In any section where the channel is to be improved, the velocity should be controlled. The basic elements necessary to do this are a debris basin to retain bed load, a stabilized channel of the proper grade and cross section, drop structures as necessary to maintain the grade, and a means of returning the storm water to an existing channel section at a suitable velocity.

CHANNEL RIGHT-OF-WAY WIDTHS

The determination of the width of the right-of-way for the channel to dispose of the storm water is dependent upon the method used to contain the flood waters. The two methods that will be discussed are flood plain zoning and channel improvements.

Flood plain zoning is the regulation of land use by the County or City Planning Commissions within the area that is subject to flood waters. Usually, an ordinance or other legal instrument is drawn that defines the flood plain zone and the land use allowed therein. Some land uses that have been allowed are parks, recreational facilities, storage yards and limited industrial use, but residential use is not normally allowed. This ordinance is then debated by the jurisdictional body and adopted with amendments.

Many agencies have used flood plain zoning as a temporary measure to protect the public safety until adequate flood control measures could be constructed. The width of the flood plain zone could be based on the top width of water surface as shown on Plates 4-7, 4-8, and 4-9. If no further investigation is done, our widths should be increased somewhat to compensate for possible inaccuracies arising from our assumptions.

To limit the amount of land dedicated to flood use, channel improvements can be made to confine the flood waters within a narrower strip of land. The levels of flood protection should be in accordance with the discussion in this chapter and in Chapter 7. It is suggested that the basic channel width adopted should be sufficient to pass the ten-year peak flow without levees and the project peak flow with levees.

A stage construction program for a particular reach could be as follows:

1. Clean and widen the channel to pass the 10-year peak flow.
2. Construct the base portion of the levees to an elevation to provide protection for the 25-year peak flow.
3. Raise the elevation of the levees to provide protection for the 100-year peak flow.
4. Streamline the channel hydraulics by the use of impervious linings to provide for the project peak flow protection.

The above stage construction program assumes earth channels with debris basins, drop structures, and transition structures for Items 1 through 3. Item 4 would be the ultimate development with an almost continuous use of man-made channel lining material.

An example of this approach is illustrated on Plate 4-10 for the tidal reach of Lagunitas Creek. The channel width as shown on Plate 4-10 is based on the 10-year peak flow, and before it is used the additional tidal information should be obtained and computations made for the 100-year peak flow.

Section 4 of Chileno Creek has been analyzed in accordance with the above stage construction schedule, and it is shown on Plate 4-3. The existing ground slope has been extended above 50 feet on each side of the section, and this extension is an assumption. The basic channel width is 60 feet, and the height of the levee on the left side for the 10-year peak flow is Elevation 135. The top of the levee for the 100-year peak flow is Elevation 141, which allows for a two-foot freeboard above the water surface in both cases. The design velocity for this analysis is four feet per second, and the flows are from Table 4-1. The right-of-way width required is 185 feet.

The selection of right-of-way width for any channel must be considered for the entire channel from the lowest elevation to the limit of the possible future improvements. The method of improvement and topography must be considered, then channel right-of-way widths can be adopted that are adequate and possess continuity. In order to perform this detailed planning, the method of flood plain zoning or channel improvement must be adopted for each section of the creek. For the sections that will have channel improvement, the typical channel section must be adopted and the dimensions can be determined using the flow values presented in Table 4-1.

SUMMARY

Flooding in these watersheds can be controlled by improvements to the channels and enlargement of the waterway openings of various bridges. On Walker Creek, three bridges and the most downstream three miles need improvement to control flooding. Chileno Creek needs more channel capacity and three bridges are undersized. The tidal area of Lagunitas Creek needs channel improvement, and the bridges at Sections 9, 11, and 12 should be enlarged. The San Geronimo valley area needs better urban drainage structures in Woodacre and modification to Section 8. The minimum level of protection for all of these areas should be determined, and plans made to improve the present situation.

Control of the velocity of the storm water flows is important to limit channel bank erosion. In many channels, should new earthen levees be exposed to the existing velocities of flow, they will not last very long. A resultant of this erosion is sedimentation in Tomales Bay and in the channel along the way, which can cause flooding where it is not now experienced.

The last item of concern in this chapter is the acquisition for control purposes of adequate channel right-of-way to pass the expected flows. Improvements in these channels have little value if they cannot be protected from encroachment. Proper maintenance of the improvements will preserve the quality of the original construction. The channels, therefore, should become the responsibility of a jurisdictional agency with adequate police power and financial capabilities.

INTRODUCTION

The principal purposes of this chapter are to set forth the factors which affect erosion and sedimentation in the Tomales Bay drainage basin and to discuss, on a theoretical basis, the sediment yields of the component watersheds.

CONCLUSIONS

1. The study area is made up predominantly of rocks and associated soils which are slightly to moderately erodible. The only appreciable quantities of easily erodible materials are in the alluvial deposits of the stream valleys and upland basins.
2. The Pleistocene and Recent geologic history suggest that the area has been relatively stable, subject primarily to gradual uplift and warping. Late Pleistocene sea level changes have had significant consequences. The recent history of Tomales Bay probably was initiated by a rise in sea level about 10,000 years ago.
3. Annual sediment yields for the Walker Creek and Lagunitas Creek watersheds are probably similar to, or slightly lower than, those of similar basins in the northern California coastal mountains. Arbitrary, but probably conservative, annual sediment yield values assigned to Walker Creek are 250 to 300 tons per square mile. The assigned values for Lagunitas Creek are 200 to 250 tons per square mile.
4. Problems of local gullyng, bank erosion, channel silting, and flooding, should receive individual study and treatment as required. Individual and cooperative programs of conservation should be continued and encouraged. There are no major, widespread problems of erosion or sedimentation in either watershed at the present time.

5. Potential changes most likely to increase erosion in the Walker Creek and Lagunitas Creek watersheds are overgrazing and/or cultivation of the grasslands. In the Lagunitas Basin there is the added hazard of forest fires. Urbanization poses a potential problem in either area, but is probably more significant in the Lagunitas Creek basin because of the steepness of the land and the probability of greater hillside development.

6. The reservoirs in the Lagunitas Creek watershed probably have reduced by about one-half the amount of sediment contributed to the downstream basins. Within the study area, the only other major reduction in sediment yield likely to occur, would result from the construction of Walker Dam for water supply purposes. The need for the construction of basins specifically for sediment control could not be established solely on the basis of this study.

7. General programs of suspended sediment measurements, because of their expense, are not recommended at this time. Individual sediment studies may be warranted in connection with specific proposed stream control measures. A reasonable approximation of sediment yield in the Walker Creek area may be determined, at relatively low expense, by means of silting surveys of Nicasio Reservoir, since the tributary areas are quite similar.

REGIONAL GEOLOGY

One of the more important natural factors affecting erosion and sedimentation in the study area is the geology, since it determines or influences many of the other factors. Further, an understanding of the geologic origins and history of the area will assist in evaluation of the various regional aspects of erosion and sedimentation.

GEOLOGIC STRUCTURE. The dominant structural feature of the Tomales Bay area is the San Andreas fault zone (see Plate 5-1). The trace of this major crustal rupture parallels the sides of the bay and extends along the Olema Creek valley to Bolinas Lagoon. There is a distinct and fundamental separation in bedrock geology between the east and west sides of the fault, with the line of separation located along the western boundary of the fault zone (see discussion of Rock Units). Displacement along the San Andreas is considered to be primarily horizontal although locally uplifts may have occurred on one side relative to the other. The only other fault mapped within the

within the area is the Burdell Mountain fault, which dies out near the northeast edge of the Walker Creek watershed.

The older rocks on both sides of the San Andreas zone have been affected by repeated episodes of folding, faulting, and igneous intrusion. Since Pliocene time, however, broad structural uplift and warping are more apparent in this area than the intensive folding which is characteristic of much of the central California coast ranges. Structural uplift of southern Marin County has created bold headlands along the coast and has formed the elevated mass of the Mount Tamalpais area. This has affected the Lagunitas Creek basin by steepening the profiles of San Geronimo Creek and Lagunitas Creek above San Geronimo Creek.

Broad warping has affected the Walker Creek basin also. It has been concluded that Lagoon Pass, an alluvium filled divide east of Laguna Lake, was formed by structural warping in mid-Pleistocene time. This warping reversed the direction of flow of San Antonio Creek, formerly a part of the Chileno-Walker Creek system (see Higgins, 1952, pp. 218-219; and Holway, 1914). Associated with this change in direction of flow of San Antonio Creek was flattening of the slopes of the Chileno Creek headwaters. This resulted in the formation of a basin of alluvial deposition and of a natural dam creating Laguna Lake. Appreciable remnants of these late Pleistocene alluvial deposits are still preserved in this area.

Since the Lagoon Pass warping took place, the headwater regions apparently have been relatively stable. This has had the effect of allowing much of the Lagunitas Creek and Walker Creek watersheds to develop to a stage of geomorphic maturity.

In their downstream areas the two main streams have cut through a pronounced ridge (a continuation of Bolinas Ridge) which runs along the east side of Tomales Bay. The streams have graded profiles and incised meanders into the relatively resistant bedrock. These features show that downcutting of the streams has kept pace with the slow uplift of the ridge. ✓

Another indication that slow, progressive uplift and warping have been the dominant forms of structural change in the area are the pronounced concordant summits between 500 and 600 feet in the lower reaches of Walker Creek. These probably are relics of the old erosion surface upon which the Pliocene Merced formation was deposited. They conform to the position of the Merced-Franciscan contact which is well exposed immediately to the north.

ROCK AND SOIL UNITS. The geologic map on Plate 5-1, showing the bedrock units, was compiled from published sources (primarily Weaver, 1949; Travis, 1952; and Lawson, 1915).

The Point Reyes peninsula area, west of the San Andreas fault zone, is underlain by pre-Tertiary granitic rock (quartz diorite) which was intruded into metamorphic rocks of unknown (probably Paleozoic) age. The Miocene Monterey formation overlies a portion of the quartz diorite. Like the latter rock, it is cut off by the San Andreas fault (see cross section C-C' on Plate 5-1). The Monterey formation in this area consists of consolidated and moderately well indurated shale and sandstone.

The San Andreas fault zone and the area east of it, including the watersheds of Walker and Lagunitas Creeks, are underlain predominantly by rocks belonging or related to the Jurassic-Cretaceous Franciscan formation. This formation consists of generally hard, well-indurated sandstone with interbedded shale, conglomerate, and chert. Associated igneous rocks include basalt and diabase, as well as intrusive masses of peridotite and serpentine.

Near the northern divide of the Walker Creek watershed there are occurrences of Pliocene Merced formation sandstone and conglomerate. These rocks are poorly indurated and are more readily eroded than the underlying Franciscan rocks. Consequently, this area has developed lower and more gently rounded topography than is found elsewhere in the Walker and Lagunitas Creek watersheds. Keys Creek, a short tributary of Walker Creek, is located mainly upon the area of the Merced formation.

In the trough of the San Andreas fault zone there are small, scattered occurrences of unconsolidated Pleistocene marine and non-marine gravel, sand, silt, and clay, designated as the Millerton formation. These occurrences appear to be eroded terrace remnants of materials deposited prior to the last glacial stage. Either the terraces have been uplifted along with the extension of Bolinas Ridge, or they were deposited during an interglacial period of higher sea level. Later, the formation of glaciers caused a lowering of the sea level and consequent erosion of these materials which, at least partially, had filled the valley of Tomales Bay.

Geologically Recent deposits include extensive areas of dune sand at Dillon Beach and Bolinas and two units of alluvium. Field data and examination of air photos provided the basis for outlining the areas of these alluvial deposits. The Upland Alluvium includes alluvial materials in a state of transport (such as in stream channels) and

materials deposited in the upland valleys and basins as valley fill alluvium and terrace deposits. As discussed previously, some of the Upland Alluvium in the Laguna Lake area may be of Late Pleistocene age. Basin Alluvium is the material deposited at or near the final base level (Tomales Bay). It is, therefore, subject to only limited future movement.

SOIL ERODIBILITY. Field observations by the Soil Conservation Service indicate that soil in the bedrock areas is generally thin to moderate in depth (from 0 to 3 or 4 feet thick). In the alluvial valley areas the topsoil may be somewhat deeper. However, since the parent alluvium approximates the topsoil developed from it in its erosion characteristics, no distinction need be made between them for the purposes of this report.

It has been found that the geologic parent material is more significant in determining soil erodibility than are other factors in soil development such as climate, vegetation, topographic relief, and time (Anderson and Wallis, pp. 4-5, 1963). Andre and Anderson (1961) derived an erodibility relationship between soils developed from specific geologic parent materials. For the geologic parent materials in this study area, the progression of soil erodibility is as follows:

Serpentine and Peridotite	-	very low erodibility
Basalt and Diabase		
Franciscan Formation	-	low erodibility
Monterey Formation		
Merced Formation	-	moderate erodibility
Unconsolidated Sediments	-	
Granitic Rocks		
Alluvium	-	high erodibility

GEOLOGIC HISTORY

PRE-PLISTOCENE. For the area east of the San Andreas fault, it has been noted that the late Pliocene marine sedimentary deposits of the Merced formation were laid down upon an eroded surface of Jurassic-Cretaceous Franciscan formation rocks. Studies by others suggest that the Merced formation once covered all of the Walker Creek watershed and portions of the Lagunitas Creek basin near the San Andreas fault. Since late Pliocene time (approximately one million years ago) progressive uplift and warping has raised the central part of the Walker Creek basin 600 feet or more and even

greater uplift has occurred to the south. In these areas the Merced rocks have been entirely removed by erosion. Northward the Merced-Franciscan contact lies at lower and variable elevations indicating less uplift but illustrating the slight warping that has occurred.

The area west of the San Andreas fault has a different bedrock geology and history. Lateral movement along the fault has shifted the Point Reyes landmass many miles northwestward relative to the mainland. Since the time the Merced formation was deposited, there is no record of additional marine deposition on either side of the fault, and uplift and erosion apparently have been dominant.

PLEISTOCENE TO RECENT. The Mount Tamalpais area appears to have been one of uplift since pre-Pleistocene time and some renewed or continuing uplifts seem to have occurred since then. From San Gerónimo Creek south, the stream canyons have a youthful geomorphic appearance.

In contrast, the valleys of Nicasio Creek, Arroyo Sausal, Salmon Creek, and Chileno Creek are moderately broad and are reaching geomorphic maturity. Apparently this is due to the absence of Recent structural changes in these portions of the study area. To some extent, the broadening of the valleys is due to deposition which accompanied the mid-Pleistocene warping that caused the reversal of San Antonio Creek.

As already noted, the lower reaches of Walker and Lagunitas Creeks have maintained themselves through a ridge system uplifted on the east side of the San Andreas fault zone. Although the main streams are in graded adjustment with their upstream reaches, the tributary streams in this area are quite youthful.

Uplift of the Bolinas Ridge system may have involved movement along the San Andreas fault. The fault zone in this area forms a graben or trough structure which is presently occupied by Tomales Bay and Olema Creek.

Historical movements along the San Andreas fault in this area have occurred about in the middle of the fault valley and do not appear to have strongly influenced the lower portion of Lagunitas Creek. The present course of the creek crosses the valley and impinges on the west side of the fault zone before being deflected northwestward into Tomales Bay.

During the last glacial advance, in Pleistocene time, the level of

the sea was lowered a maximum of about 300 feet below present sea level (Higgins, p. 242, 1952). This affected all of the streams in this area by lowering their base level. However, at the end of the Pleistocene period (approximately 10,000 years ago) the level of the sea rose approximately to its present level. This raising of the base level accounts for the alluvial filled lowermost reaches of Lagunitas and Walker Creeks.

ORIGIN OF TOMALES BAY. Fault activity probably caused relative uplift on both sides of the San Andreas fault zone trough, and accelerated erosion in the weakened rocks of the fault zone. These actions resulted in formation of a pronounced valley between Bolinas and Dillon Beach. The comparative effects of faulting and erosion in the formation of this trough have not been established. Erosion may have been dominant, since at various times in the Pleistocene era, Lagunitas and Walker Creeks apparently cut their courses through this valley to reach the sea. A submerged extension of these creeks may be the deep, narrow channel along the west side of the bay. Sand bars formed by long shore currents have filled this channel at the mouth of the bay.

About 10,000 years ago the raising of the level of the sea to its present height transformed this valley into a bay with maximum depths of over 50 feet. Sedimentary filling of the bay commenced at that time and has continued to the present. Except for the areas of the Lagunitas and Walker Creek deltas, much of the bay presently has a depth of around 20 feet. This may represent the original depth in the central portion of the bay, since rock bottoms are found there and deep sedimentation apparently has not occurred over at least part of this area. In the delta areas the water shallows progressively and roughly a third of the deltas of both streams are exposed at low tide and are submerged at high tide.

EROSION AND SEDIMENTATION FACTORS

GENERAL. Evaluation of sediment yield from an entire drainage basin must be based upon quantitative data obtained from within the basin or from a comparable watershed. The prediction of future sediment yield requires evaluation of factors which will change with time or through the action of man. Unfortunately, for the watersheds under study there are no direct data available from within the basins. A number of research studies, however, have led to the recognition of the more important sedimentation factors (see Anderson and Wallis, 1963). These are presented in synopsis in Table 5-1.

There is no intent in Table 5-1 to rank the importance of the various factors nor to indicate the interrelationships between the factors. These aspects are discussed in succeeding sections as they apply to the magnitude of sediment yield from the study area and to the areas and rates of sediment deposition.

One of the factors, the geology, has been presented previously in some detail because it controls the distribution of erodible materials, determines the topography of mountains and lowlands, and influences the pattern and rate of stream erosion. The topographic expressions of the geology, in turn, strongly affect some of the variable natural elements such as rainfall, runoff, and vegetation.

As a consequence of their geologic history, Lagunitas and Walker Creeks and their major tributaries are well graded and, in part, fit a mature topography. The minor tributaries are eroding a youthful topography, but sleet or gully erosion is not severe. Large quantities of easily erodible materials are not present in most of the tributary areas. Potential heavy sediment yields consequently would appear to be likely only from bank erosion of valley and terrace alluvium.

TOPOGRAPHIC SETTING

LAND SLOPE AND ELEVATION. The slope area map shown on Plate 5-3 shows the location and area of very flat (0% to 5%), flat to moderate (5% to 20%), and moderate to steep (over 20%) slopes. It is known that erosion increases at a relatively uniform rate up to slopes of about 36% (20°). With slopes steeper than 20°, erosion increases rapidly until it reaches a maximum at a slope of 40°, and decreases at still steeper slopes. Examination of topographic maps reveals that, while much of the area is steeper than 20%, only relatively small portions of the watersheds have slopes steeper than 36% (20°).

Differences in elevations are shown in detail on the topographic base of the drainage area map sheets. Spot elevations are shown on Plate 5-3. The elevation of the area ranges from tidewater to 2571 feet at Mount Tamalpais. Except for Mount Tamalpais and Big Rock Ridge in the Lagunitas watershed, and Hicks Mountain which is the highest point in the Walker Creek watershed, the peaks in the study area are below 1500 feet. However, ten of the peaks shown on Plate 5-3 are higher than 1250 feet. Most of the areas of both Walker Creek and Lagunitas Creek watersheds lie above 400 feet. Elevation

differences in themselves do not appear to be of great significance to the erosional regimen of the study area. Their primary influence is on the pattern of annual precipitation. The correlation of elevation and rainfall is particularly well developed in the Mount Tamalpais area.

STREAM CHANNEL SLOPES. Although research studies have developed a number of sophisticated stream channel parameters for geomorphic analyses (see Leopold, et al., p. 149, 1964), their application is beyond the scope of this study. Stream lengths and slopes have been obtained from the stream profiles (Plates 4-7, 4-8 and 4-9). Also, a number of stream cross sections were surveyed in the field for this study. These cross sections may be used in the future for comparative purposes to detect channel erosion or sedimentation.

Except for San Geronimo Creek, which has some reaches with gradients over 3%, the greater part of the main stream courses have gradients below 0.5% and steepen to around 1.5% only near the headwaters. The secondary tributaries, however, are much steeper. Accordingly, down-cutting and headward erosion are dominant along the tributaries, whereas lateral channel bank erosion primarily affects the main streams.

VARIABLE NATURAL ELEMENTS

RAINFALL AND VEGETATION. The vegetation and rainfall map (isohyetal) map, Plate 5-2, shows the interrelation of vegetation and rainfall. The vegetation cover data were obtained from examination of air photos. The meaning and development of the isohyetal data have been described already in Chapter 2. The effect of increased rainfall on the type and the amount of vegetation is very evident. Total annual precipitation, and the vegetation type and density which are largely dependent on it, are among the most significant factors affecting the total sediment yield of a watershed. This relationship is discussed in more detail in the section on Sediment Yield. *See 5-12*

HYDROLOGIC CHARACTERISTICS. Stream runoff and peak discharge rates are closely related to the rainfall characteristics as well as to the stream patterns and gradients and to the watershed areas. The manner of development of this data is presented in Chapter 3.

Rapid runoff and high peak discharge have an obvious relationship to potential flood hazards. It is also recognized that the major

part of channel erosion and sediment production takes place during conditions of high peak flows. The specific consequences to channel bank stability and sediment yield, however, may not show a simple or proportional relationship to the stream flow factors, because other factors such as sediment supply and type and geomorphic conditions of the stream may have an important modifying effect. In youthful streams with steep gradients, for example, downcutting, which predominates, will tend to form rock channels, thereby limiting the supply of available sediment. The same effect is likely to be present along any bedrock reach, irrespective of channel gradient.

It has been found (Gottschalk, 1957, and U.S.G.S., 1962) that erosion and transport of coarser sediment, the bed load, is largely a function of flow characteristics, such as velocity and turbulence. The suspended load is more a function of sediment supply since, at peak flows, streams generally have an excess carrying capacity for the finer materials. Total sediment yield may be quite large with a moderate flood if appropriate conditions of stream flow and sediment supply are present, and conversely, may be relatively small even in a major flood if sediment sources are not available.

Channel and channel bank erosion may likewise exhibit complex relationships. Bank erosion, for example, may occur with only a moderate stream flow if the stream is deflected against the channel bank by formation of a bar. The bar is formed where the stream's capability to transport sediment is reduced by gradient flattening. In such a case, locally severe erosion might take place while the sediment yield of the entire drainage area is little affected.

BURNED AREAS. In general, any vegetated area may be subject to fire. The consequences of such a fire on erosion and sediment yield, and on hydrologic characteristics, may be of great significance. The duration of the effects of such a burn is also important. Grasslands naturally will re-establish equivalent cover density more rapidly than brush or forest lands.

Since a burn affects both runoff and erodible soil supply, the quantitative effect of a burn is difficult to assess. Under some combinations of soil, slope and rainfall, sediment yield could be increased a hundred-fold or even a thousand-fold for the burned area, and the effect may persist in diminishing amount for 100 years or even longer.

The effects of a burn are greatest in a semi-arid area of mountainous topography. For a more humid region, such as the study area, the effects of a forest fire may be largely erased in 10 to 25

years, depending on the type of new growth established. The effects of a grassland burn may nearly disappear in one or two years. In all cases, however, some small effects may be detectable for many years, since no burned area can restore itself perfectly in a short time.

MAN-CONTROLLED ELEMENTS

LAND USE. Almost any land use will have an affect on erosion and sedimentation. In most cases, land use by man will increase erosion. With care, this increase may be kept to a minimum. However, when man's use of the land takes no cognizance of erosion factors, the increase in erosion may approximate or exceed that of a burn.

Erosion and sedimentation are usually increased greatly by logging operations and by bare land cultivation. Logging may have an effect similar to but less severe than a forest fire, since seldom is the entire ground cover destroyed. Bare ground cultivation likewise may cause heavy erosion, but this can largely be controlled by conservation practices.

Cover crops, grazing, and urbanization normally increase erosion, but to a smaller degree, dependent upon local soil, slope, or runoff conditions. Urbanization may cause either a diminished or a greatly increased sediment yield from the developed area. A flat-lying, paved, landscaped housing development may show lower yield, while a hillside development in a previously forested area may develop greatly increased erosion.

From the above discussion, it is apparent that the effects of land use vary widely, and can be assessed fully in particular areas only by means of specific studies.

MAN-MADE STRUCTURES AND ALTERATIONS. The long-term effect of most of the items listed in this category on Table 5-1 is to decrease erosion and sedimentation. An exception is road construction. Road or other earthwork construction exposes cut and fill slopes to the effects of runoff. Establishment of vegetation, or other slope protection measures, will eventually minimize, but not entirely remove, this source of increased sediment yield. Other types of construction activities probably will, at least temporarily, increase sediment yield.

Most stream-control measures eventually will tend to reduce erosion

✓ and sediment yield, either because they are designed to this purpose, or as a side effect, such as sediment trapping by reservoirs. Other less desirable consequences may occur, however, particularly in downstream or upstream areas. For instance, discharges of clear water from reservoirs conceivably could cause accelerated erosion in the downstream channel. Channelization for flood control purposes, by altering the natural stream regimen, may introduce additional erosion or sedimentation in places away from the protected area.

Because of the number of factors involved, stream-control measures, like variations in land use, can be evaluated only on an individual and specific basis.

SEDIMENT YIELD

✓ GENERAL. Sediment yield is a quantitative measure of the total erosional regimen of a watershed, and is a resultant of the action and interaction of all the factors within that watershed which affect erosion and sedimentation. Consequently, prediction or measurement of sediment yield may be very complex; also to some extent, the figure expressing sediment yield has varying significance, depending on what method is used to determine it.

Formulae for the prediction of sediment yield have been developed (Anderson and Wallis, 1963). Aside from the applicability of these formulae, both the development and use of such an approach, since it is based on sophisticated statistical methods, calls for a specialist's treatment far beyond the scope of this study.

Direct field measurement of sediment yield may be accomplished in several ways. One method is the measurement of the actual sediment deposition over a known span of time in reservoirs, depositional basins, or flood plain areas. This method produces a result which, depending on the trapping efficiency, expresses the total sediment production of a watershed area and is therefore significant in predicting debris basin life, reservoir silting, and depositional filling of natural basins. The longer the time span used, the more the result will reflect average conditions.

Another method of sediment yield determination involves measurement of sediment being transported by streams either as bed load, suspended load, or a combination of these. Theoretically, accurate determin-

ation of both bed load and suspended load movement would give a figure approximating total sediment yield. Bed load movement, however, is very difficult to ascertain. Measurement of comparative streambed cross sections may give an idea of bed load transport, but conditions of aggradation or degradation may vary so widely, particularly in an area of intermittent streams and variable rainfall, that several comparisons over a relatively long time span may be required to establish a meaningful set of measurements.

Suspended load studies give a direct and relatively accurate result. Sediment yield based on such studies, however, is not a measure of total sediment production, but of only that portion which is subject to rapid and easy transport. This figure, therefore, may be significant in studies of channel silting or single-flood damage prediction.

Suspended load studies should be based on a series of measurements taken at various places in a watershed and over a span of years in order to provide an accurate result. Furthermore, sampling should be done so as to survey the entire cross section of the stream from bed to surface and bank to bank. Isolated sampling has little significance, and may lead to erroneous conclusions.

SEDIMENT YIELD QUANTITIES. When no data are available for a watershed, sediment yield prediction probably can be best accomplished by comparing the study area with other, similar watersheds for which specific determinations of sediment yield have been made.

It is possible to establish a range of sediment yields which give an upper and lower limit for a majority of watersheds. Langbein and Schumm (1958) found that sediment yield was, on the average, a reflection of total annual precipitation. Based on a nationwide collection of data, their range was between 400 and 1600 tons per square mile for annual sediment yields determined on the basis of reservoir silting studies. Somewhat less representative data, based on suspended load measurements, mostly in the central United States, gave a range of between 200 and 800 tons per square mile, or as might be expected, about half of the values determined from the silting studies. Langbein and Schumm's studies suggest that annual sediment yield, which is zero at zero precipitation, rises rapidly and reaches a peak when average annual precipitation is between 10 and 20 inches. It then decreases, as precipitation increases, to a relatively uniform value when annual precipitation is over 40 inches. Their sediment yield figures are, of course, averages from a large number of determinations. The extremes, averaged out, would reflect a variety of unusual soil, topographic and hydrologic conditions.

Since the Walker Creek and Lagunitas Creek watersheds do not possess abnormal or unusual erosion potential to any great extent, it is possible that their sediment yields will fall within the ranges given. Specifically, based only on the figures presented by Langbein and Schumm, Walker Creek, with an average annual precipitation of between 23 and 34 inches would have a total annual sediment yield of 800 to 1000 tons per square mile and Lagunitas Creek, with an annual average precipitation of 30 to 53 inches, would have a total annual sediment yield of around 400 to 600 tons per square mile.

A much wider range of predicted values is given by Anderson (1954) in a study of western Oregon. For the coastal mountain areas in the extreme southwestern corner of Oregon, which most closely approximate the Marin County area, Anderson's range for annual suspended sediment yield is 70 to 300 tons per square mile, except for an area containing easily erodible sediments for which he predicts 300 to 700 tons per square mile.

Average annual sediment yields in California drainage basins, based on reservoir silting studies, have been published by the Soil Conservation Service (1955). For the entire state the range of yields was from about 26 tons per square mile, for Upper Bear River in the Sierra Nevada, to 28,000 tons per square mile, for a one-quarter square mile ravine in the San Gabriel Mountains. Most of the extreme figures were for small basins in the southern California mountains.

It is generally recognized that the smaller the watershed area, the more likely that it will have high sediment yield, since these smaller basins often occupy the higher or steeper portions of the region.

For eight basins in the northern California coast ranges, the values ranged from 175 to 1670 tons per square mile. The two basins most comparable in size to the Walker and Lagunitas watersheds were those of Stony Creek in Glenn County and Little Stony Creek in Colusa County, both of which had average annual sediment yields of 234 tons per square mile. The basins of Forsythe Creek and James Creek in Mendocino County were most like the study area in geology and climate. These two small basins had yields of 312 and 241 tons per square mile, respectively.

From the above figures, it is possible to assign arbitrary but conservative values to the annual total sediment yields for Walker and Lagunitas Creeks. Walker Creek, with lower average rainfall and more sediment supply than Lagunitas, probably has a yield of 250 to 300 tons per square mile, though the actual figure may be as low as 150

or as high as 500. ⁽¹⁾ For Lagunitas Creek, ignoring the affects of the reservoirs, the probable annual total sediment yield is 200 to 250 tons per square mile while the range may be from 100 to 400. As base values, these figures can be applied to the appropriate sub-watersheds with modification as required for watershed area, soils, rainfall, land use, or other factors.

The sediment yield values assigned to the study area are somewhat lower than the ranges given by Langbein and Schumm. This is logical since the factors of land use, soil erodibility, and vegetation are all more favorable in the study area than in the average basin considered by Langbein and Schumm.

EFFECTS OF CHANGED CONDITIONS. Changes in watershed variables may have a significant affect on sediment yield. No quantitative evaluation of these potential changes can be made at this time, however, since applicable field data are not available. As discussed previously, land use, particularly logging and cultivation, is a major factor governing sediment yield. In the study area, the occurrence of brush or timber fires is one of the more likely potential causes of increased sediment yield. Urbanization, depending on the specific circumstances, may or may not increase erosion and sediment production.

One factor of great importance in reduction of sediment yield to downstream areas is the presence of reservoirs or debris basins. Silting in reservoirs, however, may not in itself be a desirable feature. Unless the reservoirs are provided with sufficient excess capacity to accommodate the silting, loss of storage will require either corrective maintenance or abandonment. Similarly, unless check structures or debris basins are designed with sufficient capacity they will require excessive maintenance.

WALKER CREEK WATERSHED

DESCRIPTION. The total area of the watershed is 73.1 square miles. Assuming a high trap efficiency for Laguna Lake, the watershed area may be reduced to about 66 square miles for sediment yield considerations.

The watershed consists of three geomorphic units. The basins of C Chileno, Salmon, and upper Walker Creeks and Arroyo Sausal, are partially alluviated upland valleys with steeper tributaries on the bounding ridges. Downstream of these basins, Walker Creek flows in

a narrow valley out through a resistant bedrock ridge. The lower portion of the watershed predominantly consists of a short alluviated valley and the delta. Keys Creek is the only tributary entering Walker Creek below the bedrock reach.

The range in elevation of this watershed is from tidewater to 1530 feet. The northern divide lies mostly between 400 and 600 feet. It has a low elevation of 119 feet and a maximum elevation of 853 feet. The southern divide with the Lagunitas Creek watershed is predominantly between 800 and 1200 feet in elevation. Some of the higher portions of the watershed are near the eastern divide but its lowest point, 255 feet at Lagoon Pass, is only 30 feet higher than Laguna Lake. The extension of Bolinas Ridge, at an average elevation of about 600 feet, forms the western boundary for most of the watershed, although it is breached near its northern end by Walker Creek. The upland valleys, constituting much of the watershed area, have maximum elevations near or below 400 feet.

Annual rainfall ranges from 23 to 34 inches. The low rainfall area, with yearly totals of 23 to 26 inches, forms an east-west belt extending through Lagoon Pass. In the southern portion of the watershed the annual rainfall reaches a high of 30 inches. An annual rainfall of up to 34 inches occurs in the northern divide area.

Vegetation shows little response to the rainfall pattern.. About two-thirds of the watershed is grassland. The remainder is brush and open woodland, concentrated mostly on ridge crests and north-facing slopes.

EROSION. Soil and rock materials are distributed in four units. The Franciscan sedimentary and associated igneous rocks which underlie most of the area are relatively strong and tend to form ridges. Occasionally the rocks and overlying soils form landslides and creeping masses which may account for down-slope movement of great quantities of material. Soils formed on the Franciscan rocks are generally thin and relatively resistant to erosion. Moderate gully erosion may take place when the vegetative cover is disturbed.

The Merced formation which underlies portions of the northern divide area and the soils developed on it are relatively erodible. In the course of geologic time, they have formed an area of subdued topography. Consequently, rapid erosion in this area is not common at the present time. Disturbance of the cover, however, could result in significant sheet and gully erosion in this formation.

Recent alluvial deposits which are found in the valley of Walker Creek downstream of the bedrock reach and in the delta are highly erodible. The area is one in which deposition is predominant, however, so that erosion generally is a consequence of local bank erosion, lateral channel migration, and the occasional formation of new distributary channels on the delta.

Appreciable quantities of relatively erodible valley-filling alluvium occur as stream terraces in the upland basins, particularly in Chileno and Hickes valleys. Bank erosion by the major streams in this area is potentially the largest source of sediment in the Walker Creek system. Sheet and gully erosion also may appreciably affect the gently sloping alluvial terraces if the vegetative cover is disturbed.

Most of the sediment contributed to the Walker Creek system is probably in the clay, silt, and fine sand sizes. Introduction of gravel to the major streams may occur from tributaries draining very steep hillslopes. Most of the gravels available, however, probably are recycled materials eroded from the alluvial terraces. While the total volume of the gravel bed load may be small, the material may range up to boulder size. It is probable that the rate of transport of the bed load is comparatively low.

SEDIMENTATION. Sediment deposition takes place both in the upland valleys and in the lower valley and delta areas. Sediment in transport through the bedrock reaches forms only small, generally temporary, deposits.

The upland valleys form a local base level for the tributary streams and surrounding ridges. Deposition in these basins may take place along the base of the ridges, as a result of local sheet and gully erosion, thus continually supplying materials to the alluvial terraces. Probably more significant is the stream channel aggradation which occurs as the gradients of the tributaries flatten upon entering the major stream valleys. Deposition in the upland areas probably has been continuous since Pleistocene time. Continual erosion and downstream transport apparently have maintained a general balance with this deposition.

The final sedimentation basins for this area are the lower valley of Walker Creek and Tomales Bay. The deposition in this area probably dates from the close of the last glacial age, roughly 10,000 years ago. Since the bay is the final base level for Walker Creek, no further transport of sediment from the area can take place by normal

sub-aerial processes. The generally fine-grained nature of the sediment, however, suggests that marine processes, such as tidal scour, may be relatively effective in moving material from the Walker Creek delta.

EFFECT OF CHANGED CONDITIONS. The Walker Creek watershed may respond to alteration of some of the factors controlling erosion and sedimentation quite differently than the Lagunitas Creek area. Primarily this is due to the greater quantity of sediment available for channel bank erosion, and the predominant grassland vegetation. The absence of reservoirs is also significant, although the upland valleys themselves constitute a type of silting basin for the upstream tributary areas.

Increased erosion as a consequence of storms and high peak stream flows is probably of greater significance in Walker Creek because of the potential for channel bank erosion.

Because of the large amount of grass cover, the long-term effects of fires, on the average, will be less severe than in forested areas. Conversely, the grass cover is more susceptible to damage from overgrazing, and the grass areas are more liable to come under cultivation. Consequently, agricultural conservation practices may be comparatively more important in the Walker Creek watershed.

As discussed previously, the potential effects of urbanization must be considered individually. The affect of developed areas on increasing peak flow intensity, however, might be more significant in the Walker Creek area because of the bank erosion potential.

CONTROL MEASURES. Major, widespread erosion and sedimentation do not appear as serious problems in the Walker Creek area at the present time. The principal aspects which may require control are local bank erosion throughout the watershed, and channel silting and occasional flooding. These problems should be treated on a local basis as required.

Sediment yield of the entire watershed to the lower valley and delta area might be controlled by relatively large silting basins upstream of the bedrock reach of Walker Creek, since most sediment production occurs above this point. The desirability and long-term effects of such structures, however, should be subject to further study. The proposed Walker Dam probably also would be effective as a sediment control structure.

LAGUNITAS CREEK WATERSHED

GENERAL. Except for the Nicasio Creek sub-basin, which is similar in many ways to the Walker Creek area, the Lagunitas watershed is sufficiently different to warrant separate discussion. The reservoirs in the Lagunitas area represent one major difference. Others are the larger area of higher elevation, the greater annual rainfall, and the existence of forested land.

DESCRIPTION. The total area of the Lagunitas Creek watershed is 103.0 square miles, of which 35.9 square miles lie behind Nicasio Dam and 21.5 square miles are upstream of Peters Dam. The remainder, consisting of San Geronimo Creek, Lagunitas Creek below Peters Dam and Olema Creek comprises, therefore, 45.6 square miles.

The range in elevation for this latter area is 1466 feet, with many of the ridges being between 800 and 1200 feet. Inverness Ridge, west of Olema Creek, also rises to over 1400 feet in elevation. The southern divide of the Olema Creek basin, in the San Andreas fault trough, is only 47.6 feet in elevation. Except for the broad valley area now partly filled by Nicasio Reservoir, the valleys of the Lagunitas Creek basin are long and narrow.

The yearly rainfall for the Nicasio Creek basin is between 30 and 42 inches (see Plate 5-2). The remainder of the Lagunitas Creek system has an annual rainfall range of 32 to 53 inches. The highest rainfall occurs in a southeast trending band extending from Inverness Ridge to the high ground near Kent Lake and thence to Mount Tamalpais.

The rainfall pattern, elevations, and north facing slopes all influence the distribution of woodland and forest vegetation. Over half of the Nicasio Creek watershed is grassland whereas the Lagunitas Creek watershed area above Peters Dam is mostly forest and woodland. The remainder of the Lagunitas Creek system is about one-half grassland and one-half forest with little brush or open woodland.

EROSION. East of the San Andreas fault zone, the soils developed from the predominant Franciscan rocks have, like their counterparts in the Walker Creek basin, moderately low erodibility. In the Lagunitas Creek area the soils are subject to higher rainfall and occur on generally steeper slopes than in the Walker Creek basin. Consequently, the protective function of vegetation is quite important. For the portion of the area in grassland, erosion problems may be created by overgrazing or cultivation. In the forested areas,

particularly since these normally coincide with the areas of highest rainfall and of steepest slopes, removal of the cover by fire, logging, or construction, could result in greatly increased sheet and gully erosion.

West of the San Andreas zone, in the Olema Creek watershed, the soils developed from the Monterey formation and granitic rocks possess moderately high erodibility. Most of this area is subject to high rainfall, and is covered by dense woodland and forest. Removal of this cover could create severe erosion problems. Since much of the forest is within the Point Reyes National Seashore, its protection is reasonably well assured.

Much of the Olema Creek basin lies within the trough of the San Andreas fault zone. The rocks which are strongly sheared and broken Franciscan types are relatively susceptible to weathering. Soils formed from these rocks probably are deeper, though not necessarily more erodible than those formed on the less disturbed Franciscan terrains. The area has moderate-to-gentle slopes and is predominantly grassland covered. Moderate sheet and gully erosion may occur if the grass cover is disturbed.

Unconsolidated, relatively erodible soils occur as Pleistocene terrace deposits (Millerton formation), upland valley alluvium, and lower valley or basin alluvium.

The Pleistocene terraces, consisting of gravel, sand and clay, are distributed as remnants of a once continuous deposit in the lower portion of Olema Creek basin, and along the east side of Tomales Bay. Two such remnants flank Lagunitas Creek where it emerges from the hills. These deposits are less erodible than younger alluvium, but locally may be affected by gullying and channel bank erosion, and by wave erosion along the bay margins.

Upland valley alluvial deposits, comparable in quantity to those in the Walker Creek basin, are found only in the Nicasio Creek basin above the dam. Other upland alluvium is limited to relatively narrow terraces along San Geronimo Creek and along the middle section of Lagunitas Creek. As in the Walker Creek system, these deposits are the principal source of easily erodible channel bank materials. The relatively steep gradient of San Geronimo Creek will produce high velocity flows which, in turn, probably will result in locally severe bank erosion similar to that which may be anticipated along Salmon Creek in the Walker Creek system.

The lower valley and basin alluvium, found in the lower reaches of Olema and Lagunitas Creeks and in the Lagunitas Creek delta, is similar to, though probably somewhat coarser grained, than the deposits of Walker Creek. The majority of erosion in these deposits will take place as a result of lateral channel migration and by local bank erosion where bar formation deflects flow against the banks. ✓

Because chemical weathering is often more effective than mechanical disintegration in breaking down rocks of the Franciscan formation, a large portion of the sediment contributed by this watershed will be in the clay-to-fine-sand size range. More gravel, however, probably reaches the streams in this area than in the Walker Creek basin. Primarily this is due to the larger number of steep tributaries which feed directly into the major streams. The stream terraces also appear to have a larger proportion of gravel available. Locally there are additional sources of gravel in the Pleistocene terrace deposits. It is probable that the gravel reported to be forming bars in White House pool is recycled material from a local terrace source a short distance upstream.

SEDIMENTATION. The Lagunitas Creek watershed, unlike the Walker Creek basin, has two reservoirs which act, at present, as permanent rather than temporary areas of sediment deposition. The trap efficiency of each of the reservoirs is estimated to be at least 95%, based on the ratio of their storage capacities to their drainage areas. Consequently, all bed load and a large portion of the suspended sediment derived from the Nicasio and Lagunitas basins upstream of the dams, are deposited in the reservoirs.

The effect of the reservoirs, so long as they act as settling basins, is to reduce by about half the amount of sediment contributed to the downstream areas by the entire Lagunitas Creek system. The full reduction will not be realized immediately, since large discharges of sediment-free water from the reservoirs probably will "winnow" the fine-grained sediment from the channel deposits downstream of the dams. However, equilibrium within the new conditions imposed by the reservoirs will be established eventually.

Except for the reservoirs, significant sediment deposition in the Lagunitas system occurs only in the tidewater portion of the creek and on the delta. Sediment in the valleys essentially is in transport, and deposits in these areas are local and temporary.

EFFECT OF CHANGED CONDITIONS. This area differs from the Walker

Creek basin in that it has a large amount of woodland and forest and a predominance of steep slopes. As discussed previously, either burning or logging of the forested land would have significant and long-lasting effects on erosion and sediment yield. Logging was carried on in the upper Lagunitas Creek basin, now upstream of Peters Dam, up to 60 years ago, and undoubtedly resulted in increased sediment yield. Another area tributary to Kent Lake was logged over in 1950, prior to construction of the dam (see Plate 5-2).

Areas most likely to be affected by over-grazing are the grasslands of the Nicasio basin and the Olema Creek watershed and particularly Bolinas Ridge, which has a combination of grass cover and steep slopes. Areas of potential cultivation are largely confined to the lower reaches of Olemas and Lagunitas Creeks.

Portions of the San Geronimo Creek basin have been urbanized and continued urbanization is anticipated. Because of the steep slopes and the existing forest cover, urban development and other construction are likely to increase sediment yield appreciably. This increase can probably be minimized, however, by reestablishment and maintenance of ground cover on exposed cut-and-fill areas.

CONTROL MEASURES. The principal problems of erosion and sedimentation in the Lagunitas Creek basin appear to be channel bank erosion along portions of San Geronimo and Lagunitas Creeks, and channel silting and flooding in the lower reaches of Lagunitas Creek. The former are local occurrences, and treatment should be considered on an individual basis. The flooding undoubtedly could be controlled by channel improvement.

In this watershed, effective sediment control basins would have to be relatively large, not just to minimize maintenance, but to increase trap efficiency for the predominant fine suspended load. Sites for such basins apparently are not present. The only potential sites would be restricted to small structures yielding only limited control. Further, in the apparent absence of specific or serious sedimentation problems, the need for sediment control basins cannot be established by this study.

TOMALES BAY

Sedimentation within Tomales Bay has been, for a number of years,

a topic of considerable local interest. The present discussion of this subject is both general and preliminary in nature. Specific, detailed studies of the bay would be needed to understand fully not only sedimentation from the tributary watershed areas, but also sediment derived from beach erosion, possible sediment entering the bay through long shore current or wind action, movement of sediment by tidal or other currents both into and possibly out of the bay, and other present and historical factors.

Tomales Bay is the ultimate basin of deposition for the sediment from not only the Lagunitas Creek and Walker Creek watersheds, but also from the smaller watersheds on both sides of the bay. Because of the comparatively low stream flows entering the bay, and the geometric configuration of the bay, tidal current action apparently is the only means of carrying sediment out of the bay. Most of the sediment carried into the bay is deposited initially in deltas at the mouths of the two major streams. These delta areas are shown in detail on the U. S. Coast Geodetic Survey Chart of Bodega and Tomales Bays (C. & G. S. 5603, 1961).

The Lagunitas Creek and Walker Creek deltas are also shown with dotted outlines on the "Key Map" of Plate 5-4 (Tomales Bay Depths - Comparative Profiles 1861-1961). U. S. Coast and Geodetic Survey hydrographic data from surveys in 1861, 1921, 1931, and 1961 have been used to construct the transverse and longitudinal profiles of Plate 5-4. From this 100-year comparison some trends can be seen, as well as the general magnitude of sediment deposition in the bay.

LAGUNITAS CREEK DELTA. This delta shows slow but consistent bayward filling (see Section V-VII). The exposed area above the datum (mean lower low water) has moved about 1,000 feet into the bay in 100 years, and some additional sediment has been deposited on the foreset portion of the delta (the area between Stations 40,000 and 45,000). Actually, only 1 or 2 feet of deposition were needed to raise the surface of the delta above the datum. Section IX-X shows that in 1861 water extended from shore to shore, and there were depths of up to 2 feet over three-fourths of the bay width. By 1931 only one-third of the full bay width at Section IX-X had water depths of 1 to 2 feet. In 1961, approximately the same width of water existed, but at depths of one-half foot or less.

WALKER CREEK DELTA. The Walker Creek delta is limited in its outward growth by the deep water channel along the west side of Tomales Bay. Both Sections I-II and III-IV of Plate 5-4 show the deep channel on the west side of the bay and other channels adjacent to Hog Island. It is probable that tidal scour is responsible for main-

taining these channels, and for limiting encroachment of the deltaic deposits.

The submerged part of the delta has spread both to the north, in the cove between Toms Point and Preston Point, and to the south, into the area southeast of Hog Island. The relative amounts of this lateral spreading which are accounted for by original deposition, turbidity current flows, tidal current scour or other mechanisms, cannot be determined at this time. It is probable that at least some of the sediment north of the Walker Creek delta is derived from wind-blown materials, particularly in the area between Toms Point and the bay entrance.

South of the delta, as may be seen on Section III-IV, a sand-bottomed trough up to 25 feet deep existed in 1861. Finer grained sediments had filled this area to 9 feet by 1921 and to 5 feet by 1961. During this time the portion of the delta above the datum had moved over 500 feet into the bay. The total amount of sediment required to fill this trough considerably exceeds that derived from the Walker Creek watershed, at estimated present rates of sediment yield. This discrepancy suggests an appreciably higher sediment yield for the period 1861-1921. The contribution of sediment to this trough from other sources, however, is not known, and filling of the trough could have been accomplished largely by current-moved materials.

Many of the detailed changes in the configuration of the delta can be accounted for by progressive adjustments to the migration of the Walker Creek Channel. Between 1861 and 1961 a 10 to 20 feet deep channel off Preston Point migrated 3,000 feet out into the bay (see Section I-II). This apparent movement actually is the result of periodic scouring of new channels in the soft mud and silt and the filling of the old channels.

OTHER EVIDENCE OF SEDIMENT MOVEMENT. Some sediment movement may be seasonal or otherwise recurrent. An example can be seen near Toms Point (Station 500 on Section V-VI of Plate 5-4). Here, successive surveys show depths of 1 foot, 11 feet, 5 feet, and 9 feet, indicating repeated filling and scouring. Because this area is not a headland point and not near a stream mouth, these effects must be due to storms, tidal or other current action, or possibly dredging.

Not all bay bottom changes are necessarily attributable to sediment movement. The recurrent movements along the San Andreas fault zone, which forms Tomales Bay, could result in the formation of bay-bottom sag ponds (depressions) similar to those commonly found along

the sub-aerial portions of the fault. The closed trough shown on Section VII-VIII was up to 32 feet deep as determined by the 1861 survey. However, the 1931 survey shows only a slight depression of 6 to 7 feet maximum depth below the datum, and the 1961 chart indicates no depression at all. This trough was not located in an area where current scour was likely to be effective. It was located immediately adjacent to the most recently active trace of the fault, so it is possible that it formed as a sag pond in relatively recent time. The filling of the trough that occurred between 1861 and 1931 easily could have been a result of submarine landsliding triggered by the 1906 earthquake, although normal sedimentation may also have caused the filling.

CHANGES IN THE EXPOSED DELTAS. A comparison was made of air photos of the Lagunitas Creek and Walker Creek deltas taken in 1942, 1952, and 1964. After recognizing the apparent differences resulting from the range of tidal stages at which the photos were taken, no significant changes in the configurations of the deltas could be noted over this 22-year period. The 100-year comparison afforded by the available chart and map sequences reveals considerable change in Walker Creek. Since 1861, the channel has shifted from a position on the south side of the delta to various other positions in the center and north sections at least once, and several such relocations may have occurred. In contrast, there is little evidence of channel shifting on the Lagunitas Creek delta.

The reported existence of a harbor for the town of Tomales on Keys Creek prior to 1875 (see Holway, 1914, Plate 19) appears to indicate considerable silting has occurred on the delta and along the downstream reach of Walker Creek. However, the 1861 U. S. Coast and Geodetic Survey data shows that for the delta and the channel upstream for about 1 mile, low tide depths were mostly zero but locally ranging up to 4 feet. Any harbor here in 1875 would have had to be served by a dredged channel. More recent surveys do not cover this area, but indirect evidence indicates that no significant changes in the 1861 depths have occurred near the creek mouth. Silting of any dredged channel that once may have existed represents merely a readjustment to the undisturbed condition of 1861 and does not demonstrate, in itself, increased sedimentation after 1875.

CONCLUSION. The conditions affecting sedimentation within Tomales Bay probably have not been altered significantly within historical time from what they were during the past 10,000 or more years that the bay has existed. Progressive filling of the bay is a natural process. ✓

✓ It is logical to suppose that there was an increased sediment yield during periods of logging and farming in the tributary watersheds. There is indirect evidence of some increased bay filling during this time, but the data are not very specific or conclusive. The period of probable increased sediment yield represents only one-hundredth or less of the total time that sedimentation has been occurring in the bay. For this period to have had a significant affect on the filling of the bay, therefore, a very large increase over the estimated present sediment yield would have been required. The present condition of the watersheds, in terms of gully development and general denudation, does not support an hypothesis of enormously accelerated erosion in the immediate past.

It may be significant that, at the estimated rates of present-day sediment yield, the tributary watersheds could not in 10,000 years have contributed anywhere near the amount of sediment apparently present in the existing bay fill. This fact could be interpreted as indicating higher sediment yield, both in the present and in the past. It is our opinion, however, that the sediment yield figures given in this report are reasonably conservative. Further, except during the last 150-year period of transformation from the natural state, it is unlikely that the area in its pre-historic state had sediment yields appreciably greater than those of the present.

It is possible that the bay is older than 10,000 years, an arbitrary age generally accepted as marking the end of the Pleistocene glacial epoch. There is some evidence that the last sea level rise may have started 15 to 18 thousand years ago, though it is likely that the last 50-foot rise required to form the bay occurred at a time closer to 10,000 years ago.

If there are no major errors in our assumptions, it must be concluded that an appreciable amount of the bay filling sediment, perhaps more than half of the total, has not been derived from the tributary watersheds, but has been transported into the bay from an external source. A definitive solution to this question, however, is beyond the scope of this study.

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GENERAL

Chapter 3 of this study establishes that changing land use within the study area, particularly urbanization, will affect peak flood flows and drainage patterns. The Preliminary West Marin County Master Plan¹, used as an acceptable source of information for determination of urbanization trends, indicates that urbanization has been from the eastern side of Marin County, overflowing onto Lagunitas and Walker Creek watersheds.

Areas of urbanization in 1960, and projections for 1990, are shown on Plate 6-1. Because the Point Reyes National Seashore Park development may alter current trends, new urban areas may not occur exactly as shown, but the illustration is an indication of anticipated growth to be expected by 1990.

Planning areas as shown on the Master Plan were modified to fit our watershed boundaries. Population, Urban area in acres, Urban area as a percent of total watershed, were estimated for the period from 1950 to 1990 and are shown in graph form on Plates 6-2 and 6-3. These trends may not occur at the uniform rate indicated, but the net effect will probably be realized by 1990.

¹Prepared by Mary Summers, Harold Summers, and Dan Coleman Associates, dated April 1964, pp. 38, 51, 52.

EFFECTS OF URBANIZATION

Increased peak flood flows generated by developing urban areas will necessitate that consideration be given to related changes:

- . During periods of development erosion and sediment yields are generally higher than normal, a temporary condition which will decrease as impervious surfaces increase. A government agency or developer who disturbs the natural balance should be required to take steps to control erosion and excessive sedimentation.
- . Establishment of a "zone of responsibility" concept is important in treating the problems of urban drainage. Property on high ground may not be seriously affected during periods of high runoff but the storm water from roofs, yards and streets contributes to inundation in the low areas. The high ground property owners may be indirectly affected by interruption of transportation and communication facilities which might be caused by flooding problems in the low areas.
- . Right-of-way needs should be anticipated to ensure adequate flood control facilities, which will be needed as urban areas are developed.

Developing urbanization will require liaison in such matters, determination of projected needs, and authority for cohesive action. Urban development will enlarge the tax base, and developers of these areas could be assessed to provide for drainage improvements necessitated by increased peak flood flows. It will be necessary that these funds be collected, placed in reserve, and administered by an appropriate

agency. Many agencies could provide this service, one of which is described herein.

MARIN COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

This District, created by statute of the State of California¹, has the vested power to collect monies and administer drainage improvement works. The District, whose boundaries are the exterior boundaries of the County of Marin, has three general areas of responsibility: flood control, water conservation, and recreation facilities.

Sections 3 and 11 of this statute provide that drainage zones may be established within this District. Two drainage zones could be created by the Board of Supervisors, one zone to follow the watershed boundary of Walker Creek and the other to follow the Lagunitas Creek boundary, as shown on Plate 6-1. A brief outline of the procedure for formation of such zones is as follows:

1. Resolution by the Board of Supervisors to show their intent to form a zone.
2. Publishing of notices of the public hearing on the formation of the zone.
3. Public hearing at which the zone is established, unless a written protest is filed against the proposed zone by a majority in numbers or assessed valuation of the real property holders.

Under this statute, the only elections normally required are those authorizing the issuance of bonds. The Board of Supervisors are advised by a zone advisory board composed of five residents of the zone.

¹Stats. 1953, c. 666, p. 1915.

Examples of the use of zones for the collection and administration of funds for future construction are given below:

SANTA CLARA COUNTY FLOOD CONTROL AND WATER DISTRICT

This District has designated five major zones and storm drain channels within each zone. The majority of these channels have been improved. Benefits in the higher elevations of each zone have been: erosion control in storm channels, protection of general transportation facilities, protection of communication facilities, and enlargement of the tax base by the development of area formerly flooded. Assessments, in the form of acreage drainage fees, have been levied on each new urban development within each zone, irrespective of the location of the development.

ALAMEDA COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT

This District formed its first zone in 1952 and by the end of 1963 nine zones were established. This District does not levy acreage drainage fees on each new urban development within each zone but rather relies on its taxing powers to accumulate funds to construct flood control works.

By the end of 1963 the District had authorized works in the amount of \$63,201,000 and had pioneered an agreement with the U. S. Corps of Engineers for a cooperative project on San Lorenzo Creek, completed in April 1962 at a total cost of \$6,200,000. In October of that same year the largest flood of record occurred on San Lorenzo Creek and millions of dollars in damages were prevented during that one storm. In addition, the \$17 million federal project on Alameda Creek has been authorized for which plans and specifications are being prepared by the U. S. Corps of Engineers.

CONCLUSION

The Preliminary West Marin Master Plan should be consulted for a more detailed explanation of population, future land use, highways, and other major public improvements. Planning for flood control should include consideration of the possibility of population growth greater than that predicted in the Master Plan and used as a basis for estimating hydrological changes precipitated by urbanization. A period extending beyond the 25-year projections should be considered as well as the possibility of population growth greater than projections.

GENERAL

The purpose of this chapter is to set forth certain observations and recommendations concerning the design of urban drainage facilities within the watersheds covered by this report, and to relate these to the present drainage standards and practices of the County of Marin.

The current practice of the County of Marin is to use the best available hydrologic data for the area under consideration. The County's drainage structure standards are contained in the subdivision check sheets, with standard details attached. The primary intent of this checklist is to set forth general criteria for the specific structures and the requirements to be met for maintenance purposes.

LEVEL OF PROTECTION

Urban drainage facilities shall be designed to pass the peak flow of the following storms without surcharge in the catch basins or manholes and without any ponding in the streets:

Areas up to 160 acres	-	5 Year Storm
Areas of 160 acres to 640 acres	-	10 Year Storm
Areas over 1.00 square mile	-	See Chapter 4
Areas subject to damage	-	10 Year Storm

Main storm drain interceptors and outfalls shall be sized to pass the 25-year storm in urban areas. The levels of protection in urban areas may be increased at the discretion of the County, when damage or loss of life may occur from flooding caused by undersized drainage facilities.

If a major storm water channel passes through a local urban area, the flows in the channel where it enters the urban area shall be calculated in accordance with the procedures in Chapter 3. The level of protection for these channels will be as specified in Chapter 4 of this report. In the case of a local urban drainage facility making the transition from the rational design basis for an area of less than one square mile to the regionally derived peak flow values applicable to areas in excess of one square mile, in accordance with Chapter 3, the capacity or cross-sectional area of the structure conveying the storm water should not be reduced.

DESIGN FORMULA

The rational method, which is currently standard engineering practice, will be used to determine the peak flow rate for the design of drainage facilities. This method is based on the rational formula:

$$Q = CiA$$

- where:
- Q is the peak rate of storm runoff in cubic feet per second
 - C is the runoff coefficient, expressed as the ratio of runoff to rainfall
 - i is the average intensity of rainfall, in inches per hour, for the design storm frequency over a duration equal to the time of concentration
 - A is the size in acres of the tributary drainage area.

Runoff coefficients are based on the type of development and the judgment of the engineer doing the design. The following coefficients may be considered typical to this area:

<u>Land Use</u>	<u>Runoff Coefficient, C</u>
Residential	0.35
Commercial	0.75
Unimproved (slopes=0% to 5%)	0.10 to 0.20
Unimproved (slopes=over 5%)	0.25 to 0.35
Parks	0.15 to 0.25
Playgrounds	0.25
Asphalt or Concrete Pavement	0.85

Drainage areas are determined and delineated for design purposes from U.S.G.S. maps or other available topographic maps. The drainage divides are normally apparent except in flat areas, where the divides are located by field surveys. Each tributary has to be delineated, and the area in acres computed.

The time of concentration is the time required for water to flow from the most hydraulically remote part of the watershed to the point under consideration. Determination of the average intensity of rainfall from Plate 2-3 requires an estimation of the time of concentration.

For natural watershed areas which would be tributary to an urban development, and which would remain undeveloped, the modified Kirpich formula adapted from the Santa Clara County Drainage Manual may be used. This formula is as follows:

$$T_c = 0.0078 \left[\frac{L^{3/2}}{H^{1/2}} \right]^{0.77} + 10$$

where: L is the maximum horizontal length of travel in feet
H is the difference in elevation along the effective slope line in feet

T_c is the time of concentration in minutes.

The effective slope line is obtained by plotting a profile of the watercourse from the drainage divide at the upper end to the point of discharge at the lower end. A straight line is drawn from the lower end point of the profile to intersect the profile again such that the area above the profile (between the profile and the straight line) is equal to the area below the profile (between the straight line and the profile). This straight line is the effective slope line. The dimension L in the above formula is the horizontal length of the effective slope line and the dimension H is its total difference in elevation. The graphical solution to the above formula is shown on Plate 7-1 and the effective slope line is illustrated in Plate 7-2.

For urban areas only, the time of concentration is the sum of the overland flow from the urban lots and the travel time in ditches and conduits. A reasonable value for overland flow time from residential lots of average depth is ten minutes, and the flow time in gutters may be computed with sufficient accuracy from the following table:

APPROXIMATE MEAN VELOCITY OF FLOW IN GUTTERS
(asphalt or concrete with 6-inch curb)

<u>Gutter Slope</u>	<u>Velocity/feet per second</u>
0.001	1.0
0.002	1.4
0.004	1.9
0.006	2.4
0.008	2.8
0.010	3.1
0.015	3.8
0.020	4.4

The flow time in conduits can be determined from the Manning equation for pipe flow using the approximate lengths of conduit to the

point being considered.

When the time of concentration has been determined, the corresponding rainfall intensity in inches per hour is then read from Plate 2-3, in the Appendix. The next step is to find the location of the area being considered on Plate 2-4 and read the indicated "K" value. The intensity value is then multiplied by the "K" value, and the product is the intensity value to be used in the rational formula. An example of this procedure is as follows:

DESIGN THE URBAN DRAINAGE FACILITIES FOR AN AREA ADJACENT TO THE OLEMA CEMETERY. The storm drain outfall will pass under the existing Bolinas Highway and empty into Olema Creek. At what rate must this facility convey water under the highway?

The designer determines the following information:

1. Undeveloped area is thirty acres with a time of concentration (Plate 7-1) of 22 minutes at the upper end of the development. The pipe flow time through the development is three minutes.
2. The residential lot area of the development will be twenty acres.
3. The area in pavement within the development is ten acres.
4. The flow time within the development is composed of ten minutes over the lot areas, three minutes in the gutters (Table 7-1), and two minutes in the pipeline. The total urban flow time is 10 plus 3 plus 2, for a total of 15 minutes.

The rate of flow of the storm water is then calculated:

1. Time of concentration is the time at which the entire area is contributing. In this case, the time of concentration is 25 minutes.
2. Entering Plate 2-3 at a time of concentration of 25 minutes, we read an intensity of 2.4 inches per hour for 25 year event, which is used in this case because this is a main storm drain outfall.
3. Consulting Plate 2-4, we find a "K" value of 1.6.
4. Intensity for this design is the product of 2.4

times 1.6, or 3.84 inches per hour.

5. The quantity of storm water at the peak flow, using the typical runoff coefficients cited above, is:

$$Q = CiA = [(0.25)(3.84)(30)] + [(0.35)(3.84)(20)] + [(0.85)(3.84)(10)]$$

$$Q = 88.32 \text{ cfs}$$

DRAINAGE STRUCTURE CAPACITIES

On Plate 7-3 are found the Flow Characteristic Curves for flows in a two-foot wide gutter with a two-inch difference in elevation between lip and face of curb. The graph can be entered from the Discharge to the Gutter Slope, then horizontally to the Cross Slope of the road surface, then vertically downward to the width of the flow from the gutter face. The pavement cross slope can be intersected again in the lower part of the graph, and then horizontally to the left to read the depth of flow at the curb face.

The width of flow should be limited to five feet for roads 28 feet or less in width from face of curb to face of curb. The width of flow should be a maximum of eight feet in all other cases.

The location of catch basins is governed by four main considerations:

1. The geometrics and profiles of the roads dictate low spots and places of abrupt grade change that will require catch basins.
2. The current practice requires access to the storm drain pipe at 300 foot intervals, and this access can be combined with a catch basin.
3. The current practice requires a drainage structure at all changes in alignment of the storm drain pipe, and this structure can be combined with a catch basin.
4. A catch basin is required when the spread of storm water in the gutter exceeds the allowable spread.

The capacity of the current standard catch basin which has a two-foot square grate opening and a curb opening of five and a half feet is shown on Plate 7-4 for a continuous slope. It is good practice to assume that the catch basin intercepts ninety percent or less of the total gutter flow. In hilly locations, the curb opening length of the catch basin should be increased to ten feet in order to intercept the high velocity flows.

The capacity of the current standard catch basin is shown on Plate 7-5 for the case when the catch basin is located at a low point, or "sump." The curb opening capacity in this case is not calculated, but it is available should the grate become clogged. The design limitation for this case is the width of the spread of the storm waters from the face of the curb.

The capacities of the storm drain pipes and conduits should be designed through use of the Manning formula. The Institute of Transportation and Traffic Engineering of the University of California publishes compilations of graphical solutions for various conduits, and this publication is helpful in design. In hilly locations care should be exercised that inlet conditions are such that the pipe's carrying capacity can be realized within acceptable velocity ranges. When excessive velocities are to be encountered, care should be exercised in the areas where hydraulic jumps may occur. In addition, culverts should be checked for the possibility of either inlet or exit control which would limit the carrying capacity of the conduit.

GENERAL

This study revealed a deficiency in basic data which is essential for the design of a specific drainage system. The recommendations indicate what steps should be taken so sufficient data will be available when plans are prepared for the necessary improvements.

DATA COLLECTION

At least three recording rain gages should be installed and operated. Locations that appear to be desirable are Woodacre, Point Reyes Station, and Tomales.

One stream gage should be installed, and one gage reactivated. The new gage should be located on Lagunitas Creek below Nicasio Creek, between Channel Miles 4 and 6. An old gage was in use on Walker Creek near Channel Mile 17 between Arroyo Sausal and Salmon Creek, and it should be reestablished if at all possible.

Stream gage installation can be a joint effort with the U. S. Geological Survey, who will provide all or part of the initial cost and assist in reading and maintaining the gage. Where a water supply aspect is present, the State Department of Water Resources will participate in

operation, maintenance, and publication of the gage data. New stream gage installations range in cost from \$5,000 to \$15,000.

Liaison between agencies that would derive benefits from access to hydrology records should be encouraged. Agencies that would find such data useful are: Marin County Soil Conservation District, the County of Marin, the Marin Municipal Water District, the North Marin County Water District, the State Department of Water Resources, the U. S. Army Corps of Engineers, the U. S. Geological Survey, and the U. S. Coast and Geodetic Survey. A cooperative effort to collect, evaluate, tabulate and publish this hydrological information would permit the work to be accomplished by staff members of an agency with a seasonal work load, or through the use of a consultant. Reporting and publishing should be done at least annually.

The Marin County Soil Conservation District could provide a catalytic leadership in accomplishing a cooperative data collection program. The expenses for such an effort will be paid back many times over for improved hydrologic data will provide information for proper sizing of flood control projects.

DESIGN CRITERIA

Uniform design criteria for local urban drainage facilities, as detailed in Chapter 7, provide a stable base for the development of improvements as they are needed.

IMPROVEMENTS TO EXISTING CHANNELS

Locations that merit immediate attention are:

1. The nine culverts in Woodacre.
2. The fish ladder at Channel Section 8 in San Geronimo Creek.
3. The bridges at Channel Sections 5 and 11 in Lagunitas Creek.
4. The tidal reach of Lagunitas Creek in the vicinity of Point Reyes Station.
5. The bridges at Channel Sections 2 and 5 in Walker Creek.

A desirable level of protection should be determined for each of these locations and improvements planned to relieve the flooding problems.

EROSION AND SEDIMENTATION CONTROL

The farm and ranch cooperative soil conservation program should be continued with vigor because this is a fine method to limit erosion at its source.

A soil survey to evaluate existing soil conditions, as prepared by the U. S. Soil Conservation Service, should be completed. ✓

Erosion in construction work should be regulated. Any government agency or private landowner who disturbs the natural balance should be required to control erosion.

Major reservoirs such as Kent Lake and Nicasio Dam accomplish substantial control of smaller size sediments and this is an indication that the proposed Walker Dam would derive similar benefits. Sediments of small size that are not trapped in the reservoirs will be deposited in Tomales Bay where the only positive method of removal is by dredging.

ADMINISTRATIVE STRUCTURE

As urbanization develops there will be a progressively increasing need for leadership: to develop detailed planning and policy, to anticipate right-of-way needs, to establish assessments, collect funds, and be financially responsible for improvements, to maintain facilities and enforce established policies, and to provide liaison with other agencies.

A determination should be made very soon of what authority would best provide these services and act as a cohesive force to accomplish a foresighted and dynamic program.

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TRIBUTARY AREAS AND FLOWS

Concentration Point	Tributary Area in Sq. Mi.		Peak Flood Flows in C.F.S.		
	Total	Effective	2.33 yr.	10 yr.	100 yr.

WALKER CREEK

W-15	1.8	1.8	220	440	770
W-14	18.3	18.3	1,850	3,700	6,480
W-13	24.1	24.1	2,390	4,780	8,360
W-12	25.7	25.7	2,510	5,010	8,790
W-11	30.6	30.6	2,920	5,840	10,200
W-10	34.9	34.9	3,360	6,710	11,800
W-9	37.1	37.1	3,520	7,040	12,300
W-8	39.0	39.0	3,690	7,390	12,900
W-7	59.3	59.3	5,400	10,800	18,900
W-6	62.3	62.3	5,630	11,300	19,700
W-5	63.5	63.5	5,800	11,600	20,300
W-4	65.8	65.8	5,950	11,900	20,800
W-3	66.8	66.8	6,100	12,200	21,400
W-2	71.8	71.8	6,450	12,900	22,600
W-1	73.1	73.1	6,550	13,100	23,000

KEYS CREEK

K-4	1.5	1.5	190	380	665
K-3	2.7	2.7	320	640	1,120
K-2	4.3	4.3	500	1,000	1,750
K-1	4.7	4.7	540	1,040	1,890

CHILENO CREEK

C-10	4.6	4.6	520	1,040	1,830
C-9	5.8	5.8	650	1,300	2,290
C-8	7.3	7.3	810	1,620	2,860
C-7	10.5	10.5	1,110	2,220	3,880
C-6	11.5	11.5	1,200	2,400	4,200
C-5	13.5	13.5	1,400	2,800	4,900
C-4	15.7	15.7	1,610	3,220	5,640
C-3	17.4	17.4	1,790	3,580	6,260
C-2	17.9	17.9	1,800	3,600	6,300
C-1	19.8	19.8	2,000	4,000	7,000

SALMON CREEK

S-4	1.0	1.0	100	260	455
S-3	2.5	2.5	300	600	1,050
S-2	4.4	4.4	510	1,020	1,790
S-1	5.1	5.1	580	1,160	2,030

ARROYO SAUSAL

A-8	1.3	1.3	165	330	580
A-7	2.1	2.1	260	520	910
A-6	3.2	3.2	380	760	1,330
A-5	7.6	7.6	830	1,660	2,910

TRIBUTARY AREAS AND FLOWS (continued)

Concentration Point	Tributary Area in Sq. Mi.		Peak Flood Flows in C.F.S.		
	Total	Effective	2.33 yr.	10 yr.	100 yr.
ARROYO SAUSAL (continued)					
A-4	9.9	9.9	1,060	2,120	3,720
A-3	11.7	11.7	1,220	2,440	4,260
A-2	14.3	14.3	1,490	2,980	5,210
A-1	15.6	15.6	1,600	3,200	5,600
LAGUNITAS CREEK					
L-12	9.9	6.7	740	1,480	2,590
L-11	21.5	14.6	1,500	3,000	5,250
L-10	31.5	24.6	2,410	4,820	8,430
L-9	32.7	25.8	2,510	5,020	8,780
L-8	33.5	26.6	2,600	5,200	9,100
L-7	36.8	29.9	2,890	5,780	10,100
L-6	38.9	32.0	3,070	6,140	10,800
L-5	41.5	34.6	3,300	6,600	11,600
L-4	79.6	60.1	5,400	10,800	18,900
L-3	81.2	61.7	5,500	11,000	19,300
L-2	82.5	63.0	5,750	11,500	20,300
L-1	103.0	83.5	7,300	14,600	25,800
NICASIO CREEK					
N-10	1.6	1.6	200	400	700
N-9	3.9	3.9	450	900	1,570
N-8	9.3	9.3	1,000	2,000	3,500
N-7	11.7	11.7	1,210	2,820	4,240
N-6	22.0	22.0	2,190	4,380	7,650
N-3	35.9	24.4	2,400	4,800	8,400
N-2	36.7	25.2	2,490	4,980	8,710
N-1	37.0	25.5	2,500	5,000	8,750
HALLECK CREEK					
H-5	2.5	2.5	300	600	1,050
H-4	3.8	3.8	440	880	1,540
H-3	5.3	5.3	600	1,200	2,100
H-2	7.9	7.9	860	1,720	3,010
H-1	8.5	8.5	920	1,840	3,220
SAN GERONIMO CREEK					
G-6	1.0	1.0	130	230	455
G-5	3.6	3.6	420	840	1,470
G-4	5.7	5.7	640	1,280	2,240
G-3	7.1	7.1	780	1,560	2,730
G-2	8.9	8.9	960	1,920	3,360
G-1	9.3	9.3	1,000	2,000	3,500

TABLE 3-1

TABLE 3-2

<u>Predominant Land Use</u>	<u>Impervious Surface Area as Percent of Total Drainage Area</u>		<u>"X" Coefficient</u>	<u>"K" Factor</u>
	<u>Range</u>	<u>Average</u>		
Industrial, Commercial, High Density Residential	60%-100%	80%	0.85	1.31
Medium Density Residential	40%-60%	50%	0.775	1.20
Low Density Residential	0%-40%	20%	0.70	1.08

TABLE 3-3

<u>Point</u>	<u>Tributary Area</u>			<u>(K) Factor</u>	<u>(C) Factor</u>	<u>[(K) (C)]</u>	<u>Ten-year Peak Flood Flow (CFS)</u>	
	<u>Total Sq.Mi.</u>	<u>Urbanized Sq.Mi.</u>	<u>% Total</u>				<u>Q Non-Urban</u>	<u>Q Urban</u>
G-6	1.0	1.0	100	1.20	1.46	1.75	230	400
G-5	3.6	2.0	56	1.11	1.26	1.40	840	1175
G-4	5.7	2.0	35	1.07	1.16	1.24	1280	1540
G-3	7.1	2.0	28	1.06	1.13	1.20	1560	1870
G-2	8.9	2.0	23	1.05	1.11	1.17	1920	2240
G-1	9.3	2.0	22	1.04	1.10	1.14	2000	2280

TABLE 3-2

TABLE 3-3

TABLE 4-1
FLOW CONVEYANCE CHARACTERISTICS

SECTION	EFFECTIVE DRAINAGE AREA SQ. MI.	BANKFULL CAPACITY			MEAN-ANNUAL FLOOD PEAK			10 - YEAR FLOOD PEAK			25 - YEAR FLOOD PEAK			100-YEAR FLOOD PEAK		
		DISCHARGE C.F.S.	DEPTH FT.	TOP WIDTH FT.	DISCHARGE C.F.S.	DEPTH FT.	TOP WIDTH FT.	DISCHARGE C.F.S.	DEPTH FT.	TOP WIDTH FT.	DISCHARGE C.F.S.	DEPTH FT.	TOP WIDTH FT.	DISCHARGE C.F.S.	DEPTH FT.	TOP WIDTH FT.
LAGUNITAS CREEK																
1	96.1				8,490			17,000			22,000			29,800		
2	94.9				8,300			16,600			21,600			29,100		
3	76.1				6,800			13,600			17,700			23,800		
4	75.2	7,400	17.0	123	6,750	16.0	121	13,500	21.7 *	200 *	17,500	24.0 *	203 *	23,800	27.2 *	209 *
5	74.5	5,850	21.0	191	8,700	*	*	13,400	*	*	17,400	*	*	23,400	*	*
6	72.7	6,300	12.0	103	6,600	12.7	115	13,200	17.2	162	17,200	19.2	170	23,100	21.5	181
7	35.6	33,400	24.0	265	3,400	9.1	130	6,800	13.0	173	8,840	14.4	187	11,900	16.3	199
8	35.4	10,600	12.5	169	3,400	7.6	159	6,800	10.0	164	8,840	11.3	166	11,900	*	*
9	33.7	9,450	22.0	120	3,250	13.3	71	6,500	18.3	93	8,450	20.8	116	11,400	*	*
10	32.4	17,500	17.0	167	3,100	7.7	73	6,200	11.1	102	8,050	12.6	117	10,900	14.2	133
11	30.9	3,600	11.0	92	2,990	10.0	86	6,000	*	*	7,770	*	*	10,500	*	*
12	30.1	8,000	25.0	122	2,900	16.7	98	5,800	21.4	110	7,540	23.5	118	10,200	*	*
13	26.6	11,700	20.5	126	2,600	9.4	83	5,200	13.2	98	6,760	15.0	105	9,100	17.5	116
14	25.8	8,900	15.5	85	2,510	7.4	67	5,030	11.1	76	6,520	12.8	79	8,800	15.3	85
15	15.3	6,000	18.0	96	1,550	10.6	72	3,100	14.0	83	4,030	15.1	87	5,420	17.5	95
NICASIO CREEK																
1	36.9	13,000	24.0	125	2,500	11.0	63	5,000	15.5	84	6,500	17.7	96	8,750	20.3	111
2	36.7	16,300	24.5	114	2,490	7.3	69	4,980	11.3	80	6,470	13.5	86	8,720	16.1	91
SAN GERMINO CREEK																
1	9.2	3,900	18.3	82	990	8.0	55	1,980	11.9	64	2,580	14.0	69	3,460	16.7	74
2	8.9	4,700	11.5	70	960	4.7	41	1,920	7.1	49	2,500	8.1	51	3,360	9.6	56
3	8.7	2,730	12.5	70	950	7.8	46	1,900	10.7	61	2,470	12.0	69	3,320	*	*
4	7.1	3,380	13.0	31	780	6.3	31	1,560	14.0	31	2,030	10.4	31	2,730	11.9	31
5	5.8	3,900	15.0	73	650	7.0	39	1,300	9.3	52	1,690	10.3	56	2,280	11.8	61
6	4.6	2,400	14.0	43	520	5.8	28	1,040	9.4	34	1,350	11.0	37	1,820	12.7	40
7	4.0	2,560	16.0	19	460	5.6	18	920	8.5	18.5	1,200	10.0	18.5	1,610	12.1	18.5
8	4.0	685	3.5	28	460	2.8	28	920	*	*	1,200	*	*	1,610	*	*
9	2.8	1,220	9.5	27	330	3.9	21	660	6.4	24	860	7.6	25	1,150	9.1	26
10	1.3	650	7.0	24	165	3.0	33	330	5.4	37	430	6.5	38	580	7.6	39
WALKER CREEK																
* 1	73.4				6,600			13,200			17,200			23,100		
* 2	71.9				6,500			13,000			16,900			22,750		
* 3	67.1				6,200			12,400			16,100			21,700		
4	67.0	2,700	8.0	96	6,200	*	*	12,400	*	*	16,100	*	*	21,700	*	*
5	39.2	3,700	14.0	89	3,700	14.0	89	7,400	*	*	9,620	*	*	12,950	*	*
6	37.9	12,250	19.0	124	3,590	10.5	88	6,990	15.1	109	9,340	17.1	119	12,590	*	*
7	35.4	9,200	16.0	151	3,350	11.0	105	6,700	14.3	128	8,700	15.7	144	11,700	*	*
8	34.9	12,750	18.0	148	3,300	8.9	117	6,600	12.3	127	8,590	14.3	134	11,600	17.1	144
9	30.7	24,000	20.5	164	2,950	8.5	69	5,900	12.1	84	7,660	13.1	105	10,300	15.2	142
10	26.0	18,500	20.0	160	2,540	6.8	92	5,080	10.1	110	6,600	11.9	115	8,900	14.0	127
11	24.8	8,570	19.0	110	2,420	10.2	82	4,840	13.9	94	6,300	16.5	102	8,500	19.0	110
12	18.9	14,450	21.0	94	1,900	7.7	65	3,800	11.2	75	4,940	12.9	79	6,650	15.0	87
13	18.4	11,750	18.0	187	1,880	7.0	51	3,760	10.6	66	4,890	12.2	72	6,600	14.1	86
CHILENO CREEK																
1	19.8	6,420	13.5	80	1,990	8.0	60	3,980	10.9	70	5,170	12.2	76	6,980	* 14.0	100
2	17.9	6,300	17.5	81	1,800	9.7	53	3,600	13.7	66	4,680	15.5	76	6,300	17.5	81
3	16.0	3,680	14.0	69	1,630	10.2	49	3,260	13.6	66	4,240	* 14.5	* 71	5,700	* 15.1	75
4	15.7	1,600	8.6	45	1,600	8.6	45	3,200	*	*	4,160	*	*	5,600	*	*
* 5	12.0	1,900	8.0	100	1,250	7.1	83	2,500	*	*	3,250	*	*	4,380	*	*
SALMON CREEK																
1	4.9	5,740	17.0	74	550	3.2	42	1,100	5.1	48	1,430	6.1	53	1,930	7.7	57
2	3.8	19,500	17.5	159	440	4.3	40	880	6.1	47	1,140	6.9	48	1,540	7.2	58

*-EXCEEDS BANKFULL CAPACITY OR STRUCTURE CAPACITY

*-RATING IS FOR BRIDGE SECTION; TEMPORARY TRACTOR CROSSING WILL CAUSE ADDITIONAL FLOODING

TABLE 4-1

DESIGN FLOW VELOCITIES FOR PLANNING PURPOSES

<u>Channel Section</u>	<u>Velocity for a Natural Channel (feet per second)</u>
Walker Creek	
1 to 4	Tidal
4 to 5	4 to 6
5 to 13	4 to 5
Chileno Creek	
1 to 2	6
2 to 5	3 to 4.5
Salmon Creek	
1 to 2	3 to 4.5
Lagunitas Creek	
1 to 4	Tidal
4 to 7	4 to 5
7 to 15	3 to 4.5
Nicasio Creek	
1 to 2	6
San Geronimo Creek	
1 to 10	3.5 to 6

TABLE 4-2

FACTORS AFFECTING EROSION AND SEDIMENTATION

I CONSTANT NATURAL ELEMENTS		II VARIABLE NATURAL ELEMENTS	III MAN CONTROLLED ELEMENTS**
A WATERSHED AREA* (See Reservoir Construction under III)	B TOPOGRAPHIC CHARACTERISTICS	A METEOROLOGICAL CHARACTERISTICS	A LAND USE
C GEOLOGIC CHARACTERISTICS	B HYDROLOGIC CHARACTERISTICS*	C NATURAL LAND CONDITIONS*	B MAN MADE STRUCTURES OR ALTERATIONS

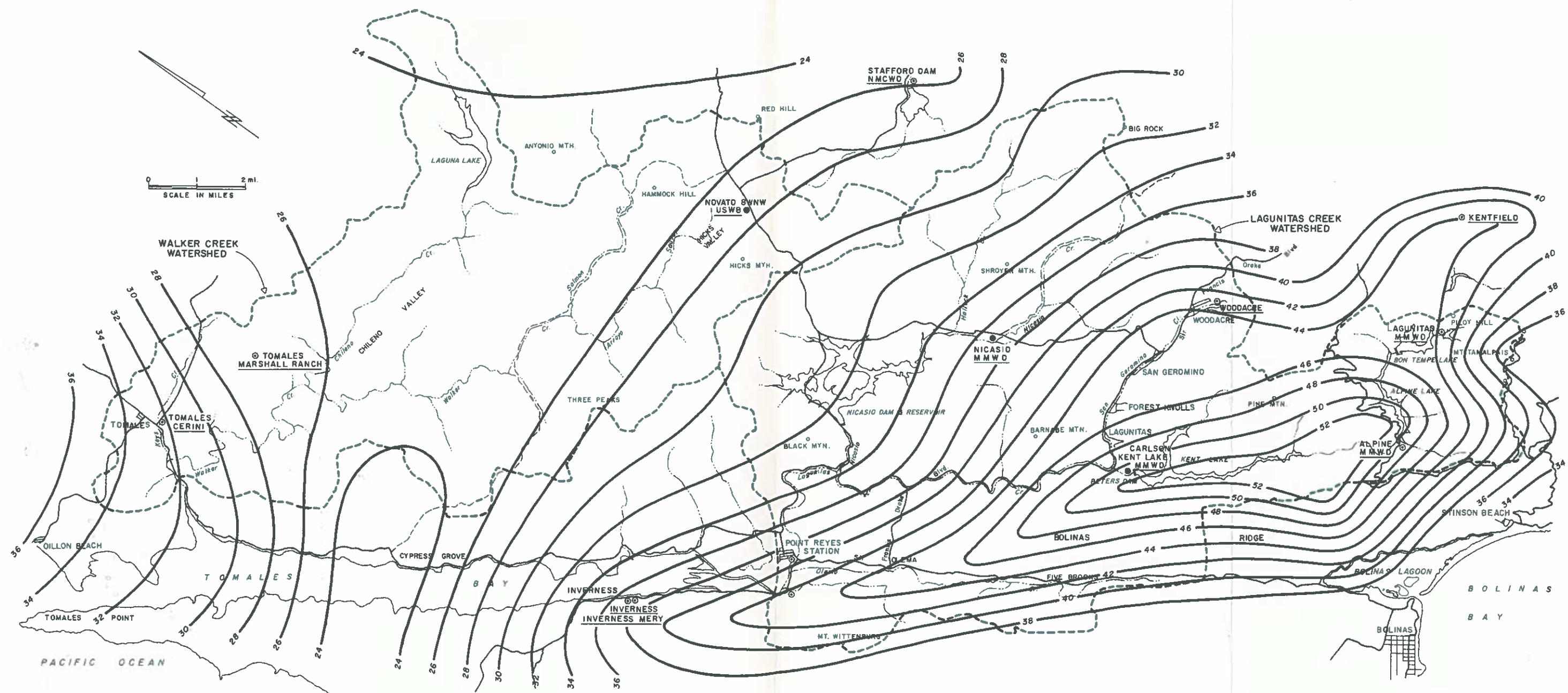
* Modifications by man are possible.

** Sediment yield or movement may be increased (+) or decreased (—) by each element.

TABLE 5-1

LEGEND

- STANDARD RAIN GAGE
- RECORDING RAIN GAGE
- 30 — ISOHYETS — WHICH ARE LINES OF MEAN SEASONAL PRECIPITATION IN INCHES. THESE LINES ARE BASED ON AN ISOHYETAL MAP BY THE U.S. ARMY ENGINEER DISTRICT CORPS OF ENGINEERS, SAN FRANCISCO, CALIFORNIA. THE BASE PERIOD FOR THE ISOHYETS IS JULY 1906 TO JULY 1956



ISOHYETAL MAP
LAGUNITAS AND WALKER CREEK WATERSHEDS
MARIN COUNTY CALIFORNIA

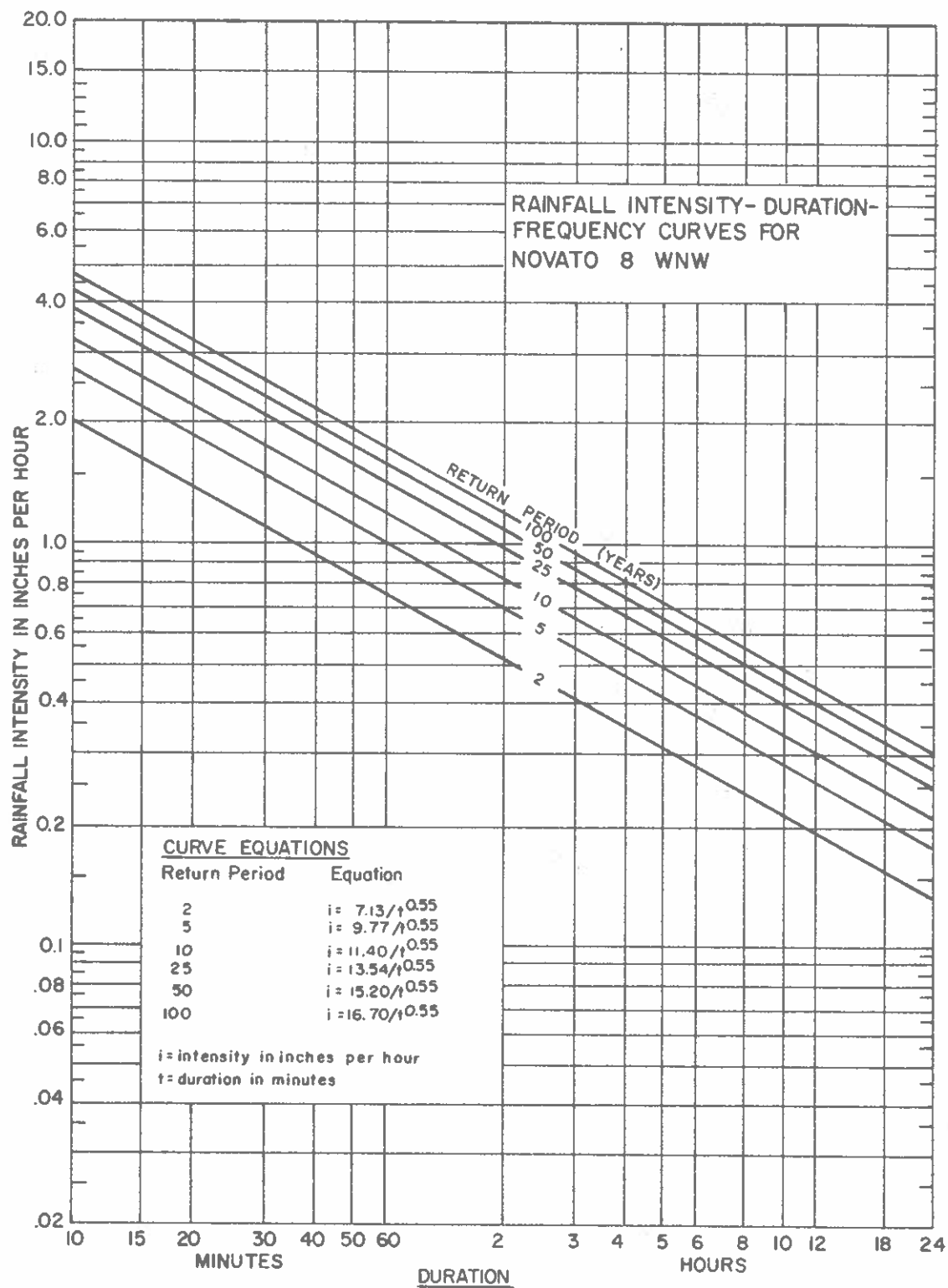
GEORGE S. NOLTE, CONSULTING CIVIL ENGINEERS, INC.
JANUARY 1965

SUMMARY OF RAIN GAGE DATA

GAGE NAME	GAGE TYPE	M.S.P. * INCHES	1960	1955	1950	1945	1940	1888
KENTFIELD	STD.	46.46						
LAGUNITAS (MMWD)	STD.	46.61						
ALPINE (MMWD)	STD.	55.04						
WOODACRE	STD.	44.41						
KENT LAKE (MMWD)	STD.	53.20						
KENT LAKE (MMWD)	REC.	—						
NICASIO (MMWD)	STD.	* *						
NICASIO (MMWD)	REC.	—						
STAFFORD (NMCWD)	STD.	28.14						
NOVATO 8WNW	REC.	30.22						
PT. REYES STA. (CHEDA)	STD.	41.08						
PT. REYES (NOREN)	STD.	* *						
INVERNESS	STD.	35.08						
INVERNESS MERY	STD.	37.69						
TOMALES (CERINI)	STD.	36.73						
TOMALES (MARSHALL RCH)	STD.	* *						

* M.S.P.'S BASED ON PERIOD 1888 - 1964

** NO M.S.P.'S COMPUTED FOR THESE GAGES



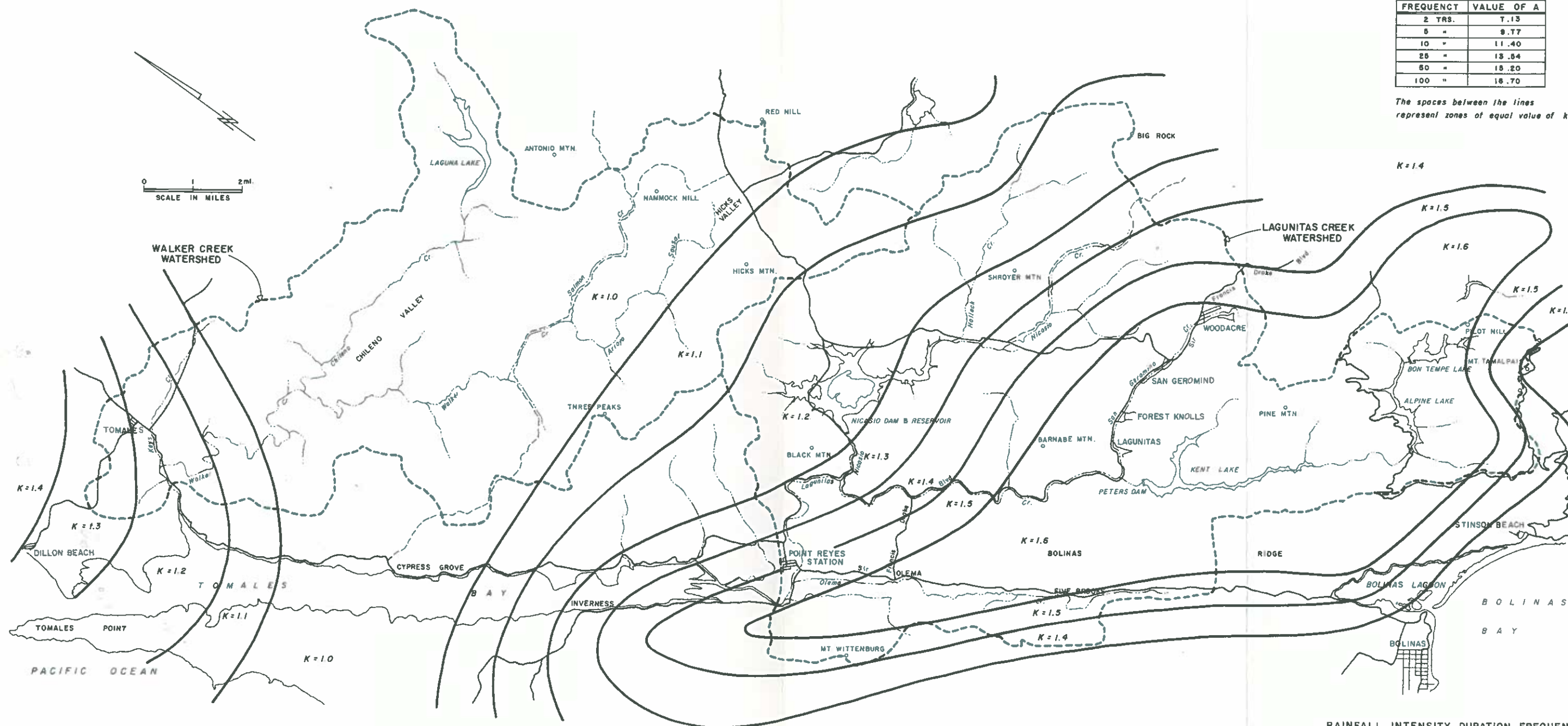
VALUE OF k FOR USE IN THE EQUATION :

$$I = \frac{kA}{t^{0.88}}$$

where : i is RAINFALL INTENSITY (IN INCHES PER HOUR).
 t is THE DURATION OF RAINFALL IN MINUTES.
 A is A CONSTANT FOR EACH FREQUENCY AS TABULATED BELOW —

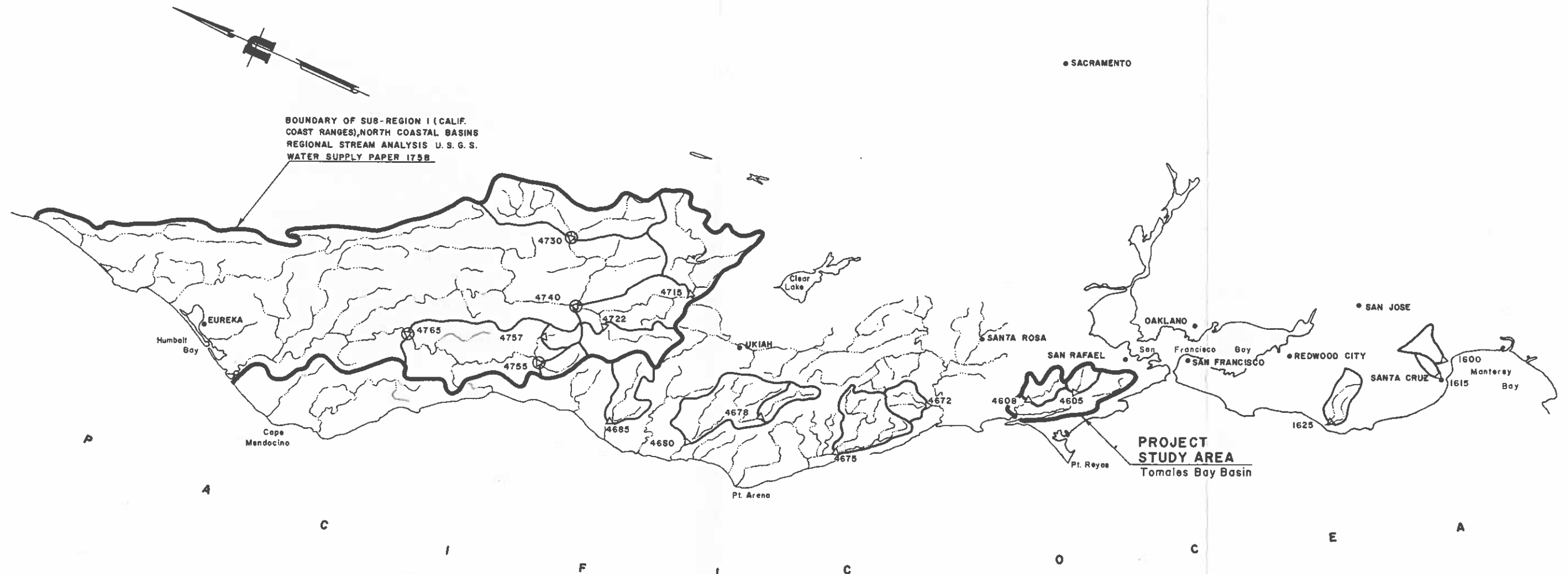
FREQUENCY	VALUE OF A
2 YRS.	1.13
5 "	9.77
10 "	11.40
25 "	13.54
50 "	15.20
100 "	16.70

The spaces between the lines represent zones of equal value of k .



RAINFALL INTENSITY DURATION FREQUENCY CURVE
 LAGUNITAS AND WALKER CREEK WATERSHEDS
 MARIN COUNTY CALIFORNIA

GEORGE S. NOLTE, CONSULTING CIVIL ENGINEERS, INC.
 JANUARY 1965



STREAM GAGE DATA

INDEX NO.	NAME	DRAINAGE AREA SQ. MI.	PERIOD OF RECORD			M.S.P. IN.
			FROM	TO	TOTAL	
1600	SOQUEL CREEK	40.2	1951	1963	12	40
1615	BRANCFORTE CREEK	17.3	1940	1943		
			1951	1963	15	36
1625	PESCADERO CREEK	45.9	1951	1963	12	40
4605	ARROYO NICASIO	36.2	1953	1960	7	31
4608	WALKER CREEK	37.1	1959	1963	4	25
4672	AUSTIN CREEK	63.1	1959	1963	4	65
4675	SOUTH FORK GUALALA RIVER	161	1950	1963	13	65
4678	RANCHERIA CREEK	65.8	1959	1963	4	45
4680	NAVARRO RIVER	304	1950	1963	13	55
4685	NOYO RIVER	105	1951	1963	12	60
* 4715	EEL RIVER	349	1909	1963	54	52
* 4722	OUTLET CREEK	162	1956	1963	7	55
* 4730	MIDDLE FORK EEL RIVER	367	1951	1963	12	60
* 4740	EEL RIVER	1484	1911	1913		
			1951	1963	14	49
* 4755	SOUTH FORK EEL RIVER	43.9	1946	1963	17	80
* 4757	TENMILE CREEK	50.3	1957	1963	6	65
* 4765	SOUTH FORK EEL RIVER	537	1939	1963	24	70

* GAGED STREAMS LOCATED IN MOST SOUTHERLY PORTION OF THE NORTH COASTAL BASINS REGIONAL STREAM ANALYSIS

NO.	REVISIONS	BY	DATE
INDEX GAGING STATIONS			
NORTH COASTAL REGIONAL STREAM ANALYSIS			
LAGUNITAS AND WALKER CREEK MASTER DRAINAGE AND SEDIMENT CONTROL PLAN			
SCALE	DRAWN BY	EES	JOB NO. 8022 64
DATE NOVEMBER, 64	CHECKED BY	EGH	DRAWING NO.
GEORGE S. NOLTE			
CONSULTING CIVIL ENGINEERS			
Palo Alto	—	Santa Clara	—
San Rafael	—	Walnut Creek	

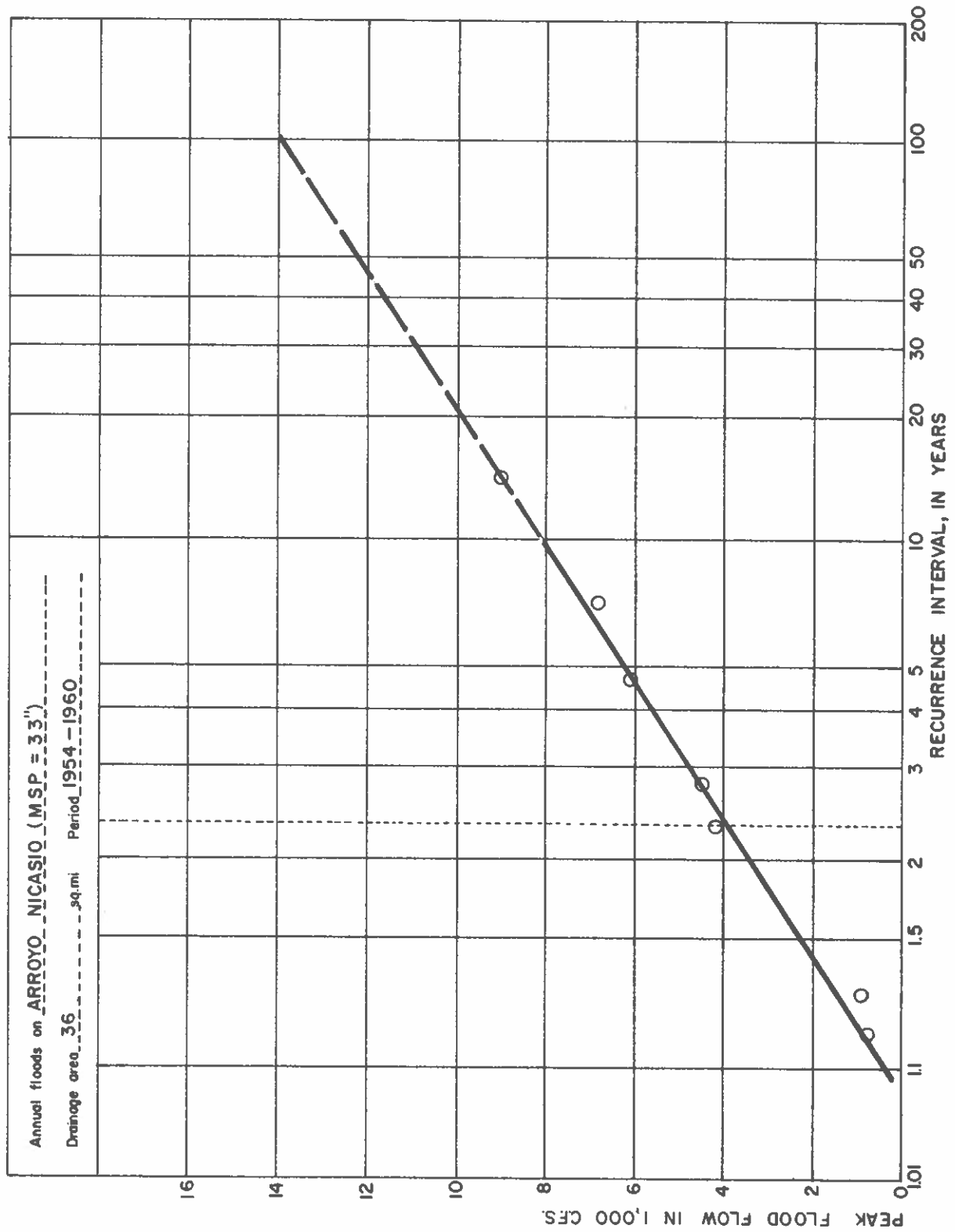


PLATE 3-2

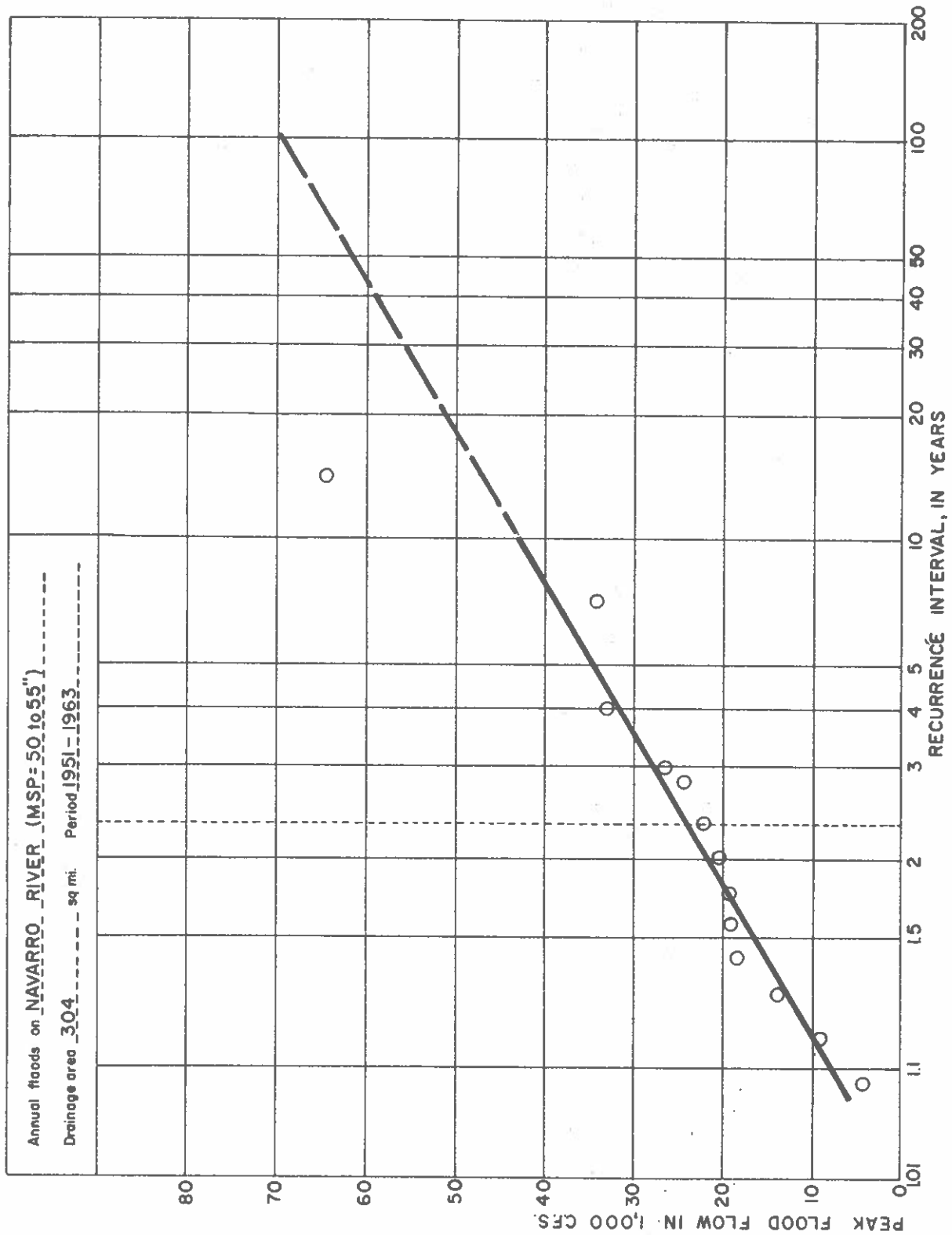


PLATE 3-3

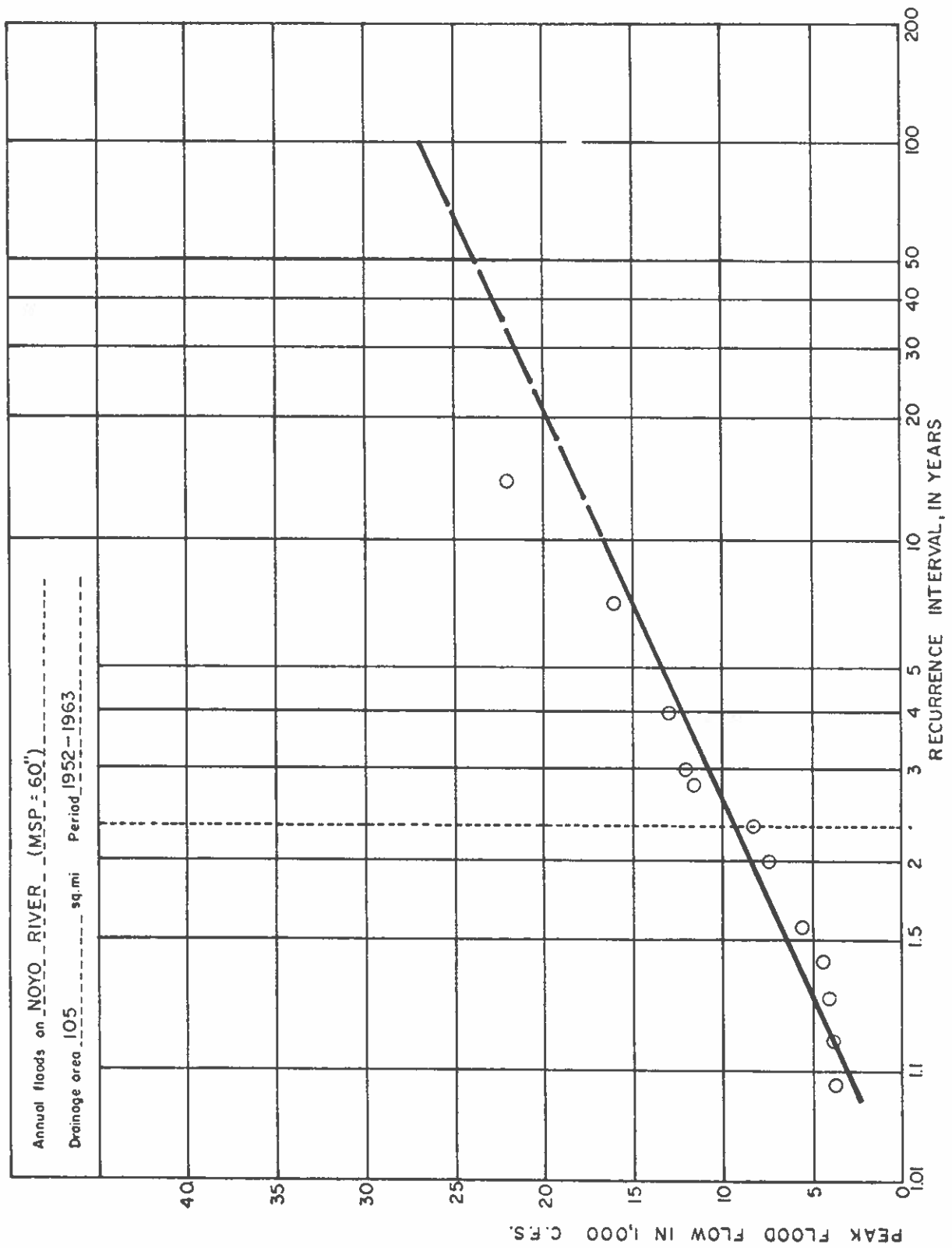


PLATE 3-4

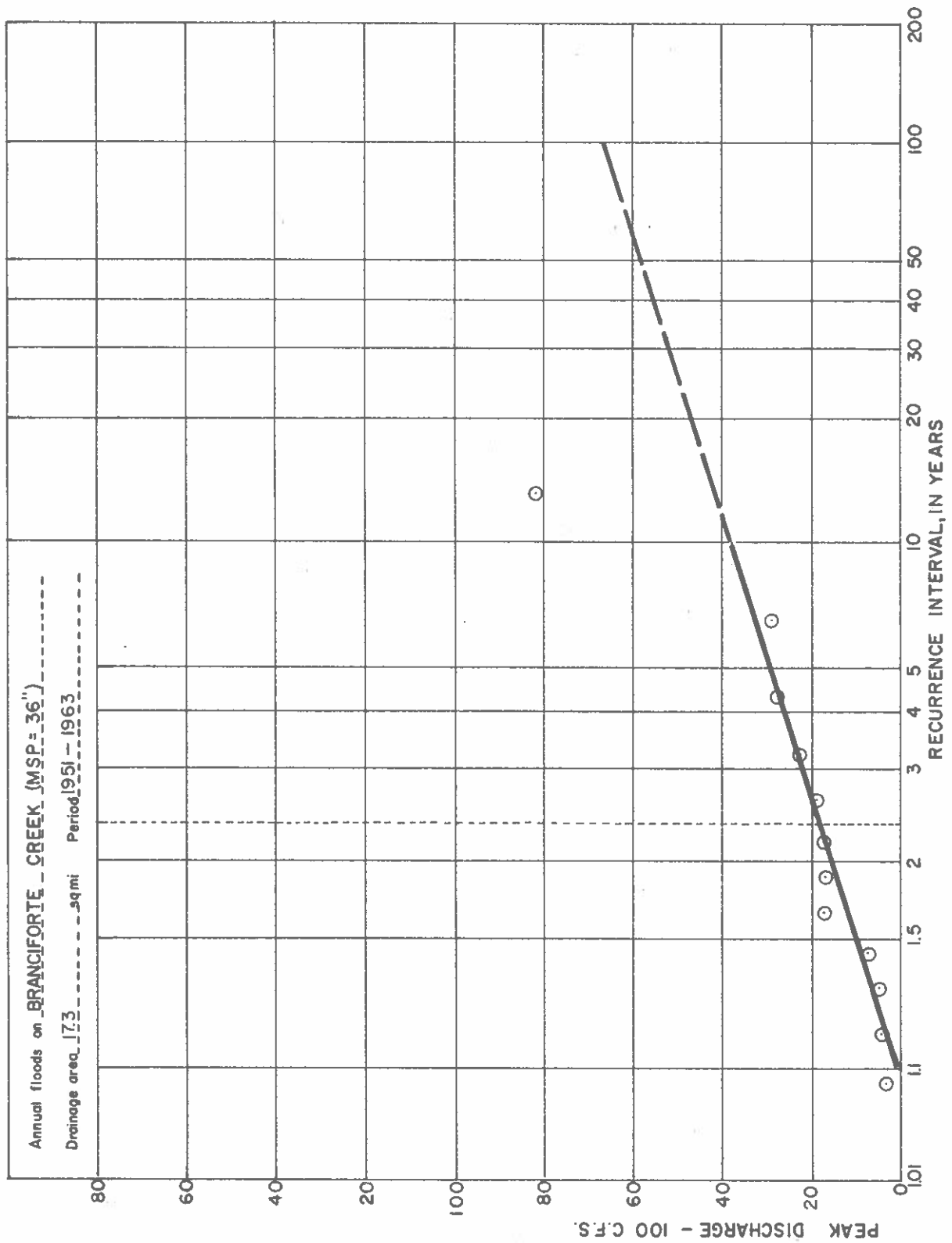
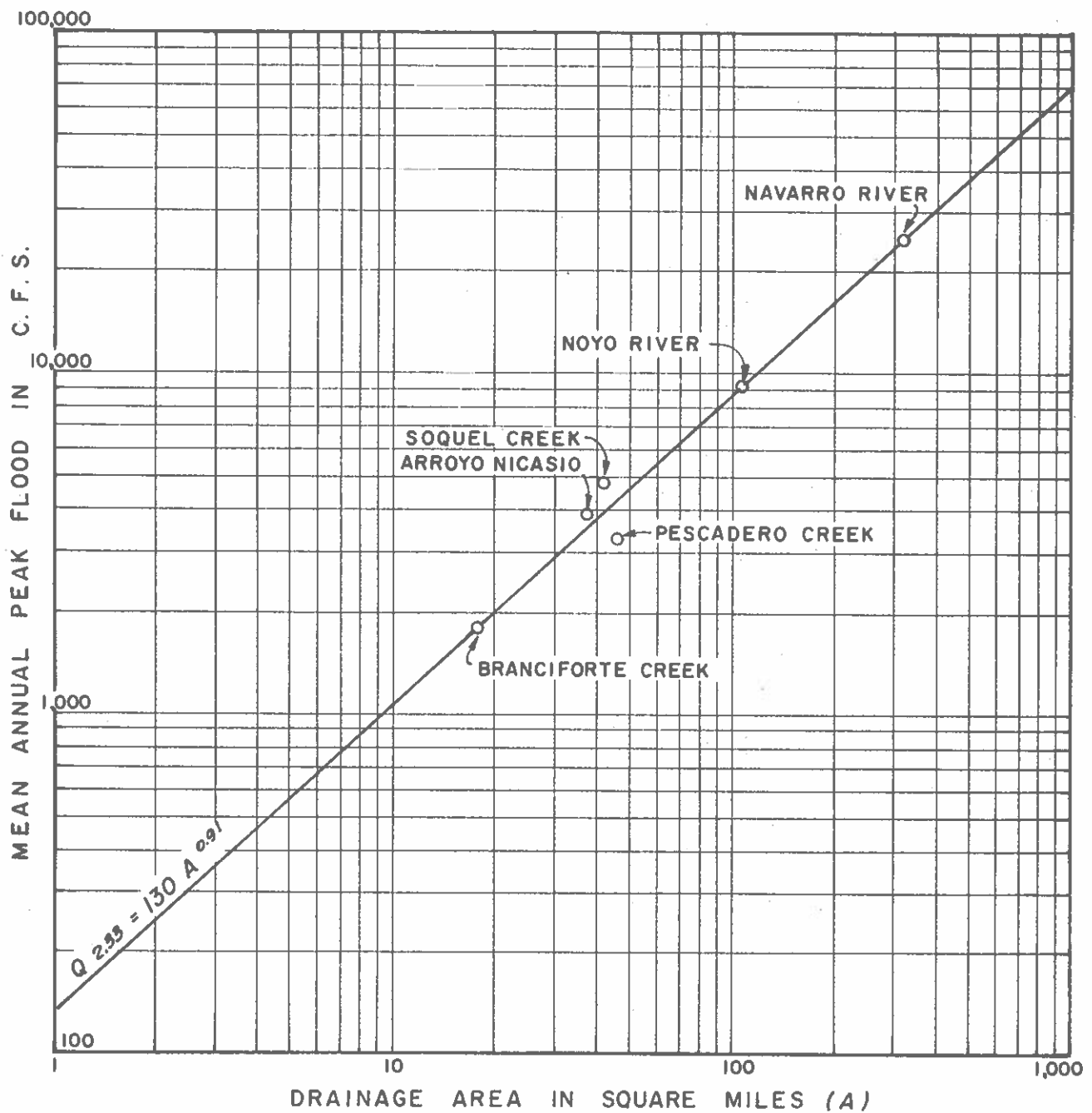
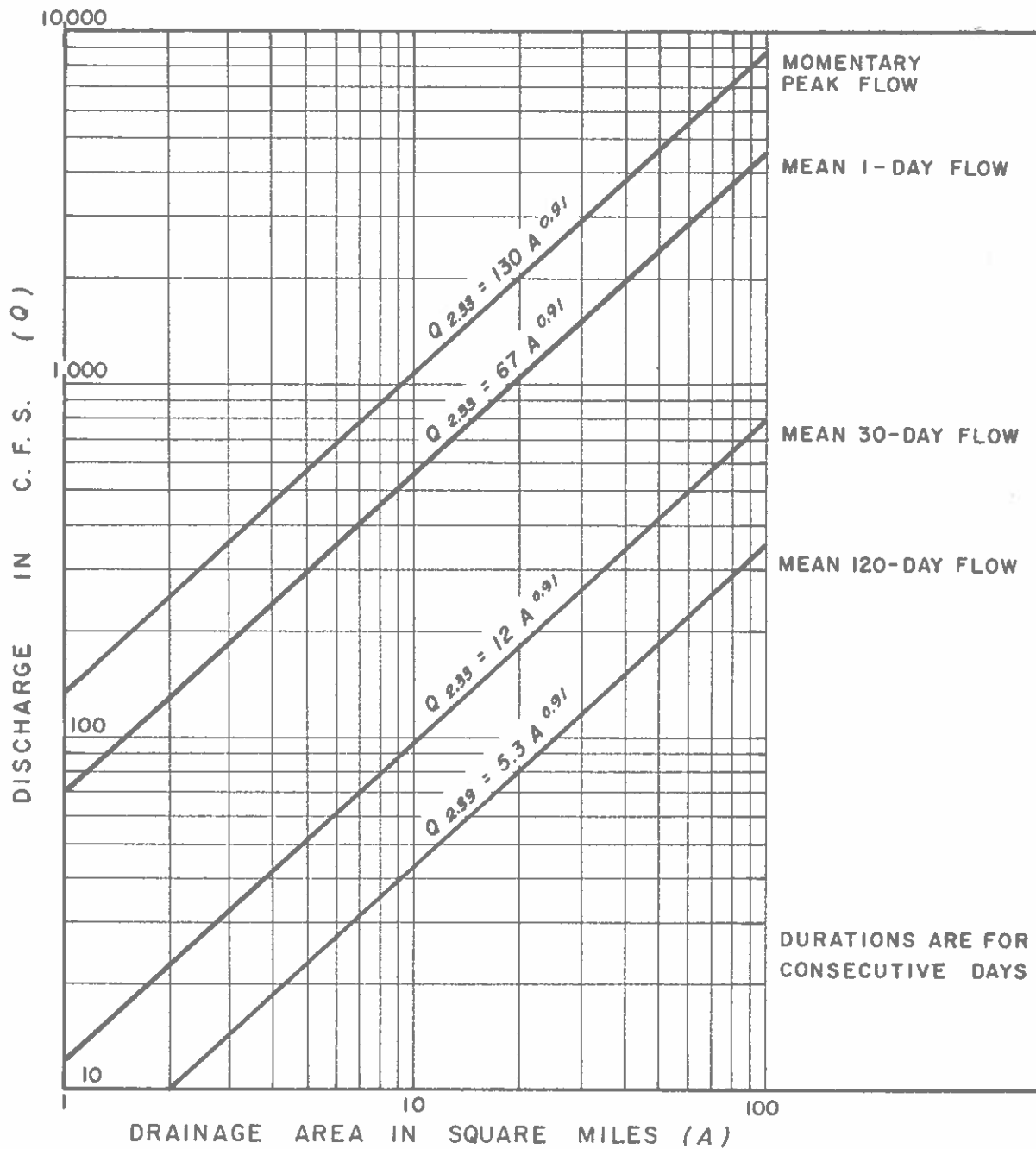


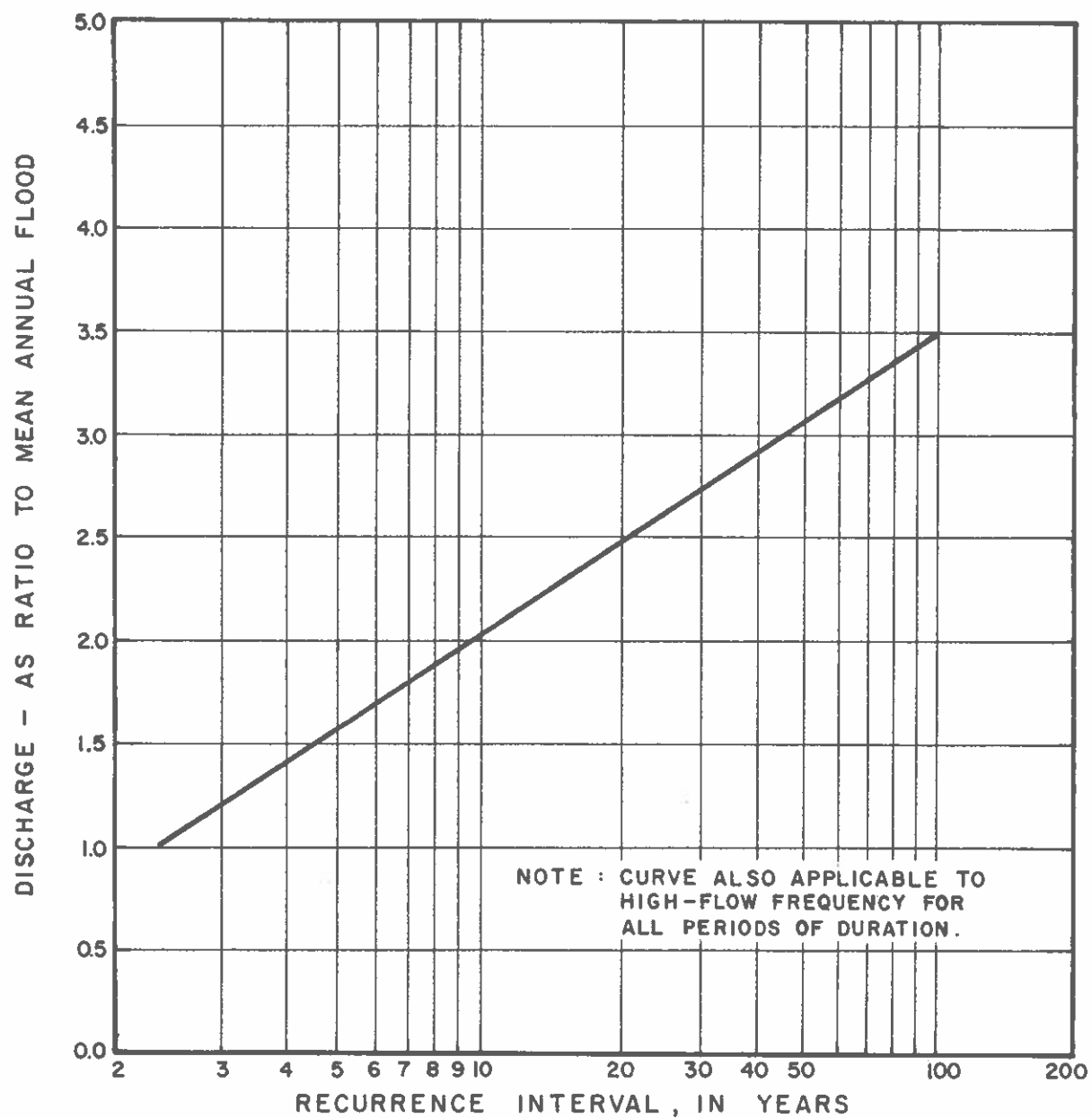
PLATE 3-5



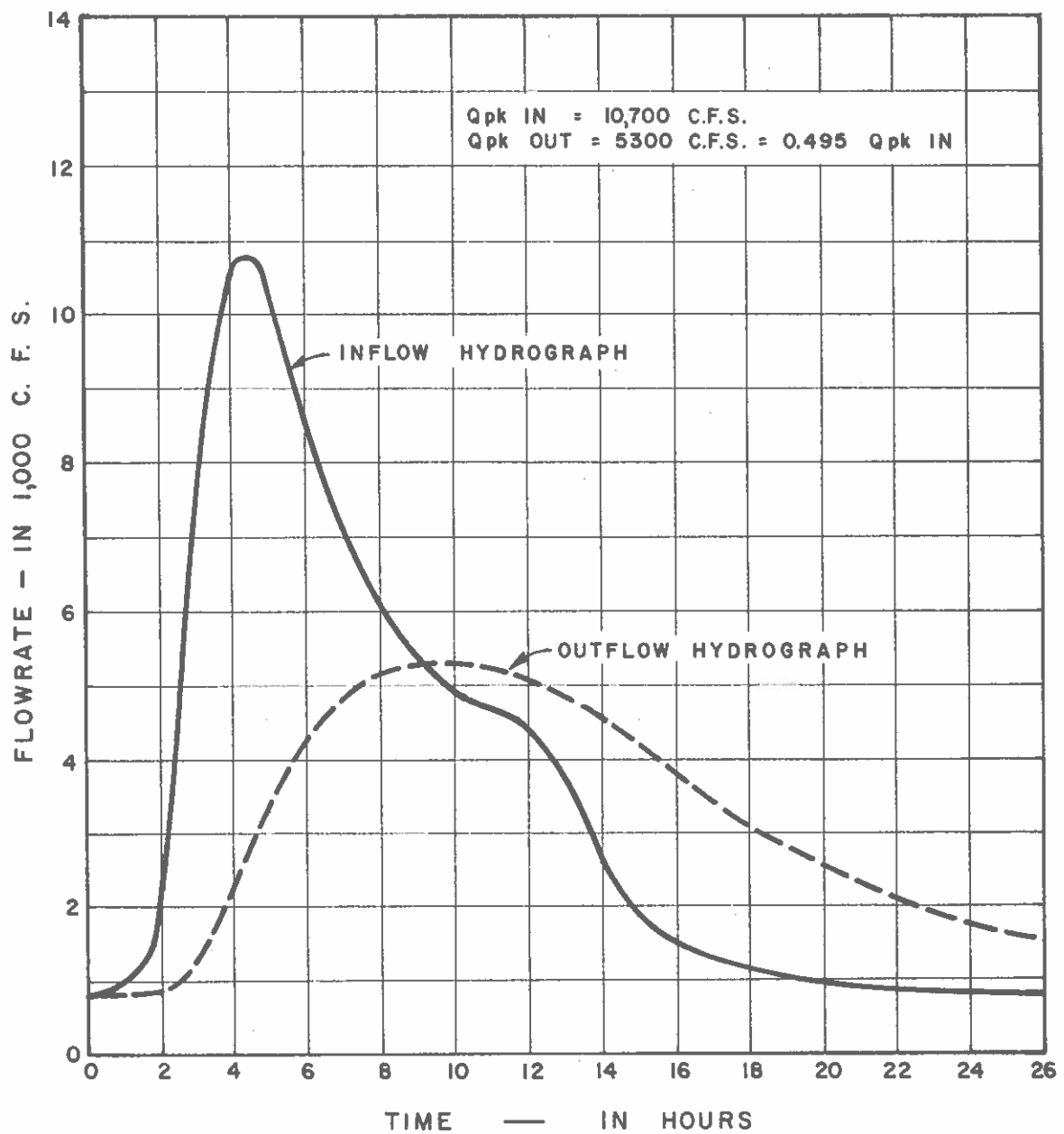
COMPARISON OF INDEX WATERSHEDS
TO REGIONAL CORRELATIONS



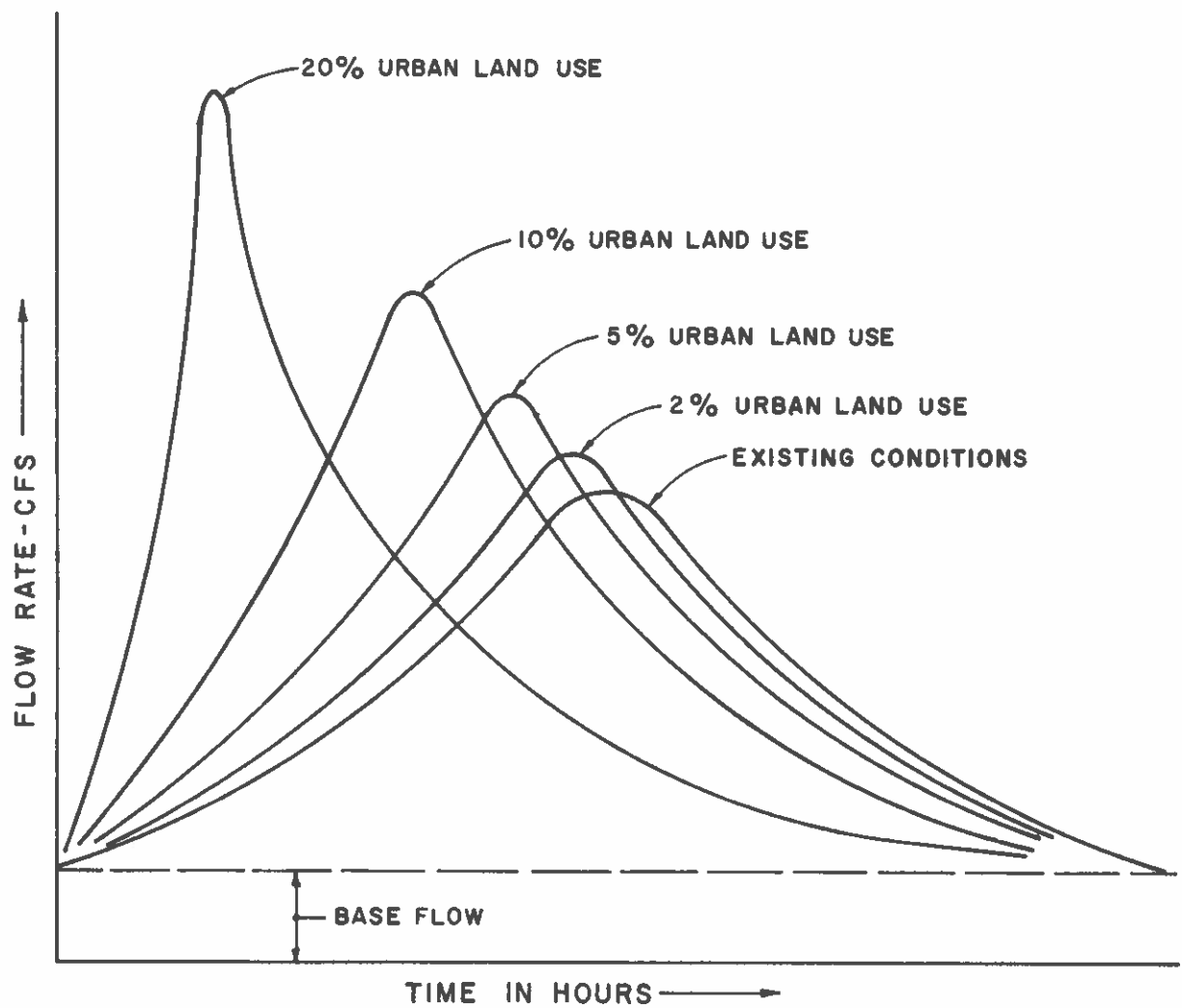
MEAN ANNUAL DISCHARGE -
DRAINAGE AREA RELATIONSHIPS
TOMALES BAY WATERSHEDS



DIMENSIONLESS FLOOD - FREQUENCY CURVE
TOMALES BAY WATERSHEDS

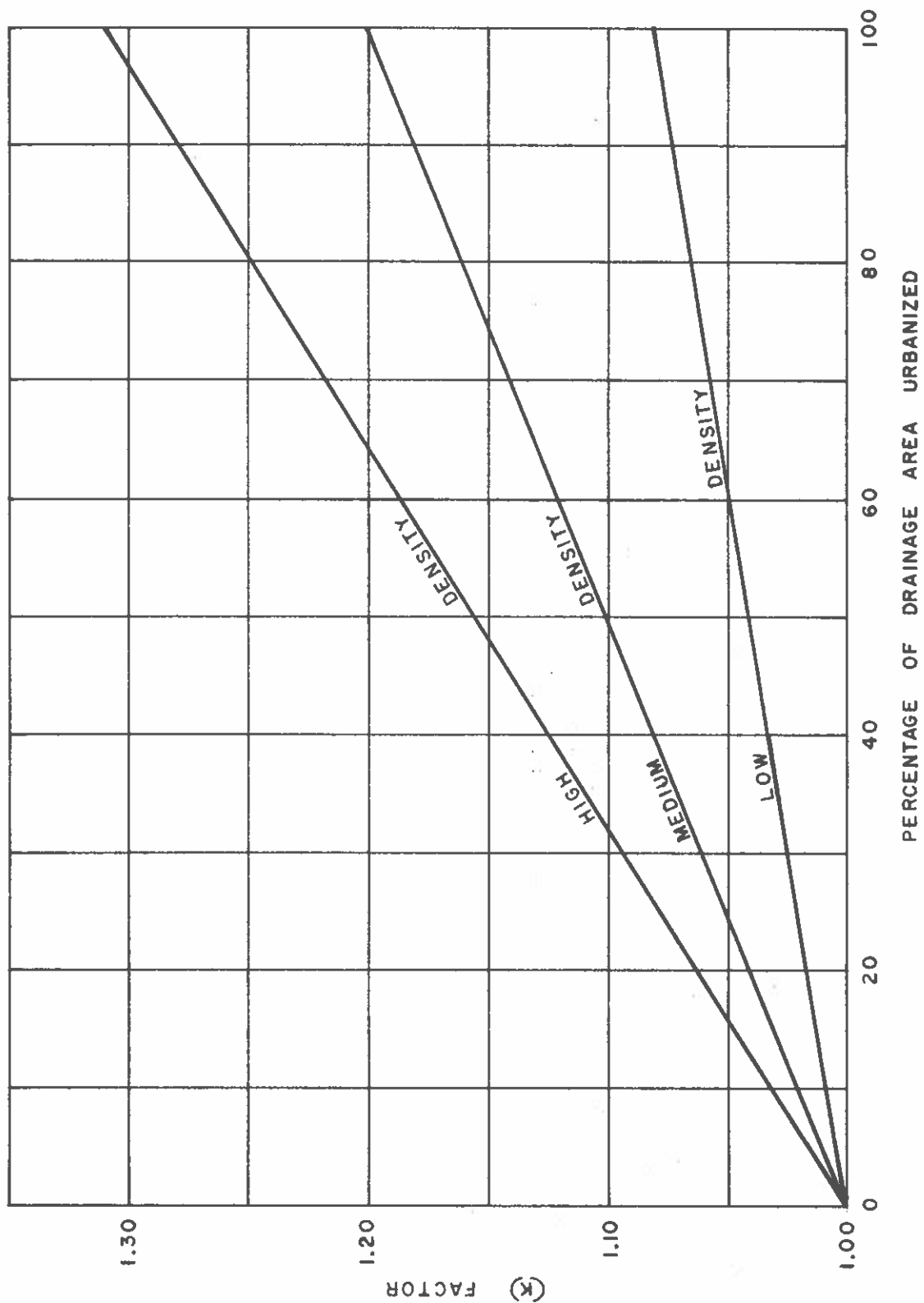


RESERVOIR FLOOD ROUTING
NICASIO DAM AND RESERVOIR
DURATION OF RAINFALL = 12 HOURS

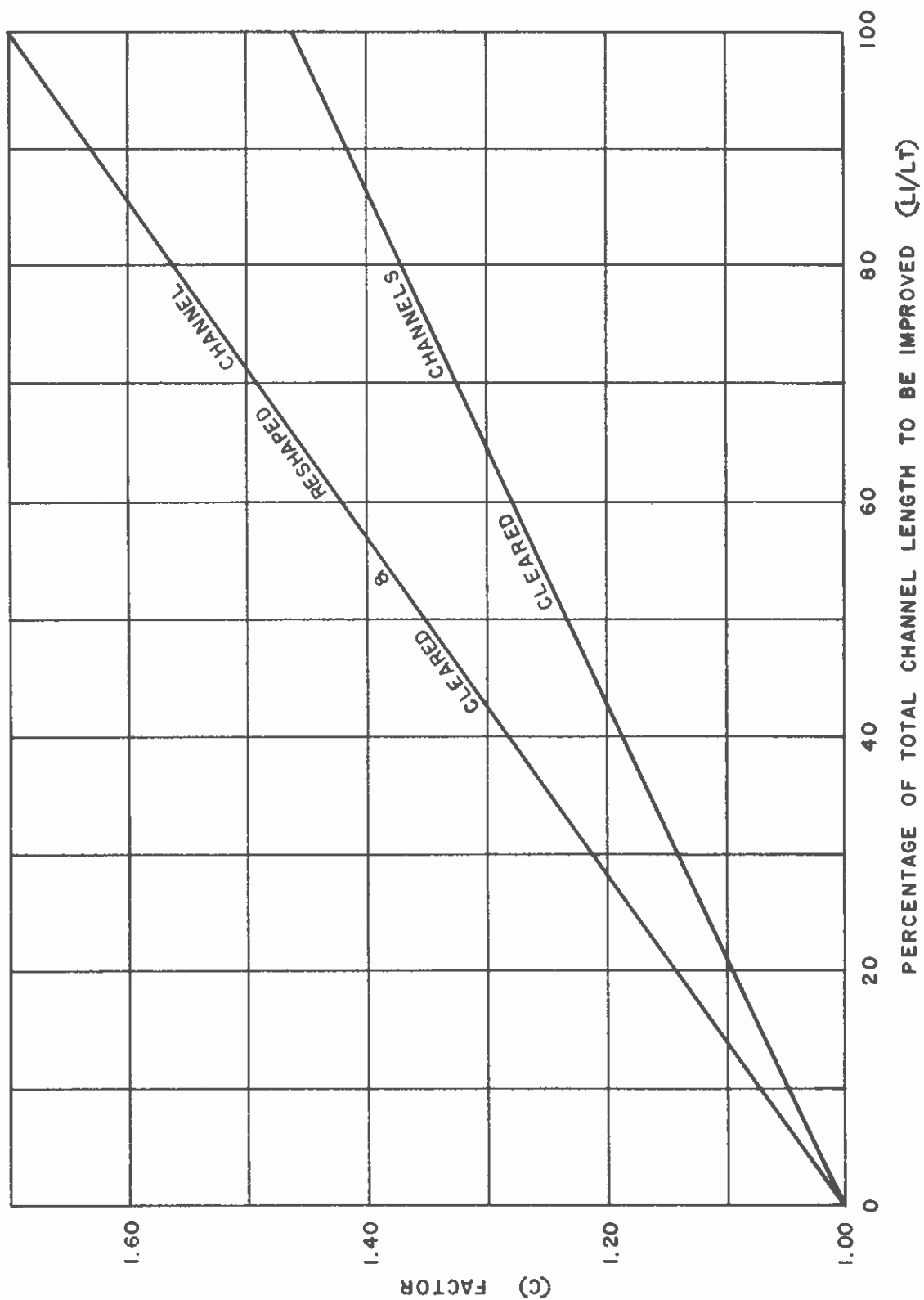


DIMENSIONLESS FLOOD HYDROGRAPH

IMPERVIOUS SURFACE FACTOR

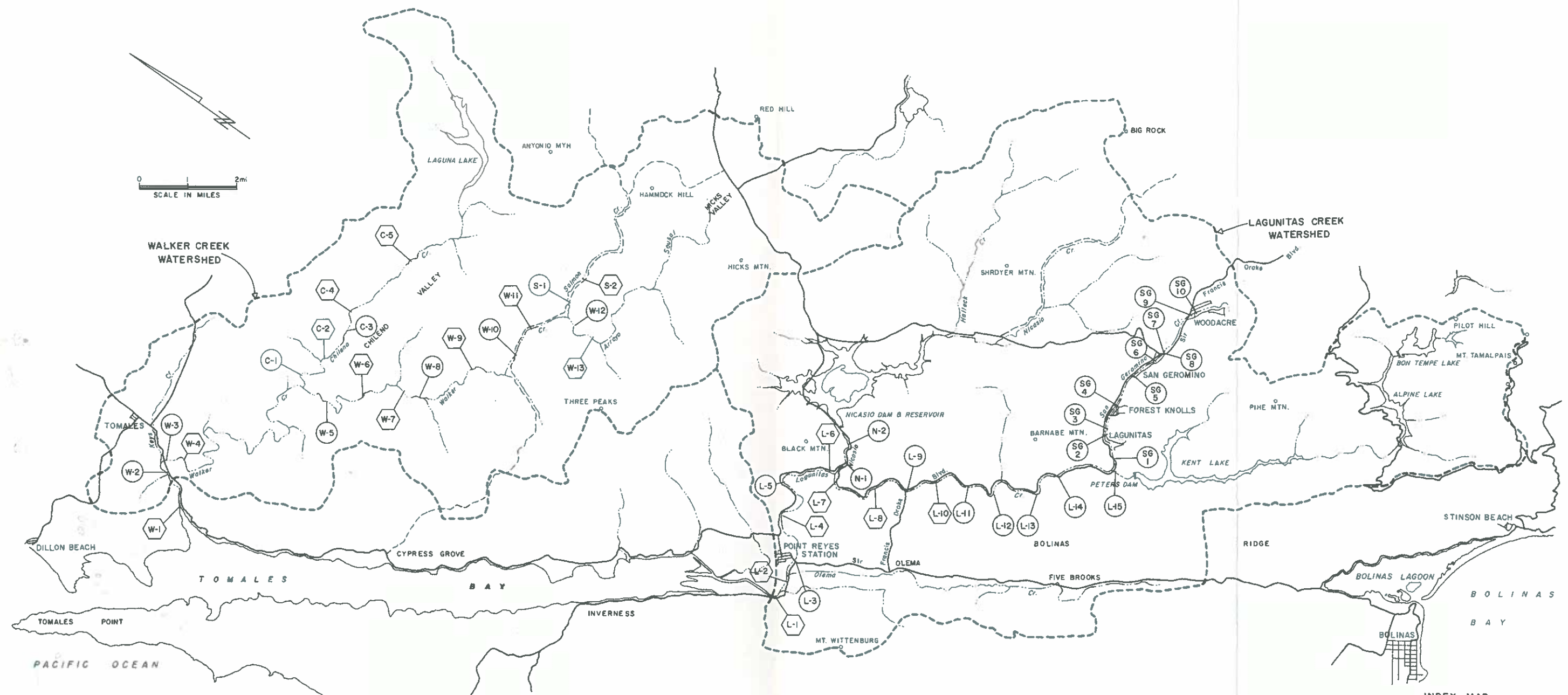


CHANNEL IMPROVEMENT FACTOR



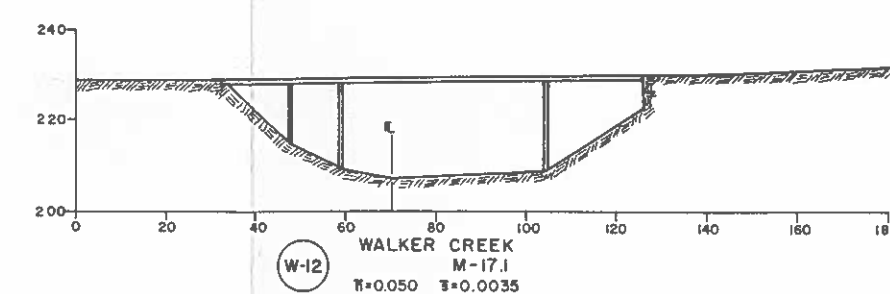
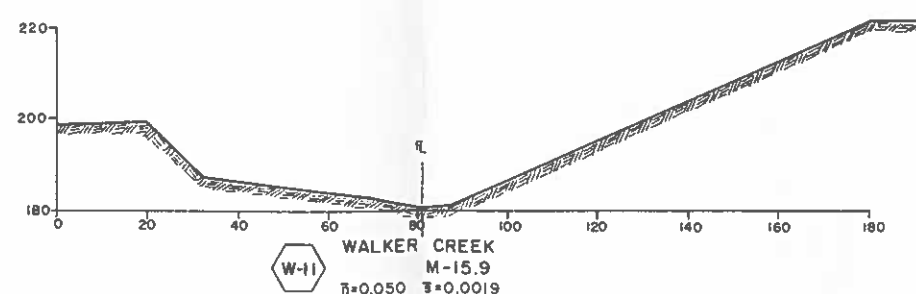
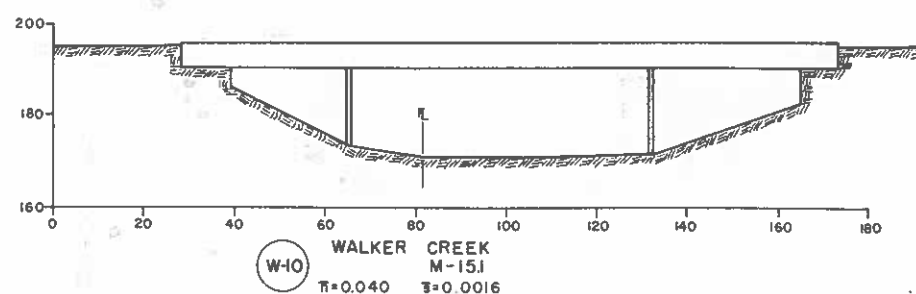
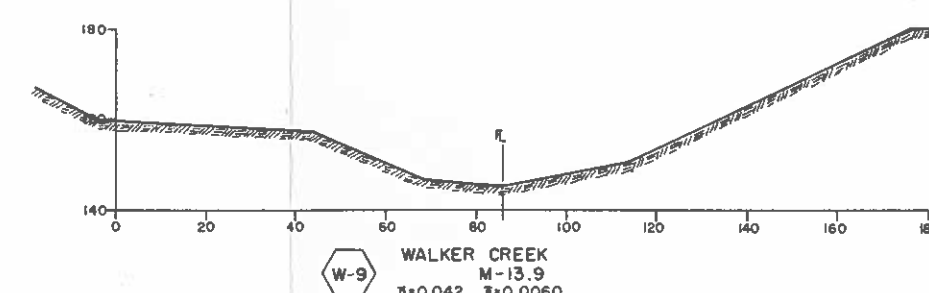
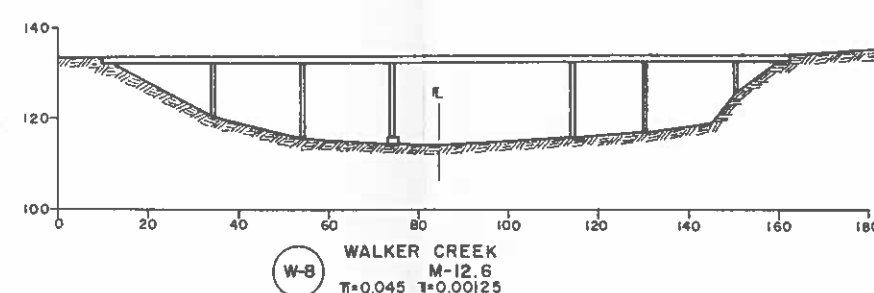
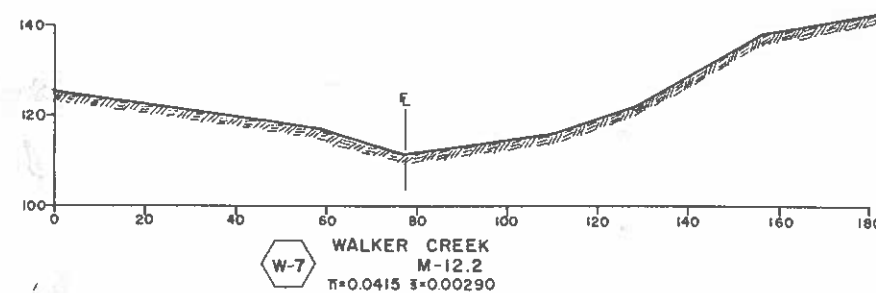
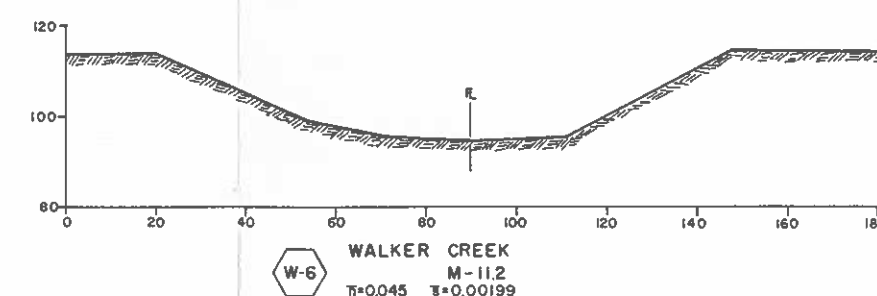
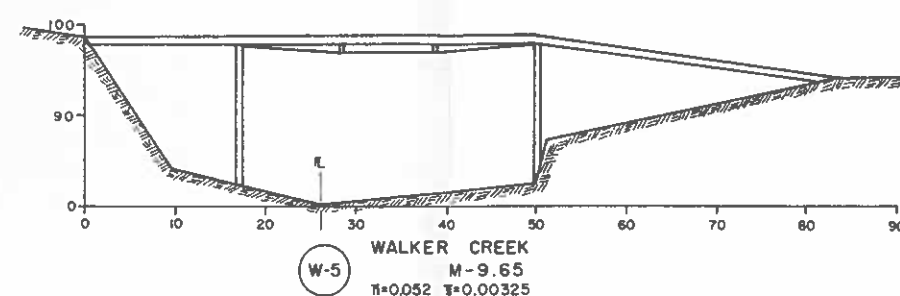
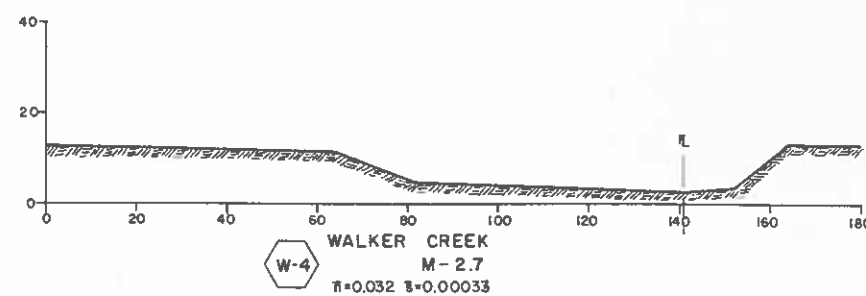
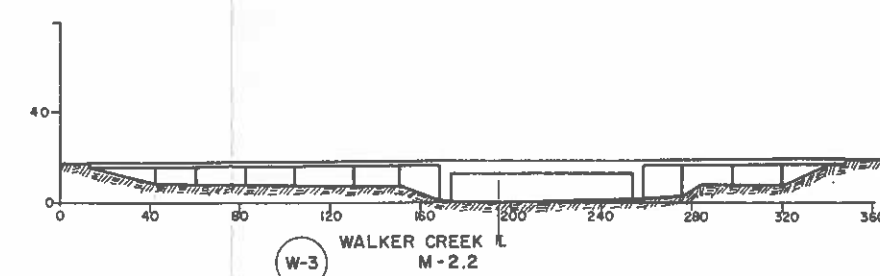
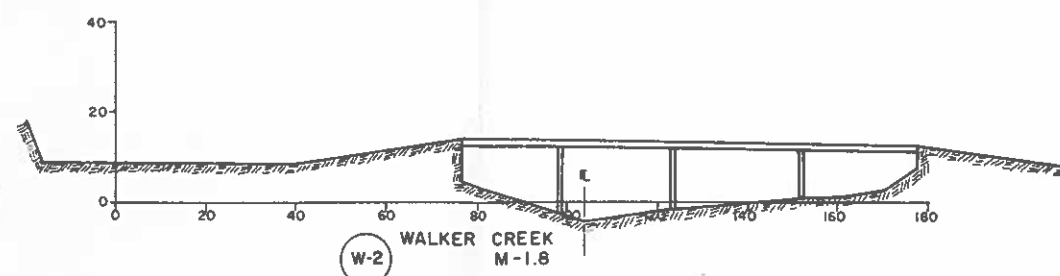
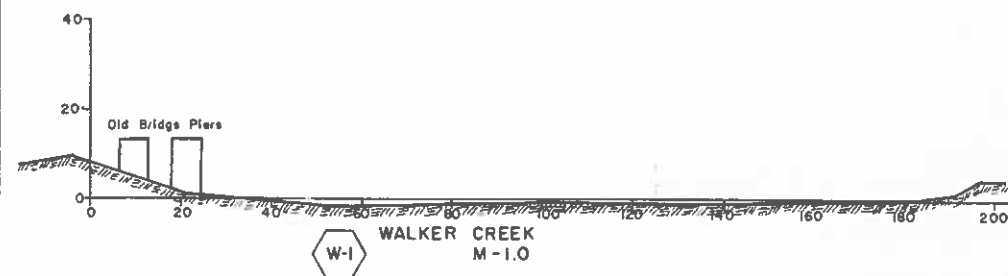
LEGEND

- N SECTION AT NATURAL CHANNEL
- N SECTION AT ORAINAGE STRUCTURE



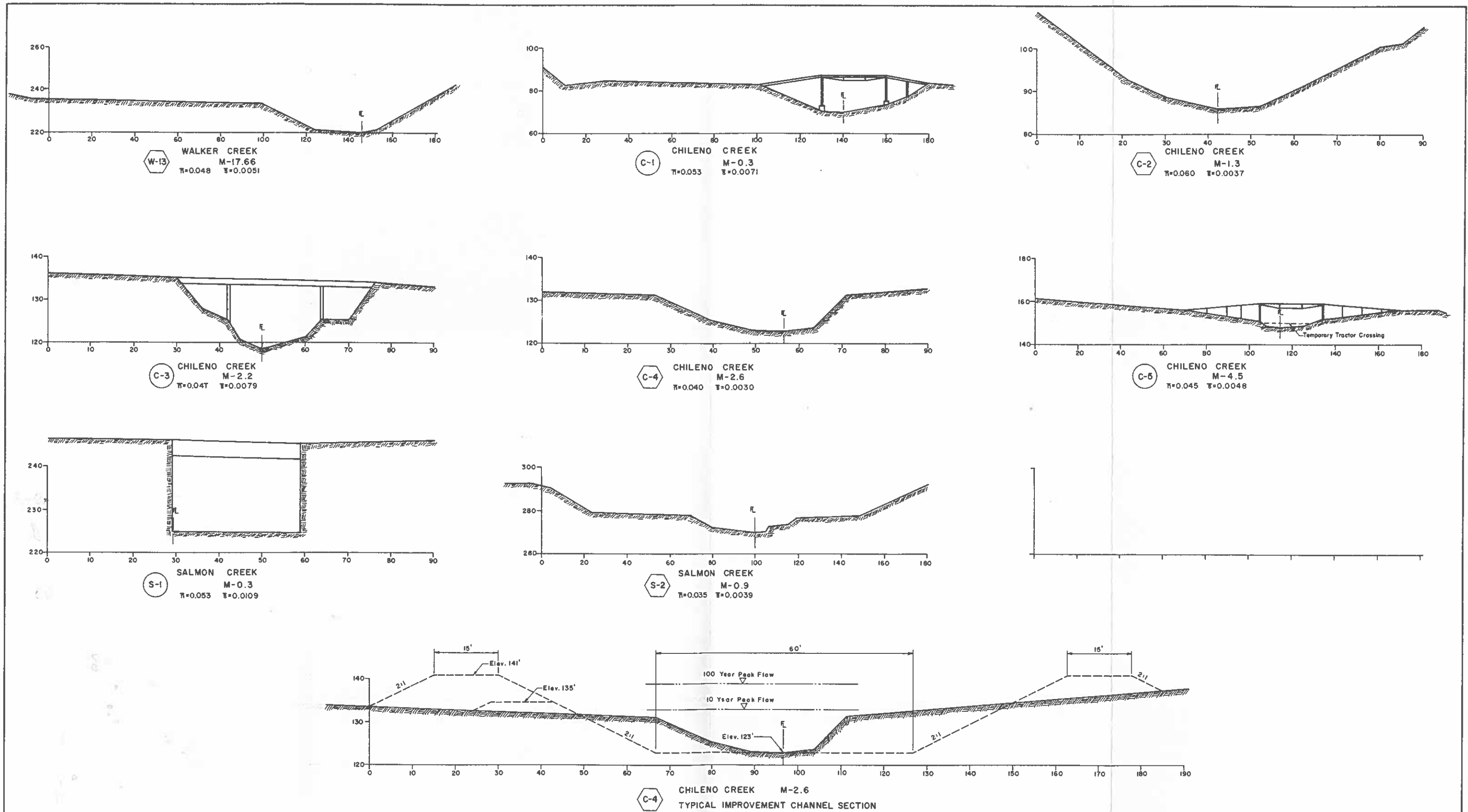
INDEX MAP
LOCATION OF CHANNEL SECTIONS

GEORGE S. NOLTE, CONSULTING CIVIL ENGINEERS, INC.
JANUARY 1965



CHANNEL CROSS-SECTIONS
WALKER CREEK WATERSHED
MARIN COUNTY CALIFORNIA

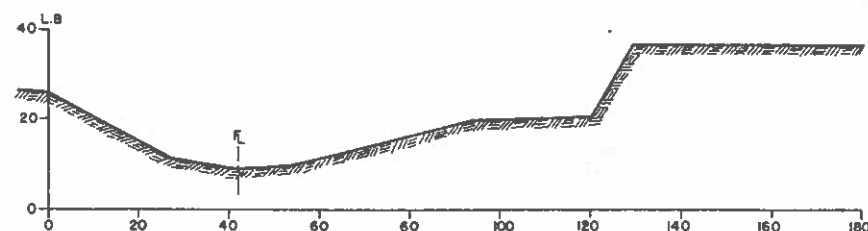
GEORGE S. NOLTE CONSULTING CIVIL ENGINEERS, INC.
FEBRUARY 1965



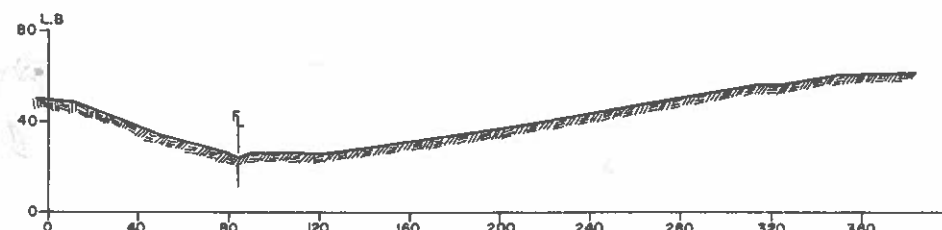
CHANNEL CROSS-SECTIONS
 WALKER CREEK WATERSHED
 MARIN COUNTY CALIFORNIA

GEORGE S. NOLTE CONSULTING CIVIL ENGINEERS INC.
 FEBRUARY 1965

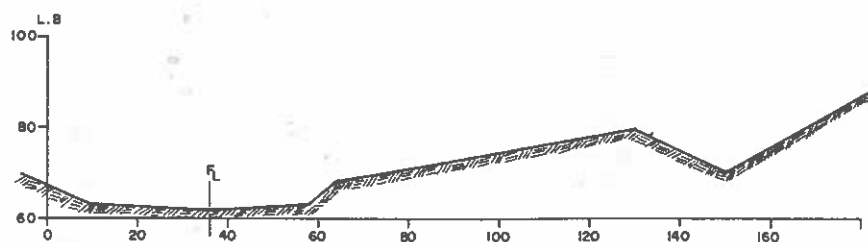
L-1 LAGUNITAS CREEK
M-1.8



L-4 LAGUNITAS CREEK
M-3.8
 $\bar{n}=0.058$ $\bar{s}=0.003$

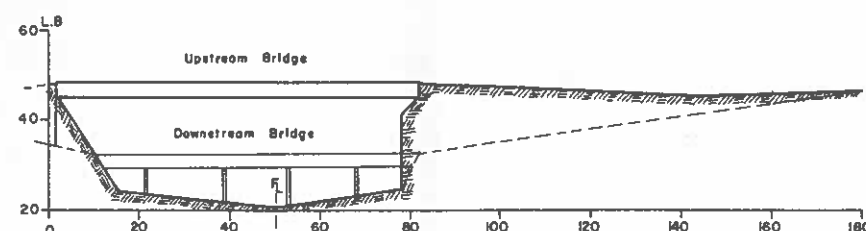


L-7 LAGUNITAS CREEK
M-6.3
 $\bar{n}=0.045$ $\bar{s}=0.0023$

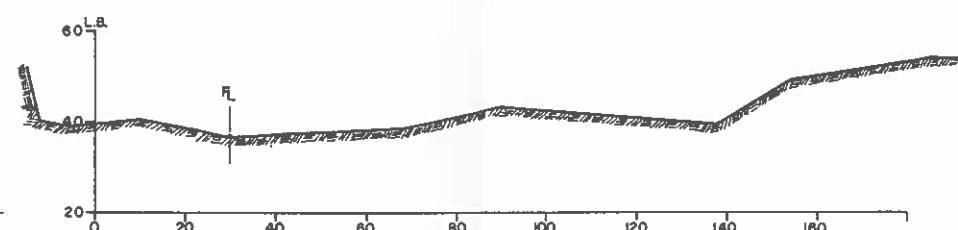


L-10 LAGUNITAS CREEK
M-8.7
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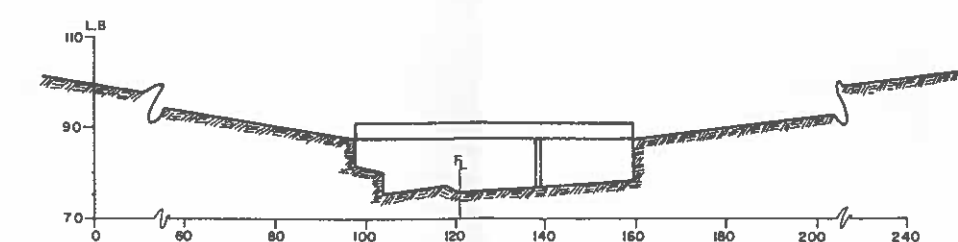
L-2 LAGUNITAS CREEK
M-1.3



L-5 LAGUNITAS CREEK
M-4.8
 $\bar{n}=0.063$ $\bar{s}=0.0014$

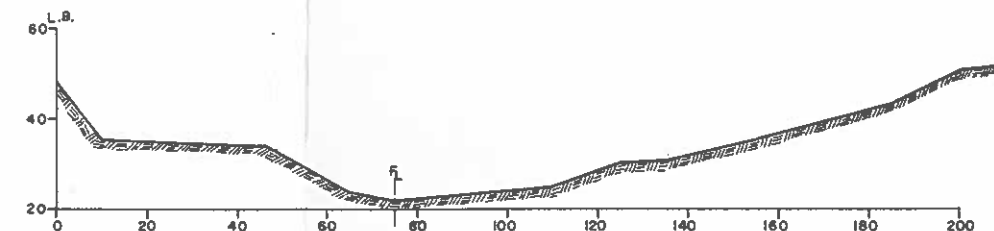


L-8 LAGUNITAS CREEK
M-7.3
 $\bar{n}=0.048$ $\bar{s}=0.0033$

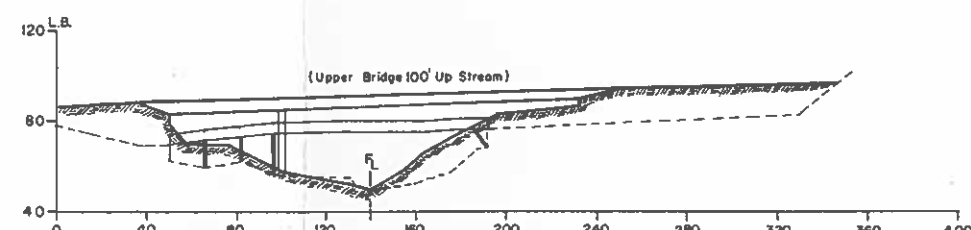


L-11 LAGUNITAS CREEK
M-9.4
 $\bar{n}=0.053$ $\bar{s}=0.0033$

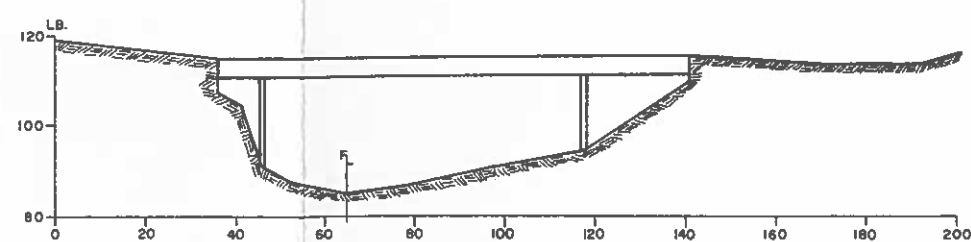
L-3 LAGUNITAS CREEK
M-2.7



L-6 LAGUNITAS CREEK
M-6.0
 $\bar{n}=0.058$ $\bar{s}=0.0060$



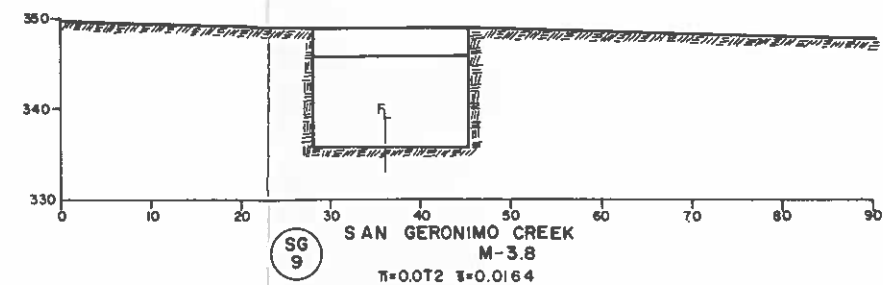
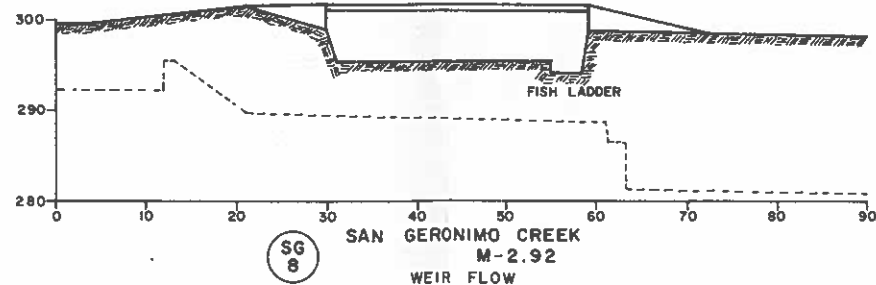
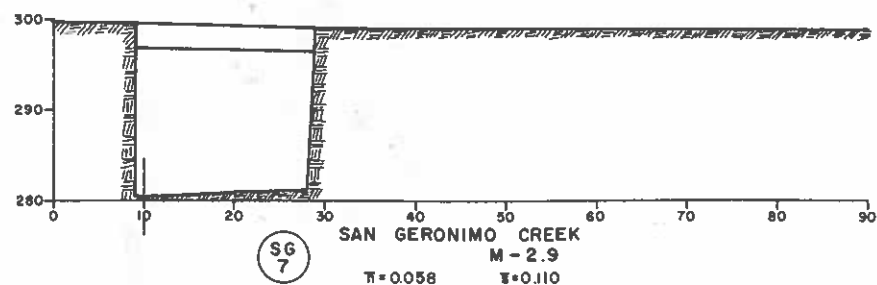
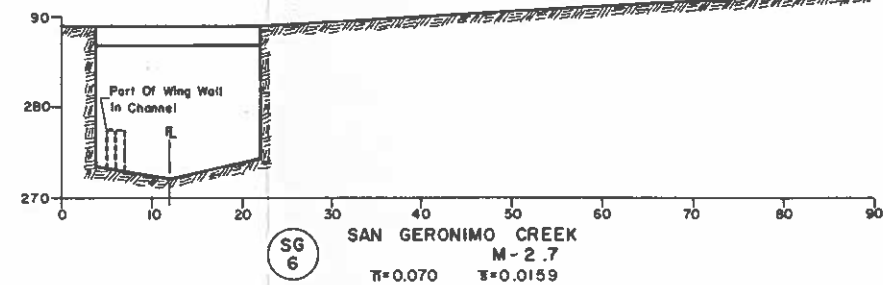
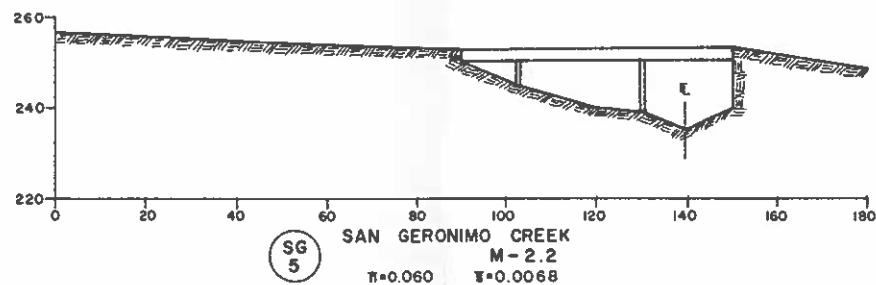
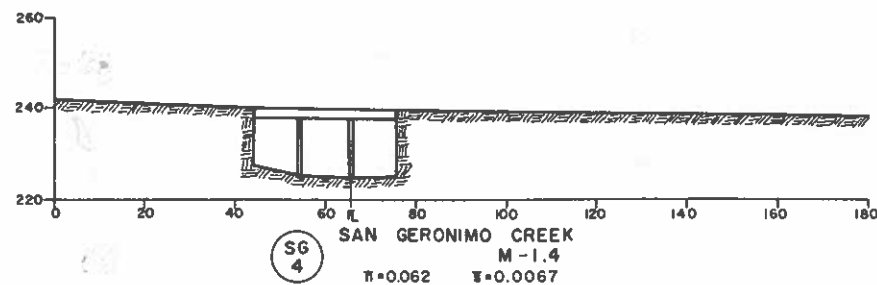
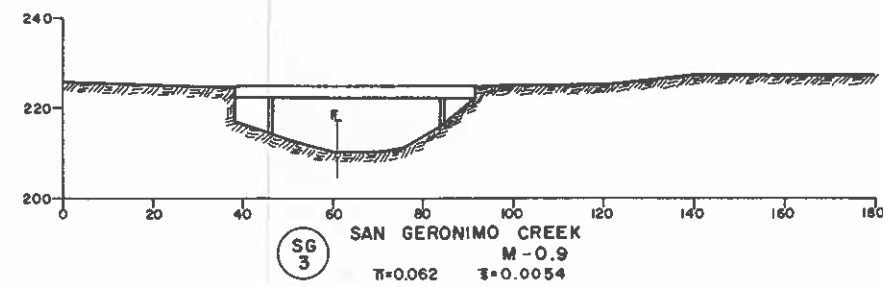
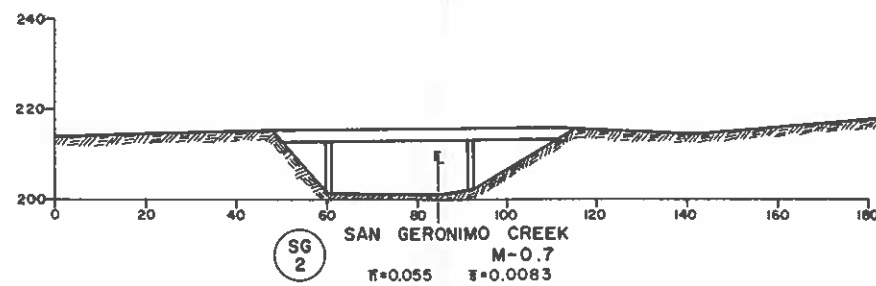
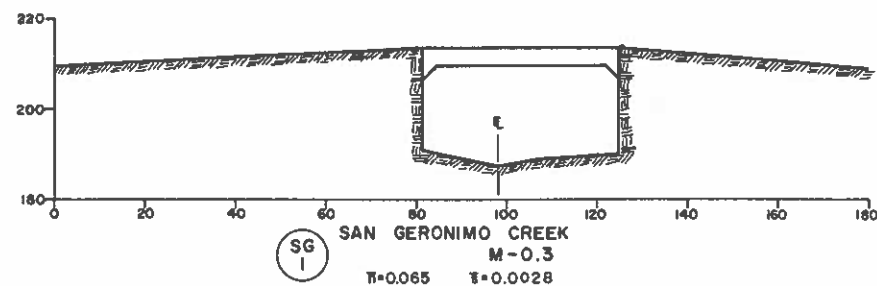
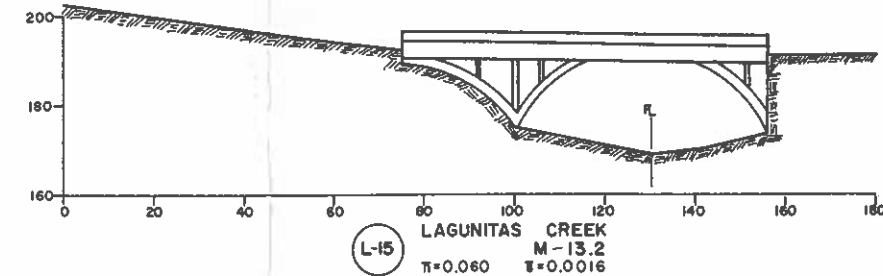
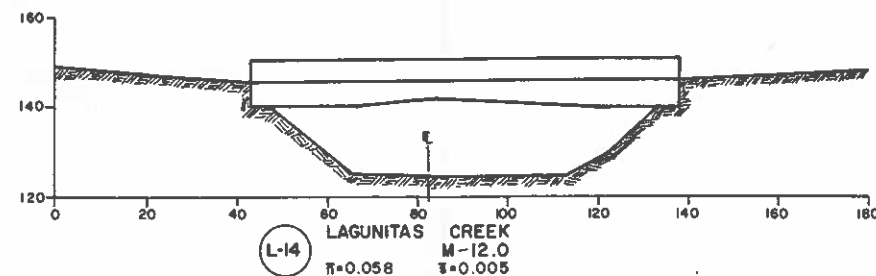
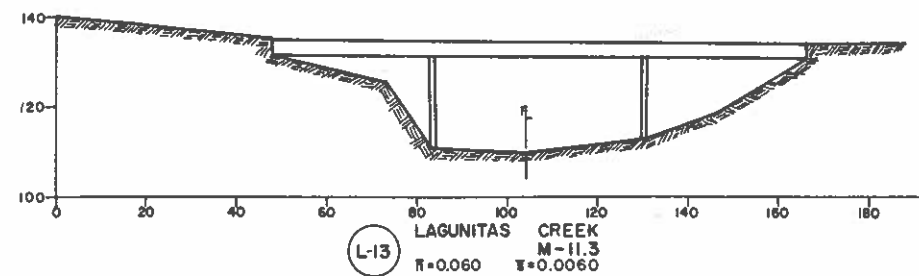
L-9 LAGUNITAS CREEK
M-8.1
 $\bar{n}=0.055$ $\bar{s}=0.0031$



L-12 LAGUNITAS CREEK
M-10.1
 $\bar{n}=0.068$ $\bar{s}=0.00125$

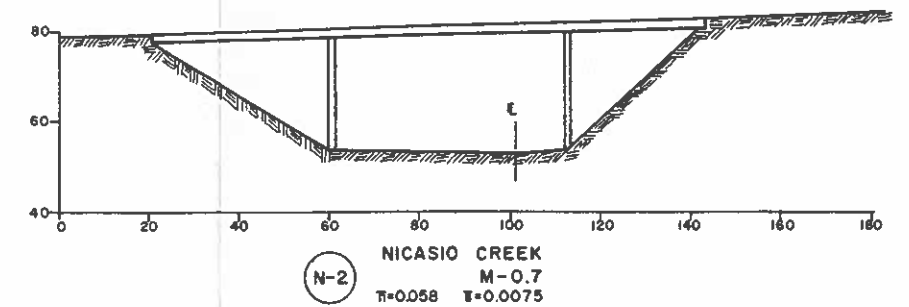
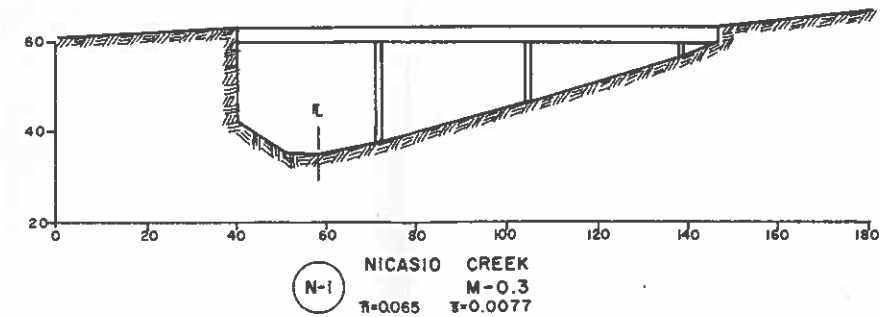
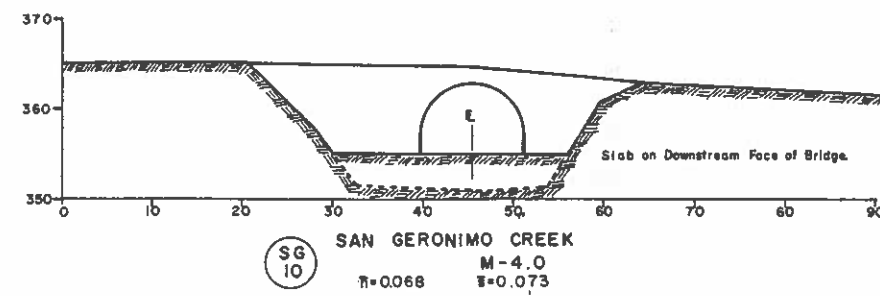
CHANNEL CROSS-SECTIONS
LAGUNITAS CREEK WATERSHED
MARIN COUNTY CALIFORNIA

GEORGE S. NOLTE CONSULTING CIVIL ENGINEERS, INC.
FEBRUARY 1965



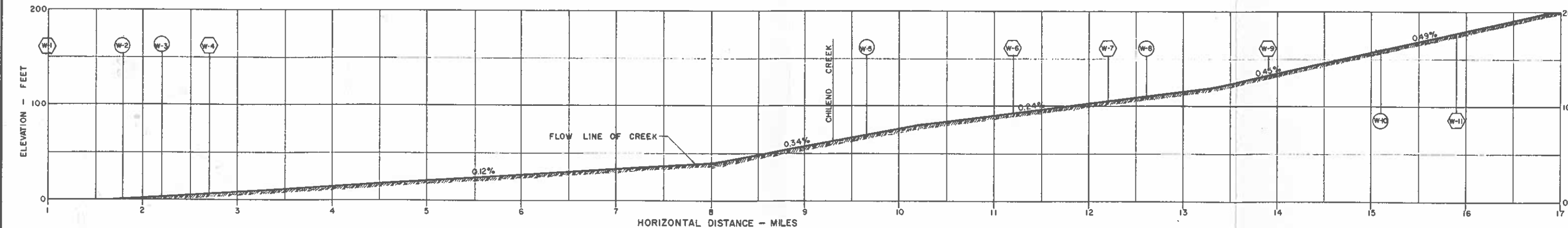
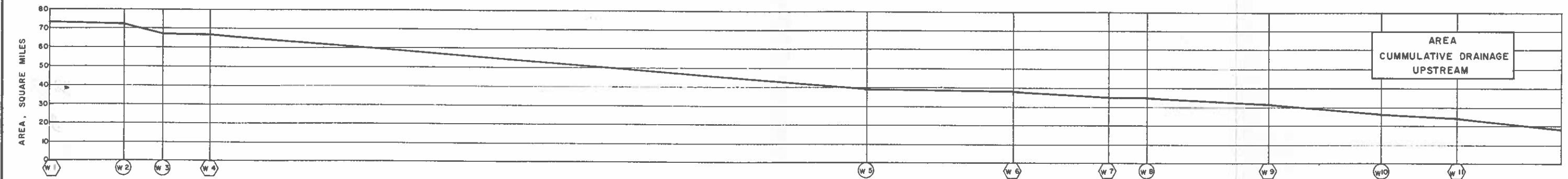
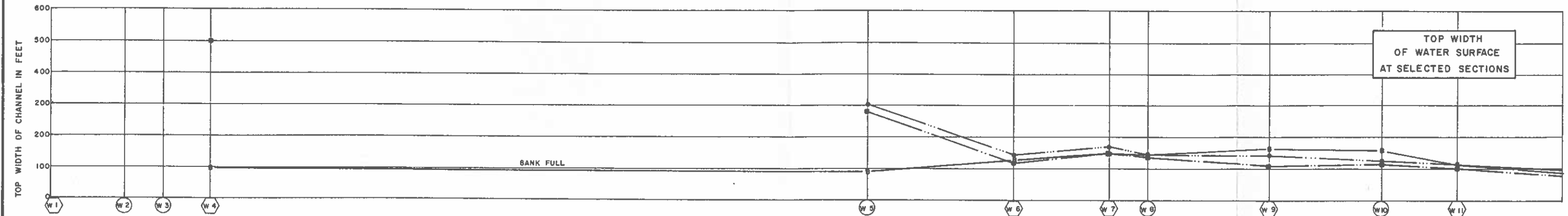
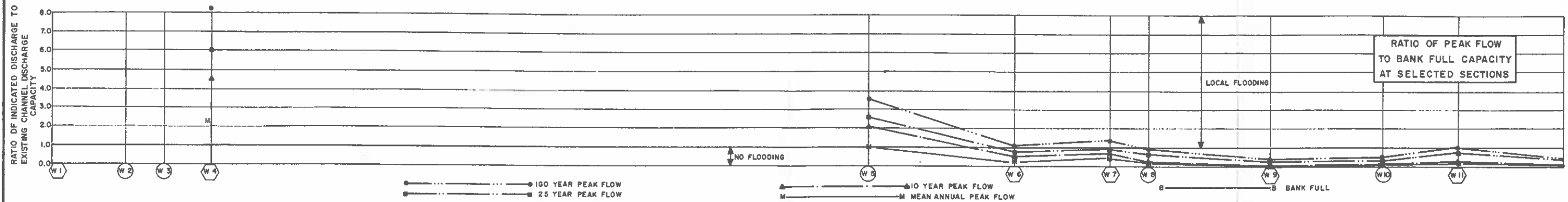
CHANNEL CROSS-SECTIONS
LAGUNITAS CREEK WATERSHED
MARIN COUNTY CALIFORNIA

GEORGE S. NOLTE CONSULTING CIVIL ENGINEERS INC.
FEBRUARY 1965



CHANNEL CROSS-SECTIONS
LAGUNITAS CREEK WATERSHED
MARIN COUNTY CALIFORNIA

GEORGE S. HOLTE CONSULTING CIVIL ENGINEERS INC.
FEBRUARY 1965



W-1 SECTION AT DRAINAGE STRUCTURE

W-2 NATURAL SECTION

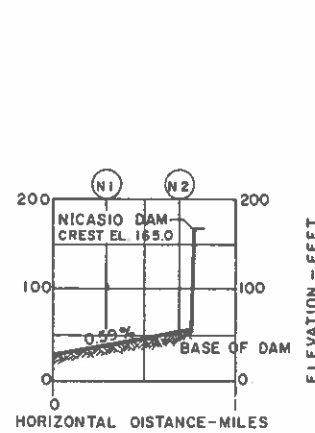
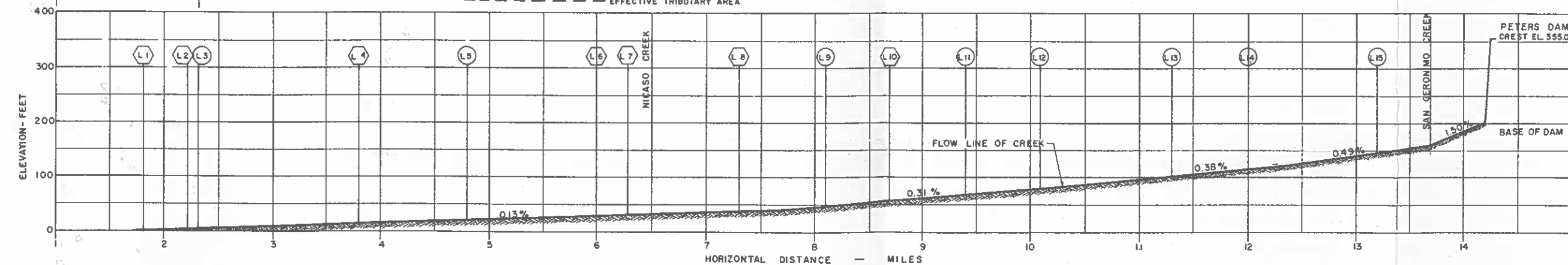
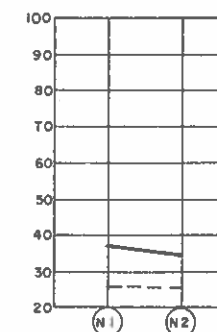
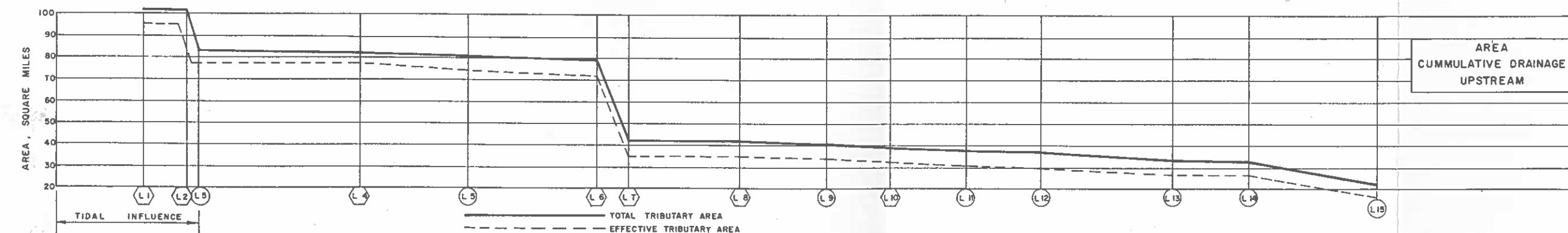
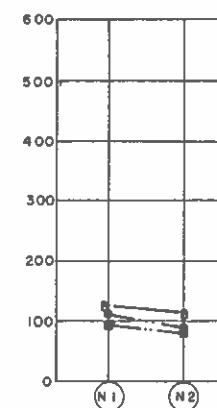
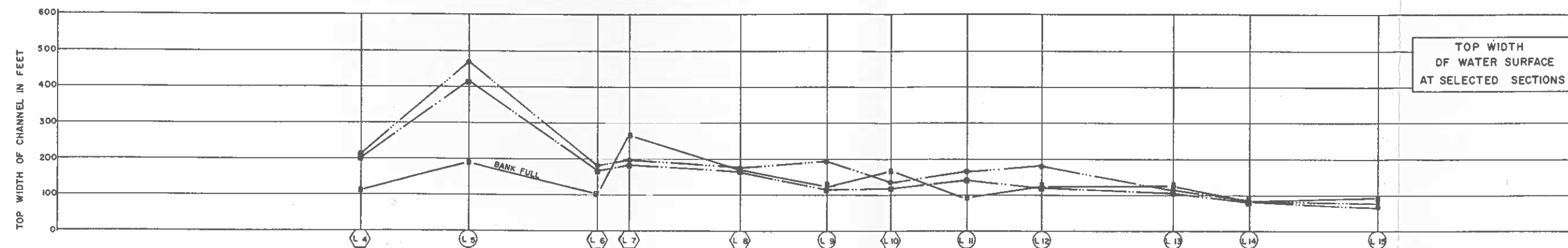
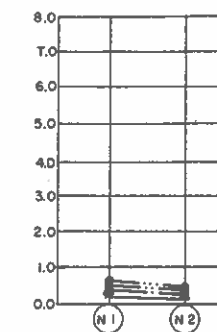
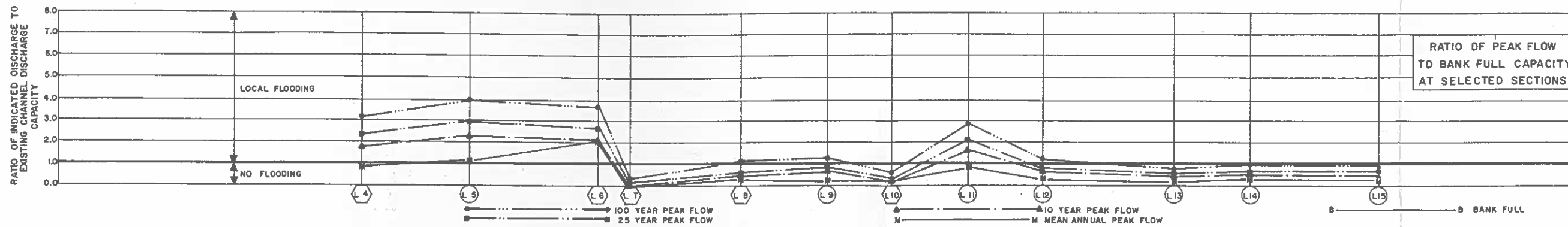
NOTE: AT SECTIONS OTHER THAN THOSE INDICATED, FIELD SURVEYS WILL BE NECESSARY TO DETERMINE CORRECT VALUES FOR BANKFULL CAPACITY, TOP WIDTH AND FLOODING.

WALKER CREEK
MILES - 2.20 MILE AT WALKER CREEK AND TOMALES BRIDGE

STREAM PROFILE AND CONVEYANCE CHARACTERISTICS
SHEET 1 of 3

GEORGE S. NOLTE CONSULTING CIVIL ENGINEERS, INC
FEBRUARY 1965

PLATE 4-7



(W1) SECTION AT DRAINAGE STRUCTURE

(W2) NATURAL SECTION

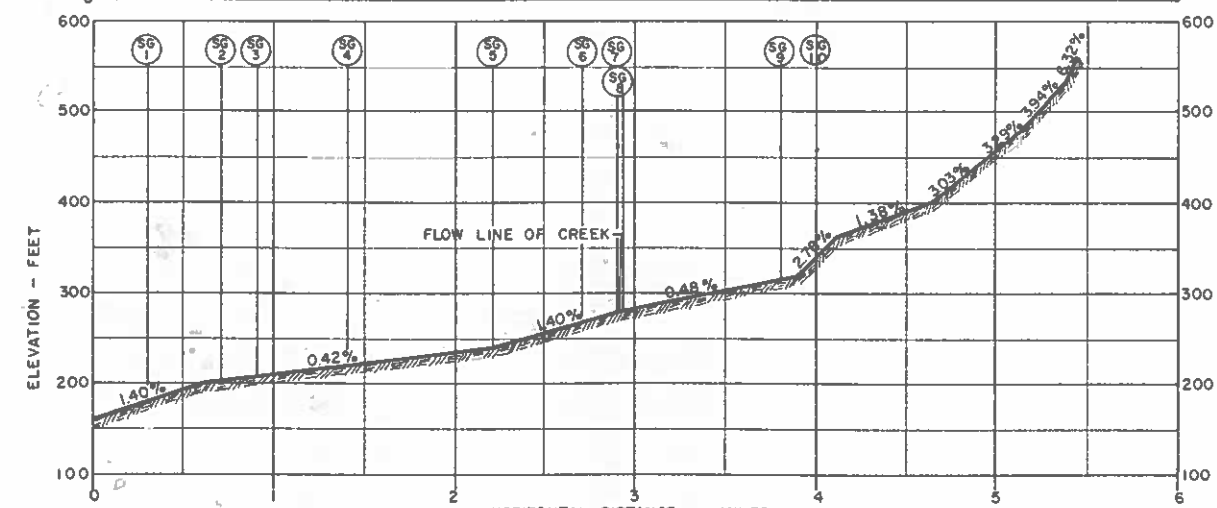
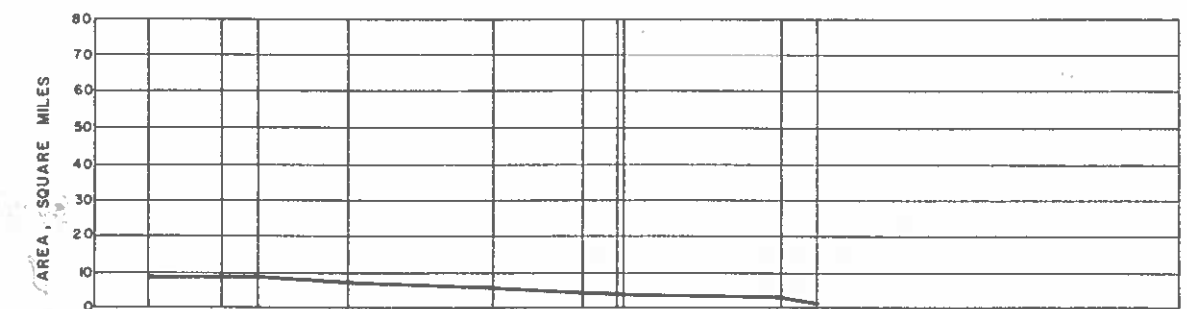
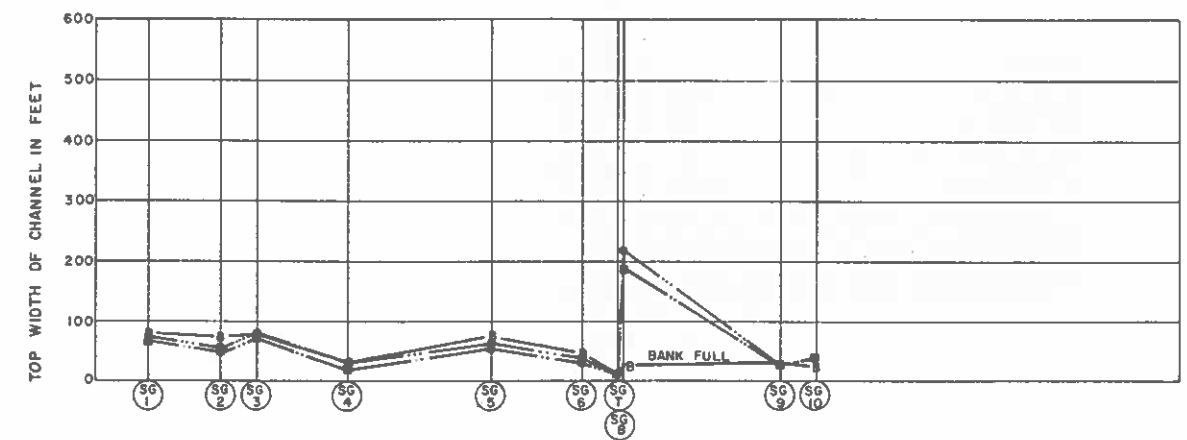
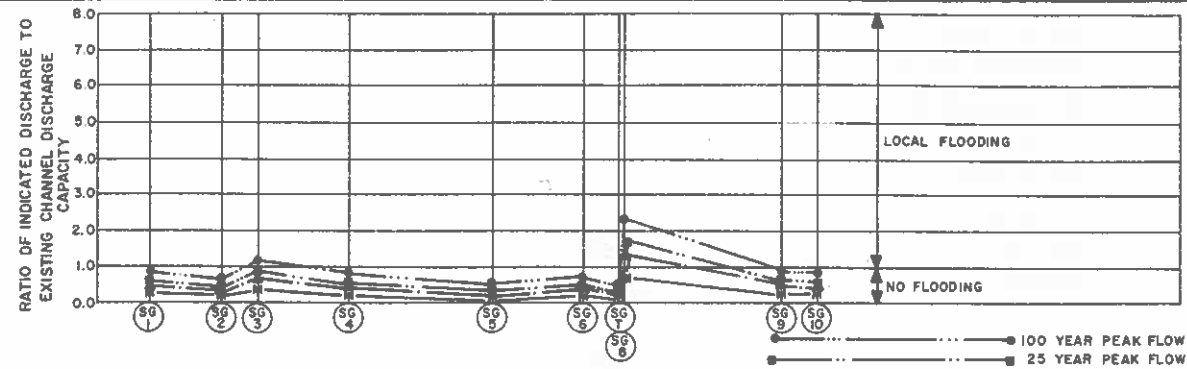
NOTE: AT SECTIONS OTHER THAN THOSE INDICATED, FIELD SURVEYS WILL BE NECESSARY TO DETERMINE CORRECT VALUES FOR BANKFULL CAPACITY, TOP WIDTH AND FLOODING

LAGUNITAS CREEK
MILES - 2.70 MILE AT LAGUNITAS CREEK AND PT. REYES STATION

STREAM PROFILE AND CONVEYANCE CHARACTERISTICS
SHEET 2 of 3

GEORGE S. HOLTE CONSULTING CIVIL ENGINEERS, INC.
FEBRUARY 1965

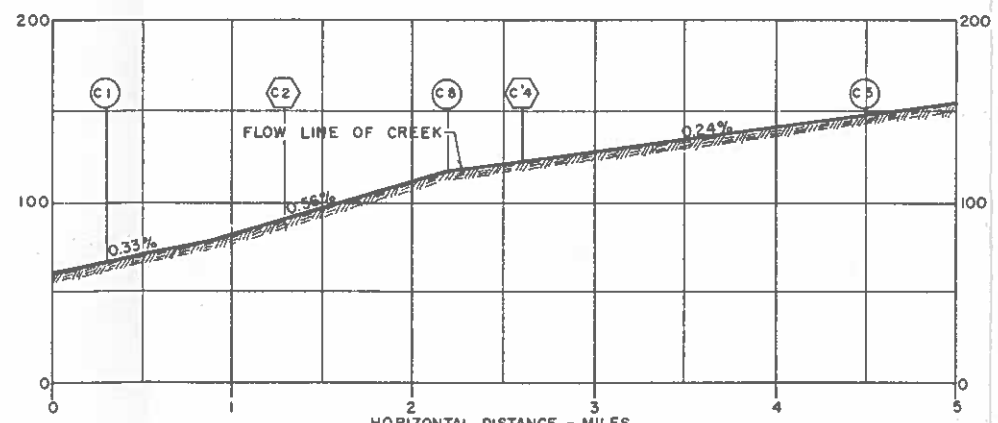
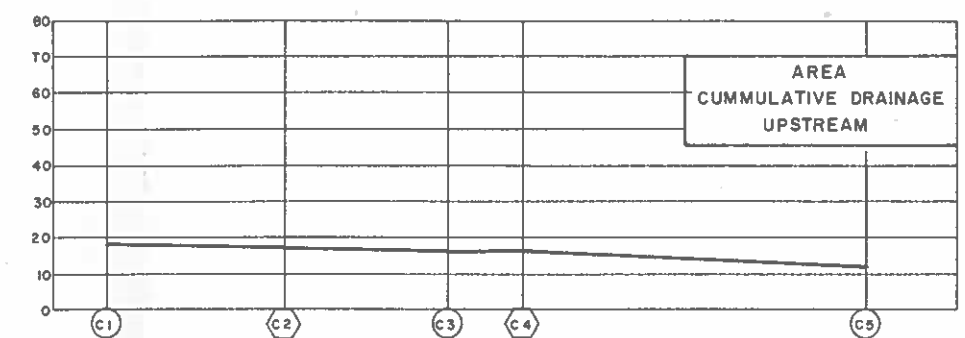
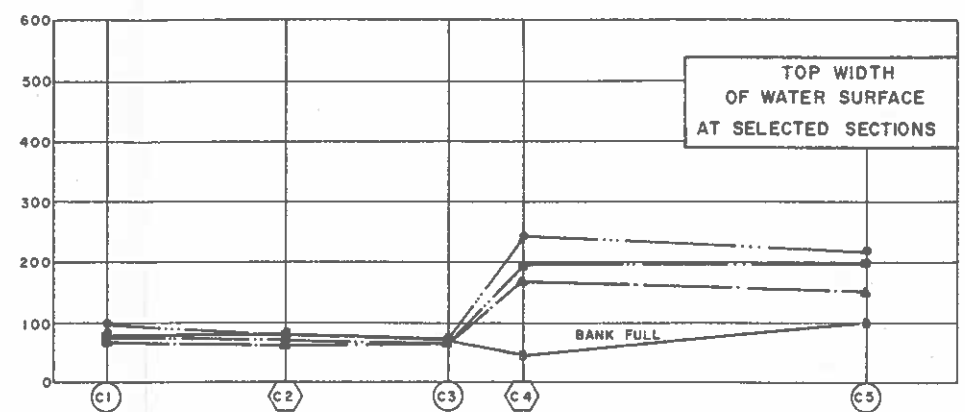
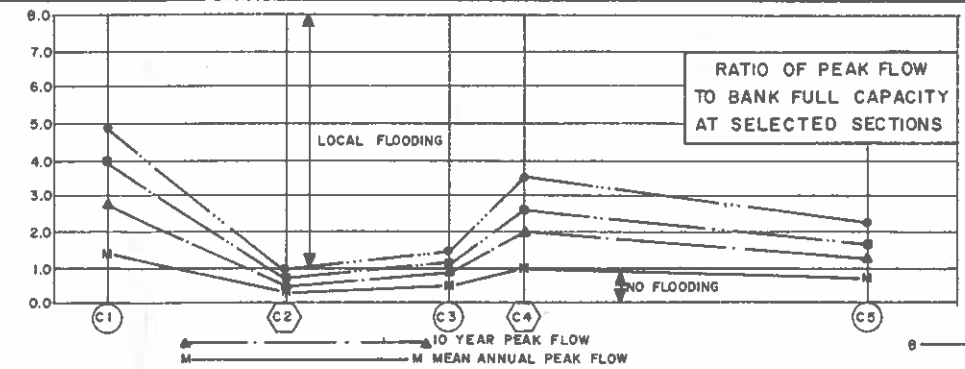
PLATE 4-8



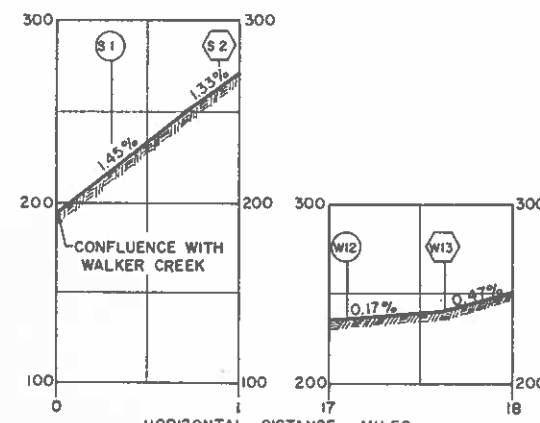
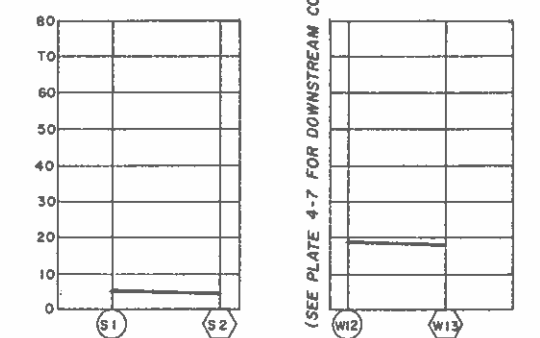
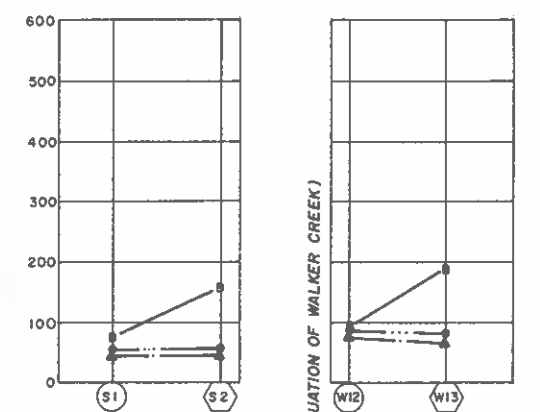
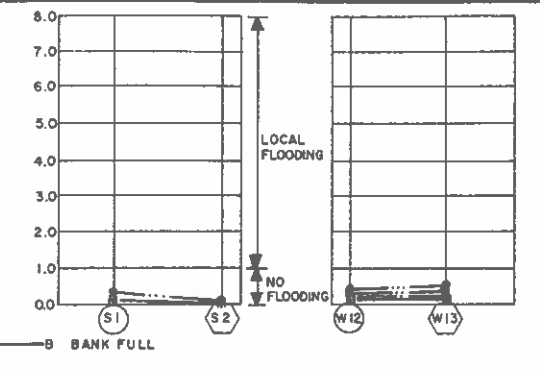
(C1) SECTION AT DRAINAGE STRUCTURE
(C2) NATURAL SECTION

MILES - 0.0 AT CONFLUENCE WITH LAGUNITAS CREEK

NOTE: AT SECTIONS OTHER THAN THOSE INDICATED, FIELD SURVEYS WILL BE NECESSARY TO DETERMINE CORRECT VALUES FOR BANKFULL CAPACITY, TOP WIDTH AND FLOODING.



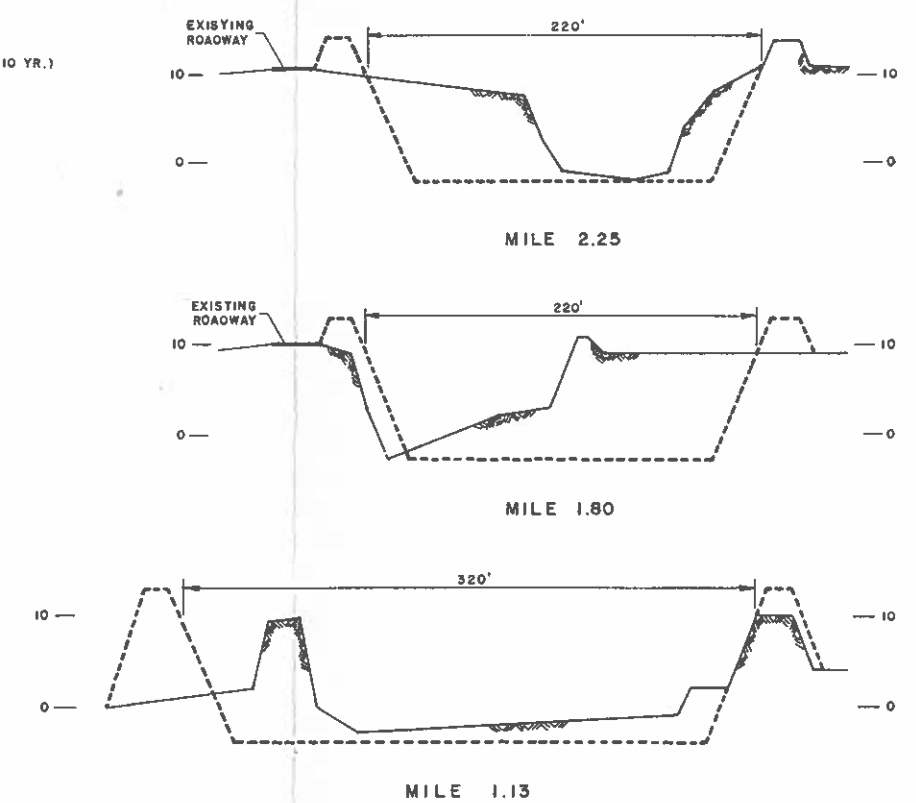
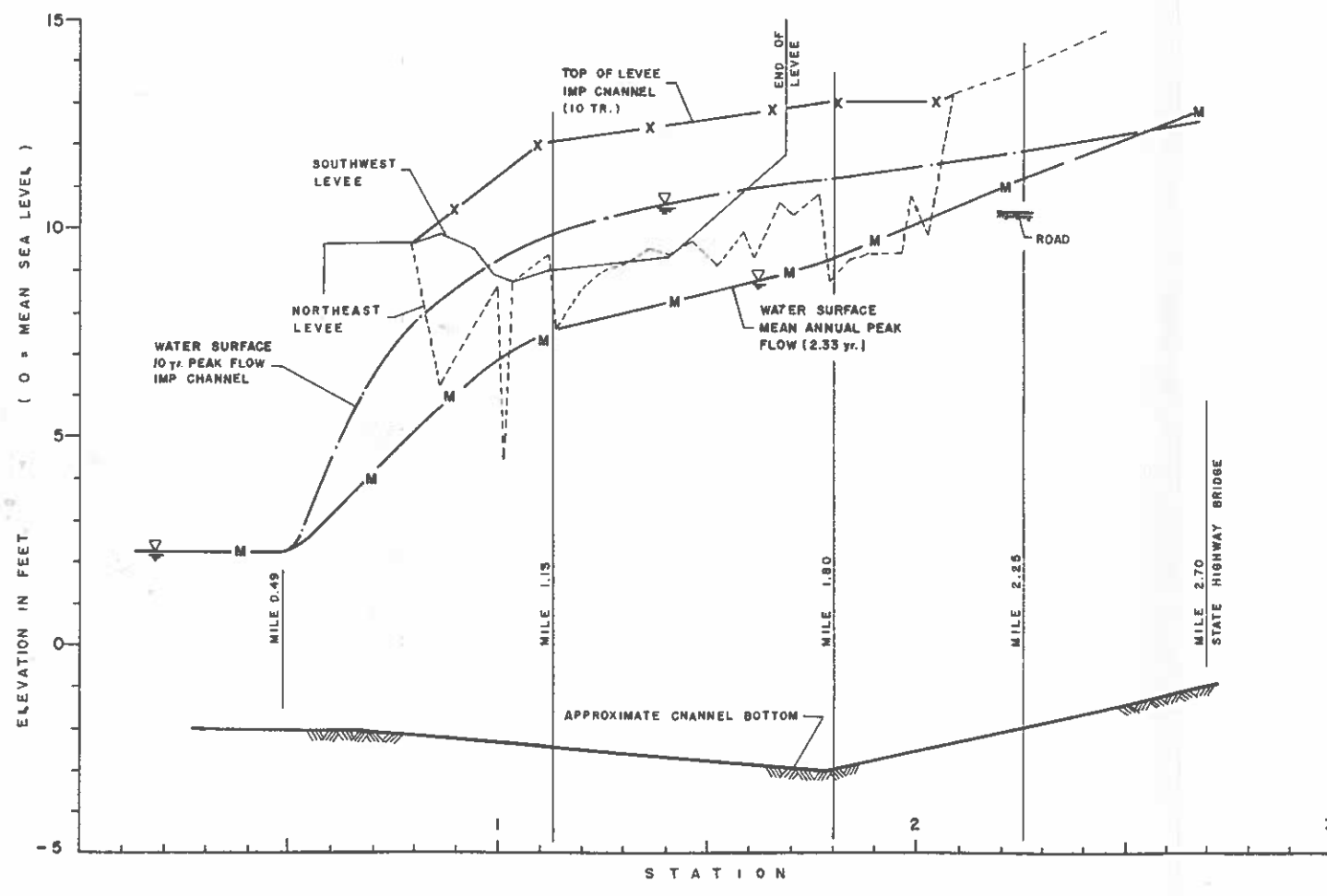
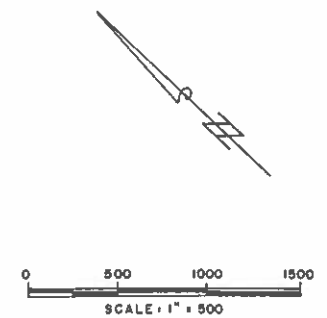
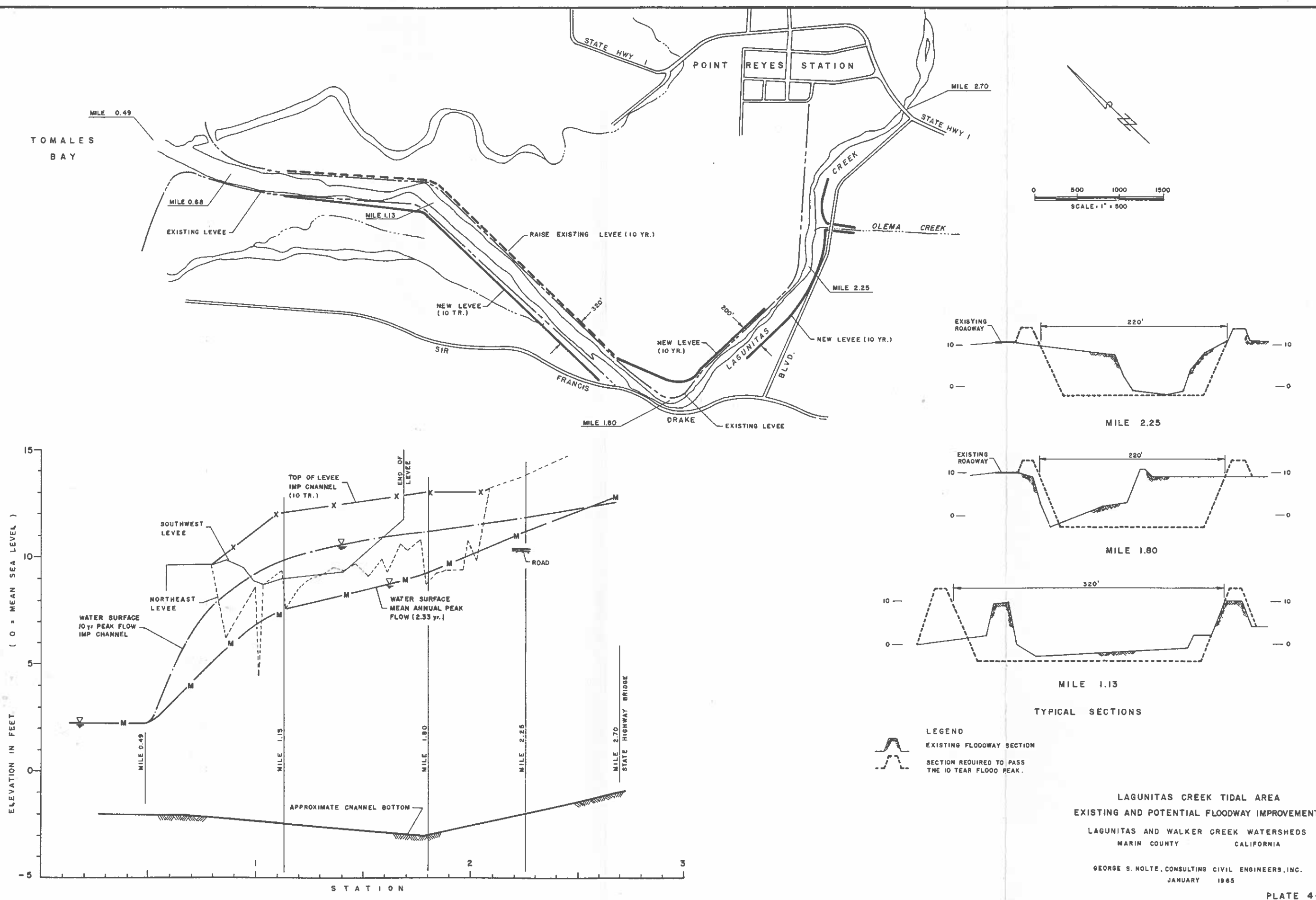
MILES - 0.00 AT CONFLUENCE WITH WALKER CREEK



MILES - 0.00 AT CONFLUENCE WITH WALKER CREEK

STREAM PROFILE AND CONVEYANCE CHARACTERISTICS
SHEET 3 of 3

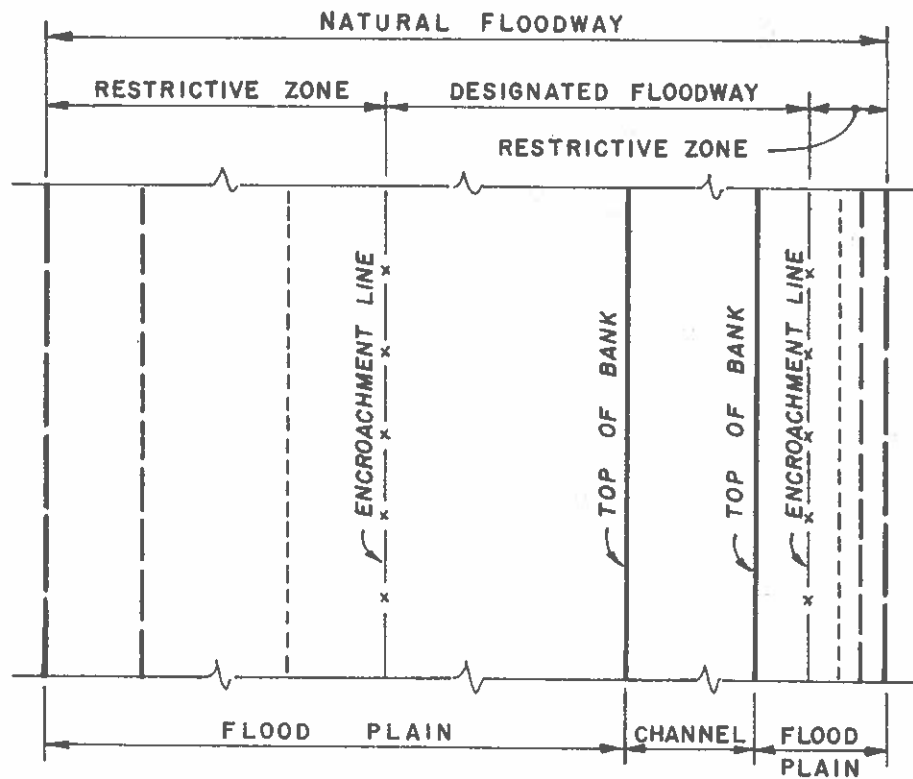
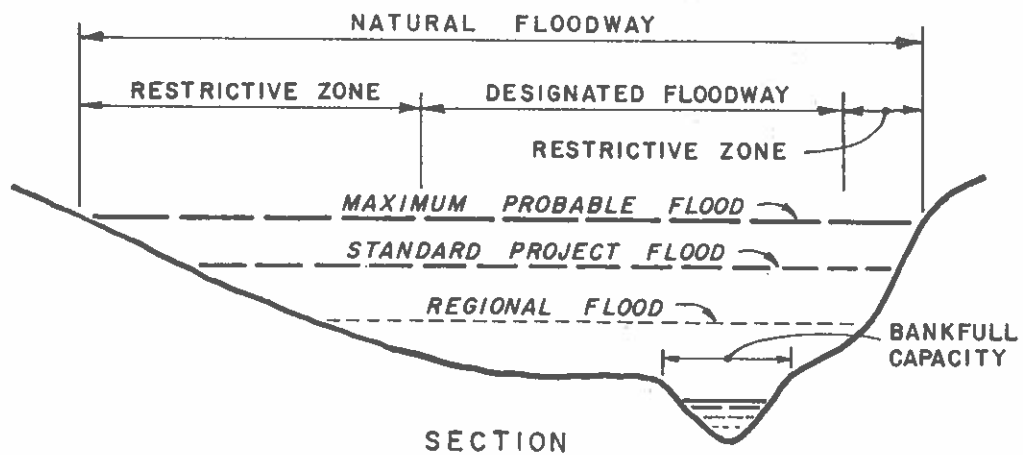
GEORGE S. NOLTE CONSULTING CIVIL ENGINEERS, INC.
FEBRUARY 1965



LEGEND
 EXISTING FLOODWAY SECTION
 SECTION REQUIRED TO PASS THE 10 YEAR FLOOD PEAK

LAGUNITAS CREEK TIDAL AREA
 EXISTING AND POTENTIAL FLOODWAY IMPROVEMENTS
 LAGUNITAS AND WALKER CREEK WATERSHEDS
 MARIN COUNTY CALIFORNIA

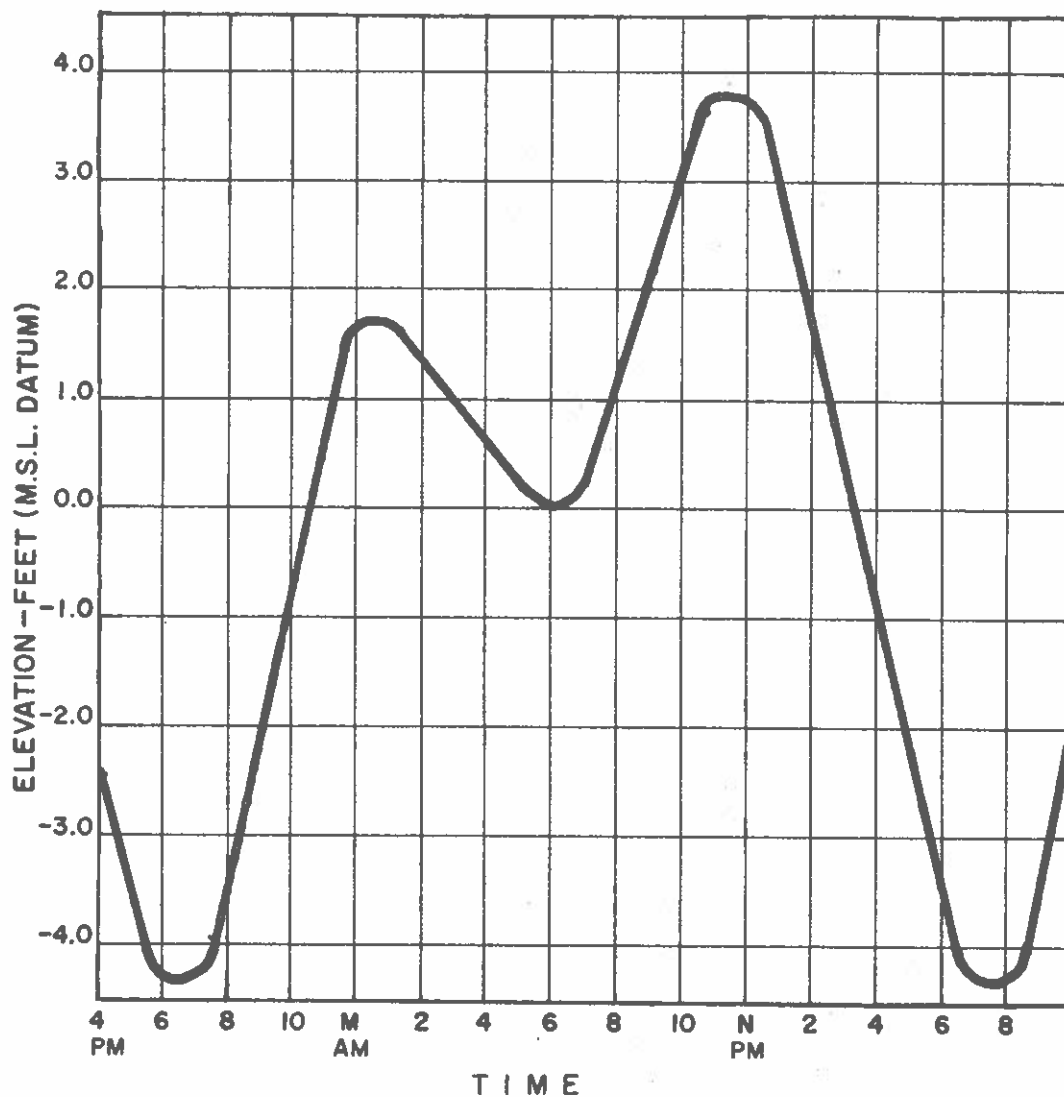
GEORGE S. NOLTE, CONSULTING CIVIL ENGINEERS, INC.
 JANUARY 1965



DESIGNATED FLOODWAY AND RESTRICTIVE ZONES

from 'GUIDE FOR THE DEVELOPMENT OF FLOOD PLAIN REGULATIONS'
 by TASK FORCE ON FLOOD PLAIN REGULATIONS
 COMMITTEE ON FLOOD CONTROL, HYDRAULICS DIV.
 A. S. C. E., JOURNAL OF THE HYDRAULICS DIV.
 VOL. 88 NO. HY 5 SEPT. '62, PART I

PLATE 4-11

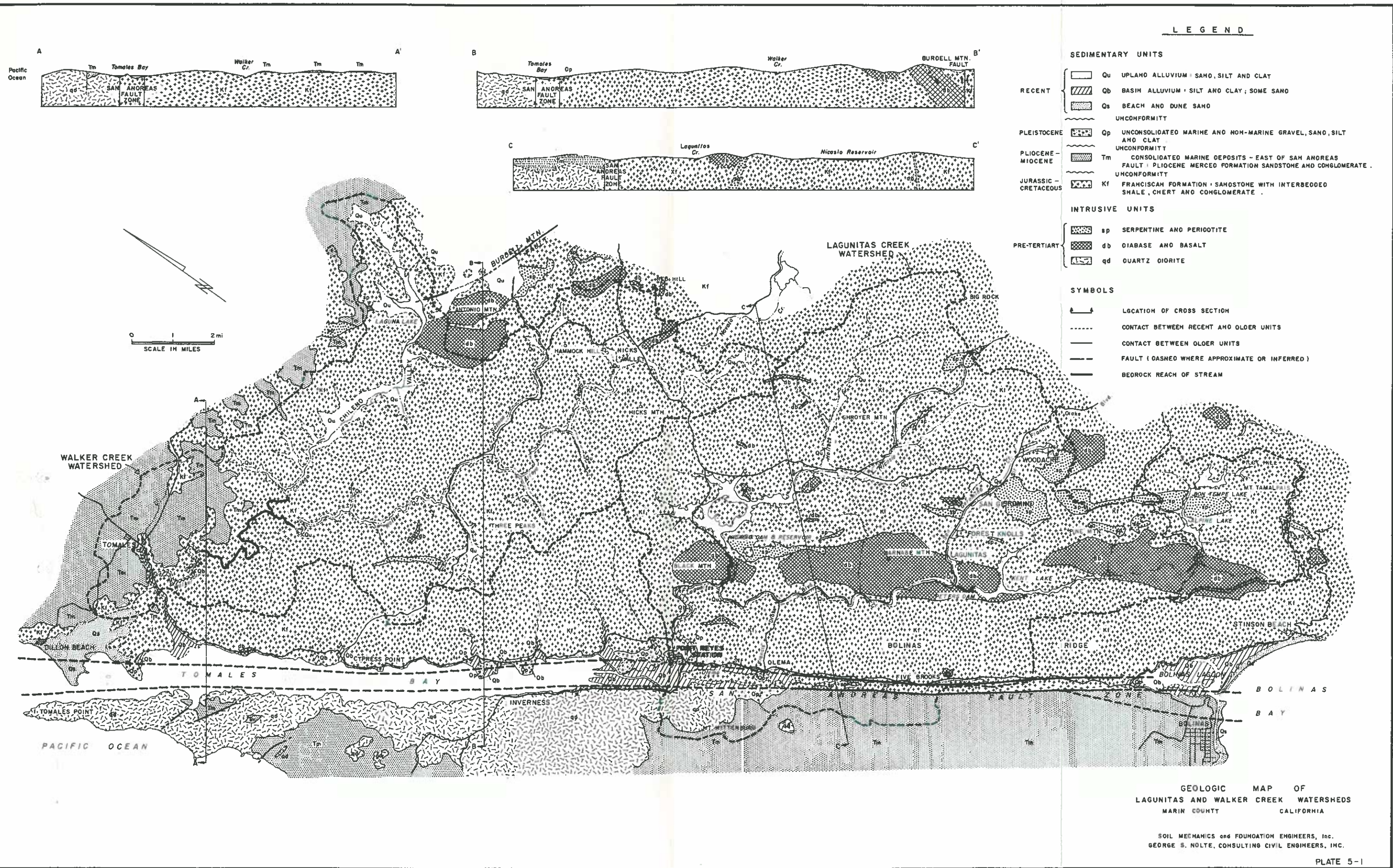


ELEVATION TERMS	WALKER CREEK		LAGUNITAS CREEK	
	MLLW DATUM	MSL DATUM	MLLW DATUM	MSL DATUM
MEAN HIGHER HIGH WATER (MHHW)	5.2	2.6	5.3	2.8
MEAN HIGH WATER (MHW)	4.5	1.9	4.7	2.2
HALF TIDE (MEAN TIDE LEVEL)	2.7	0.1	2.8	0.3
MEAN SEA LEVEL (MSL)	2.65	0.00	2.51	0.00
MEAN LOW WATER (MLW)	1.0	-1.6	1.0	-1.5
MEAN LOWER LOW WATER (MLLW)	0.0	-2.6	0.0	-2.5

TIDAL ELEVATION INFORMATION

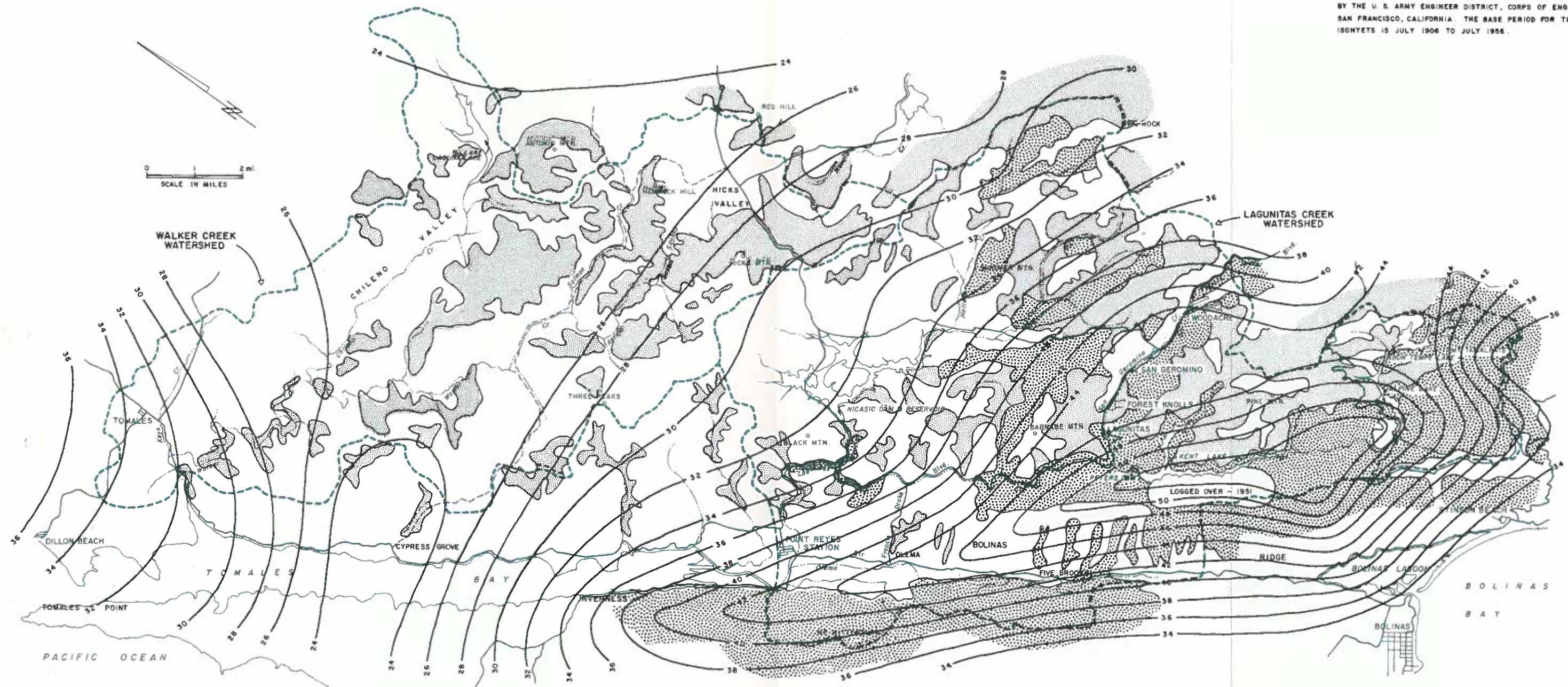
FIGURE 4-1

PLATE 4-12



LEGEND

-  GRASSLAND (less than 10% brush or trees)
-  BRUSH AND OPEN WOODLAND
-  FOREST AND DENSE WOODLAND
-  30— ISOHYETS—WHICH ARE LINES OF MEAN SEASONAL PRECIPITATION IN INCHES. THESE LINES ARE BASED ON AN ISOHYETAL MAP BY THE U. S. ARMY ENGINEER DISTRICT, CORPS OF ENGINEERS, SAN FRANCISCO, CALIFORNIA. THE BASE PERIOD FOR THE ISOHYETS IS JULY 1906 TO JULY 1955.



VEGETATION AND RAINFALL MAP
LAGUNITAS AND WALKER CREEK WATERSHEDS
MARIN COUNTY CALIFORNIA

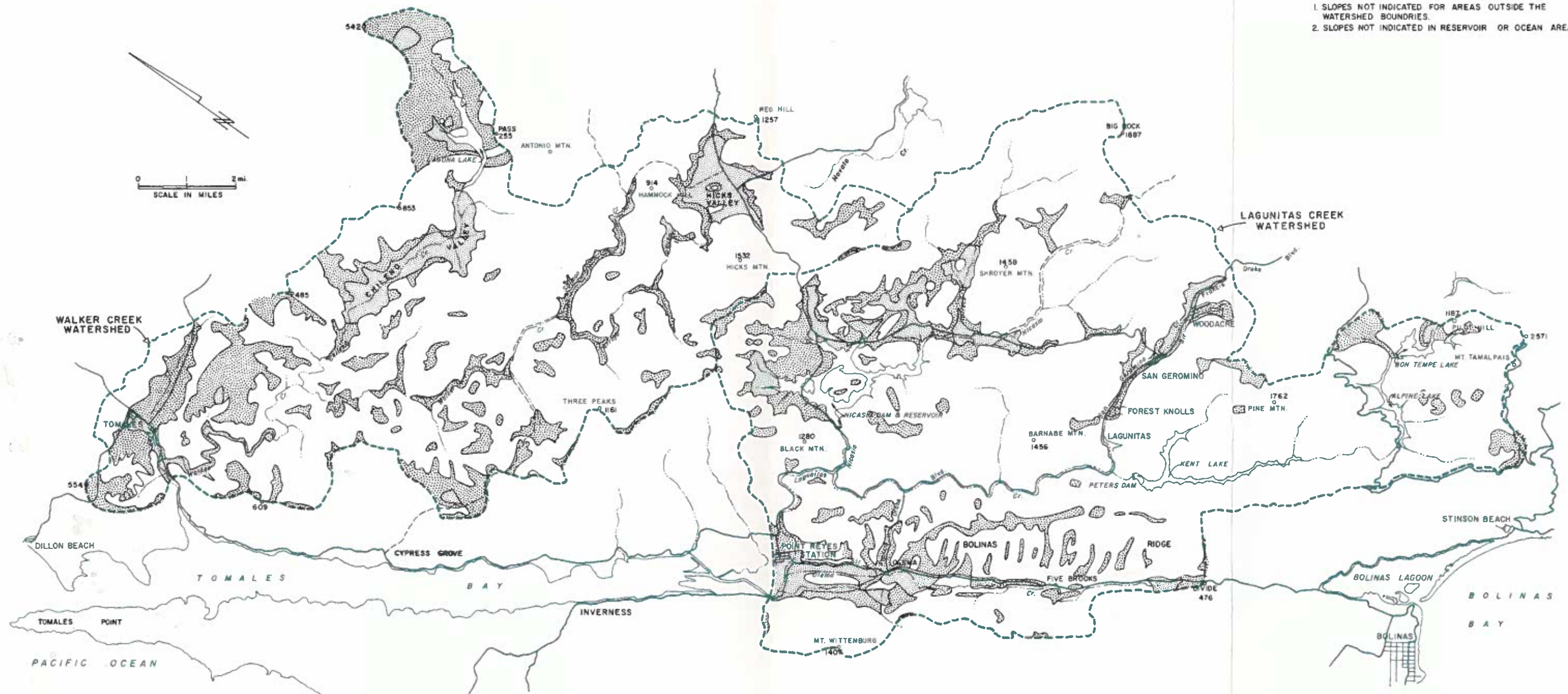
SOIL MECHANICS and FOUNDATION ENGINEERS, Inc.
GEORGE S. NOLTE, CONSULTING CIVIL ENGINEERS, INC.

LEGEND



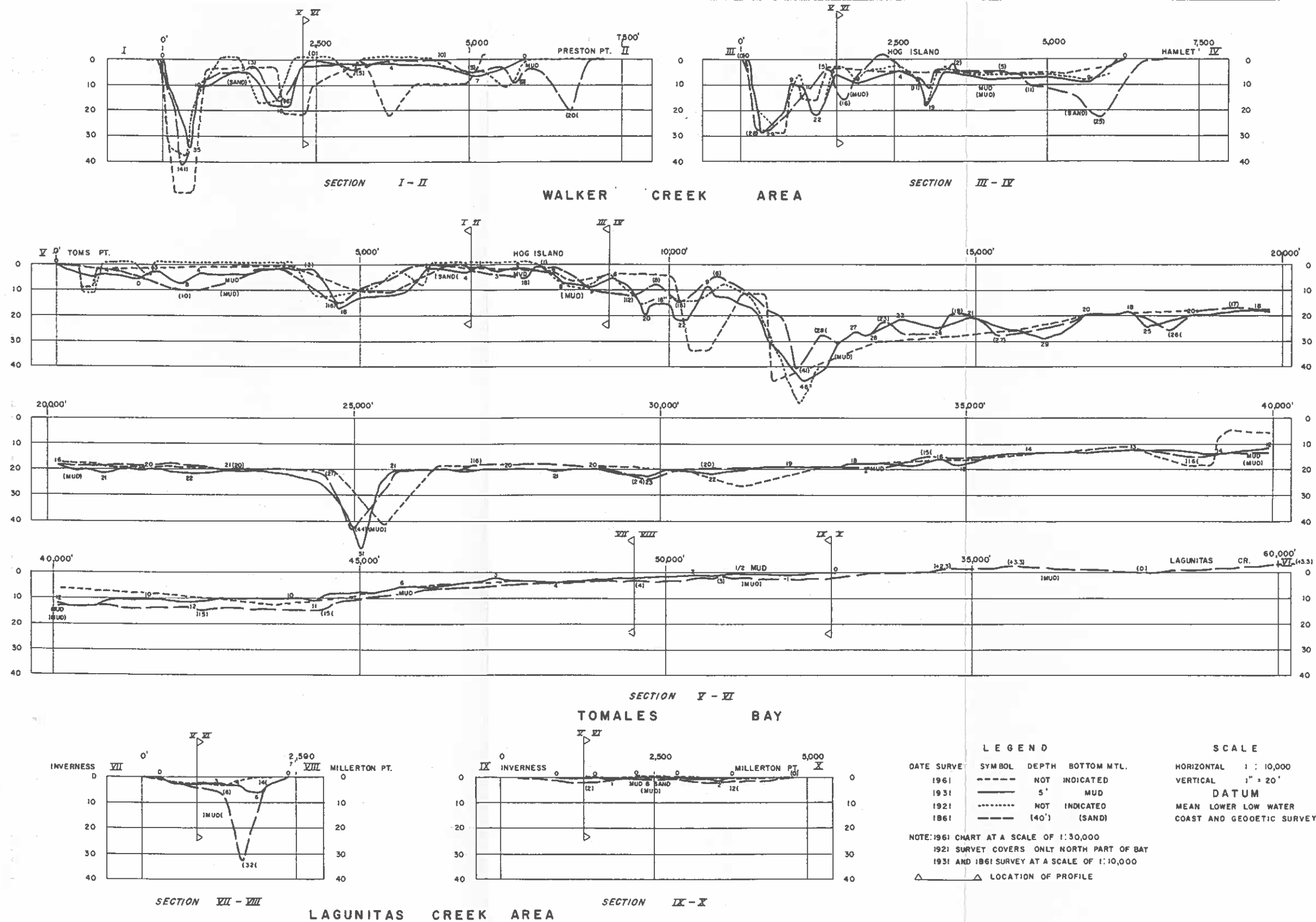
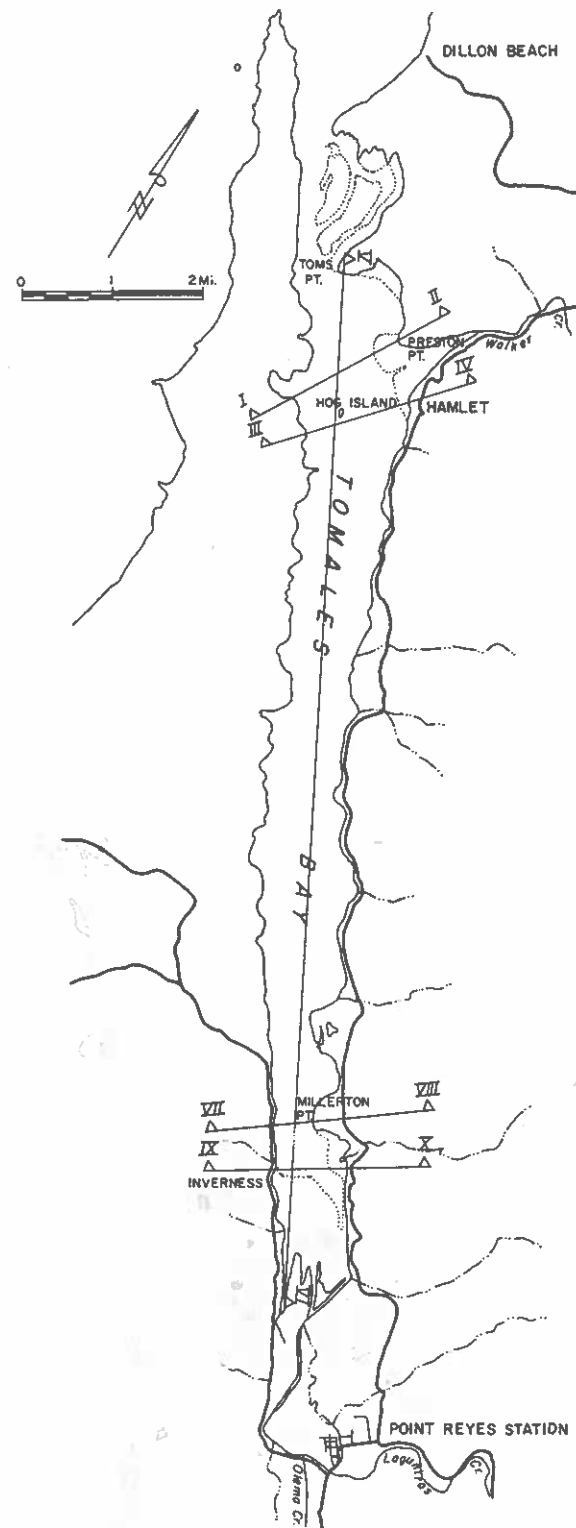
NOTES:

1. SLOPES NOT INDICATED FOR AREAS OUTSIDE THE WATERSHED BOUNDRIES.
2. SLOPES NOT INDICATED IN RESERVOIR OR OCEAN AREAS.



SLOPE AREA MAP
LAGUNITAS AND WALKER CREEK WATERSHEDS
MARIN COUNTY CALIFORNIA

SOIL MECHANICS and FOUNDATION ENGINEERS, Inc.
GEORGE S. NOLTE, CONSULTING CIVIL ENGINEERS, INC.

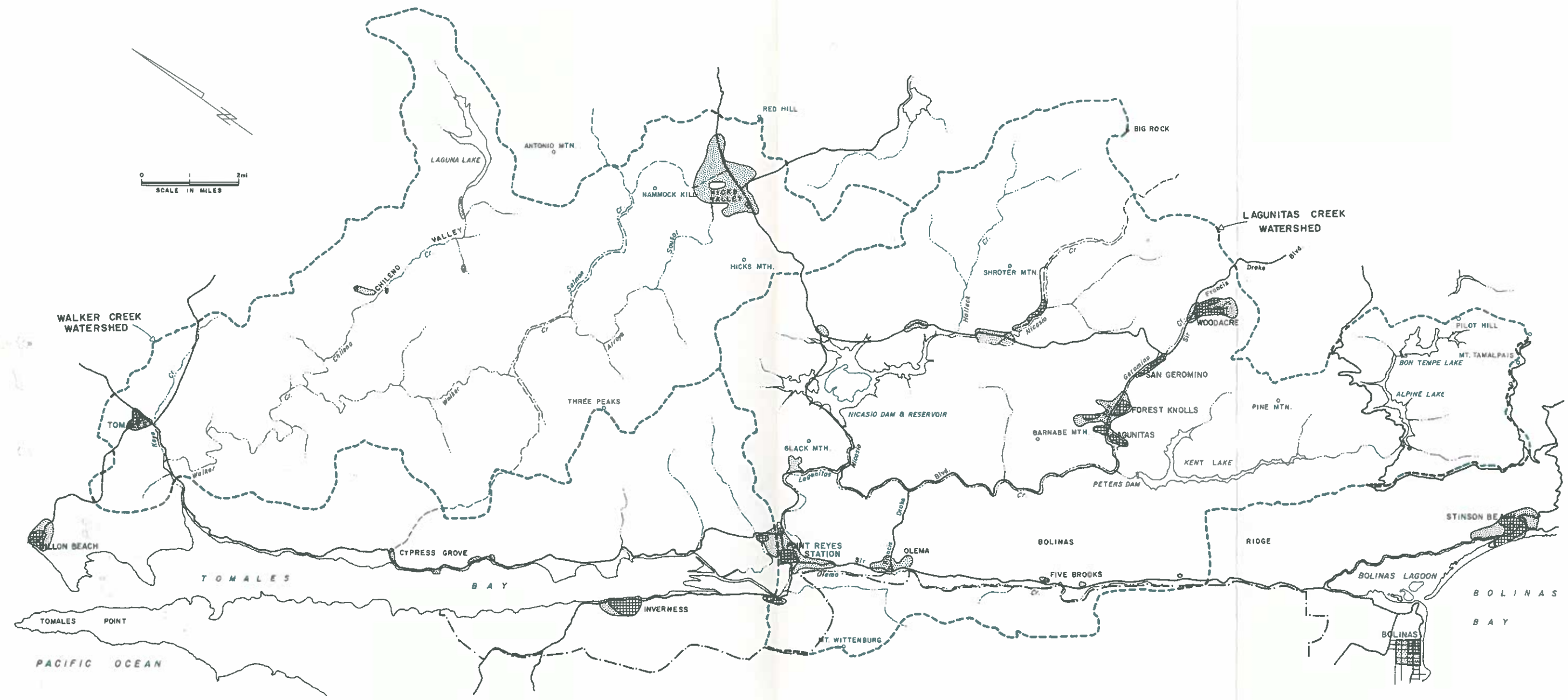


TOMALES BAY DEPTHS
COMPARATIVE PROFILES 1861-1961
LAGUNITAS AND WALKER CREEK WATERSHEDS
MARIN COUNTY CALIFORNIA

SDI MECHANICS and FOUNDATION ENGINEERS, Inc.
DECEMBER 1964

LEGEND

- URBAN LANDS AS OF 1960
- URBAN LANDS BY 1990
- LIMITS OF POINT REYES NATIONAL SEASHORE PARK



LAND AREAS IN URBAN USES
LAGUNITAS AND WALKER CREEK WATERSHEDS
MARIN COUNTY CALIFORNIA

GEORGE S. NOLTE, CONSULTING CIVIL ENGINEERS, INC.
JANUARY 1965

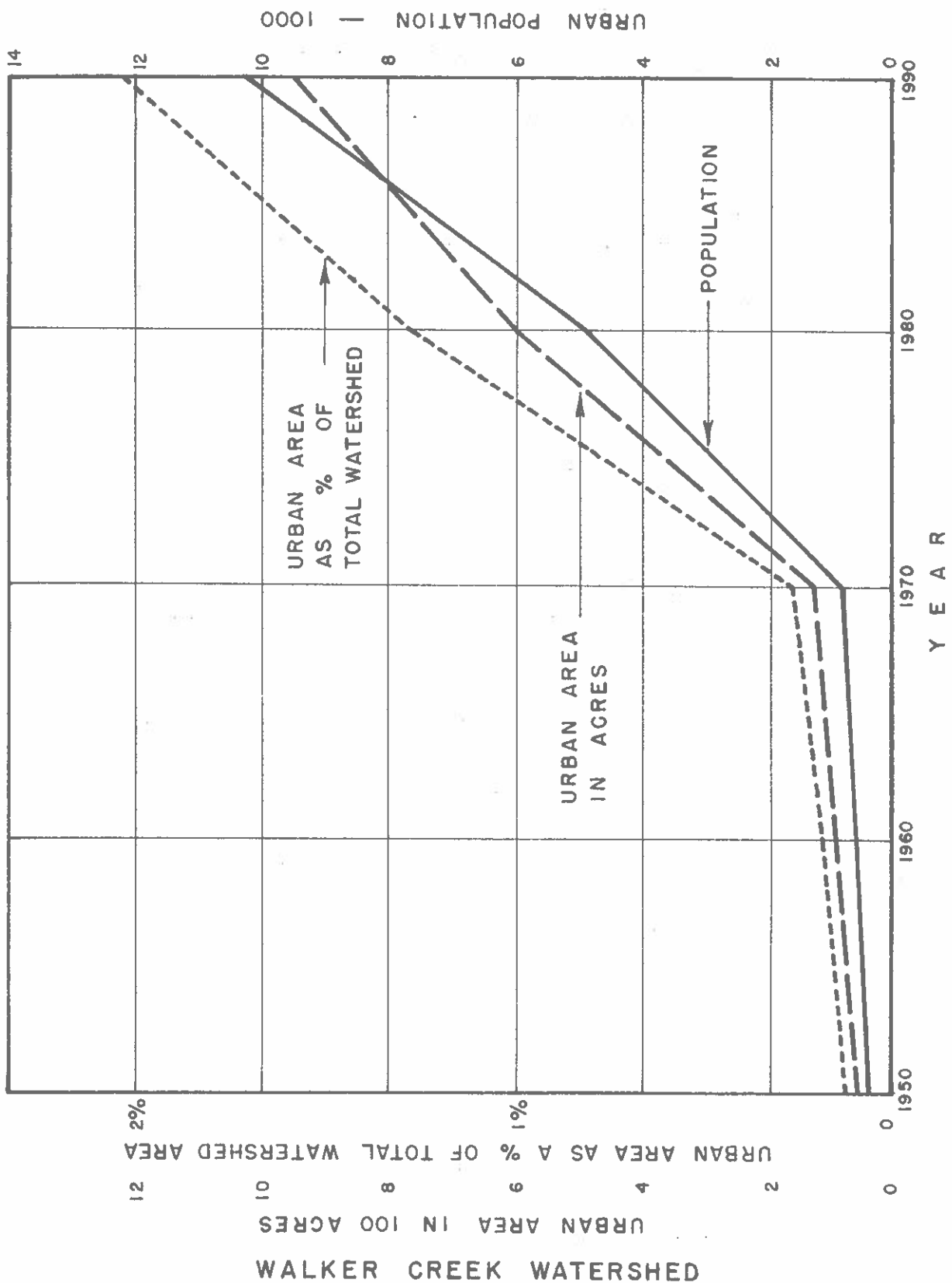
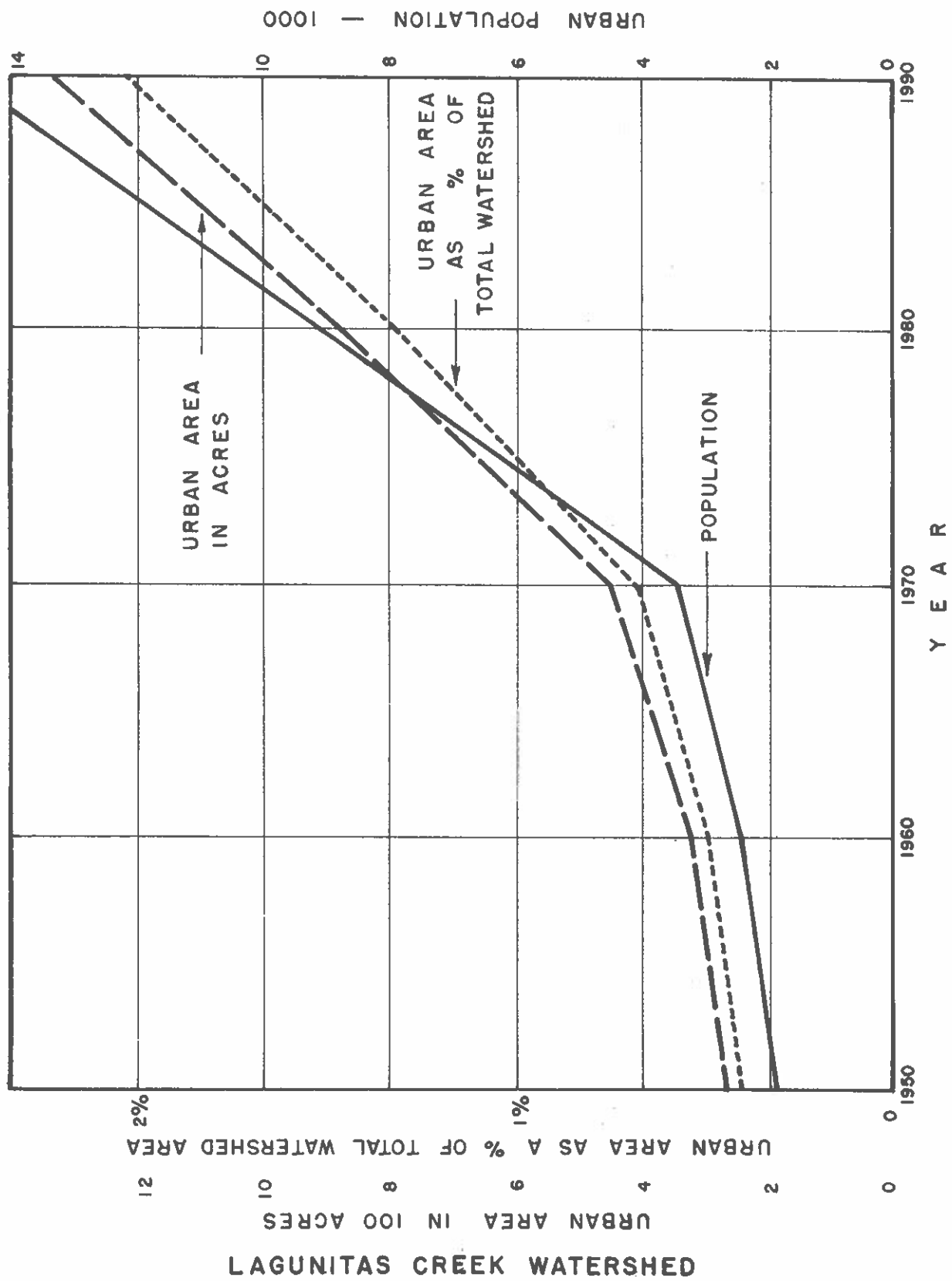
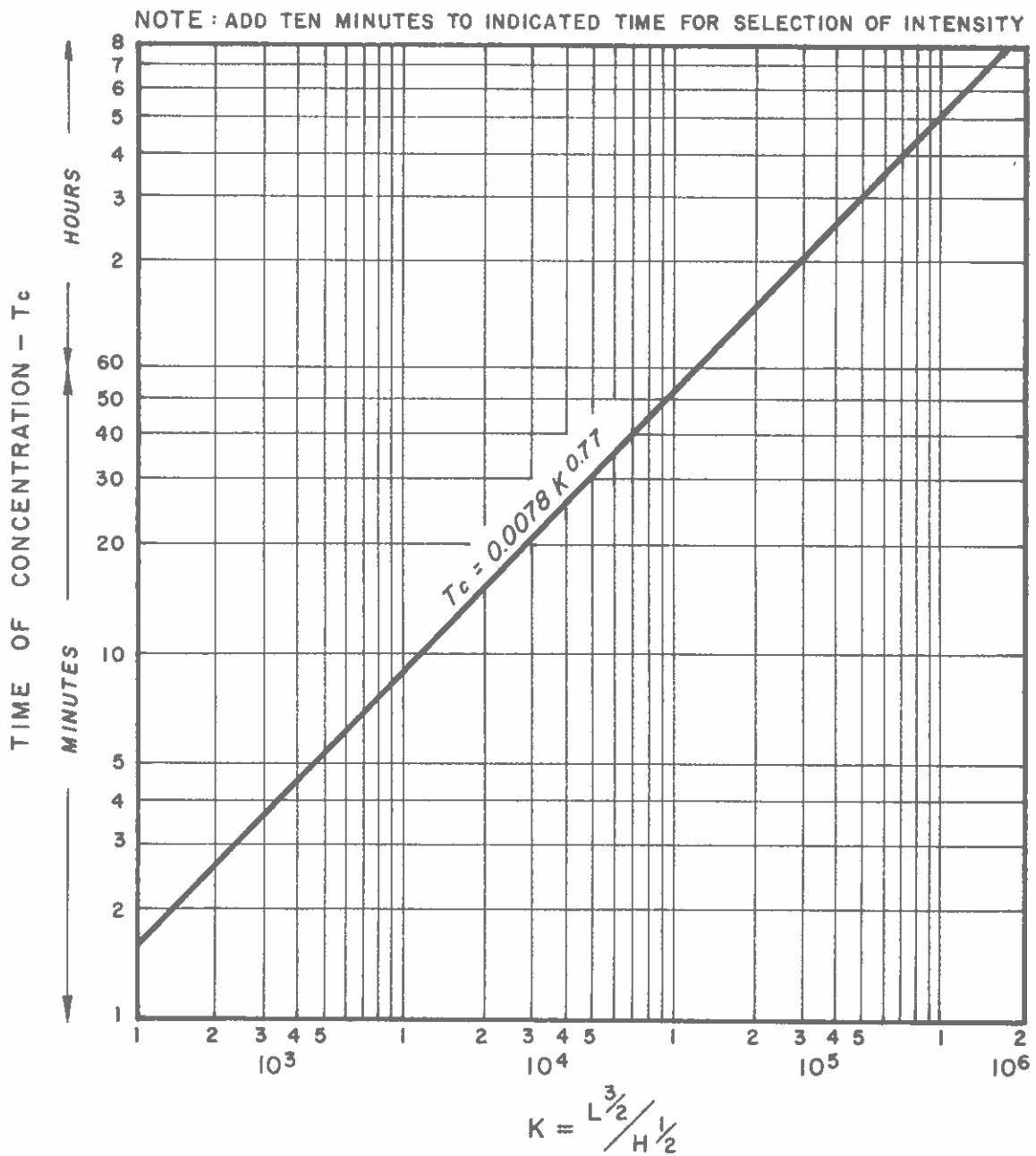


PLATE 6-2





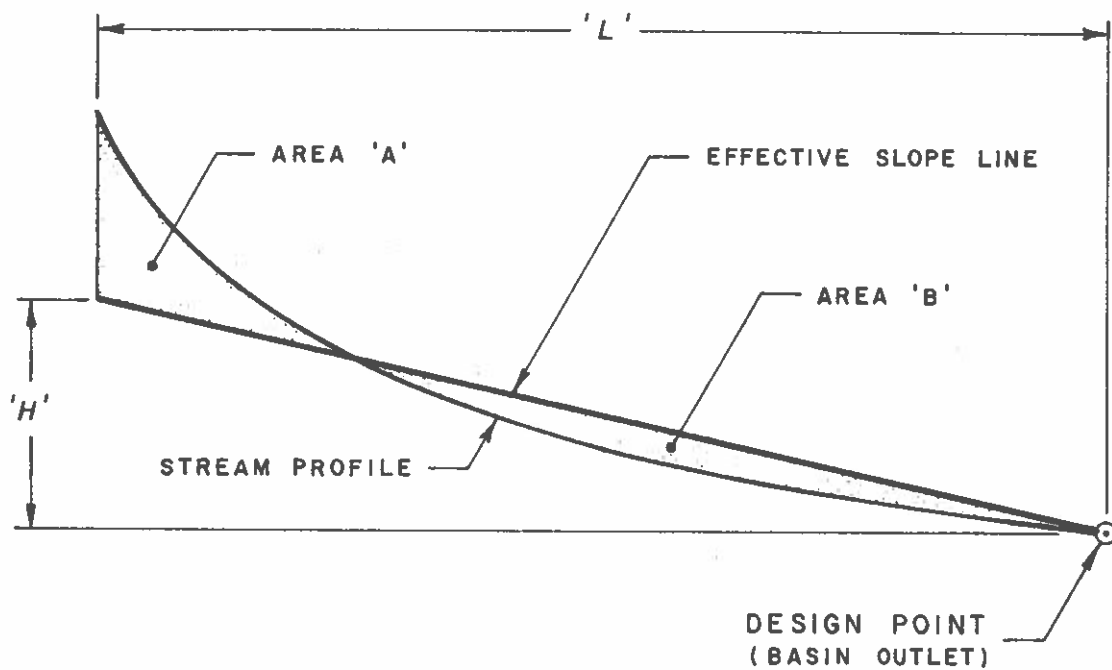
L = MAXIMUM LENGTH OF TRAVEL
IN FEET

H = DIFFERENCE IN ELEVATION
ALONG EFFECTIVE SLOPE LINE
IN FEET

TIME OF CONCENTRATION
BY EFFECTIVE SLOPE

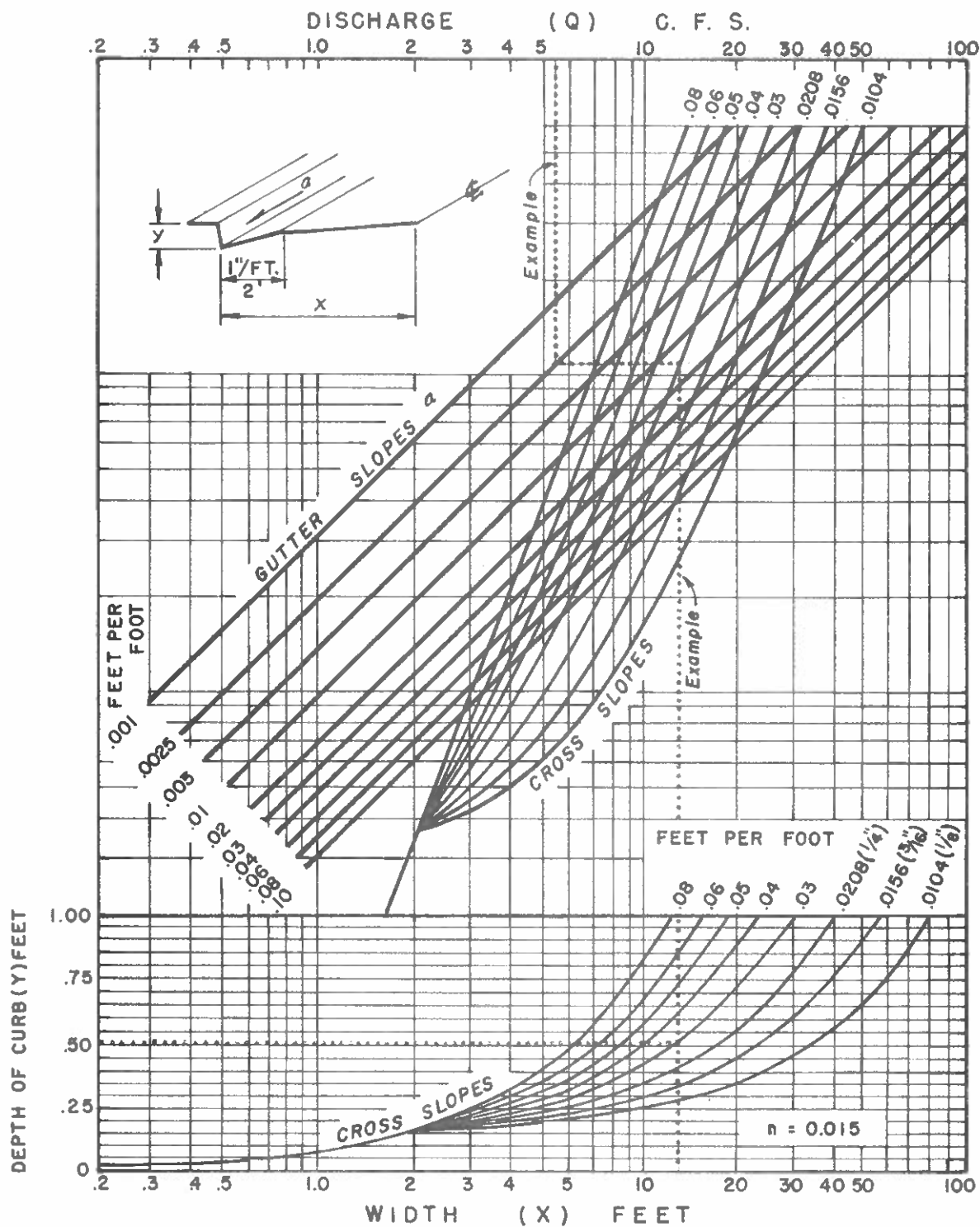
PLATE 7-1

FOR COMPUTATION OF CONCENTRATION TIME



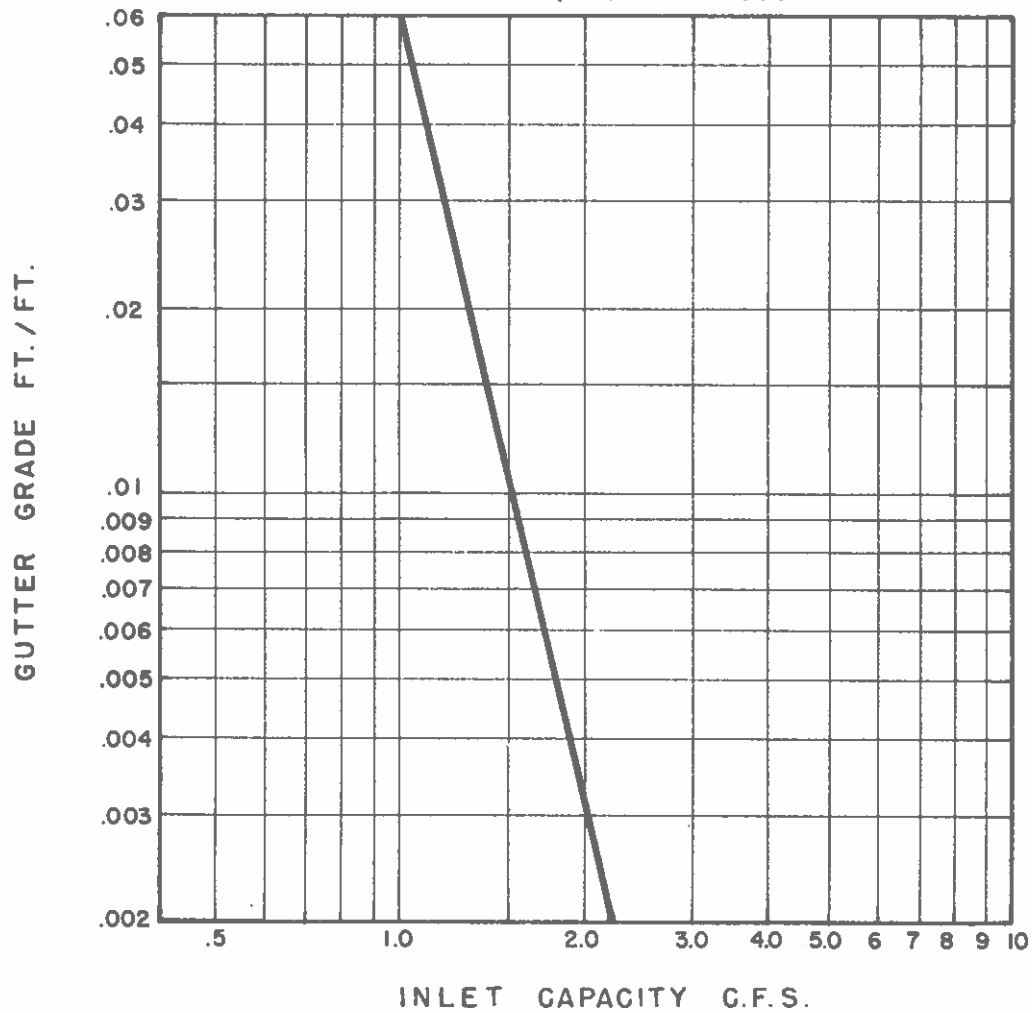
$$\text{AREA 'A'} = \text{AREA 'B'}$$

EFFECTIVE SLOPE LINE



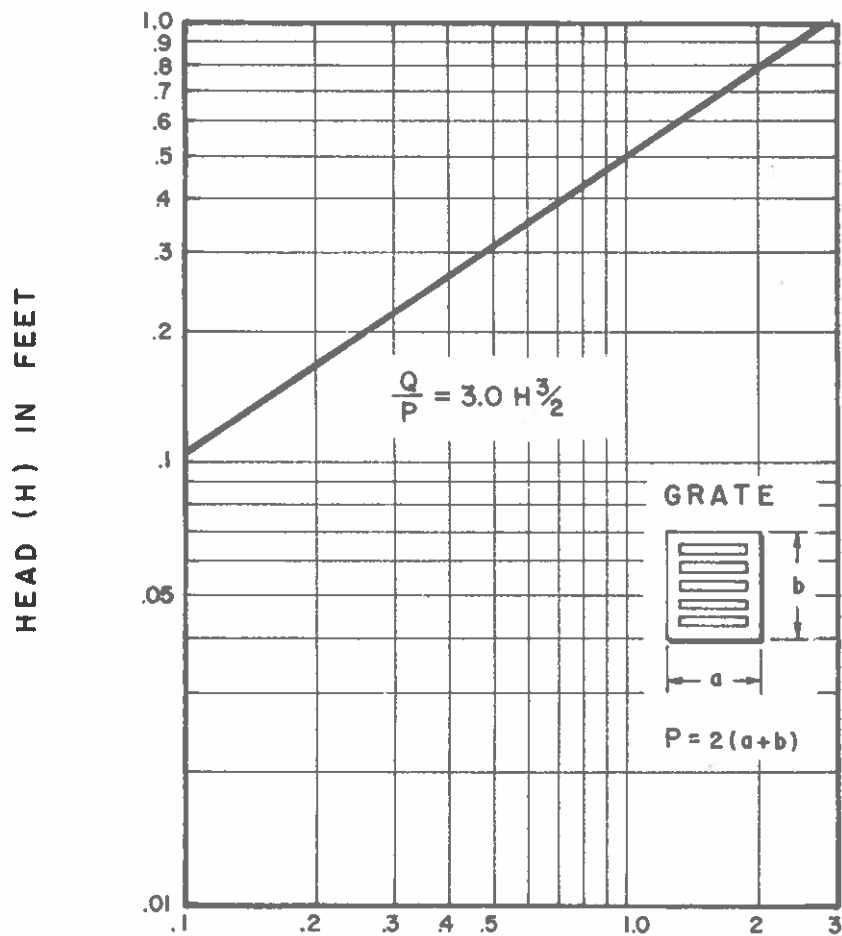
STRAIGHT CROSS SLOPES, CURB & 2 FT. GUTTER
FLOW CHARACTERISTIC CURVES

INLET CAPACITY CURVES BASED ON FIG. 7-832.9A,
 'DRAINAGE DESIGN IN HIGHWAY PRACTICE', INSTITUTE OF
 TRANSPORTATION AND TRAFFIC ENGINEERING,
 UNIVERSITY OF CALIFORNIA, JANUARY 1960



MARIN COUNTY STANDARD CATCH BASIN
 LENGTH OF CURB OPENING 5.5'

PLATE 7-4



C. F. S.
DISCHARGE PER FOOT OF PERIMETER $\left(\frac{Q}{P}\right)$

CAPACITY OF GRATE INLET IN SUMP WATER PONDED ON GRATE

BUREAU OF PUBLIC ROADS
DIV. 2 WASH. D. C.

PLATE 7-5

PROPERTY OF
POINT REYES LIBRARY

 **GEORGE S. NOLTE CONSULTING CIVIL ENGINE**

Palo Alto, California