SEDIMENT-TRANSPORT AND STREAM-FLOW CHARACTERISTICS FOR JACOBY CREEK, CALIFORNIA

by

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ABSTRACT: Sediment transport as a function of turbidity, sediment concentration, precipitation, stage height and discharge levels have not been investigated for Jacoby Creek in northern California. Instantaneous concentration, discharge and precipitation measurements were collected at six major gaging points on Jacoby Creek.

Precipitation data was modified to a form of the antecedent precipitation index. Sediment transport as a function of Pa (antecedent precipitation index) was poorly defined and generally unacceptable. A more sensitive approach is needed to properly account for the time lag involved in precipitation measurements using standard rain gages.

Special consideration was made to determine the quantity of suspended sediment transported into Humboldt Bay. Here the Corps of Engineers continues its annual dredging program which has resulted in the excavation of 648,570 cubic yards of sediment in the past five years at a cost of $689,000.

A family of curves was derived to examine sediment transport as a function of discharge. These curves represent the various sampling stations located on the main stream.

An individual storm was measured to more clearly understand the various hydrologic interreactions. Total discharges for a single storm shows that between 1280-1400 tons or 730-800 cubic yards of sediment may be transported into Humboldt Bay during a 54-hour, 1.61" rainfall. Dredging costs for this storm totaled $1,272, based on 1971 cost estimates (assuming sediment depositions were to be dredged). Annual estimates project a minimum of 10 times this volume, with the cost being absorbed by the taxpayer.

Stepwise linear regression computer analysis results indicate that turbidity plus water discharge is capable of increasing the sediment transport predictability by more than 8% for a sampling station located near U.S. Highway 101 south of Arcata, California. These two factors account for 84% of the variance.

Two sub-units in the upper reaches of Jacoby Creek were examined in light of road construction and tree harvest activity. The continuous instability (mainly from landslides) from previous logging and road placement completely obscures any effects that were measured due to current activity.

ACKNOWLEDGMENTS

First and always, I thank Mom and Dad, who knew I could do it all along. I am happy to make them proud.

I thank my committee, Mr. Jog, Dr. Koplin, and Dr. Thornburgh, for their support, and especially my major professor, Dr. Dean Freeland, who has given me more than just a classroom education.

Acknowledgments are in order to Del (computer programmer), Ken and Ken (photographers), Ernie (private pilot) and the many Watershed Management graduate students who assisted in various ways.

Uncle Burton Hoyle and Kenneth Beatty are especially thanked for their gifts of continued encouragement and motivation needed to pursue this research project.

I will never forget the good humor an unnamed gentleman provided one rainy day. I was standing waist deep in the middle of the stream, conscientiously collecting stream data, with clip board, pencil, stopwatch, head phones, umbrella, current meter and a tangle of wires clinging to me, when this stranger casually asked if I had caught any fish yet.

Continuous spirit and support for this project was always (and most importantly) present from loving Christine.

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CHAPTER I

INTRODUCTION TO THE PROJECT

Detailed stream flow and sediment data for tributaries to Humboldt Bay on the north coast of California are not available. One such tributary, Jacoby Creek, is located between Arcata and Eureka.

This study is designed to investigate the "sediment transport and water discharge" relationship for different sampling stations along Jacoby Creek.

I examined the possibility of using turbidity measurements to predict sediment concentration. Measurement of a single storm is designed to more clearly define the various hydrologic and meteorologic interreactions that exist in the field. Raw data parameters that I measured are precipitation, water discharge, temperature, stage height, turbidity and sediment concentration.

Ecological effects on the esturine characteristics of the Bay by possible changes in sedimentation rates (as compared to former rates under which the ecosystem evolved and became established) is recognized. Furthermore, such information is important from an economic standpoint to the general public as well as the residents of Humboldt County. Annually the Corps of Engineers performs dredging operations in Humboldt Bay. During the past five fiscal years

648,570 cubic yards of silt and sediment have been excavated from the Bay at a cost of $689,000. Further financial losses are experienced by property owners in the Jacoby Creek Watershed during flood periods. Bridges and roads are destroyed, agricultural land is heavily damaged by erosion, scour and deposition of sediment and debris.

CHAPTER II

DEFINITION OF HYDROLOGIC TERMS

The basic hydrologic terms used in this research paper are essentially those of Harris and Williams (1971).

Bedload is the sediment that moves by sliding, rolling, or skipping on or very near the streambed.

Cubic feet per second (cfs) is the rate of discharge of a stream whose channel is one square foot in cross-sectional area and whose average velocity is one foot per second.

Gaging station is a particular site on a stream, canal, lake or reservoir where systematic observations of gage height or discharge are obtained. When used in connection with a discharge record, the term applies only to those gaging stations where a continuous record of discharge is obtained.

Milligrams per liter (mg/l) for suspended sediment is computed as one million times the ratio of weight of sediment to the volume of the mixture of water and sediment.

Prediction limits are lines about the regression curves for a selected significance level within the range of previously experienced values. They are computed from the equation:

95% Prediction: $UL[y'+(1.96)(Se) < Y < y'-(1.96)(Se)]LL$

Se - Standard Error of Estimate

UL - Upper Limit

LL - Lower Limit

Runoff is that part of the precipitation that appears in surface streams.

Sediment discharge is the rate at which dry weight of sediment passes a section of a stream or is the quantity of sediment, as measured by dry weight, or by volume, that is discharged in a given time.

Suspended sediment is the sediment that at any given time is maintained in suspension by the upward components of turbulent currents or that exists in suspension as a colloid.

Pounds per hour is the quantity of a substance in solution or suspension that passes a stream section during a 60-minute period.

CHAPTER III

REVIEW OF SEDIMENT AND STREAMFLOW LITERATURE

The problems of sediment and the methods of sediment estimation have become widely recognized in the past two decades. Nearly every outdoor agency is presently designing simple-to-elaborate measurement programs to obtain sediment data. The reason for this sudden intensive research is well stated by J. Moore (1969), who considers sediment in lakes, rivers, and reservoirs to be of a very serious nature in terms of dollars and cents.

> Consider just two aspects of the problem. First, each year it is necessary to dredge some 38 million cubic yards of silt-eroded earth from the nation's harbors and waterways. This dredging costs an estimated $125 million each year. Second it has been estimated that the annual reduction in existing reservoir storage capacity--caused by the inflow of silt--amounts to some $100 million.
>
> Considering these two factors alone, dredging requirements and loss of reservoir storage space --sedimentation costs this nation about $225 million annually. And this does not take into account the loss of invaluable top soil or the severe degradation of water quality caused by sediment.

A reconnaissance study of the environment and physiographic features precedes the actual data collection. Nearly every author cited has shown similar format and style.

A common method for studying sediment-transport characteristics at a sampling point is to graphically evaluate the relationship of sediment discharge and water discharge (Knott 1971; Inter-Agency Committee on Water Resources, Sub-Committee on Sedimentation 1963; Morisawa 1968; Bureau of Reclamation 1969; Hawley and Jones 1969).

Estimation of sediment transport is based on a bulk density factor or a unit weight/cubic foot. The Bureau of Reclamation used 75 pounds per cubic foot for the Pa Mong Reservoir, Thailand, and, in the United States, 462 samples were collected in 21 reservoirs from which a unit weight of 119 pounds per cubic foot was used for the bedload fraction (Knott 1971). Fredriksen (1970) used 62 pounds per cubic foot, the approximate bulk density of fresh water. The South Dakota Agriculture Research Service reports 62 lbs/ft^3 for fine-textured watersheds and 81 lbs/ft^3 for medium-textured watersheds (Bureau of Reclamation 1970).

Water-sediment mixture collecting techniques range from a number of different sophisticated sediment samplers (Inter-Agency Committee on Water Resources 1963) to the open-mouthed bottle method (Fredriksen 1970). A vast range of interpretations are available. In South Carolina researchers (Einstein, Anderson and Johnson 1940) indicate the suspended sediment concentration peak occurs prior to water discharge peaks for a 2-day flood runoff in August 1939. Boucher (1970) has determined that water discharge peaks precede sediment discharge crests for a 5-day storm in February 1963.

Boucher further indicates that 22% of the runoff accounts for 81% of the sediment discharge. Other researchers (Inter-Agency Committee on Water Resources 1963) report 95% of sediment discharge may occur in 5% of the storm. This follows the reasoning of Hewlett and Nutter (1969), who note that carrying power of water geometrically increases as water volume increases.

Other researchers have reported that less than 25% of the storms are significant from the standpoint of sediment production (Bureau of Reclamation 1969) in Mississippi.

The majority of sediment production is initiated by man's activity (tree harvest, road construction and other construction activities) rather than natural influences (Knott 1969; Fredriksen 1970; Kroll and Porterfield 1969; Boucher 1970).

Sediment loads have been shown to increase significantly after logging in 1965-1966 in the Alsea River Basin. Production is gradually decreasing as new vegetation growth occurs (Bureau of Reclamation 1970).

Landslides, slumps, slips, road failures and gully erosion are reported to be major contributors to transported sediment by Harris and Williams (1971) and Fredriksen (1970).

The use of turbidity samples to predict suspended sediment concentration is a relatively new concept being examined by the U.S.G.S. (Brown and Ritter 1970; Bureau of Reclamation 1969).

Suspended sediment concentration estimates are historically quantified by tons/day/square mile. Bedload volumes are difficult to derive and estimates are often made. These estimates range between 5% and 95% of the suspended sediment load (Hawley and Jones 1969; Inter-Agency Committee on Water Resources 1963) respectively.

Most sediment transport studies are conducted on large watersheds. No such studies have been carried out on small, flashy drainage basins in northern California.

CHAPTER IV

PHYSICAL SETTING

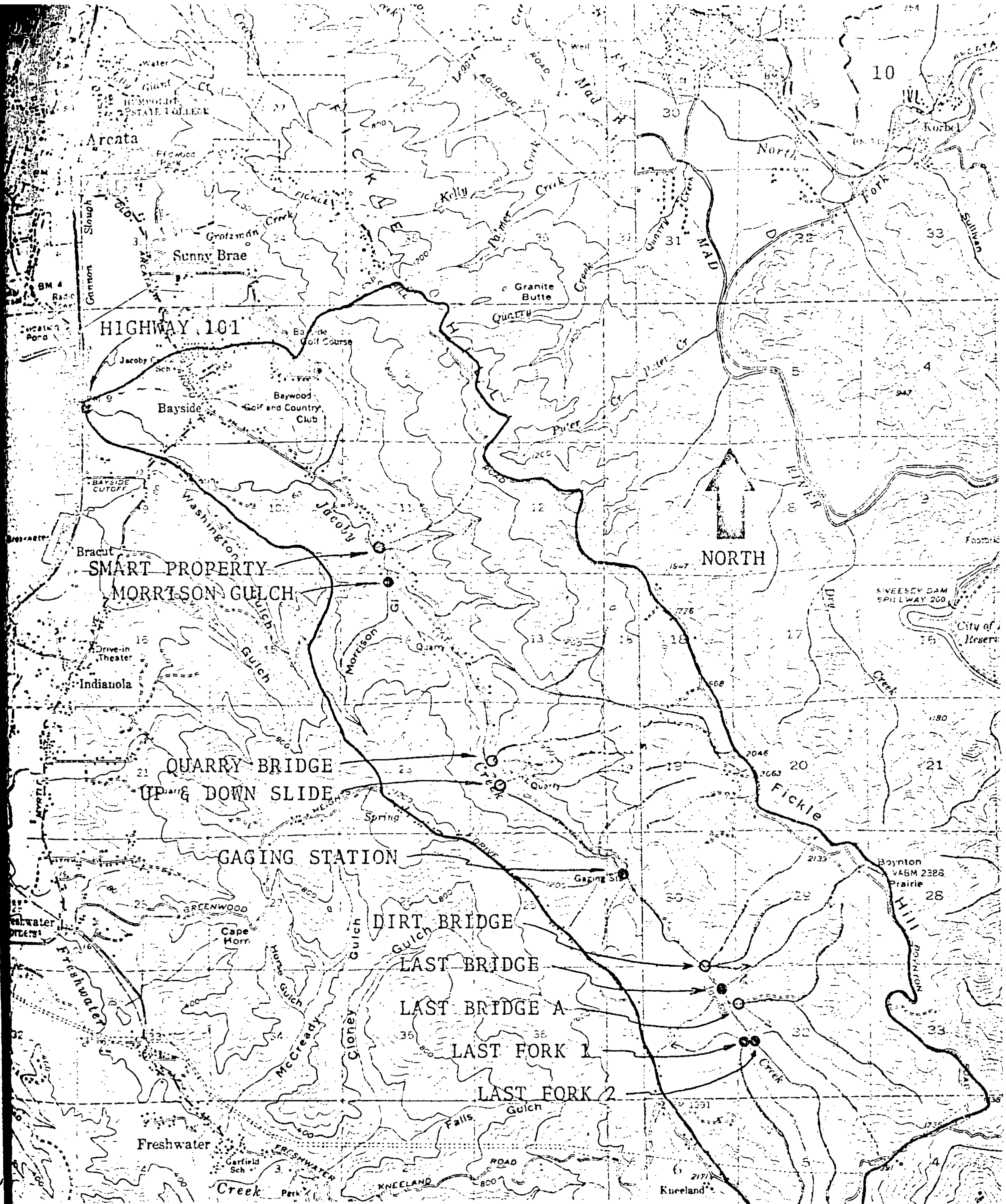
Location

Located southeast of Arcata and northeast of Eureka, Jacoby Creek watershed is somewhat rectangular in shape, the main channel being 11.1 miles long, flowing in a general northwesterly direction (Fig. 1). Planimeter results determine the area of the basin to include 17.34 square miles or 11,090 acres. Flowing into Humboldt Bay, the main channel averages a slope of 196 feet/mile or 3.7%.

Jacoby Creek is bounded on the north by Fickle Hill Road, easterly by Boynton Road, and southerly by a portion of Greenwood Heights Drive. Extreme elevations range from Boynton Prairie (2388 feet) to the creek's junction with Humboldt Bay at 0 feet.

Climate and Weather

The middle and lower reaches of Jacoby Creek Basin lie in the fog belt along the north coast of California. The basin has a Mediterranean-type climate and is rainfall-deficient during the summer months. Summers are characterized by long periods of mild, dry weather with infrequent precipitation, and winters are cool and mild. Between November and April approximately 90% of the annual rainfall



● Major Sampling Stations

o Minor Sampling Stations

Scale: 1 inch to 1 mile

FIGURE 1. Jacoby Creek and Vicinity

occurs (Environmental Science Services Administration 1969-1970). During heavy winter storms, snow temporarily exists generally above the 1000-foot level. The watershed has a mean annual precipitation of 60.65 inches, as determined by the U.S. Geological Survey 1955-1964. The delta portion benefits from approximately half of the direct precipitation that falls on elevations above 1000 feet. The water has a mean annual temperature of 51.9° F. Air temperature during the period of study ranged from a high of 72° F. to a recorded low of 31° F. at the U.S. Post Office in Eureka, California (Environmental Science Services Administration 1969-1970). Higher elevations (above 800-900 foot levels) record 80° F. weather consistently on clear days. Storms normally move in from the west-northwest, but do approach from the southeast and south occasionally. All reported directions of storm movement were observed during the field measurement period.

Streamflow and Runoff

Jacoby Creek yields approximately 90% of its runoff during the rainy months of October through April. The U.S.G.S. operated a stream gaging station during 1955-1965, which received runoff from the upper 6.29 square miles of the watershed. The average discharge from 1955-1960 was 15.6 cubic feet per second (cfs), or 11,290 acre-feet per year. During the dry season stream flow is extremely low and is almost entirely supplied by the slow release of ground and bank storage to maintain a continuous flow.

Vegetation Cover

The middle and upper sectors of the watershed is of the redwood forest type. Species of trees prevalent in the forest areas are: redwood (Sequoia sempervirens), Douglas-fir (Pseudotsuga menziesii), Sitka spruce (Picea sitchensis), red alder (Alnus rubra), western red cedar (Thuja plicata), western hemlock (Tsuga heterophylla), and willows (Salix spp.). Understory species include evergreen huckleberry (Vaccinium ovatum), salal (Gaultheria shallon), Pacific rhododendron (Rhododendron macrophyllum), blue blossom (Ceanothus thrysiflorus), salmonberry (Rubus spectabilis), and six species of ferns: sword (Polystichum munitum), lady (Athyrium felix-femina), five-finger (Adiantum pedatum), deer (Struthiotteris spicant), leather-leaf (Polypodium scouleri), and bracken (Pteridium aquilinum var. lanuginosum). See Photo 1.

The lower portion of this drainage unit consists of grassland with woody streamside vegetation.

Photo 1. Many species of ferns are found adjacent to this tributary of Jacoby Creek (February 1971).

Geology and Soil Characteristics

Johnson (1969) describes the geology and soil characteristics of Jacoby Creek Watershed as follows:

> The primary geologic formation found in the upper two-thirds of the watershed, the part with which this report deals, is the Franciscan Formation.
>
> The Franciscan formation is a eugeosynclinal accumulation of detrital sedimentary rocks, chemical sedimentary rocks, and volcanic rocks. These include mainly, massive graywacke and minor amounts of platy, dark-grey shale, thin bedded chert, greenstone where undifferentiated, and minor amounts of glaucophone schist. Generally the rocks of the Franciscan formation are sheared, deformed, and dislocated, and are intruded widely by mafic and ultramafic rocks. The Franciscan formation is often characterized by shear zones. These zones

collect water and have numerous slumps and slips. For this reason, much of the Franciscan formation is considered a poor formation for road-building.

The primary soils found in the watershed are the Atwell (823), Hugo (812), Melbourne (814), and the Larabee (914) soil series. The Atwell and Hugo series are the primary soils found along the creek areas and in sections of the watershed where roads are located. The Atwell soil is dark grayish brown to pale brown on the surface. It is composed of clay loam and gravelly clay loam with the parent material being sandstone and shale. The topography and slope classes found in the watershed are hilly to very steep. Permeability of this series is slow and the general drainage is imperfect. Erosion hazard is considered to be moderate. This series is very poor for road building, usually considered to be slide prone even before logging.

The Hugo series is composed of Loam and gravelly clay loam. The soil depth range is between 30 - 60 feet with the parent material being sandstone and shale. Slopes range from 30 to 70%. Permeability is moderate and drainage is good. Estimated uses of the soil for timber production are high to very high with erosion hazard being moderate.

The depth range of the Larabee soil series is 40 to 70 feet. Texture of the surface is loam with subsoil composed of clay loam. Parent material is soft sedimentary rock. Slopes of this soil in the watershed range from less than 30 to 70%. Permeability is moderate with general drainage being good. Erosion hazard of this soil series is high.

Boomer (7118), Kinman (855), Mendocino (915), Yorkville (752), and Orick (813), soil series are also present but only in very local areas and are not of much significance to the watershed as a whole.

Drainage Basin Characteristics

A dendritic drainage pattern is characteristic of this watershed. The upper stretches of the basin consist of extremely steep slopes, many between 60% and 85% for hundreds of feet. The steep stream gradient prevalent in this area, coupled with precipitous side slopes, induce a high amount of down-cutting commonly found throughout the upper two-thirds of the main stream channel. Destruction due to slumping and sliding occurs after every major storm. Sediment loads are moderate to heavy in these areas. Basin characteristics are summarized in Table 1 below.

TABLE 1

SUMMARY OF BASIN CHARACTERISTICS

Minimum elevation	0000 feet sea level
Maximum elevation and total relief	2388 feet
Mean elevation by area	1134.3 feet
Median elevation by area	1145
Basin altitude index	620
Main channel slope index	
in feet	220'/mile
in percent	4.65%
Mean slope of main channel	
in feet	196'/mile
in percent	3.7%
Drainage density	1.74 miles of stream per square mile
Compactness coefficient	1.875
Mean slope of watershed	40.55%

Stream Profile

Stream profile for the main channel and side tributaries are found on Figures 2 and 3.

Land Use

Railroad logging of this drainage unit first took place at the turn of the century. Intensive logging from 1964 (which is presently continuing) has occurred in the upper reaches of Jacoby Creek watershed (Photo 2). Caterpillar logging on slopes of 30% and greater is commonly seen. Highlead logging is only performed on the steepest slopes. Dirt dams have been constructed in several places,

FIGURE 2. Stream Profile, Jacoby Creek, California

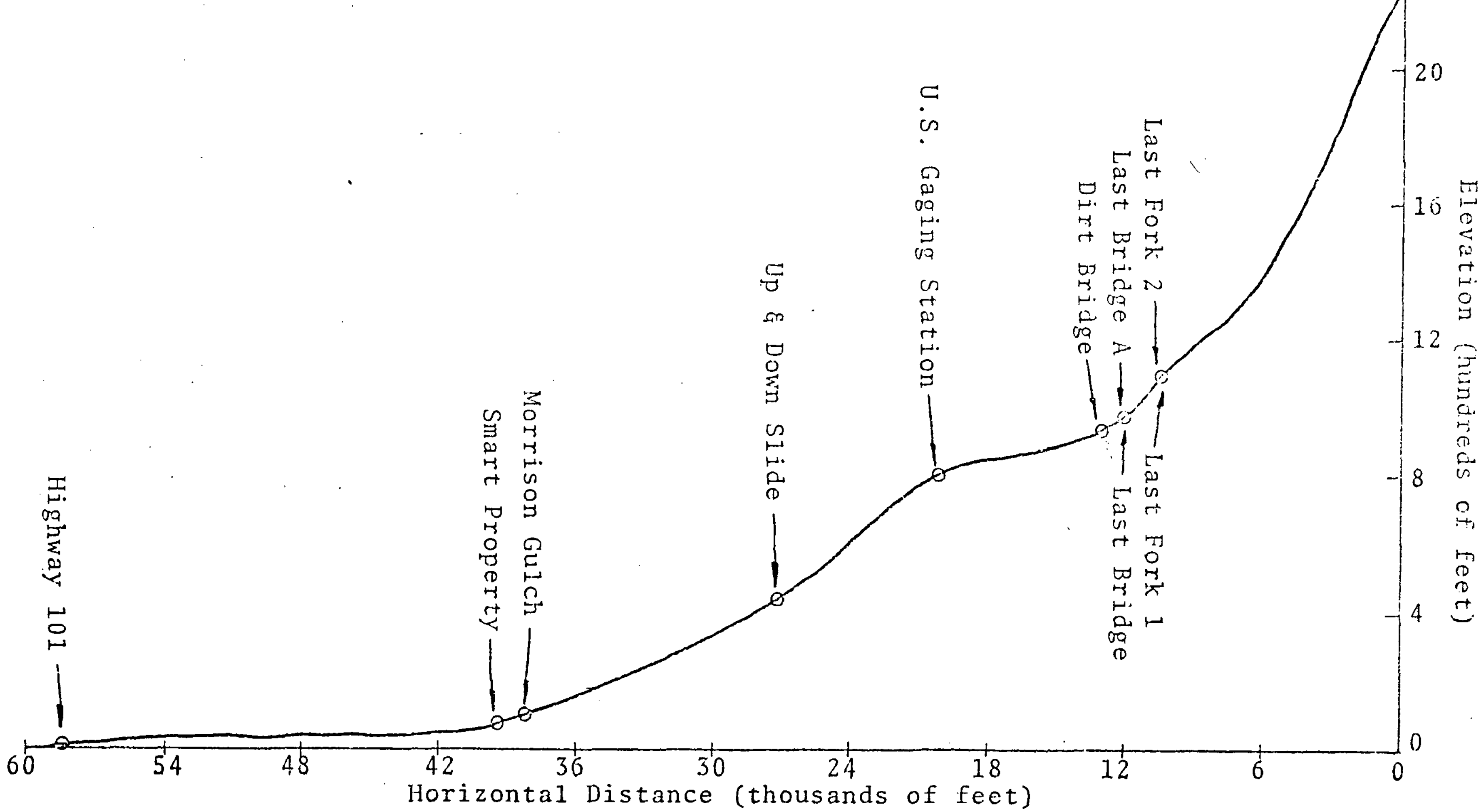
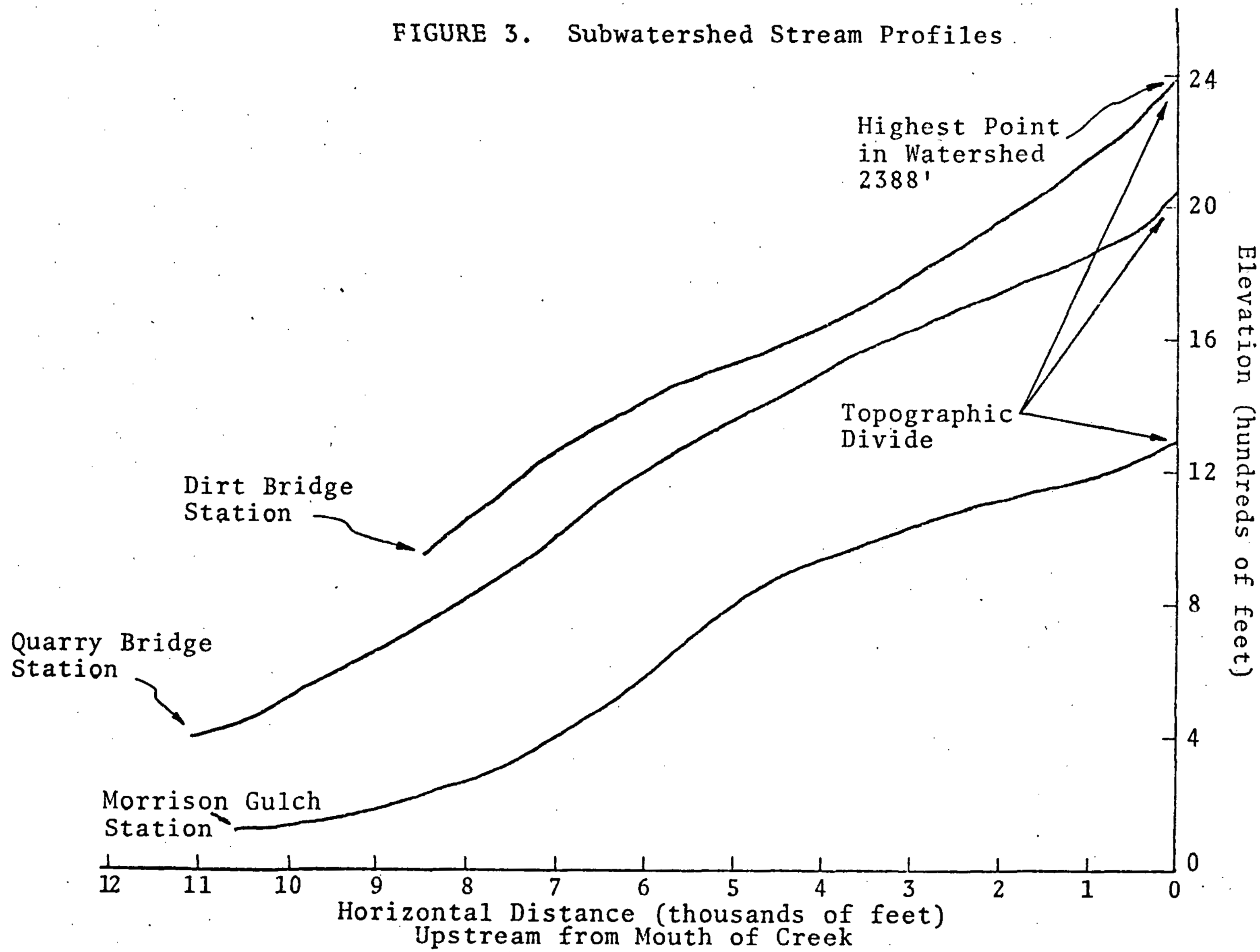


FIGURE 3. Subwatershed Stream Profiles



with logs being used for support. Debris which has fallen or slid into the streams has not been removed. In several areas massive road slides have blocked the main stream for hundreds of feet, forcing the water to rise and go around

Photo 2. Log and earth bridge location at the mouth of Last Fork 1 subwatershed. Picture comparison to a similar photograph taken in 1969 by William Johnson shows no hint of slope stability or increase in vegetation cover (April 1971).

the obstruction (Photo 3). Landings are located adjacent to the stream (Photos 4 and 5). Logging roads and skid trails are found on slopes between 10-30% and up to 40%, respectively (Photo 2). Side slopes in much of this logged area are 65-85%. Information concerning logging responsibilities can be obtained from the California State Division of Forestry in Fortuna, where all logging permits are filed.

A contracting firm has excavated rock from a quarry just below the U.S.G.S. gaging station. Apparently one side of the road (between the quarry and the stream) caved in and slid into the main channel. Fill (consisting of mud and rock) from the quarry was used to re-establish the bank. Presently there is a 200-foot-long, 70-foot-wide layer of mud and rock stretching between the road and main stream (Photo 6). This layer ranges from 4 to 10 feet in depth. As the main channel washes the lower areas away, slumping and slippage occur, bringing down this "never ending" supply to the stream. Rivulets cascading down to the creek are laden with sediment during heavy rains. Analysis indicates that over 2000 mg/l of sediment-water concentrations are carried down to Jacoby Creek to mix with the water during a 1.61-inch storm. Samples were collected both upstream and downstream from this slide area. Only a small number of samples were collected from this location. No statistical data could be derived, yet these simple measurements suggest a problem area that needs to be investigated in detail.

Little or no grazing exists on the ridge tops of the area in this watershed. Extensive grazing is conducted on the alluvial flood plains east of Highway 101. No sedimentation observed can be attributed to this activity.

The housing "construction-pattern" as documented by Figure 1 and Photo 17 is confined to the lower alluvial areas, especially in or near the community of Bayside. However, a few scattered dwellings stretch up the stream, and a handful are located around the basin perimeter.

Throughout the forested sections, a broken ownership pattern is noted, with the majority of area in the hands of a number of private land owners. Smaller areas are owned by the City of Arcata.

Photo 3. This long-time log jam shows yesterday's logging debris. Note the U.S.G.S. gaging station at top (March 1971).

Photo 4. A log landing adjacent to the main stream is a primary producer of sediment as documented above (March 1971).

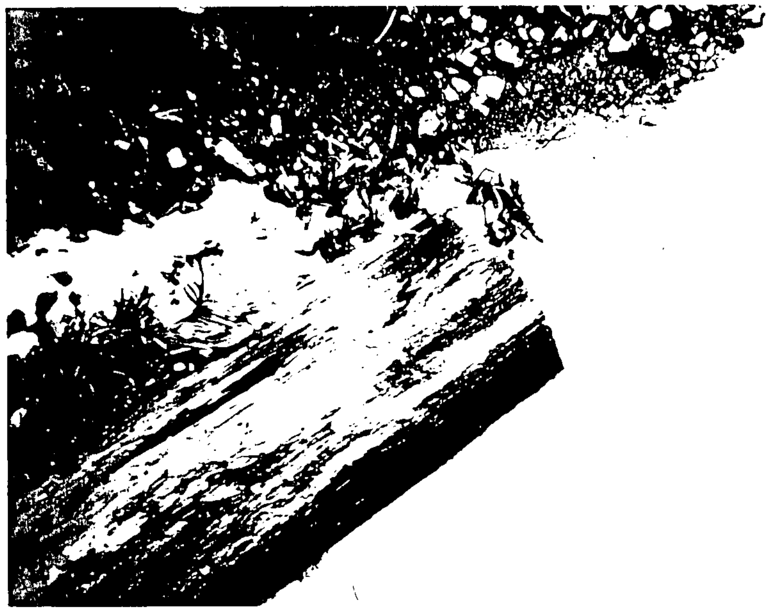


Photo 5. An enlarged section of the previous photo shows the mixing of sediment into Jacoby Creek from the logging landing (March 1971).

Photo 6. A massive rock and mud slide feeds directly into Jacoby Creek. Note the mud line on the redwood trees. A rivulet in this stretch carried more than 2000 mg/l of suspended sediment into the main channel (March 1971).

CHAPTER V

DESIGN AND METHOD OF STUDY

Ten storms totaling a period of 40 days and 40 nights occurred during a 14-week period. The collected data were sufficient to produce the necessary range of data and generate an accurate confidence level of analysis.

Actual field work commenced January 12, ending May 3, 1971. This time allowed 20 separate periods of data collection for a total of 211 sediment samples.

Description of Sampling Stations

Twelve original points were chosen from which to gather data. These sampling stations (Figure 1 and Table 2A) were selected with respect to topography, accessibility and land utilization immediately upstream as well as throughout the subwatershed unit from this point. The sampling program was not specifically designed to pin-point areas of high-sediment productivity, but rather to show change due to large land use regions and physiographic conditions.

Six of the original sampling points were selected for intensive survey. A brief description and discussion of each is tabled below. Accessibility, uniformity of stream bottom and physical setting were all major considerations used to determine the location of each sampling point.

Explanation of data symbols are: water discharge (Q), temperature in degrees Fahrenheit (T), suspended sediment sample (SSS), precipitation with the standard rain gage (PPT), and stage height (SH).

TABLE 2A

SAMPLING STATION DESCRIPTION

<u>Last Fork 1</u>: NW/4, SW/4, Section 32, T5N, R2E, HBM. Measurement at this point (Photo 7) will include 1.03 square miles of subwatershed above this station. This finger joins Last Fork 2 approximately 200' downstream. Q, T, SSS, PPT.

<u>Last Fork 2</u>: NW/4, SW/4, Section 32, T5N, R2E, HBM. Measurement at this point will include 0.78 square miles of drainage. Q, T, SSS, PPT.

<u>Last Bridge</u>: NE/4, NE/4, Section 31, T5N, R2E, HBM. This station is located a short distance downstream from the junction of the main channel (L.F. 1 & 2) and the Last Bridge A finger. Q, T, SSS.

<u>Gaging Station</u>: SW/4, NW/4, Section 30, T5N, R2E, HBM. A V-notch weir was constructed in 1955 by the U.S.G.S. Also a gaging station was erected (Photo 8). Although in disuse, Humboldt State College students were able to keep the weir area under general maintenance during the sampling period. Q, SSS, T, PPT, SH.

<u>Morrison Gulch</u>: NE/4, NW/4, Section 14, T5N, R1E, HBM. This tributary to the main stream is the only one for which discharge levels were measured. The point of measurement (at the junction of Kirkpatrick-Quarry Road and Morrison Gulch (M. Gulch) commands a 1.00 square mile area extending to the watershed boundary. Q, SSS, T.

<u>Highway 101</u>: NW/4, SW/4, Section 4, T5N, R1E, HBM. This point (Photo 9) provides measurement of final discharge level and sediment load for Jacoby Creek Watershed before discharging into Humboldt Bay. Q, SSS, T, PPT.

The remaining stations were established for various specific purposes and are described in the appendix.

Water Discharge Measurement

Once the station location was determined, a corrugated metal stake was driven into the opposite bank. A two-fold purpose, that of permanent location and of attachment of cloth tape for width measurement, was effected. Further, the stake location insured exact duplication of position during the sampling sequence.

Cross section measuring points across the width of the stream were made every 3.0 feet from shore to shore. A

Photo 7. The Price Current Meter is used to compute discharge. At Last Fork 1, the depth is being determined from the wading rod (February 1971).

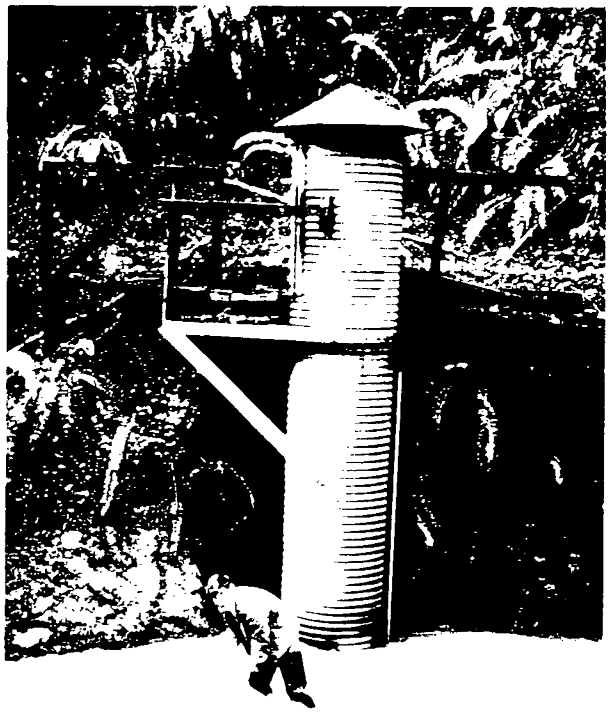


Photo 8. The U.S.G.S. Gaging Station offered an excellent sampling point (March 1971).

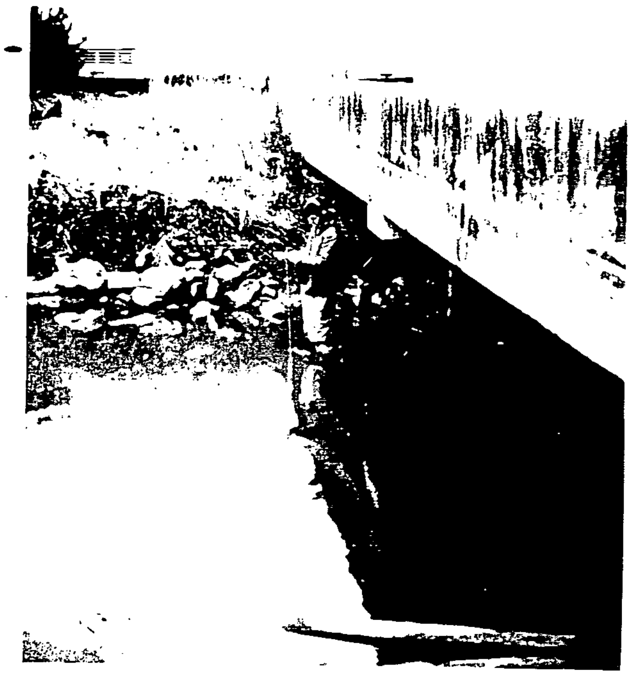


Photo 9. Looking south at the Highway 101 sampling station on Jacoby Creek (March 1971).

Photo 10. The wading rod, fin and propeller of the current meter in Jacoby Creek are needed to determine the volume of water discharge in cubic feet per second (April 1971).

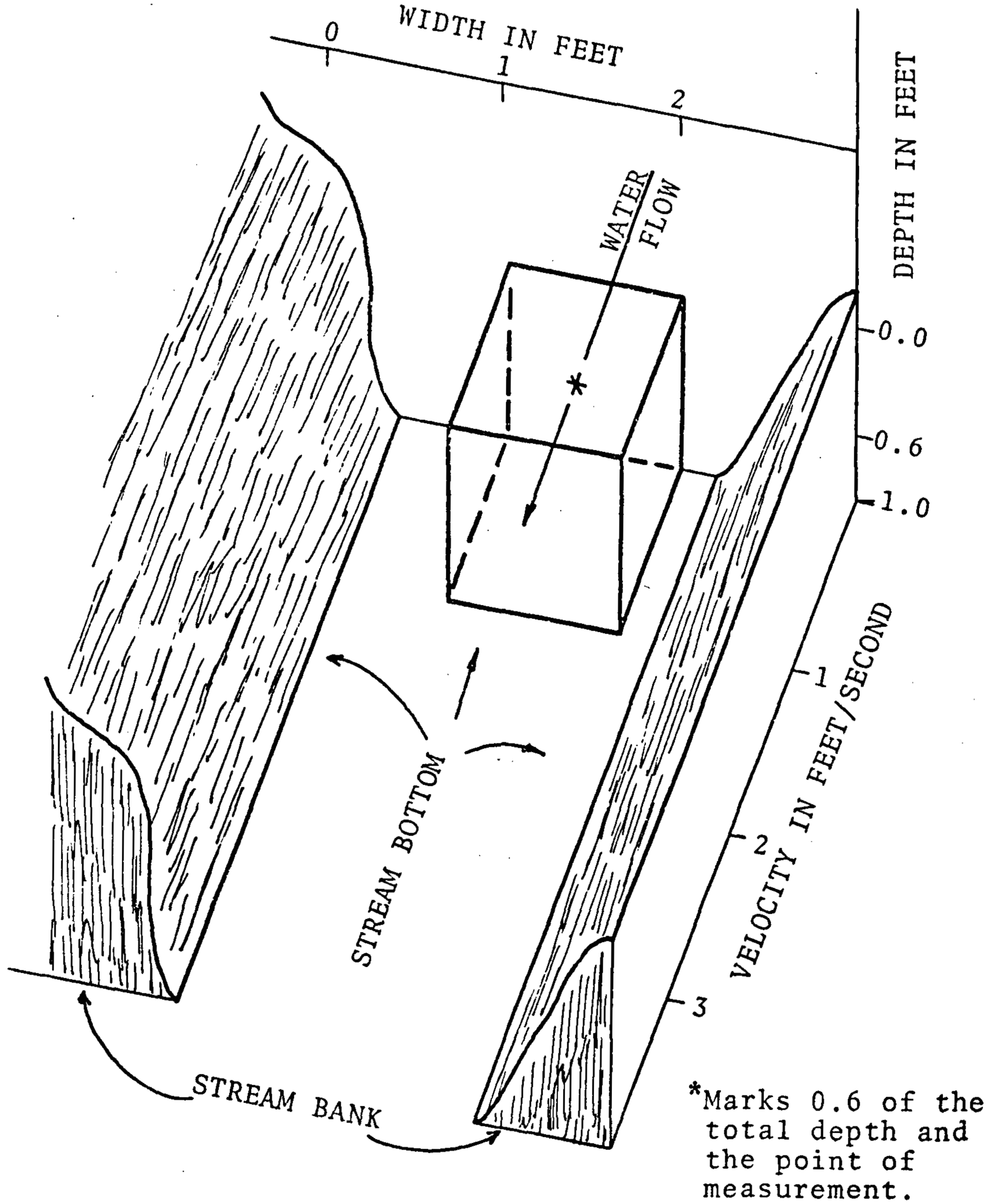
cloth tape was strung between two stakes to facilitate this procedure. At each 3.0-foot interval, the depth and revolutions per second were determined with the Price Current Meter. Current Meter # 822 (Photo 10) was utilized to gather data needed to calculate water discharge in cubic feet per second (cfs). Depth was ascertained via direct readings as measured with the wading rod. It is marked into tenths of feet, with depth estimation to the nearest half tenth (0.05'). Speed of flow was read from the tabular values based on the number of seconds/revolution of the propeller. As the propeller revolves it breaks the contact which is maintained with a small pocket battery. A set of headphones is provided for exact count of the revolutions ("clicks"). Effective for slow flows was the 1-click-per-revolution, while high velocity flows were more easily measured with the wire fastened to the 1-click-per-5-revolutions terminal. A stop watch is used to record time to 1-second precision.

Area in square feet of each measuring point was calculated as a product of width and depth (Figure 4). Velocity in feet per second times area in square feet produced water discharge in cfs. A 2% reduction of obtained values is necessary when using the wading rod. A theoretical flow chart is illustrated on page 29 showing the necessary computations. Tabulation of water discharge volumes is listed in the appendix.

Disadvantages

The Price Current Meter comes equipped with a tail fin needed to stabilize the rod and propeller during rapid flows. However, in shallow water the fin hits the bottom, causing the wading rod to be tilted, throwing a possible error into the readings. Removing the fin helps during slow flows, but fast low flows remain a problem.

High turbulent flows create a vast amount of drag on the operator, representing a certain amount of danger. Doubled readings for checks were not obtained under these extreme conditions.



(Depth in feet)(width in feet)(Velocity in ft/sec.) = 1 CFS.

FIGURE 4. Theoretical Spatiotemporal Average Flow (as determined by the Price Current Meter)

Weather Data Collection and Measurement

The three standard rain gages spaced along Jacoby Creek's main channel (Photo 11) were used to calibrate storm activity as recorded at more elaborate weather stations being operated at Eureka Post Office and Humboldt

Photo 11. Humboldt State College standard rain gage located near Last Forks 1 and 2. Actual distance away from logs allows for proper rain collection (January 1971).

State College (forestry building). Storm data for the three standard rain gage locations were calibrated as follows.

Highway 101: Standard rain gage, Eureka and Humboldt State College weather data were weighted 5.0, 2.28 and 1.0, respectively. The weighted values were determined directly as a function of horizontal distance in miles to the Jacoby Creek measuring station.

The theory of antecedent precipitation was used to adjust the available data. A single storm will produce a certain quantity of runoff. However, if rainy weather has preceded this storm, ground saturation may be near capacity, small reservoirs may be full, and potential evapotranspiration will be low. Under these conditions, resulting runoff will be boosted by an unknown amount, and the storm will certainly produce a larger quantity. To examine Q as a dependent function of precipitation for the duration of the total storm requires an estimate of previous rainfall. This estimate may be obtained with the use of the antecedent precipitation index. This index includes a proportionate part of previous precipitation divided by the length of time that has passed since the rain, in addition to the daily rainfall. It is computed by Formula I.

Formula I: $Pa = \sum bP_t$ where $b = \frac{1}{t}$,

t = time in days,

P = precipitation, and

Pa = antecedent precipitation.

Example: $Pa = \frac{1}{6}(2)+\frac{1}{8}(1)+\frac{1}{10}(4)$

$Pa = 0.56''$ The newly expected rainfall is boosted by this amount. $\frac{1}{10}(4)$ means that a 4" rain occurred 10 days ago.

Since the weather data for Eureka is tabulated by the hour, this hourly amount was used to prorate the precipitation for all standard rain gage points. The following procedure was used: A correction factor (quotient of: sum of weighted value of each standard rain gage station and sum of Eureka data) was used to adjust the Pa (antecedent precipitation index) obtained from the Eureka weather data breakdown.

Pa for gaging station and L.F. 1 and 2 (both rain collecting points) was determined by a similar process, the one discrepancy being the time lag. No time lag existed at Highway 101, because the data used from Eureka were for the same hour as the sample taken at Highway 101. However, this is not true for the other standard rain gage collecting points. The precipitation at those points is prorated to the time at which the Highway 101 measurement was made by the following process. Accurate time measurements were marked at every station.

Sum of gaging station rainfall = 11.87"
Sum of Eureka rainfall data = 6.85"

therefore:

Unadjusted correction factor: $\frac{11.87''}{6.85''} = 1.73$ for gaging station.

Time lag determination: The real amount of rainfall at 5:50 p.m. (the time of measurement at Highway 101) is unknown for gaging station, since the measurement at this station was 5:05 p.m. For each measurement the time difference (difference between the time I collected the sample at gaging station and time used from the Eureka data) was determined, and the weather data at Eureka were checked to determine the resulting difference in precipitation on an hourly basis. A rainfall equivalent based on time lag (perhaps better described as a rain lag) between these two points can be calculated by Formula II.

Formula II:

$$\frac{\text{Sum of PPT at gage sta.} - \text{Sum of Eureka PPT}}{\text{Sum (Highway 101 time} - \text{Gage sta. time, hour \& minute)}}$$

Example: $\frac{11.87'' - 6.85''}{15.82 \text{ hr.}} = +0.317$ or $+0.32''$ average rain lag.

Again let me reiterate that this rain lag will be a positive value, since the amount of PPT at gage station at 5:50 p.m. is to be determined and the time of measurement was at 5:05 p.m. To complete the correction process:

(1.73)(0.32" = 0.56" added to the sum of Gage Sta. PPT (11.87" + 0.56" = 12.43"). Repeat the correction factor process until no further change occurs:

$\frac{12.43''}{6.85''}$ = 1.82 temporary correction factor.

(1.82)(0.32") = 0.58". (11.87" + 0.58" = 12.45").

$\frac{12.45''}{6.85''} = 1.82$ There is no change from the temporary correction factor; therefore 1.82 is the new and adjusted correction factor used to modify the Highway 101 Pa to represent Pa at Gage Sta.

Example:

Highway 101 Pa for February 24, 1971, is 0.77".

(1.82)(0.77") = 1.40" Adjusted Pa for February 24, 1971, for 5:50 p.m. at Gage Sta.

The percent difference created by the above-described adjustment was computed to be 3-5% and is on the conservative side. The corrected data as seen in Figures 5 and 6 are not responsible for the variance that does exist. This small adjustment would consistently raise (very slightly) the level of each curve. The data as adjusted are used throughout this discussion.

Precipitation indexing for points between standard rain gaging stations is calculated proportionate to elevational differences.

Example:

Difference in elev. from Gage Sta. to Dirt Bridge = 150 ft.
Difference in elev. from Gage Sta. to L.F. 1 & 2 = 300 ft.

Dirt Bridge correction factor: $\frac{150'}{300'} = 0.50$.

Difference between L.F. 1 & 2 Pa and Gaging Sta Pa is:

(2.21 − 2.17) = 0.04".

Then: (0.04")(0.50) = 0.02" added to Gaging Sta. Pa:

(2.07 + 0.02) = 2.19" Pa for Dirt Bridge on March 23, 1971, at 11:15 a.m.

The advantages of this adjustment procedure is readily apparent while disadvantages are more subtle. Several days of continuous rainfall often occur in this watershed. To divide a previous day's precipitation in half (Formula I) may be unrealistic for Pa determination, if precipitation has been continuous. Certainly there will be no significant infiltration or evaporation. Virtually all precipitation will return in the form of runoff. An attempt was made to handle prolonged periods of nonstop rain logically.

Recording rain gages placed in close proximity to the standard rain gages would have given a more accurate picture of the rainfall characteristics and may have provided a less distorted Pa; i.e., values up to 7 miles away would not have been prorated from Eureka.

It is very difficult to accurately measure the overland flow time for a drop of water from the time it strikes within the basin until it is recorded flowing past a sampling station. The variable time is affected by soil condition, ground cover, slope, aspect, rainfall intensity, magnitude and duration.

Lag time (referred to as rain lag) computed by Formula II follows the assumption that storm activity continues for that period.

Water Temperature

A thermometer was used to record the water temperature in degrees Fahrenheit at each station. Degrees were estimated to the nearest tenth. These extraneous data were omitted, as no computations or calculations are derived from these data for this report.

Photo 12. An outside gage attached to the stilling basin was used to determine stage height at the U.S.G.S. Gaging Station (April 1971).

Stage Height Recordings

The U.S.G.S. Gaging Station offered the opportunity to record the level of water for a given flow. A 13-foot gaging rod (Photo 12) is attached to the side of the still-ing well. These "outside gage" measurements are used to determine rise and fall of water crest and predict Q in cfs. Precision to 0.01 feet was obtained.

Data for correlation of instantaneous sediment discharge and streamflow levels with stage height and movement were assessed. Statistical analysis was used to determine confidence levels for both the rise and recession side of the hydrograph as a function of other variables.

Unfortunately the station was not operational during the period of research, as this could have produced increased confidence from the long-range records. Peak flows could be pin-pointed, and stage movement could easily be detected. Over-all the latitude of this project would have been greatly enhanced.

Turbidity Analysis

Sampling techniques, as previously described on page 23, yielded 211 separate samples. Each sample was tested for turbidity in parts per million (ppm) and concentration of suspended sediment in milligrams per liter (mg/l). This is the weight equivalent of ppm. Upon analysis examination of the relationship between turbidity and concentration is possible.

Turbidity analysis was accomplished by the Hellige Turbidimeter. This instrument measures the cloudiness or opaqueness that is present due to the amount of suspended material in solution. The observer optically discerns the point at which a particular sample allows light to pass through it. This point is manually scaled to a simple numerical reading. This numerical value is then converted to ppm from a rating chart for the particular sample volume and power of light bulb used. Many samples were too cloudy to be accurately scaled. All such solutions were diluted 10 parts of distilled water to 1 part of sample solution. It is imperative in such dilutions that a representative part of the sample is obtained. This is believed to have been accomplished by a lengthy mixing process (shaking) and then rapidly measuring out the desired quantity for dilution. The diluted solution scale reading from the turbidimeter was matched to the rating chart and a "watered down" ppm reading was obtained. The product of this value and the original dilution factor was used to acquire an accurate turbidity reading. The results are summarized in the appendix.

Suspended Sediment Sampling Techniques

For those stations indicated on page 10, a suspended sediment sample was collected for turbidity and concentration analysis. Open top sampling jars were used to quickly obtain the water-sediment mix usually at the stream centerline. Wide sections near the delta of Jacoby Creek that might vary between two or more points of the cross section were examined. Repetition of samples indicated no significant difference across the section until the depth and speed were reduced, as found near the shore. The suspended sediment sample was capped and labeled for laboratory analysis. It is interesting to note that Fredriksen (1970) regards this sampling technique as erroneous. The error "is systematic in that openmouthed bottles underestimate the true concentration carried by the stream." It is believed that results pertaining to sediment discharge are conservative.

This instantaneous method of data collection is an easy-to-execute and inexpensive program designed to furnish a large amount of workable basic information.

Analysis by weight involved the use of precise direct reading mettler balance scales. Each sample was weighed in totality (jar plus contents) to the nearest hundredth of a gram. Also for each sample one piece of filter paper was coded and weighed to the nearest 0.001 gram. After the filtrate was removed from the water-sediment mix, both the filtrate on the filter paper and the empty jar were oven-dried at 100° F. and reweighed to the nearest 0.001 gram (Photos 13 and 14). The difference

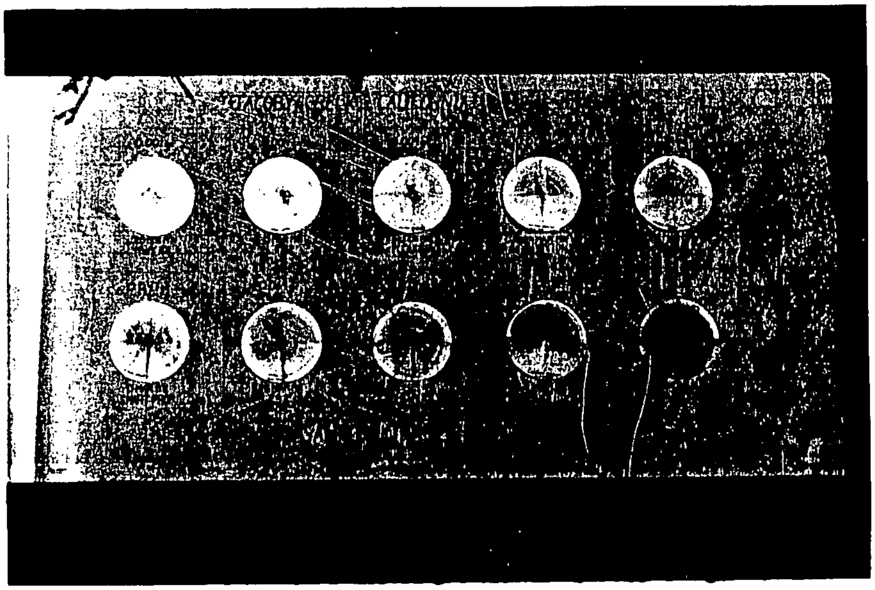


Photo 13. Sample filtrates showing various dry weight suspended sediment concentration (mg/l) for Jacoby Creek (July 1972).

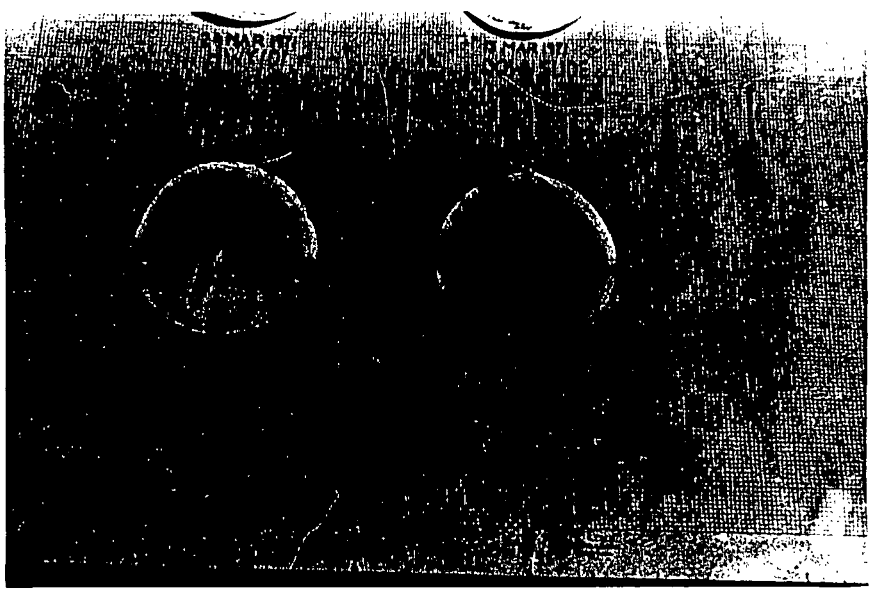


Photo 14. Close-up showing dried filtrate and paper. Dry weight is used to determine concentration in the laboratory (July 1972).

between the weight of the paper and the filtrate on the paper is the weight of the collected suspended sediment.[1] The weight of the oven dry jar subtracted from the original total weight leaves the total weight of water and sediment combined. Another subtractive process now reveals the water weight. Dividing the sediment weight by the water weight yields mg/l of concentration of sediment by weight.

Example:

Total weight of sample (jar + contents)	173.120	grams
Weight of jar after oven dried	− 77.547	gr
Weight of water and suspended sediment	95.573	gr

Oven dry suspended sediment sample + filter weight	0.793	gr
Weight of the filter paper	−0.781	gr
Weight of suspended sediment sample (oven dry)	0.012	gr

Weight of water and suspended sediment	95.573	gr
Weight of oven dry suspended sediment	− 0.012	gr
Weight of the water in sample	95.561	gr

$$\frac{\text{Weight of oven dry suspended sediment}}{\text{Weight of water in sample}} \quad \frac{0.012 \text{ gr}}{95.561 \text{ gr}}$$

= 125.57 mg/l of suspended sediment, at Dirt Bridge on March 20, 1971.

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[1]Oven drying was a problem. To overcome this, several tests were performed to determine the time and temperature needed to thoroughly dry the sample. Most important was determining the length of time at room temperature needed for the filter paper to regain its original weight. Pilot studies indicated that 10 oven drying minutes required 30 minutes at room temperature to regain the original moisture content as measured by weight.

Turbidity and Concentration Method Comparison

The turbidimeter is incapable of properly accounting for small bits of gravel and rocks that may have been collected. Pilot tests show no difference between a sample with small rocks (1 mm - 5 mm in diameter) or the same sample with the rocks removed. In reality this test shows a ppm reading of only the sediment and particulate that will readily remain in suspension and is not capable of accounting for larger particles. Turbidity measurements must not be confused with sediment concentration, although a relationship will be shown to exist.

As expected, the concentration value (mg/l) for the above-mentioned sample was considerably larger. However, concentration calculation by weight is not a complete measure of water quality either. A sample that contains a large quantity of very fine silts cannot be completely filtered out. Several such samples were noted. Repetition filtering was ineffective as a solution. The reading determined for each sample, however, will be extremely close to the actual weight in spite of the cloudy condition of the water.

CHAPTER VI

DATA COMBINATION RESULTS AND DISCUSSION

Missing Data Prediction

There were times when it was physically impossible to gather necessary measurements. At very high flows, discharge data could not be obtained by methods previously described. Knowing exactly when the stage crest passes a point may be difficult to ascertain unless around-the-clock vigilance can be maintained. Night-time measurements (Photo 15) had a wild set of troubles of their own, and they are only known to any researcher who might venture forth on the darkest of nights alone. Curious wildcats, images of Big Foot, steep muddy roads, a malfunctioning flashlight, unseen floating logs and the like have a tendency to produce questionable data at times.

A measurable value exists for the occurrence of sediment in a stream and various discharge levels. A direct correlation between mg/l of suspended sediment, turbidity and Q was noted. Concentration and Q values were examined in the form of simple linear logarithmic regression [$\log Q = a + b(\log C)$] to produce cfs for times when it could not be obtained. It must be kept in mind that this method was utilized only to predict the value of a missing point.

Photo 15. Night-time measurements had a wild set of troubles of their own . . . (March 1971).

The Influence of Precipitation

As previously stated, rainfall data have been derived in terms of Pa. Using the data obtained, it is difficult to consistently isolate the influence that precipitation has upon concentration (mg/l), discharge levels or the sediment transport rate. However, the derived Pa index did show a highly significant association with turbidity values for all stations surveyed.

Concentration (mg/l) as a function of Pa. A highly significant relationship between sediment concentration and Pa is lacking for all stations. Computed statistical parameters for this function/station are listed in Table 2.

TABLE 2

SEDIMENT CONCENTRATION AS A FUNCTION OF PRECIPITATION

Station	r^2	r	F	df	Probability (in percent)
Last Fork 1	0.509	0.714	16.67	16	1
Last Fork 2	0.176	0.420	3.22	15	G.T. 5*
Last Bridge	0.163	0.404	3.12	16	G.T. 5
Gaging Sta.	0.881	0.940	128.78	17	1
Highway 101	0.612	0.783	28.52	18	1
M. Gulch	0.247	0.497	4.92	15	G.T. 5

*Greater than 5% and not acceptable. All statistical symbols are those used by Snedecor and Cochran (1968).

As can be seen above, this relationship is either "hot or cold" with no apparent explanation for this sporadic behavior. Because of uncertain statistical and plotting correlation, another method, that of grouping the data, was employed to determine if a more consistent relationship could be obtained. Grouping data by classes tends to minimize discrepancies, yet only a general picture of increased concentration (mg/l) with increased rainfall is evident.

Six class intervals were utilized in this breakdown. Plotted values were weighted by the number of samples in the corresponding class interval. The disparity of the plotted coordinates that does exist is interpreted as those factors which slow the movement of sediment-laden rivulets and keep them from reaching the stream channel at the same instant as the raindrops striking the channel itself. A third method, that of log log curvilinear form was tested (Fig. 5). Variance was again optically dominating, and no further data were derived. It is evident that this program does not correlate these variables with any degree of confidence. There is, of course, the possibility of preparing the data to show less significant difference.

Water discharge as a function of precipitation. Plotting precipitation and discharge levels at any point in time is difficult without a series of samples taken at hourly intervals. (Perhaps even shorter time increments would be necessary.) To obtain the most reliable relationship, based on the method used to obtain data, total discharge for any given storm should be related to the total rainfall received. This, of course, eliminates problems inherent with point sampling. However, instantaneous results based on the antecedent precipitation index have resulted in a reasonably good relationship.

Q as a function of Pa was test-plotted with Pa portrayed both linearly and logarithmically. As a linear function, variance among sampled data proved to be dispersed to the point of visual confusion. On the log log scale (Fig. 6), a closer appearing relationship is seen in

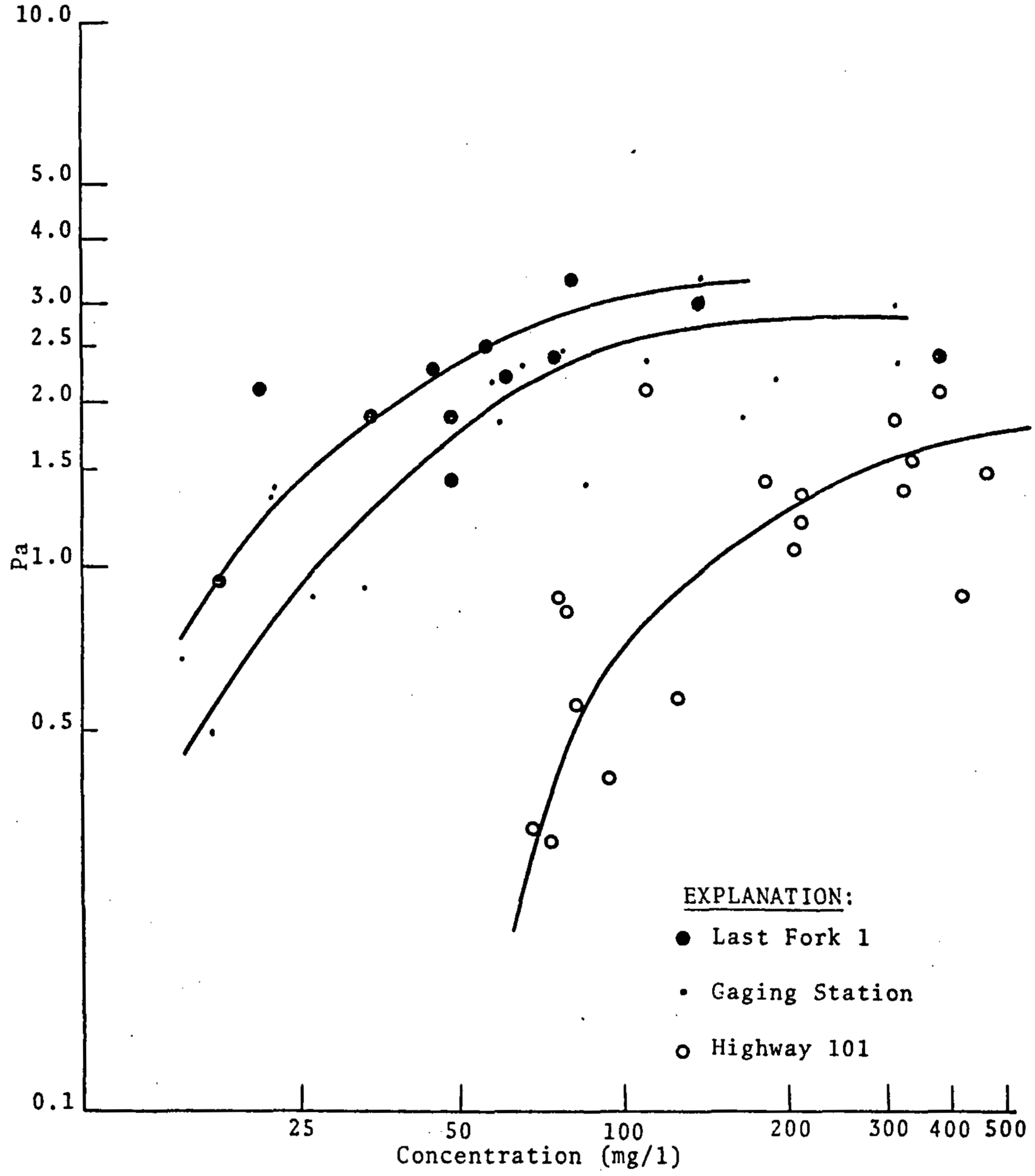
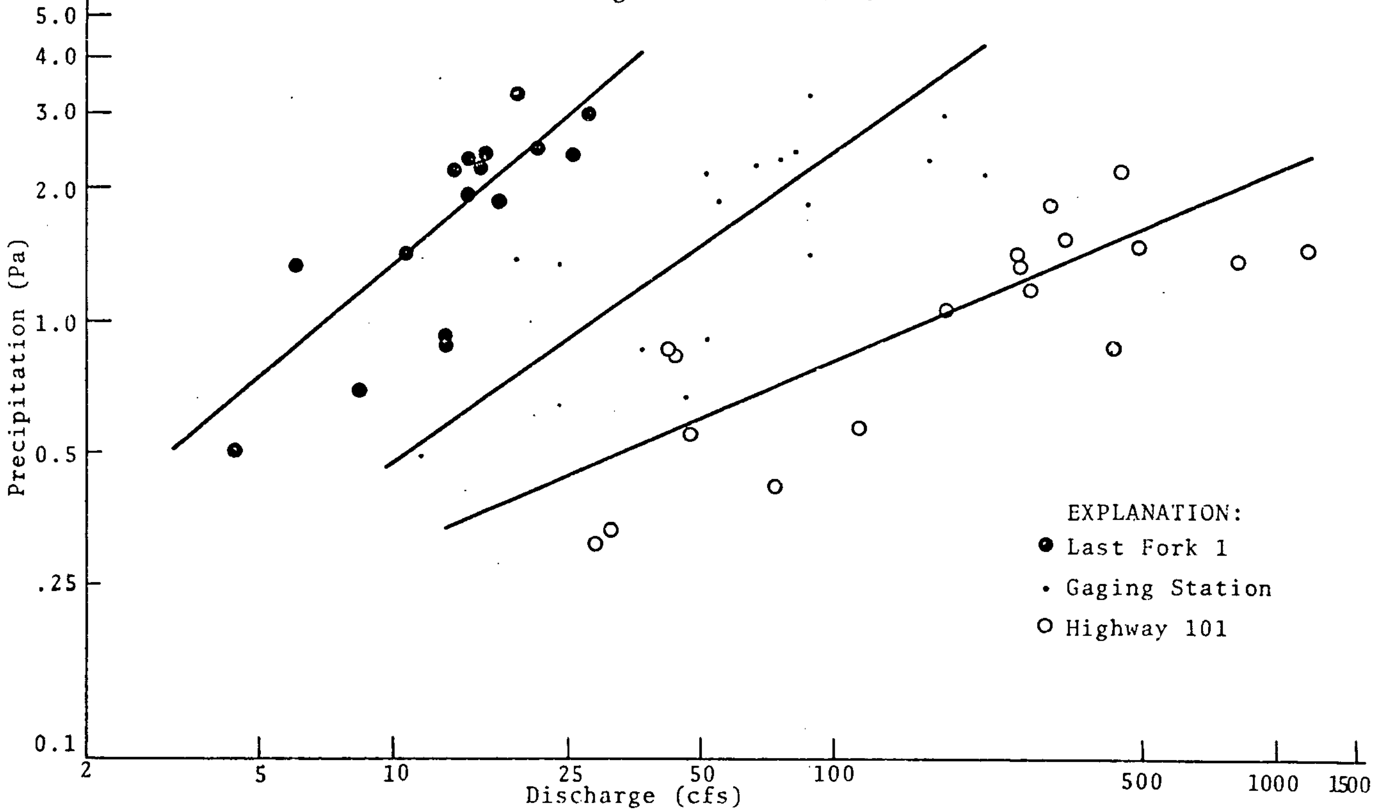


FIGURE 5. Concentration (mg/l) As a Function of Pa

FIGURE 6. Discharge as a Function of Pa



terms of a regression curve. This (as with mg/l as a function of Pa) shows a consistent curve for Last Fork 1, Gaging Station and Highway 101 sampling stations. Furthermore, results indicate that a good correlation was obtained between Pa and Q, as described in Table 3. The increasing correlation value may suggest that the design might be more reliable for larger watershed systems.

TABLE 3

DISCHARGE AS A FUNCTION OF PRECIPITATION

Station	r^2	r	F	df	Percent Significance
Last Fork 1	0.211	0.460	4.29	16	G.T. 5
Last Fork 2	0.412	0.642	10.51	15	1
Last Bridge	0.453	0.673	13.23	16	1
Gaging Sta.	0.541	0.736	20.05	17	1
Highway 101	0.620	0.787	29.32	18	1
M. Gulch	0.711	0.843	36.90	15	1

Concentration of Sediment as a Function of Water Discharge

The correlation between mg/l of suspended sediment and water discharge is probably the most important interaction in this study, considering that these two variables will be combined to compute sediment discharge and sediment transport curves.

Graphical description of the sediment concentrations to discharge relationship is shown in Figures 7, 8 and 9. Statistical interpretation complete with confidence levels are listed on Table 4.

Log C = 7.43968 – 10+(3.55011) log Q

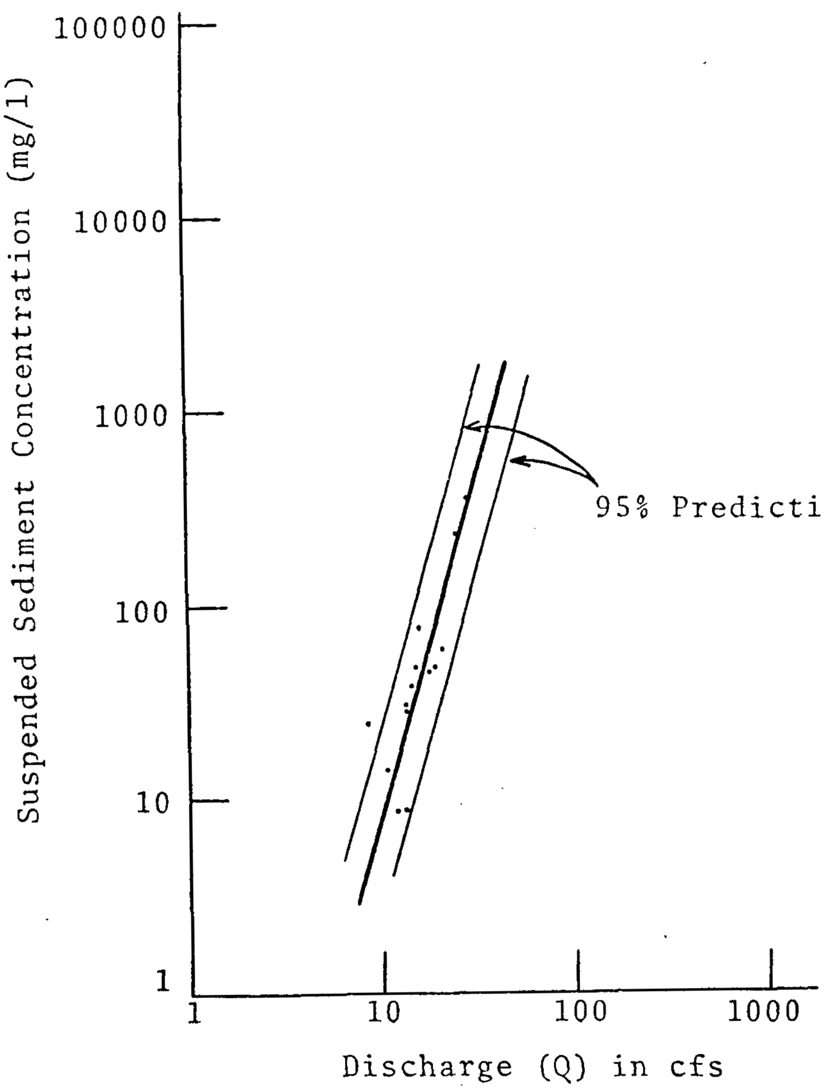


FIGURE 7. Instantaneous Concentration (mg/1) as a Function of Discharge (Q) for Last Fork 1, Jacoby Creek, Calif., January-May 1971.

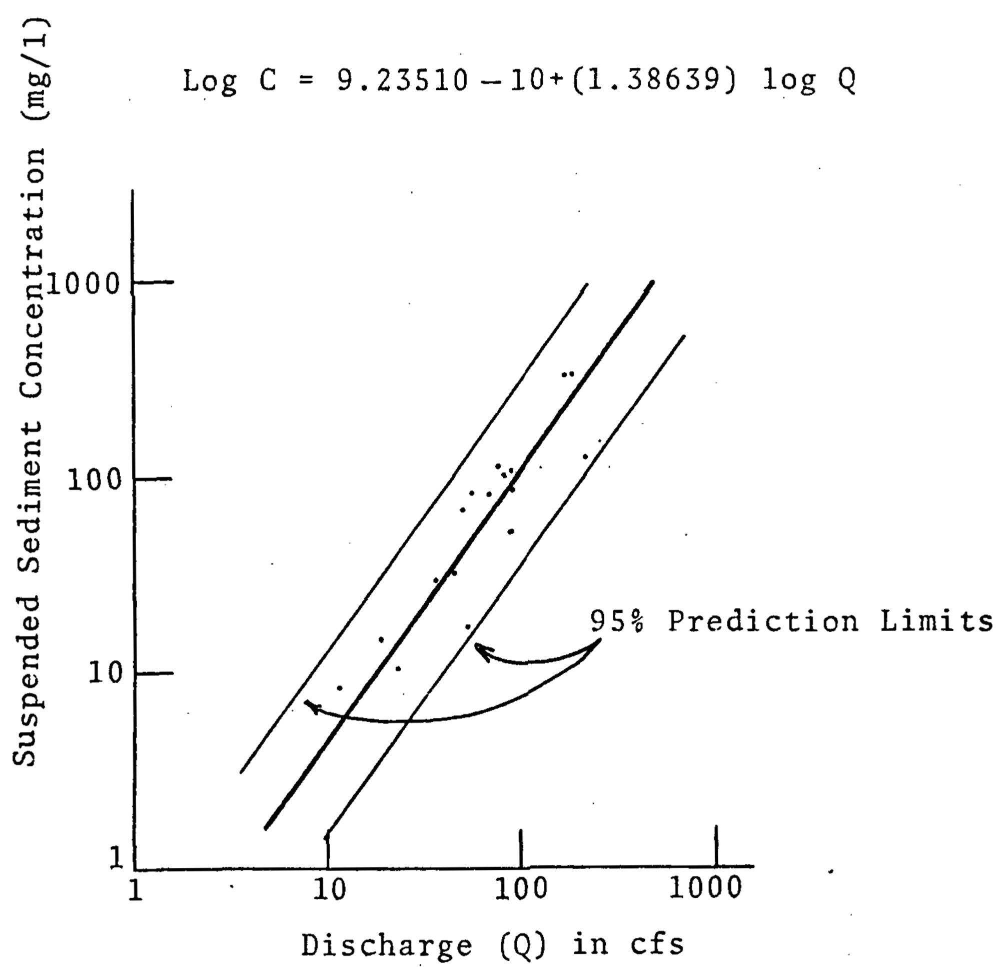


FIGURE 8. Instantaneous Concentration (mg/l) as a Function of Discharge (Q) for Gaging Station, Jacoby Creek, Calif., January-May 1971.

Log C = 9.94983 −10+(0.97809) log Q

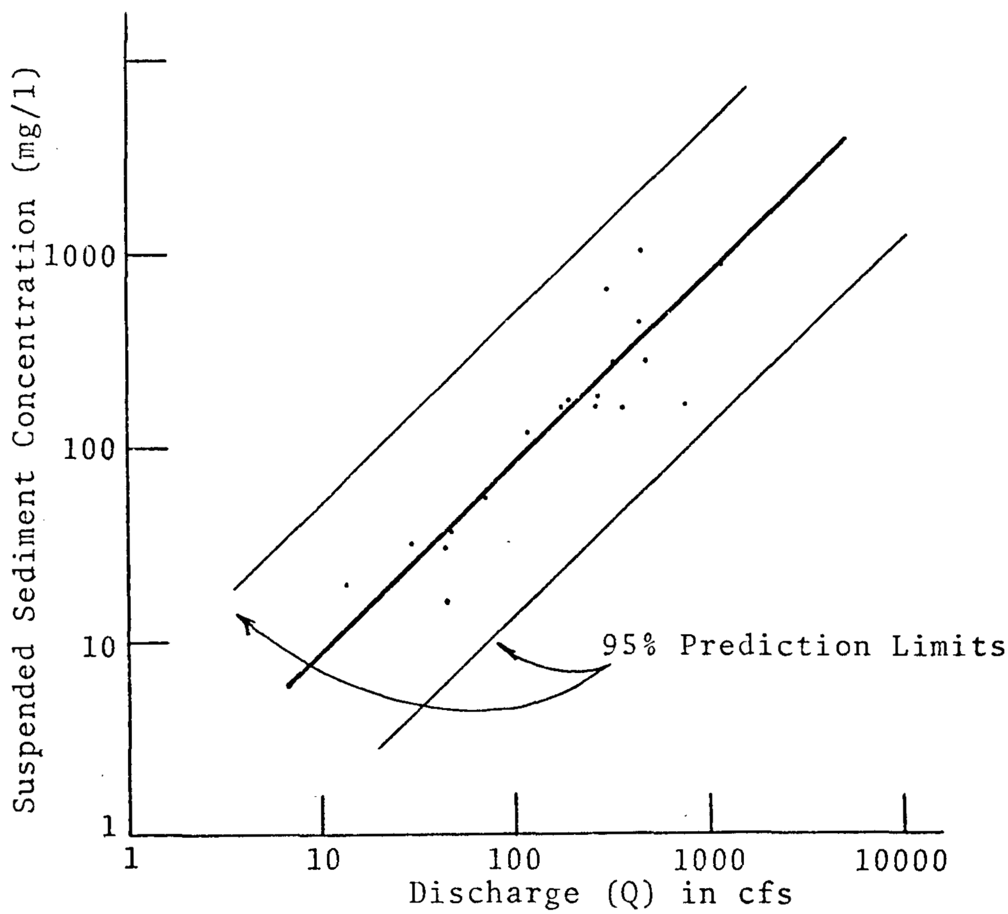


FIGURE 9. Instantaneous Concentration (mg/l) As a Function of Discharge (Q) for Highway 101 Jacoby Creek, California, January-May 1971.

TABLE 4

CONCENTRATION OF SUSPENDED SEDIMENT
AS A FUNCTION OF DISCHARGE

Station	r^2	r	F	df	Probability (in percent)
Last Fork 1	0.372	0.610	9.48	16	1
Last Fork 2	0.363	0.602	8.56	15	5
Last Bridge	0.619	0.787	25.95	16	1
Gaging Sta	0.609	0.780	26.42	17	1
Highway 101	0.510	0.714	18.72	18	1
M. Gulch	0.622	0.788	24.62	15	1

With the single exception of Last Fork 2, all stations show a significant correlation at the one percent level.

Sediment Transport Curve Derivation

With good correlation of completed data, computation of the hourly sediment load was made. Due to the relatively small suspended sediment yield, pounds/hour/square mile (#/hr./sq.mi.) rather than tons/day/square mile was determined for Jacoby Creek Watershed.[2]

The ratio of milligrams/kilogram to mililiters/liter is very nearly equal up to 15,000 milligrams. This relationship is considered to be direct for this study and is expressed in mg/1.

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[2]For quick comparison with tons/day/square mile, multiply this sediment load by a $\frac{\text{24 hours/day}}{\text{2000 pounds/ton}}$ = 0.0120 conversion factor.

Conversion of data to #/hr./sq. mi.:

1 cubic foot = 28.316 liters
and 1 liter = 1 kilogram by weight and volume at 4° C.

1 cubic foot = 28,316 grams

Temperature corrections were not applied to this project.

Discharge calculated in CFS:

(CFS)(28,316 grams) = grams/cubic foot/second ($gr./ft.^3/sec.$) of water.

then:

Formula III(a): $$\frac{(gr./ft.^3/sec.\ of\ water)(measured\ mg/1\ of\ suspended\ sediment\ in\ grams)}{one\ million}$$

= grams of suspended sediment (SS) per second.

then:

$$\frac{gr.\ of\ SS/sec}{453.6\ gr/lb.} = \text{pounds/second (\#/sec.)}.$$

(#/sec.)(3600 seconds/hour) = pounds/hour (#/hr.) of sediment.

$$\frac{\#/hr}{square\ miles} = \text{pounds per hour per square mile.}$$

Formula III(b): $$\frac{(CFS)(PPM)(0.2247302)}{square\ miles}$$

= pounds/hour/square mile.

Sediment load per square mile as a function of Q will generate a straight line relationship on log log paper (Brown and Ritter 1970). Similar logarithmic slopes were obtained for each station sampled. This suggests that like field conditions exist. The simple reproducibility of data for different stations on Jacoby Creek enhances the reliability of this relationship. These sediment transport curves are produced in Figures 10, 11 and 12 for the three

$$\text{Log } S = 7.40241 - 10 + (4.10182) \log Q$$

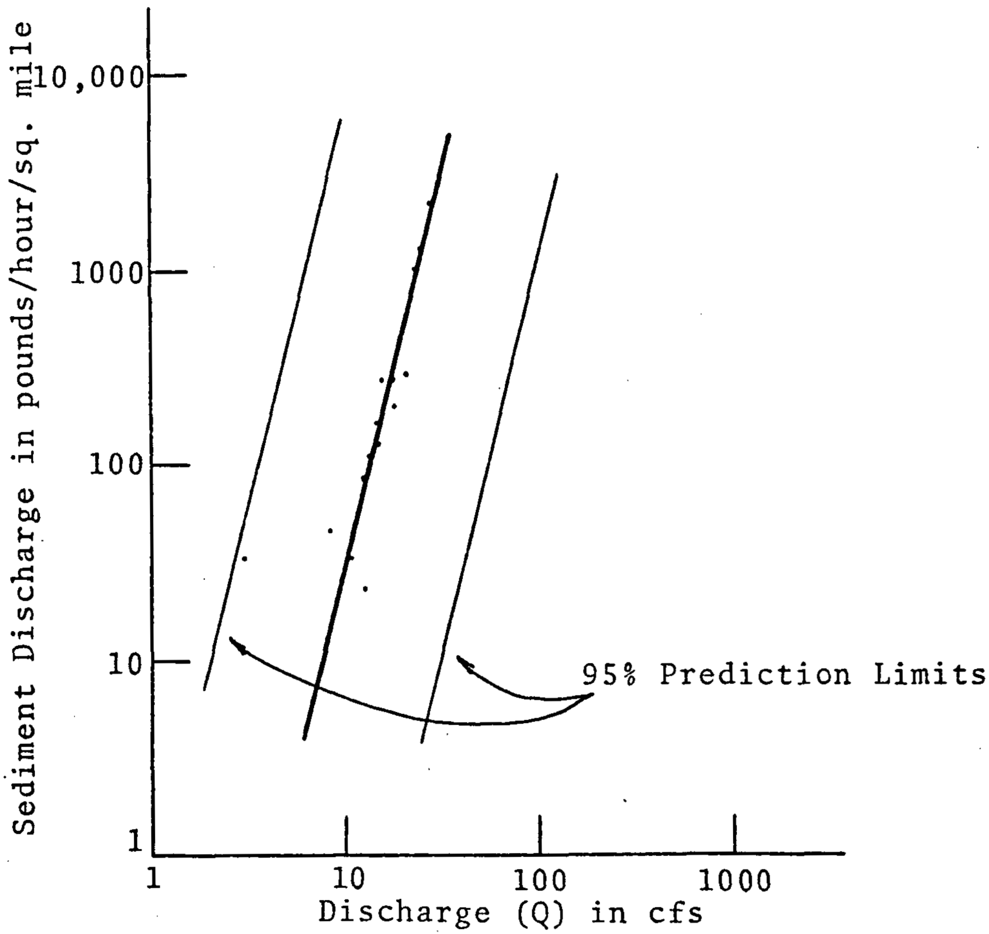


FIGURE 10. Sediment-Transport Curve for Jacoby Creek at Last Fork 1 for January to May 1971.

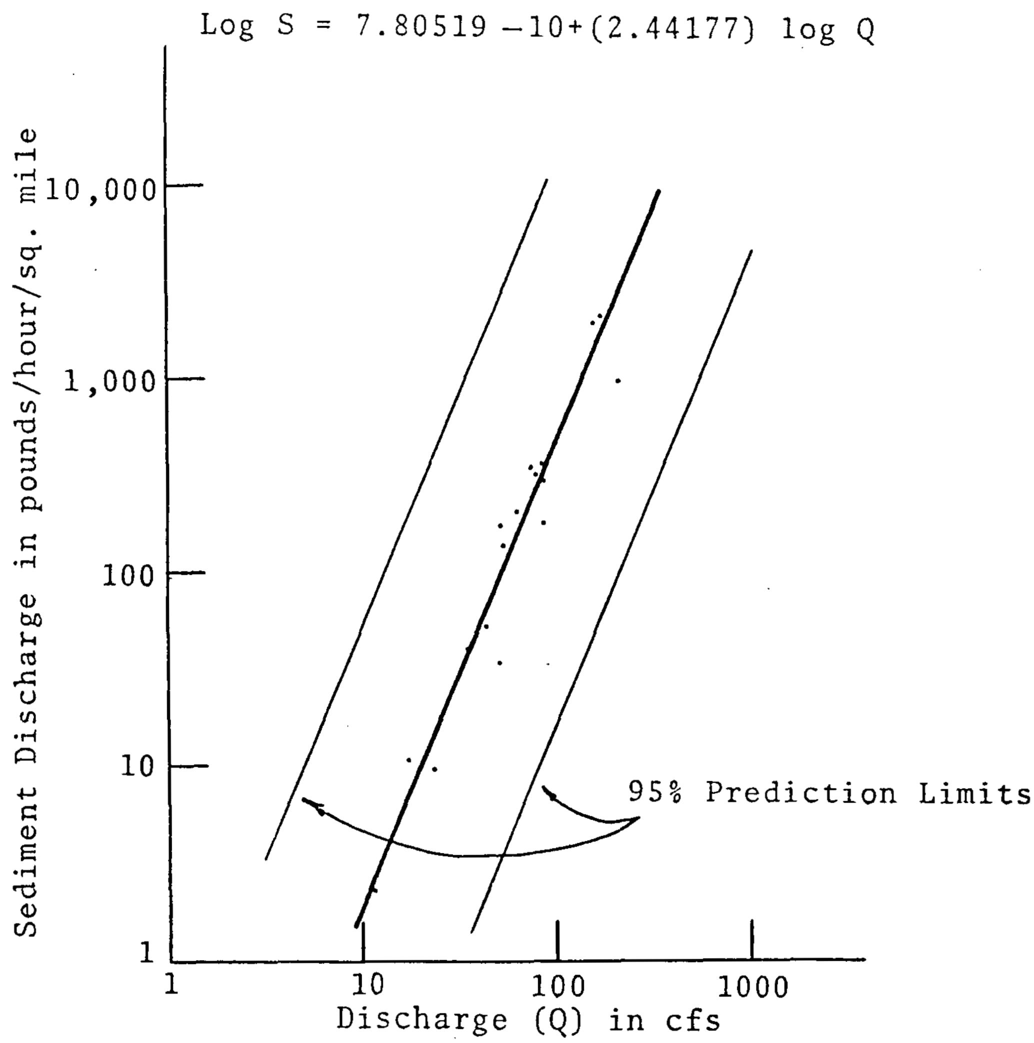


FIGURE 11. Sediment-Transport Curve for Jacoby Creek at U.S.G.S. Gaging Station for January to May 1971.

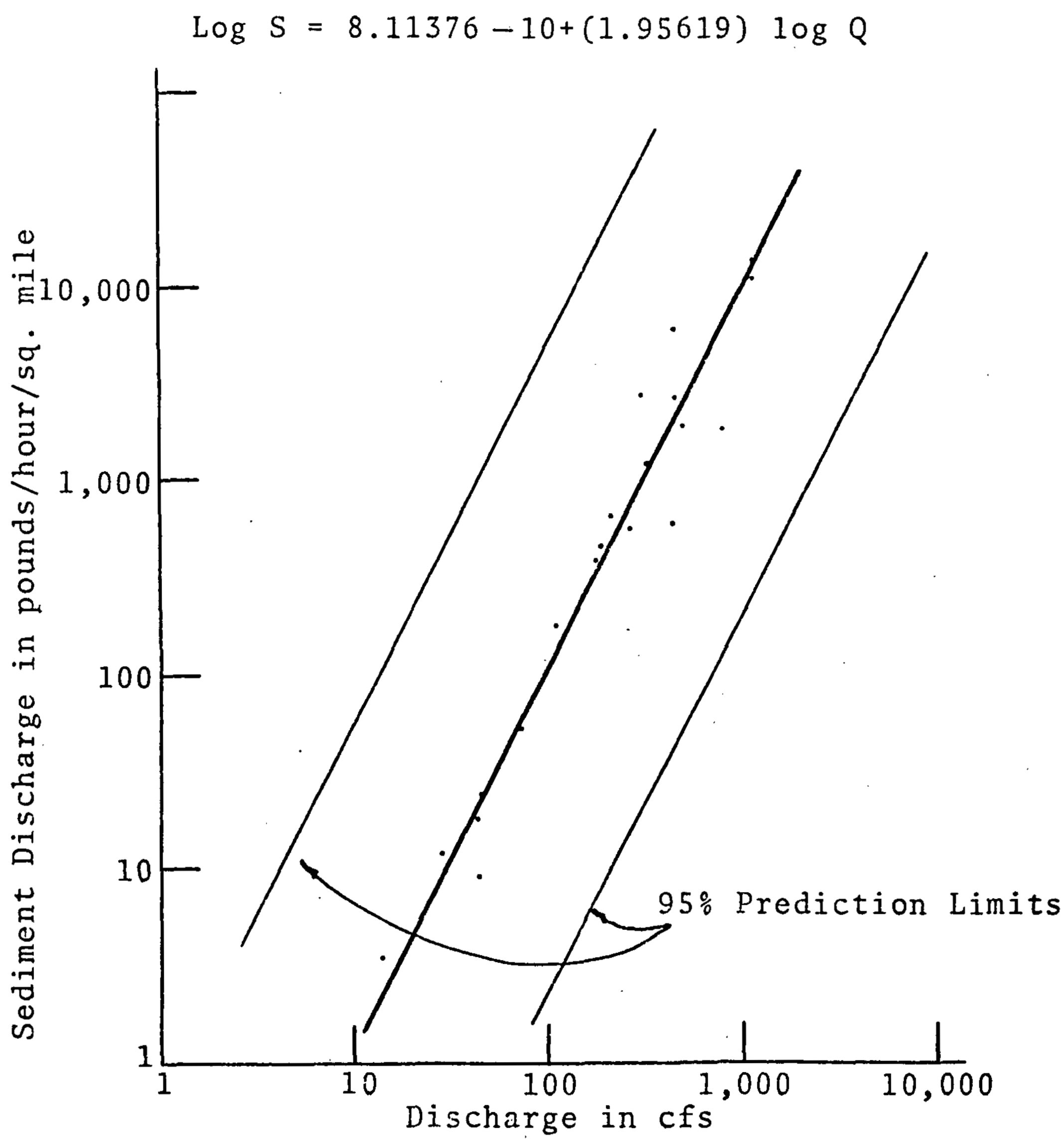


FIGURE 12. Sediment-Transport Curve for Jacoby Creek at Highway 101 for January to May 1971.

major stations located on the main channel. The data obtained and used to develop these transport curves may be found in the appendix. Formula III(b) was employed to compute pounds/hour/square mile. Statistically, good correlation has resulted with all stations significant at the 1% confidence level as noted in Table 5.

TABLE 5

STATISTICAL RESULTS FOR SEDIMENT TRANSPORT CURVE AS A FUNCTION OF Q

Station	r^2	r	F	df	Probability (in percent)
Last Fork 1	0.484	0.695	15.00	16	1
Last Fork 2	0.460	0.679	12.80	15	1
Last Bridge	0.739	0.860	45.40	16	1
Gaging Sta.	0.774	0.880	58.33	17	1
Highway 101	0.758	0.871	56.43	18	1
M. Gulch	0.760	0.872	47.46	15	1

Illustrated graphically, Last Fork 2 produces a transport curve very similar in slope and elevation to that of Last Fork 1, as does the slope and elevation of Smart Property station data to Highway 101 values. Neither of the aforementioned stations are reproduced here due to this similarity. Morrison Gulch data results in a lower slope than any other sampling point. A relatively flat slope indicates the capacity to carry sediment is increased only by a greater increase in water discharge as compared to the other sampling stations. Physically, the condition is relatively stable. The steeper slope indicates that a small increase in Q did carry a larger quantity of sediment concentration with it (unstable conditions).

Sediment transport curves need accompanying instructions. Jacoby Creek is a dynamic drainage unit. What happened in the spring of 1971 may never be duplicated again. Unless destructive activity ceases, no consistent predicability or watershed recovery is foreseen. In heavy landslide areas, recovery remains a very remote and academic discussion.

If conditions were able to stabilize, a short-term study of less than one year (as this project) is subject to seasonal restrictions. Wilson (1971), commenting on a paper authored by A. Rango (1970) reminds us that "most rivers show a seasonal pattern of sediment yield variation in relation to climatic factors." Jacoby Creek Basin experiences arid summers and a 9-month rainy season. Other factors held constant, increased sediment yield is expected annually with the first fall storms.

The Influence of Stage Movement

Group regression comparison procedures were followed to determine if slope and elevations were significantly different due to stage movement for the measured variables. These comparisons could only be examined at Gaging Station as stage movement was not recorded at any other station.

The relationship of stage height to water discharge is an important combination and needs to be carefully defined. If a good correlation does exist, a lot of work can be eliminated by simply measuring the stage height with an automatic stage recorder.

The primary calibration was made from current meter measurements and instantaneous stage height recordings. First it was necessary to determine if there was a significant difference between the rising and receding stage as a function of Q. Separate regression analysis was employed for observation, with results summarized in Table 6 and graphed in Figure 13.

Correlation results indicated that further analysis could be worthwhile. Group regression indicates that no significant slope or elevation difference occurred at the 5% confidence level.

TABLE 6

JACOBY CREEK GAGING STATION STAGE HEIGHT AS A FUNCTION OF Q

Stage Movement	F	df	r^2	r	Probability (in percent)
Rising	16.51	5	0.785	0.886	1
Recession	58.57	10	0.852	0.852	1
Combined Movement	65.67	17	0.891	0.944	1

The relationship of sediment concentration to water discharge was compared in an identical manner, again

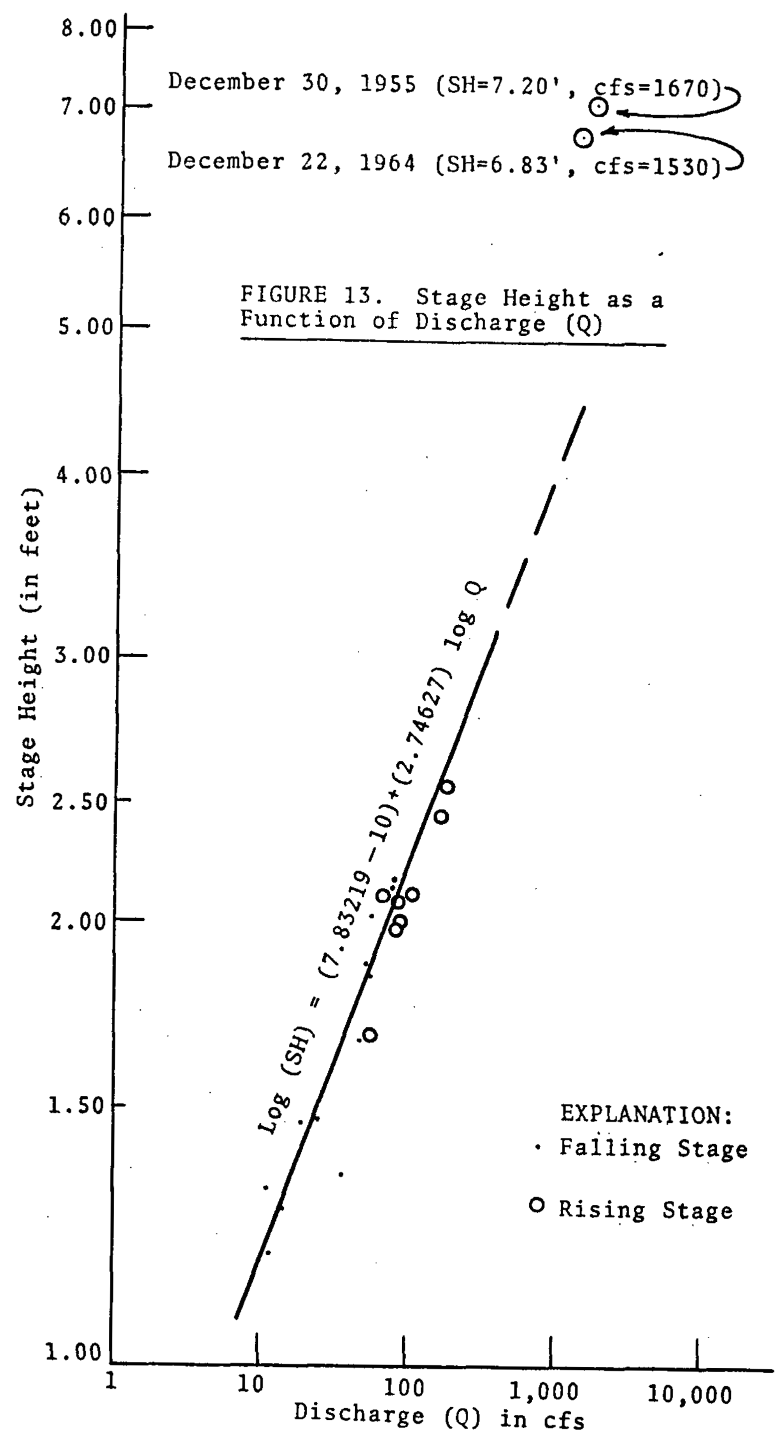


FIGURE 13. Stage Height as a Function of Discharge (Q)

showing no significant difference between the regression equations.

Inherently the above associations are naturally more sensitive than that of sediment to stage height. However, a highly significant correlation was found in the prepared data listed in Table 7.

TABLE 7

SEDIMENT DISCHARGE AS A FUNCTION OF STAGE HEIGHT

Stage Movement	F	df	r^2	r	Probability (in percent)
Rising	25.26	4	0.863	0.929	1
Recession	13.77	10	0.579	0.761	1
Combined Movement	28.71	17	0.628	0.793	1

Slope and elevation comparison again showed no significant difference for sediment discharge as a function of stage height at the 5% level.

Since no significant difference does exist due to stage movement, the rise and recession data were combined for correlation. Similar conditions were assumed to prevail throughout the main channel. Again data combination provides the proper workable form. This fit of data describes the flashyness of the watershed. Peak discharges come fast and dissipate rapidly, carrying with them a considerable quantity of sediment.

At this point in my data interpretation, several variations of analysis need to be recognized and clarified. By reviewing the graphical data, one could quickly convert a measured antecedent precipitation index (Pa) into a suspended sediment concentration value by use of Figure 5 for Station Highway 101. With reference to Figure 9, the corresponding discharge relationship is established. Figure 12 (Q vs. Sediment Discharge in pounds/hour/square mile) provides the alleged sediment transport occurring from a known quantity of precipitation. Other functional associations might be attempted from graphical illustrations in a similar manner:

(a) Pa ⟶ Q ↕ St. Ht. ⟶ Sediment Transport

(b) mg/1 ⟶ Q ⟶ Sediment Transport

Each nomogram will result in a different response. It should be apparent that with each graph-jump an adjustment (a tendency to move towards an average) is encountered. Therefore, this particular type of interpretation should be considered as a very basic trend or pattern and that no absolute values can be secured.

CHAPTER VII

INDIVIDUAL STORM ANALYSIS

Water Discharge and Sediment Transport as a Function of Precipitation

Rainfall intensity for Last Forks 1 and 2 was derived from local climatological weather data by the hour and corrected to the standard rain gage data for this junction of Jacoby Creek.

Rainfall Intensity Example:

Total ppt for storm at Eureka = 1.61" (Mar. 22 at 7:00 a.m. to Mar. 24 at 5:00 a.m., 1971.)

Total ppt for storm at LF 1 & 2 = 2.69"

To find LF 1 & 2 ppt:

$\frac{2.69''}{1.61''}$ (ppt/hr from Eureka) = rainfall intensity.

(1.61")(0.02"/hr at noon) = 0.0332"/hr or approximately 0.03"/hr at noon, March 23, 1971.

This effectively adjusts for variation in amount of precipitation due to elevation and other factors and does not correct for lag time due to physiographic and climatic factors.

These hourly values have been used as the average intensity of rainfall for that hour and are found in Figure 14. This will be sufficient in lieu of the true intensity peaks that would have to be derived from a recording rain gage chart. This information will show the average highs or average peaks of the storm flows. The storm intensities have been plotted for the station at Highway 101. Compare the effect of rainfall intensity (double bell) in Figures 15 and 16 with the discharge and sediment loads (also a double bell) for Highway 101, Figure 17. A delay of approximately 6 hours from the first rainfall intensity peak to the initial discharge peak is noted, while a 24-hour detention exists between the second intensity and discharge crest points.

Influence of Discharge on Concentration and Sediment Transport

Continual measurements were obtained for the storm from beginning of precipitation to end of high discharge levels. These values are plotted for Last Forks 1 and 2 and Highway 101 on Figures 15, 16 and 17, respectively. These illustrations reveal a surprising difference and will now be compared.

Consider now Last Forks 1 and 2, which are in the headwaters of Jacoby Creek. Last Fork 1 drains 1.03 square miles, while Last Fork 2 drains 0.78 square miles of land. The amount of sediment for each fork of Jacoby Creek is a function of water discharge is shown here. (Also see Table 8.) In both forks the sediment ratio to discharge is much greater than at the lower end of Jacoby Creek at

FIGURE 14. Mean Precipitation Intensity in inches/hour at Highway 101, Jacoby Creek

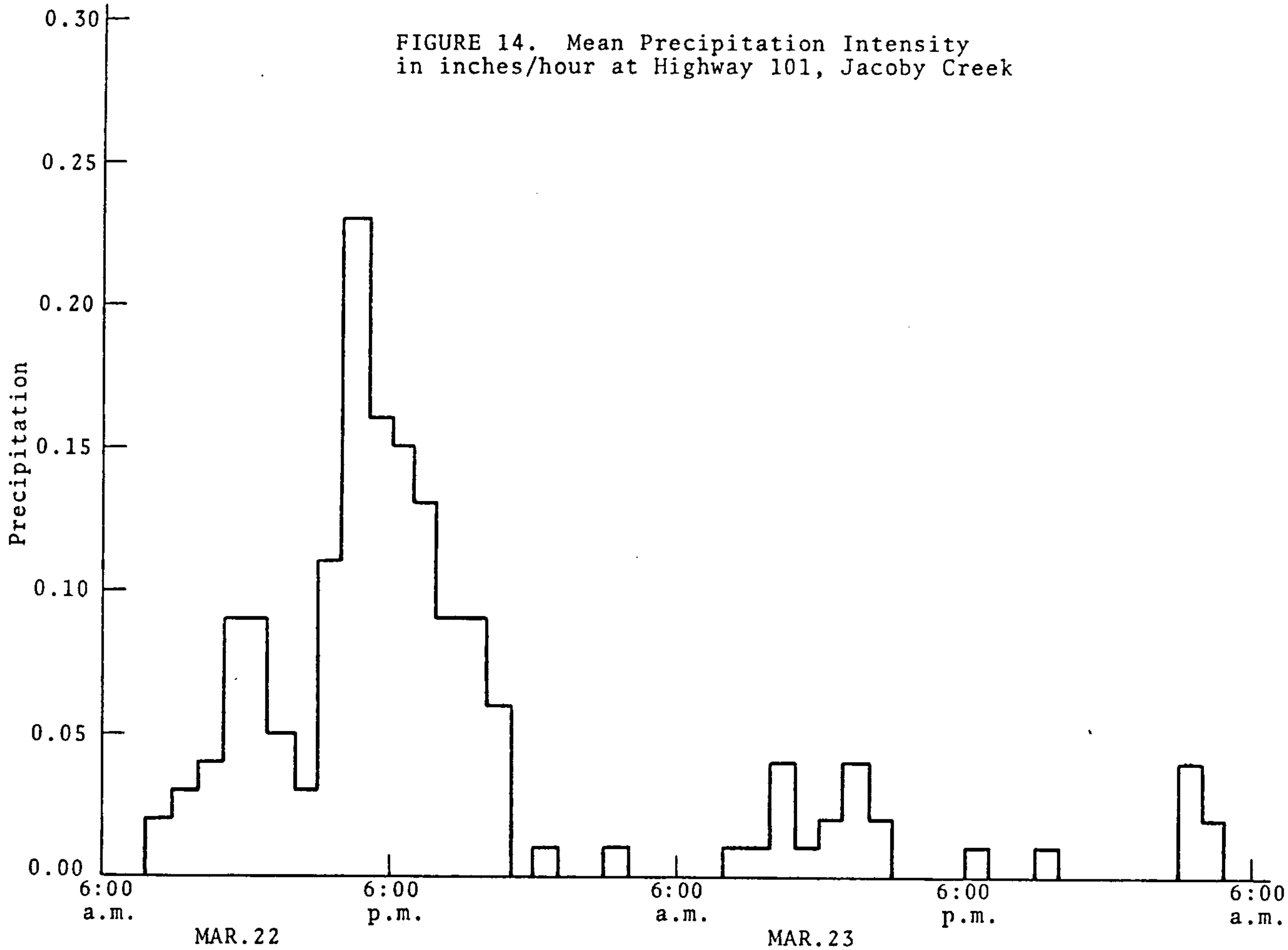


FIGURE 15. Last Fork 1 Suspended-Sediment Load and Storm Discharge Hydrograph for Jacoby Creek, California, March 22-24, 1971.

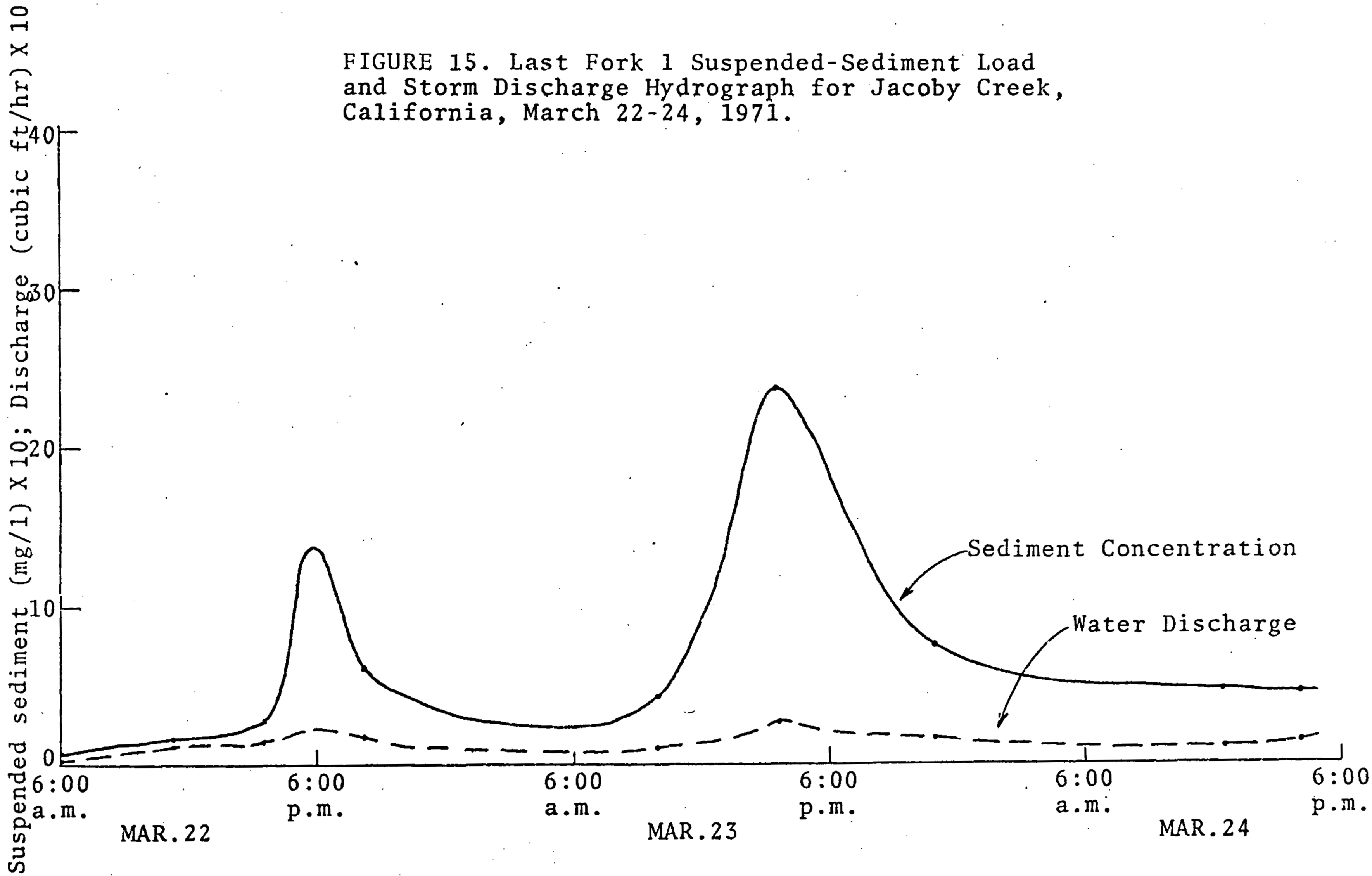


FIGURE 16. Last Fork 2 Suspended-Sediment Load and Storm Discharge Hydrograph for Jacoby Creek, California, March 22-24, 1971.

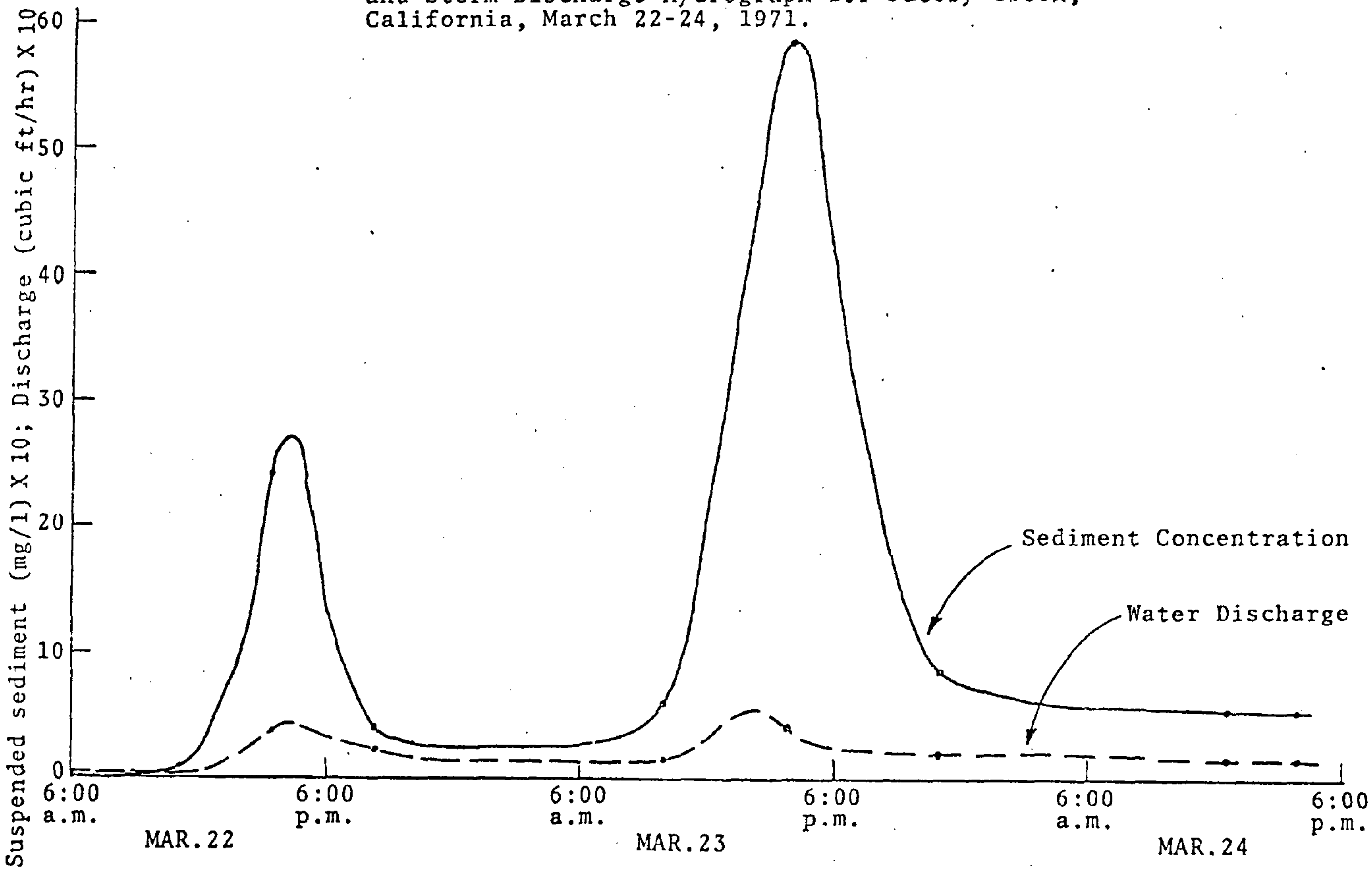
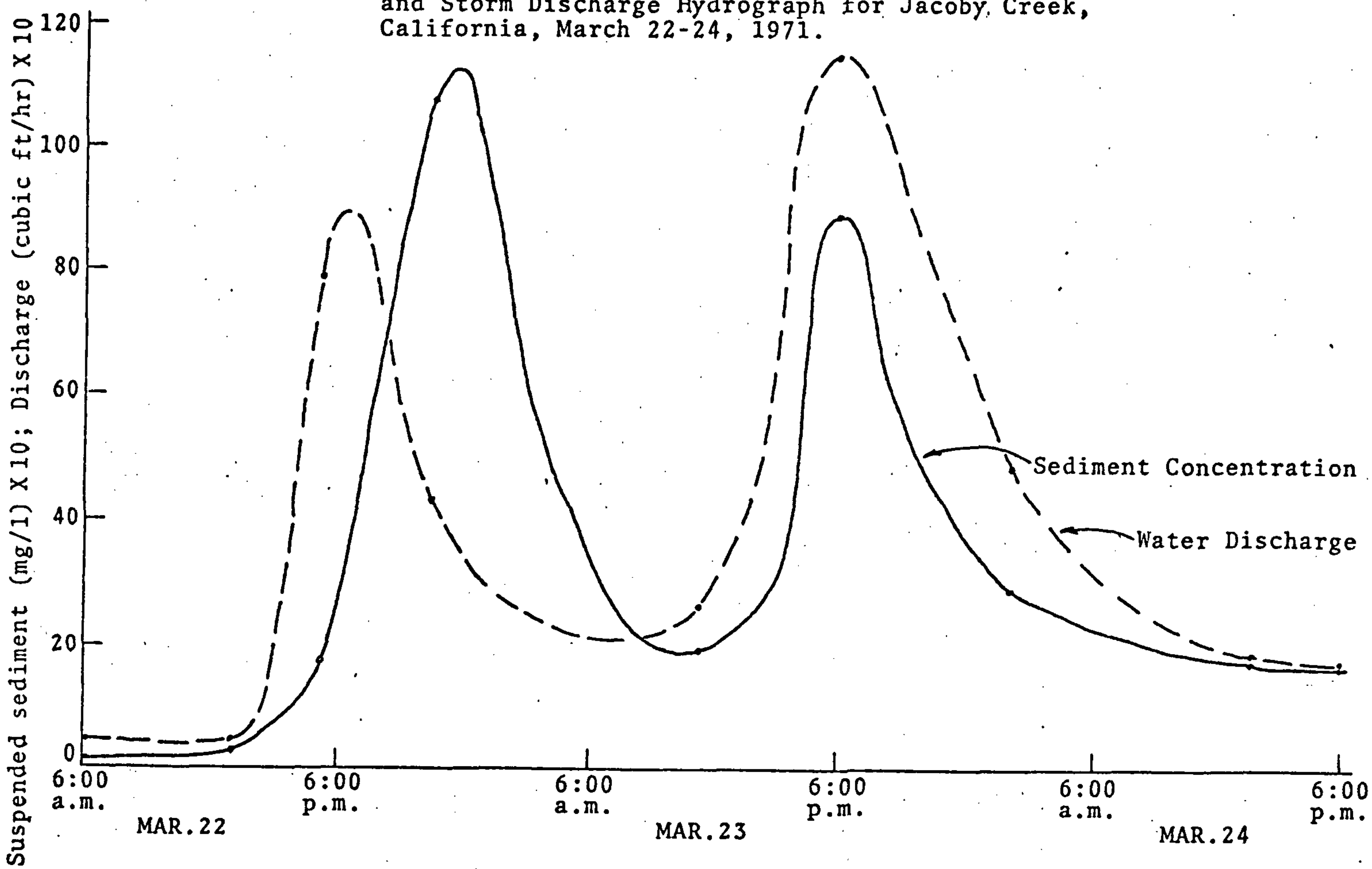


FIGURE 17. Highway 101 Suspended-Sediment Load and Storm Discharge Hydrograph for Jacoby Creek, California, March 22-24, 1971.



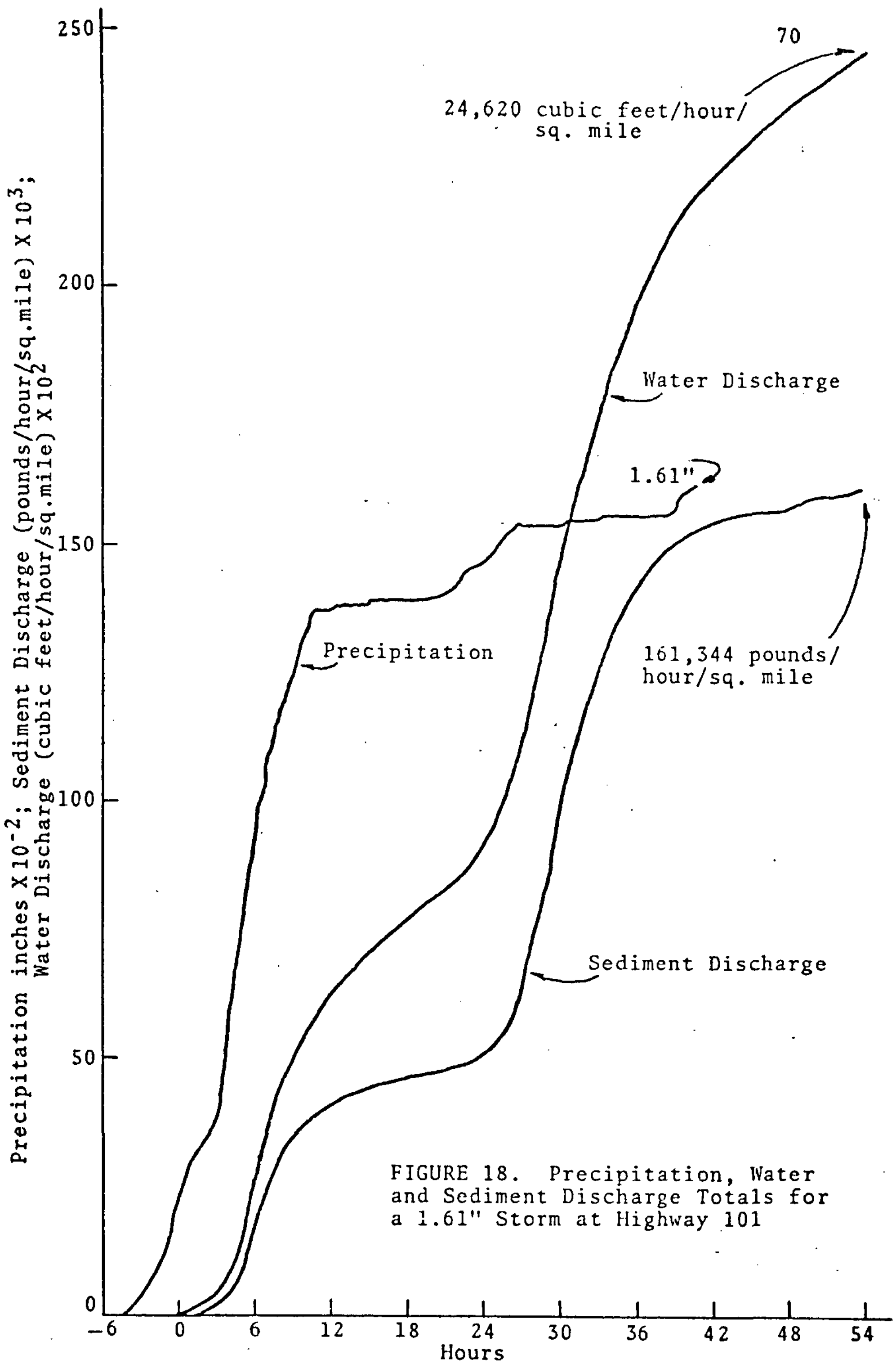


FIGURE 18. Precipitation, Water and Sediment Discharge Totals for a 1.61" Storm at Highway 101

Highway 101 (Fig. 17). However, Last Fork 2 sediment load far exceeds that of Last Fork 1, while discharge is not proportionately increased.

These hydrographs were subdivided (after Guy 1965) and evaluated from the sediment-transport curves and by Formula III(b) to compute water and sediment discharge for the respective sampled unit. The results are summarized in Table 8.

TABLE 8

SUMMARY OF WATER DISCHARGE AND SEDIMENT LOADS FOR MARCH 22-24, 1971, STORM AT LAST FORKS 1 & 2 AND HIGHWAY 101 SAMPLING STATIONS, JACOBY CREEK, CALIFORNIA

Station Sampled	Sediment Load in Tons/Square Mile *	**	Water Discharged in Cubic Feet/ Sec/Square Mile
Last Fork 1	4.2	6.6	2.6×10^6
Last Fork 2	18.3	29.0	4.1×10^6
Highway 101	80.8	74.0	88.7×10^6

*Computed from sediment transport curves, Figs. 10, 11, 12.
**Computed by Formula III(b), p.54.

Method 2 represents a detailed picture of this particular storm, while Method 1 indicates an average for the entire watershed based on more samples and consequently has a higher probability of recurrence.

The major difference between the two methods for Highway 101 is a result of the displacement between the discharge and sediment curves (Fig. 17) for the first bell effect measured from the storm.

From an interpretative standpoint, concentration and discharge hydrograph curves for Highway 101 are intriguing. It is surmised that the first peak of water being discharged is that quantity of rainfall striking near or on the channel itself (especially downstream) to produce the early crest. Until the volume increased, the sediment yield remained fairly low. Even as the first discharge peak passed into Humboldt Bay, the turbulent water was laden with sediment which followed close behind. This sediment peak is directly dependent on the discharge peak.

Small reservoirs are now filled, and the continuous rain brings a rise to the stream stage. Water quantity rising a second time easily carries with it sediment available from the first surge plus that which is transported from side slopes into the main channel.

Watershed conditions below the Last Forks 1 and 2 subunits are more stable, with very few potential erosion areas. It is assumed that the majority of sediment measured at any downstream station during this storm is a result of previous storm deposition and not from any additional erosion.

In general it is expected that a small flow such as one in the headwaters will be of greater velocity and carry more sediment/unit volume of water. Larger flows at lower velocities downstream, by contrast, will have less sediment/

unit volume of water. This decrease in carrying power is related to the reduced velocity such as would be expected across the alluvial plains of Jacoby Creek. Hewlett and Nutter (1969) indicate that the carrying power is an exponential function of velocity. For example, carrying power is increased 32 times by doubling the velocity of a stream. This velocity has the capacity to pick up particles on the stream bottom and keep them suspended, which accounts for exponentially increased sediment transport during high flows.

As the load approaches Humboldt Bay, the volume of water is increasing while the velocity has not significantly become greater, accounting for the decrease of sediment/unit volume of water, although it has increased many-fold by total volume.

Total Sediment Discharge for Single Storm

Hourly concentration and discharge subdivisions from Figure 17 were accumulated and illustrated collectively with precipitation in Figure 18 for Highway 101 sampling station.

On the basis that a 1.61" rain of like duration and intensity will transport 80 tons/mile^2 of suspended sediment into Humboldt Bay, some present evaluations and future predictions can be estimated.

Dredging by the Corps of Engineers is assessed in terms of cost/cubic yard (written comm. 1971, see appendix). To relate this sedimentation to a monetary value, conversion of suspended sediment tonnage to volume and volume cost is needed. Conversion of 80 tons/mile^2 suspended sediment to volume follows:

1 cubic foot = 28.316 liter by volume = 62.4 lbs/cubic foot.

1 cubic yard = 764.532 liter.

1 liter = 2.20462 lbs. of water.

therefore:

764.532 liters = 1685.50 pounds/cubic yard of water at 4° C.

(1685.50 lbs/cubic yard)(bulk density of 2.08)

= 3505.8 lbs per cubic yard or 1.75 tons/cubic yard.[3]

(80.8 tons/square mile)(17.34 sq. mile in watershed)

= 1401.1 tons total discharge.

$$\frac{1.75 \text{ tons}}{\text{cubic yard}} : \frac{1401.1 \text{ tons}}{X \text{ cubic yards}} = 800.59 \text{ cubic yards (total for storm).}$$

The 1971 average cost of dredging sediment from Humboldt Bay is $1.59/cubic yard (appendix, p.107).

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[3]Bulk density is determined from the weight of suspended sediment. Knott (1971), Fredriksen (1970) and Bureau of Reclamation (1970) have used various sediment weights/cubic foot. I have purposely selected a somewhat high value of 130 pounds/cubic foot or a bulk density of 2.08. This produces a conservative calculation when converting tons to cubic yards. In reverse it may give a somewhat high estimate of tonnage, but remember the original measurements were made in tons not cubic yards, and dredging costs are based on volume not weight. Separate tests need to be conducted to determine the appropriate bulk density for the area in question.

($1.59/cubic yard)(800.59 cubic yards) = $1272.94 cost for this 1.61" storm in terms of immediate dredging costs.

During the 1969 water year,[4] ten storms occurred which equaled or exceeded[5] the 1.61" 54-hour storm that was measured. Annual predictions for sediment tonnage, volume and cost would then be at least:

(1401.1 tons)(10 storms) = 14,010 tons of sediment annually.

(800.59 cubic yards)(10 storms) = 8,006 cubic yards annually.

($1272.94/storm)(10 storms) = $12,729.40 annual dredging cost to the public.

Furthermore, this estimate does not include the transportation of larger particles known as bedload. Bedload calculations could boost these values between 4-95%, depending on which author is cited. No bedload estimates were made in the field. For illustrative purposes increase these quantities by a conservative 20%.

Several conditions are implied to exist by these calculations, which need clarification.

Annual channel dredging does continue, but the material removed may not be the same material deposited

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[4]A 30-year rainfall average is 38.43". 1969 water year incurred 38.22" of rain. 1970 received the above-average 48.18" of rain. Consequently, the number of storms received from an average water year is used for the annual predictions.

[5]Note that a 4" storm over this same time period could have 32 times the effect that a 2" storm has in terms of sediment transport. A major flood may carry more sediment during those few hours than was transported in a number of previous years (Hewlett and Nutter 1969, Brown and Ritter 1971).

from Jacoby Creek effluent. It may, in fact, be many seasons before the actual storm amount will be excavated due to silting-in problems. It is difficult to assume that the estimated cost of Bay dredging is proportional to the present or past construction activity in the drainage basin.

Undoubtedly, sediment was deposited in Humboldt Bay from Jacoby Creek before man-caused activity existed. How much this volume has accelerated is not measured by this conversion to cost. However, cost data does represent potential monetary problems that are accelerated by poor land management problems.

This annual cost is very important to the taxpayer, especially on a year-to-year basis. The long-run consequence will not be ignored. However, the annual cost is really minimal in comparison to the cost of having this top soil replaced on the slopes of Jacoby Creek. Loss of soil represents possible site class reduction, continued slope stability problems and turbidity problems for wildlife. Computation of soil loss (in inches) allows comparison between other watersheds and Jacoby Creek. Soil loss in inches/year is computed below.

$$\frac{\text{80.8 tons}}{\text{square mile}} = \text{0.00580 pounds of sediment/square foot.}$$

$$\frac{\text{130 lbs/cubic foot}}{\text{12 inches/foot}} = \text{10.83 pounds/inch/square foot.}$$

$\frac{\text{0.00580 lbs/square foot}}{\text{10.83 lbs/inch/sq. foot}} = 0.000536$ inches lost from the surface of this watershed for a 1.61" storm. Adding the estimated bedload, I estimate 0.000643 inches lost from surface area for this measured storm. During this period of research (January to April 1971) there were 4 storms of this intensity and duration (or larger) that occurred.

(0.000643")(4 storms) = 0.002572" lost during the period of research. Correlation with the U.S. Weather Bureau records at Eureka estimates that 10 storms of this intensity and magnitude or greater have occurred on average water years (see footnote 4 on p.75).

(0.000643")(10 storms) = 0.00643" minimum annual loss, or at least 6.43" per thousand years.

A study on unstable soils in three western Oregon watersheds (Fredriksen 1970) was compared to my study. On a patch-cut basin with roads the following results were obtained. 97.7% of the total sediment lost was due to landslides as a result of the 1964 flood. This is not included in the comparison, as no catastrophic event was recorded during my period of research.

TABLE 9

ANNUAL SOIL LOSS COMPARISON CHART

Location	Estimated pounds/ft^3	Top Soil inches	100-year rate in inches
Oregon (Patch-cut with roads)	62	0.0032*	0.32
Jacoby Creek Watershed	130	0.00643	0.643
Jacoby Creek	62	0.01345	1.345

*Including 32 landslides occurring during the 1964-65 flood increases this value to 0.1100 inches lost; accounting for 97.7% of the total soil loss.

Characteristics of Turbidity

Up to this point little has been discussed pertaining to turbidity measurements. Over all, good results were obtained from the logarithmic regression against other collected variables.

The Pa index previously used was accurate within the 1% confidence level for all points measured. The following table describes the influence of Pa on turbidity.

TABLE 10

INFLUENCE OF Pa ON TURBIDITY

Station	F	df	r^2	r	Probability (in percent)
Last Fork 1	8.89	16	0.357	0.600	1
Last Fork 2	9.06	15	0.376	0.614	1
Last Bridge	14.62	16	0.478	0.691	1
Gaging Sta.	34.44	17	0.670	0.818	1
Highway 101	32.68	18	0.645	0.803	1
M. Gulch	18.97	15	0.558	0.747	1

Certainly a very logical relationship, but not one that is practical or useful. Turbidity samples can be obtained rapidly and quickly from field testing kits.

A second and very reasonable alliance is the effect water discharge has on turbidity rates (see Table 11).

It is interesting to note the increasing value of the correlation coefficient. This suggests something of the nature of the soil particles for the respective areas. Finer silts and clays are difficult to weigh but readily

TABLE 11

INFLUENCE OF Q ON TURBIDITY

Station	F	df	r^2	r	Probability (in percent)
Last Fork 1	8.35	16	0.343	0.586	5
Last Fork 2	12.46	15	0.454	0.674	1
Last Bridge	94.50	16	0.855	0.925	1
Gaging Sta.	95.01	17	0.848	0.921	1
Highway 101	443.72	18	0.961	0.980	1
M. Gulch	114.24	15	0.884	0.940	1

TABLE 12

RELATIONSHIP OF TURBIDITY AND SUSPENDED SEDIMENT CONCENTRATION

Station	F	df	r^2	r	Probability (in percent)
Last Fork 1	17.93	16	0.528	0.727	1
Last Fork 2	6.28	15	0.295	0.543	5
Last Bridge	27.56	16	0.633	0.795	1
Gaging Sta.	33.08	17	0.661	0.813	1
Highway 101	27.76	18	0.607	0.779	1
M. Gulch	17.42	15	0.537	0.733	1

show during turbidity tests. By observation, there are more fine soils throughout the alluvial zones than in the upper reaches of Jacoby Creek Basin. Also, this greater quantity of slower moving water (velocity) would retain the smaller particles while losing the heavier materials due to deposition. As discussed earlier, the heavier particles do not increase turbidity readings (see p.42).

The ability of a series of turbidity samples to predict sediment transport is a direct function of its correlation with sediment concentration and discharge (Q). Statistically a high correlation has been shown with water discharge; one also exists with suspended sediment concentration (see Table 12).

Brown and Ritter (1971) report very similar findings from similar methods for the Eel River, which flows into the Pacific Ocean just south of Humboldt Bay. Comparison and discussion will be arranged after their approach.

Logarithmic regression has included 99% of the variance for all stations (excepting Last Fork 2). These slopes are summarized in graphical form (Figs. 19 and 20). Computerized linear regression was employed to accurately derive the regression data. Statistical evidence is listed in Table 13. A great deal of similarity for the slope constant is apparent throughout the basin. Brown and Ritter found this to be true for the Eel River Basin for 1965-1968 water year data. Regression slope constants (b) ranged from 0.995 to 1.203, compared to my 0.79570 to 1.12577 spread. Intercept constants are also very similar.

For approximately 95% of the samples acquired, the concentration value was higher than the corresponding turbidity value. This condition is consistent with

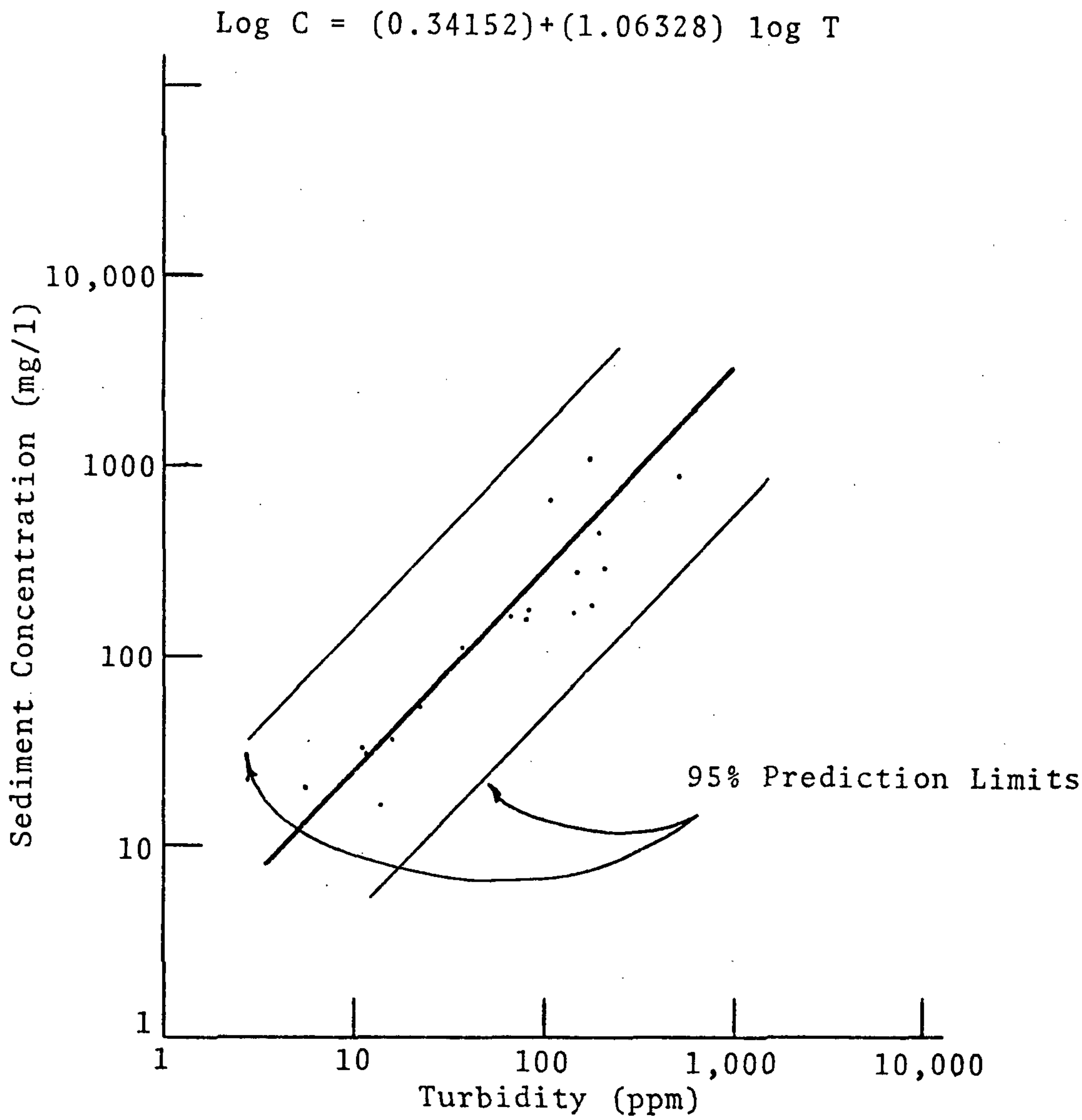

FIGURE 19. Concentration as a Function of Turbidity for Highway 101.

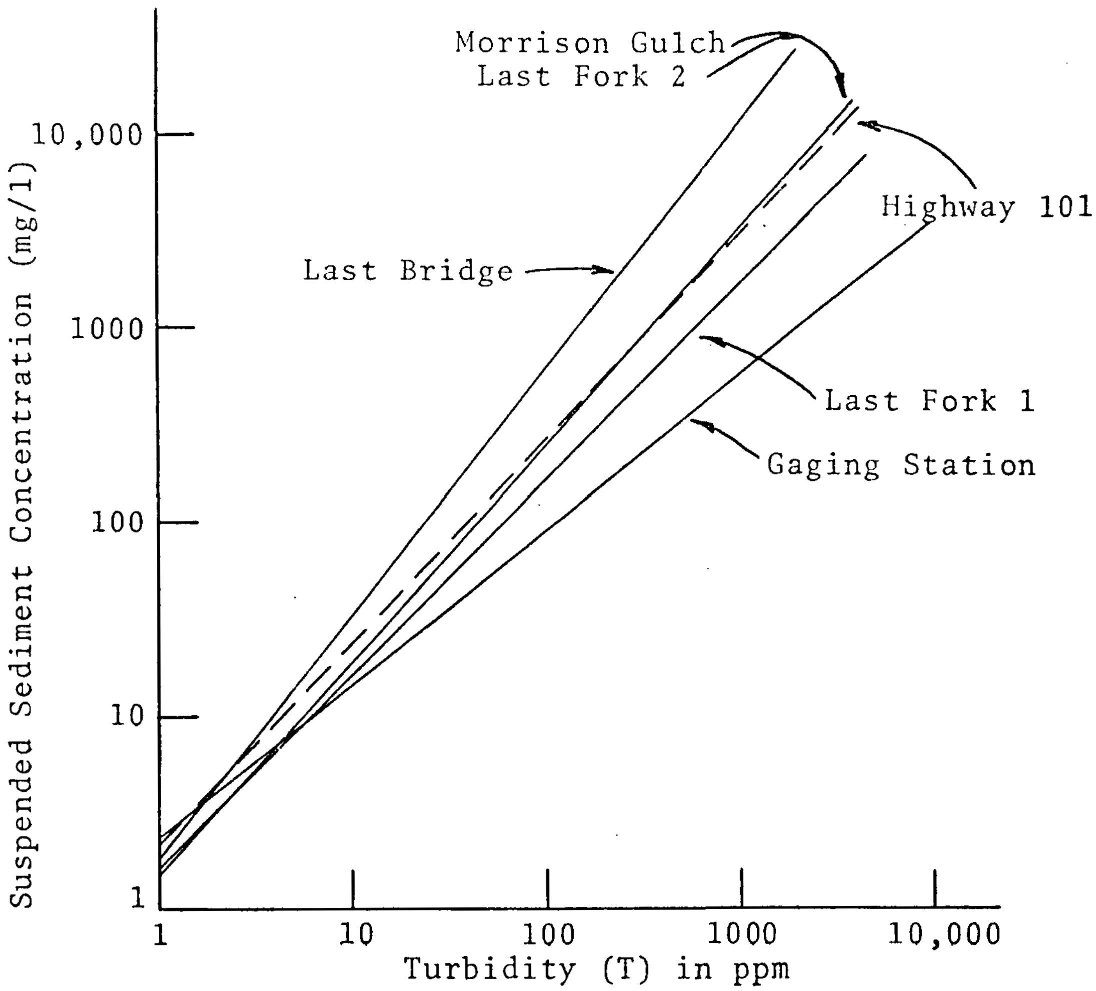

FIGURE 20. Regression Curves of the Relation between Turbidity & Concentration for Various Sampling Points along Jacoby Creek.

TABLE 13

REGRESSION EQUATIONS AND CONFIDENCE DATA
FOR CONCENTRATION AS A FUNCTION OF TURBIDITY

Station	Equation for Concentration -Turbidity Relation $C=aT^b$	df	r	Standard Error of Estimate (log units)	Probability (in percent)
Last Fork 1	$C = 0.20174(T)^{1.00522}$	16	0.727	0.2843	1
Last Fork 2	$C = 0.18410(T)^{1.11120}$	15	0.543	0.4451	5
Last Bridge	$C = 0.24763(T)^{1.08201}$	16	0.795	0.2902	1
Gaging Sta.	$C = 0.36287(T)^{0.79570}$	17	0.813	0.3398	1
Highway 101	$C = 0.34152(T)^{1.06328}$	18	0.779	0.3895	1
M. Gulch	$C = 0.14398(T)^{1.12577}$	15	0.733	0.2267	1

findings in the Eel River Watershed. In lieu of sediment concentration sampling and analysis, turbidity data could be used to gain some type of estimate of the suspended sediment concentration. Further as a general guide, turbidity measurements may be used to estimate the sediment discharge (Table 14). The danger with this assumption is that a

TABLE 14

PREDICTABILITY OF SEDIMENT TRANSPORT BY TURBIDITY LEVELS

Station	F	df	r^2	r	Probability (in percent)
Last Fork 1	19.00	16	0.543	0.737	1
Last Fork 2	7.07	15	0.321	0.566	5
Last Bridge	41.63	16	0.722	0.850	1
Gaging Sta.	61.66	17	0.784	0.885	1
Highway 101	86.66	18	0.828	0.910	1
M. Gulch	30.07	15	0.667	0.817	1

turbidity increase may not be due to an increase in water flow and has in fact been created by construction or tree harvest activity immediately upstream. Perhaps a more logical program is use of turbidity to compute sediment concentration with which a discharge (Q) correlation can be used to determine sediment transport.

CHAPTER VIII

CONCLUSIONS

Various interrelations are apparent among the variables examined. Several points are evident and are worthy of comment. Practically speaking, the direct cause-effect function of precipitation and increased runoff for given levels of the independent parameter does exist. For this environment this relationship is apparent, yet in research this phenomenon was found exceedingly difficult to correlate with a high degree of consistency. Moreover, the probabilistic causality of sediment disturbance as a product of precipitation was found to be equally elusive statistically. Correlation again was unable to make a satisfactory accounting of the relationship. It is intuitive and apparent that

$$\text{precipitation} \longrightarrow \text{increased runoff}$$

occur together in an unregulated watershed basin. Lack of a significant correlation points to the design and method of study. Failure to adequately measure and define the natural laws that govern precipitation is a design problem. Furthermore, isolation and definition of the journey of rainfall to the stream channel is a qualitative mystery.

A vast number of continuously changing parameters make clear the need for sophistication in measuring tools. This problem needs experimentation and research. There is no doubt that the solution will be complex.

Several producer-product functions were measured with enough clarity to generate acceptable probability levels. The design of the following associations have adequate correlation results.

1. Turbidity (T) ⟶ Concentration (mg/l)
2. Water Discharge (Q), Stage Height (SH) ⟶ Turbidity, Concentration (mg/l)
3. Turbidity, Concentration (mg/l), Water Discharge, Stage Height ⟶ Sediment Discharge (Sed.)

Computerized step-wise regression was programmed to tabulate and summarize the above relationships. Some interesting second-step associations were observed. The addition of a second independent variable into the regression equation has always increased predictability percentage (or rarely produced no effect). Of importance are the precipitation to turbidity, sediment concentration (mg/l) and discharge relationships. Listed in Table 15 are examples of two- and three-step interreactions that occurred at Highway 101 sampling station.

Tests IV, V and VI from Table 15 substantiates the practicability and feasibility of using turbidity measurements in conjunction with water discharge to reproduce

TABLE 15

INTERREACTIONS OF INDEPENDENT VARIABLES FOR HIGHWAY 101
JACOBY CREEK

Test	Dep. Var.	Variable in Equation	F-Level	df	r^2	% Increase in r^2	r	Probability (in percent)
I	Sed.	Pa	20.16	18	0.691	--	0.831	1
	Sed.	Pa + T	50.66	17	0.856	6.5	0.925	1
II	T	Pa	32.68	18	0.645	--	0.803	1
	T	Pa + mg/1	20.13	17	0.703	5.8	0.839	1
III	mg/1	Pa	28.52	18	0.613	--	0.783	1
	mg/1	Pa + T	17.78	17	0.677	6.4	0.823	1
	mg/1	Pa + T + Q	15.14	16	0.739	6.2	0.860	1
IV	mg/1	T	27.76	18	0.607	--	0.779	1
V	mg/1	Q	18.72	18	0.510	--	0.714	1
VI	mg/1	T + Q	17.23	17	0.670	6.3 16.0	0.818	1
VII	Sed.	Q	56.43	18	0.758	--	0.871	1
	Sed.	Q + T	44.51	17	0.840	8.2	0.916	1

concentration (mg/l). Further, Test VII indicates that the additive function of turbidity and water discharge results in an 8.2% predictability increase of sediment transport.

Again, it must be recognized that erroneous conclusions will result if turbidity is not a product of discharge.

This type of watershed sampling program is usually inexpensive, with the majority of expense involving field labor. It is a simple and easy method of obtaining a working set of field measurements that are capable of yielding an extensive amount of information which may result in high probability levels, as this study has.

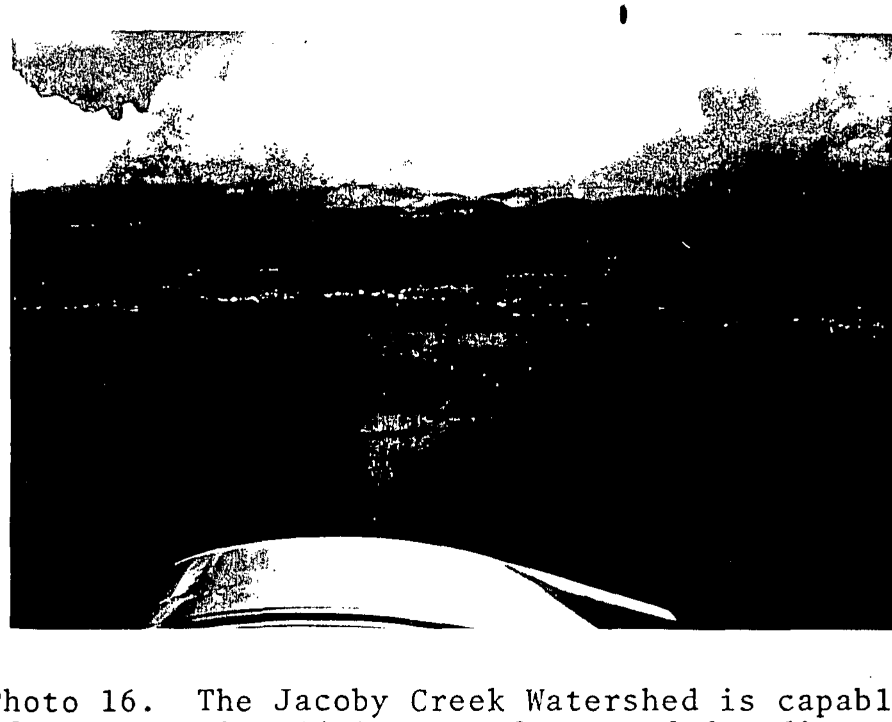

Photo 16. The Jacoby Creek Watershed is capable of transporting 1400 tons of suspended sediment into Humboldt Bay as a result of a 1.61" 54-hour storm (October 1971).

Sampling continued for 14 weeks throughout the Jacoby Creek Basin. During this time instantaneous turbidity, concentration (mg/l), precipitation and discharge data were obtained. Interrelationships were statistically tested, and the findings were discussed.

Photo 17. The Community of Bayside represents the majority of housing found in Jacoby Creek Basin. Note sediment deposition at the mouth of the main channel (October 1971).

One storm occurring between winter and spring quarters was singled out, and a more intensive system of measurement was employed to understand the individual storm situation. It was calculated that during this particular 1.61" rain, 1282 tons of suspended sediment was transported into Humboldt Bay (Photos. 16, 17 and 18) during a 54-hour period. A total of 1400 tons could normally be expected as

Photo 18. Bordered with vegetation, Jacoby Creek crosses U.S. Highway 101 and flows into Humboldt Bay. Looking north, the City of Arcata is seen. (October 1971).

determined from instantaneous field measurements. This tonnage is not comparable to the 116,000,000 tons estimated for Eel River at Scotia for a 72-hour period beginning December 22, 1964 (Brown and Ritter 1970).[6] No sediment

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[6]The total amount of suspended sediment discharge at that station for the previous 8 years amounted to 94,000,000 tons.

records are available for Jacoby Creek for the 1964 flood. However, crest stages were reported by the U.S.G.S. Stage-discharge relation was defined by current-meter measurements below 670 cfs and by critical depth measurement at 1490 cfs. Flood data reported by U.S.G.S. 1970 are:

> Maxima---December 1964 to January 1965: Discharge 1530 cfs December 22 (gage height 6.83 feet from flood marks).
> 1954 to November 1964: Discharge, 1670 cfs December 30, 1954 (gage height, 7.20 feet).

These stage height points are plotted on the stage-discharge graph (Fig. 13) for observation.

Subdrainage units feeding Last Forks 1 and 2 were compared. It is surprising that Last Fork 2 (0.78 square miles) discharges approximately 4 times the suspended sediment concentration (Photo 19) as does Last Fork 1 (1.03 square miles). Studies by Fredriksen (1970) show a definite increase in sedimentation during and immediately following logging and road construction activities. However, to confound the paradox more, Last Fork 1 has had 2-1/2 times the recent logging (by area for January 1969 to September 1971) as did Last Fork 2 and received approximately equal treatment prior to that period.

What cause could this phenomenon be attributed to? There are no physiographic differences between these two sub-watersheds that could warrant such an explanation. It is interesting that Last Fork 1 sub-watershed is where, at first glance, the sediment problem would originate. A tremendous landslide completely blocking the stream exists. However, its presence since the winter of 1968-69 is not causing more sediment discharge than is Last Fork 2.

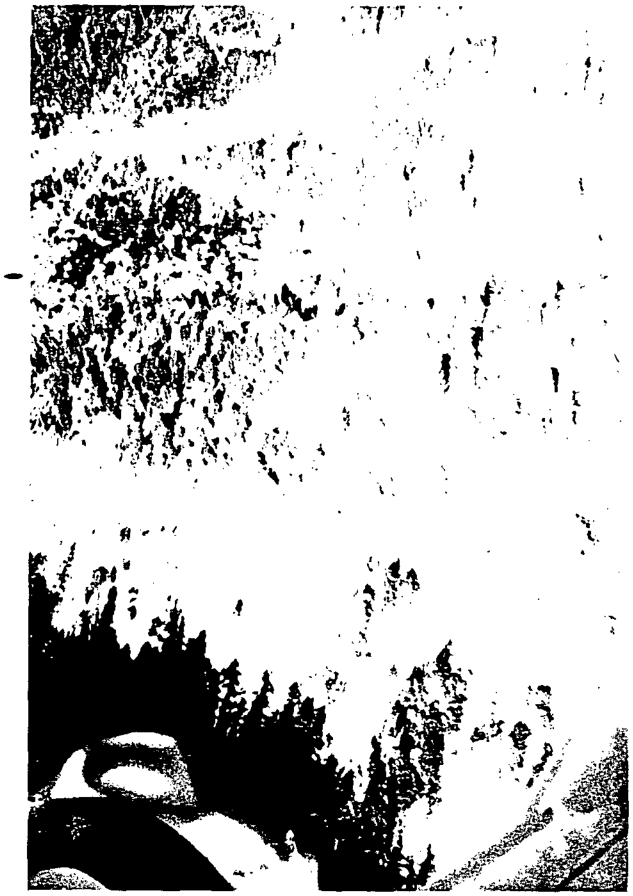
Photo 19. Last Fork 2 (on left) produced 4 times the suspended sediment volume as did Last Fork 1 (coming from right). The massive slide (Photo 23) is in the Last Fork 1 sub-unit. This picture was taken 6 hours after the start of a 1.61" rain (March 1971).

There are probably a number of interrelated reasons for this condition. Two explanations based on observations and not field measurements are discussed. First, the drainage unit of Last Fork 2 is experiencing some relogging. Roads have been reconstructed (near the stream), and perhaps this activity is producing an excessive quantity of sediment in the stream in contrast to the harvesting over the past 2 years.

Photo 20. An earth and log bridge which washed out during the winter of 1968-69 was not repaired or removed even though the road beyond was impassable. An estimated 100 cubic yards of earth once filled these cavities. Location is at mouth of Last Fork 1 (April 1971).

The major thesis is the condition of the land (especially near the stream) after the first logging show (1964-1967). The creek in Last Fork 2 has two dirt dams constructed across it, as does Last Fork 1 (Photo 20). These dams were not removed after logging and, consequently, are caving in during storm activity. Most important, the side slopes have never regained stability, as vegetation cannot establish a root system for support. This is primarily due to the continuing landslides and loss of top

Photo 21. Slumps and slides capable of moving trees and changing contours are evidenced in the upper stretches of Jacoby Creek Watershed (March 1971).



Photos 22 and 23, above, form a sequence. Note the earth and log bridge in the center of Photo 22. A tremendous landslide in Photo 23 extends to the topographic boundary of Last Fork 1 sub-unit. The slide began after the first road was constructed and logging began. Three different roads crossed into this slide at one time. Just above the slide is Last Fork 2 sub-unit (October 1971).

soil. This lack of stability is the cause of sedimentation, and at either station (Last Fork 1 or 2) the sediment discharge load does not accurately reflect present (last 2 years) logging and road construction sediment production. Past tree harvest methods and road construction (Photo 21) appear to be strong and dominating factors and are completely masking any measurable effects on present logging

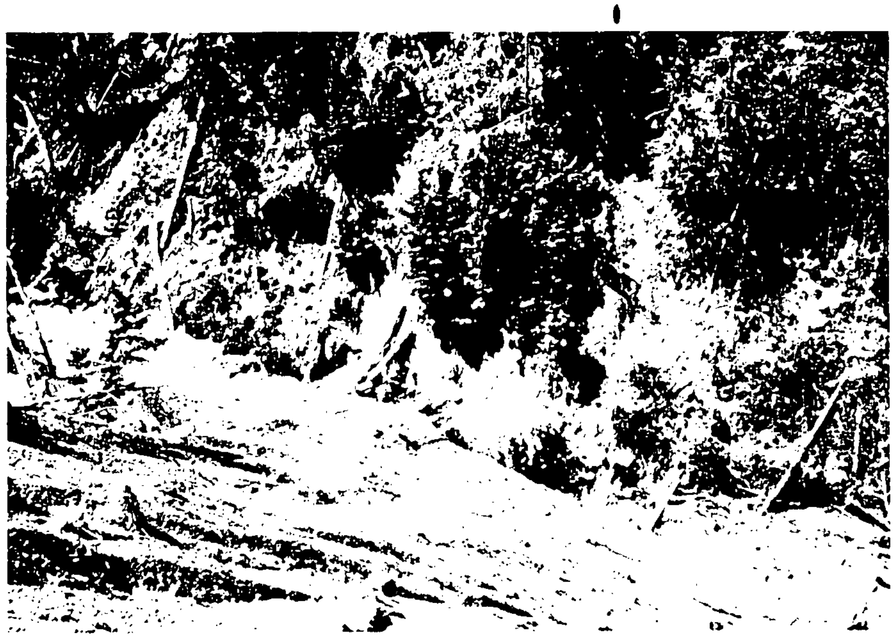


Photo 24. Standing on the landslide viewed in Photo 23 and looking into Last Fork 1 subunit. Notice the slide has blocked the stream, forcing it to detour. Down cutting on the opposite bank is a result of the detour. Unstable slopes such as these should not be logged or experience road construction (April 1971).

methods. Further, it is my contention that Last Fork 2's heavy discharge is mainly coincidental to the time of this research project. I feel that these results could be reversed during another study period, as both subwatershed units are in a highly unstable condition. For example, in Last Fork 1, high above the streambed, are numerous cracks along the road edges. Each shear zone represents a potential landslide. One such slide (Photos 22, 23 and 24) does exist. It is approximately 300 yards across by 500 yards down slope. Also, many areas of barren slopes and massive dirt slides can be found in Last Fork 1 subwatershed. In many areas the dirt is bulldozed directly into the stream; the slopes need not depend on erosion for loss of top soil. However, intense rains will continuously transport this material downstream in the future. Due to the continued road construction and harvesting practices, it will be many years before ground stability can be obtained. Large sampling variance will reflect this perpetually unstable condition.

CHAPTER IX

RESEARCH SUMMARY

This study, based on instantaneous water discharge and suspended sediment measurements, has yielded considerable data designed to estimate the sediment discharge for Jacoby Creek.

No single, easily measured variable was found that could accurately account for the sediment yield.

This project is unequivocally a conservative reconnaissance of the sediment transportation from Jacoby Creek for a number of reasons.

1. Low to high range of discharge values include 13-1146 cfs at highway 101.

2. A systematic error is introduced in that open-mouthed bottles underestimate the true concentration carried by the stream (Fredriksen 1970).

3. An extremely conservative unit weight of 130 pounds/cubic foot was used to estimate the volume of sediment moved. This further underestimates the average number of inches of top soil lost.

4. Hewlett and Nutter (1969) make clear the geometric relationship of water volume and corresponding carrying power. For the annual estimation, I simply

assumed that any storm of 1.61" or greater would produce an equal amount of suspended sediment. This assumption is probably the largest error-inducing underestimation of the study.

Photo 25. Principal constituents of the Franciscan formation are complexly faulted sandstones, shales, conglomerates and metasedimentary rocks. Rock units are highly fractured and easily eroded (March 1971).

5. Further, storms under 1.61" will still move a large volume of sediment into Humboldt Bay. There is absolutely no accounting of this quantity in the annual estimate.

In spite of the conservative nature of this study, some pertinent glaring facts do make the headlines.

1. A reliable sediment-water discharge family of curves were obtained for the sampling stations on Jacoby Creek (Figs. 10, 11, 12).

2. A more sophisticated system of precipitation recording is necessary to enlighten the influence of rainfall on stream-flow characteristics.

3. Turbidity measurements (ppm) were found to have a high correlation with suspended sediment concentration (mg/1). This infers the use of turbidity measurements to estimate suspended sediment concentration levels.

4. A 1.61" storm measured at Eureka is capable of transporting 1400 tons (800.59 cubic yards) of suspended sediment into Humboldt Bay. This represents a soil loss at the rate of 0.643"/100 years.

5. Converted to terms of potential dredging cost, it is conceivable that a cost of $12,732 could be the annual contribution of Jacoby Creek.

6. Most important is my conclusion that this sediment yield is obscured by past tree harvest and road construction practices, i.e., the moving of dirt around

the basin in close proximity to streams or steep uncovered slopes above streams. Present activity cannot be isolated, due to the large number of slides and slumps (Photo 25) that occur yearly in areas worked over in the past on these highly unstable soils.

LITERATURE CITED

Boucher, P. R. 1970. Sediment Transport by Streams in the Palousa River Basin, Washington and Idaho, July 1961-June 1965. U.S. Geol. Surv. Water Supply Paper 1899-C. 37 p.

Brown III, Bill and J. Ritter. 1970. Sediment Transport and Turbidity in the Eel River Basin, Calif. U.S. Geol. Surv. Water Supply Paper 1986. 139 p.

Colby, B. R. 1963. Fluvial sediments--a summary of source, transportation, deposition, and measurement of sediment discharge. U.S. Geol. Surv. Bull. 1181-A. p.A1-A47.

Dixson, W. J. (ed.). 1970. Biomedical Computer Programs. Univ. of Calif. Press, Berkeley. p. 233-255.

Einstein, H. A., A. G. Anderson, and J. W. Johnson. 1940. A distinction between bed load and suspended load in natural streams. Trans. Am. Geophys. Union. p.628-632.

Fredriksen, R. L. 1970. Erosion and Sedimentation following Road Construction and Timber Harvest on Unstable Soils in three small western Oregon Watersheds. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station. 16 p.

Guy, H. P. 1965. Residential Construction and Sedimentation at Kensington, Md., p.33-34. In: Proceedings of the Federal Intra-Agency Sedimentation Conference 1963. U.S. Dep. Agr. Misc. Publ. 970.

Harris, D. D. and R. C. Williams. 1971. Streamflow, Sediment-Transport, and Water-Temperature Characteristics of three Small Watersheds in the Alsea River Basin, Oregon. U.S. Dep. Int. Geol. Surv. Circ. 642. 21 p.

Hawley, N. L. and B. L. Jones. 1969. Sediment Yield of Coastal Basins in Northern California 1958-64. U.S. Geol. Surv. Open-file report. 19 p.

Hewlett, J. and W. Nutter. 1969. An Outline of Forest Hydrology. Univ. of Georgia Press, Athens. p.109-110.

Johnson, William. 1969. Unpublished Watershed Analysis Data for Jacoby Creek. Humboldt State College, Dept. of Watershed Management. Arcata, California.

Knott, J. M. 1969. Interim Report on Streamflow and Sediment Discharge in the Columa Creek Basin, Calif. U.S. Geol. Surv. Open-file report. 24 p.

________. 1971. Sedimentation in the Middle Fork Eel River Basin, Calif. U.S. Geol. Surv. Open-file report.

Kroll, C. G. and G. Porterfield. 1969. Preliminary Determinations of Sediment Discharge San Juan Drainage Basin, Orange and Riverside Counties, Calif. U.S. Geol. Surv. Open-file report. 28 p.

Moore, Joe. 1969. Effects on Watershed Changes on Water Quality. In: Effects of Watershed Changes on Streamflow, (ed.) by M. L. Moore and C. Morgan. Water Resources Number Two. Univ. of Texas Press, Austin. p.8-9.

Morisawa, Marie. 1968. Streams, Their Dynamics and Morphology. McGraw-Hill, New York, N.Y. 175 p.

Ritter, J. R. 1968. Changes in the Channel Morphology of Trinity River and eight tributaries, California, 1961-65. 60 p.

Snedecor, G. W. and W. G. Cochran. 1968. Statistical Methods. 6th edition. The Iowa State Univ. Press, Ames. p.432-436.

Bureau of Reclamation. 1970. Notes on Sedimentation Activities, Calendar Year 1969. U.S. Government Printing Office, Washington, D.C. 207 p.

________. 1971. Notes on Sedimentation Activities, Calendar Year 1970. U.S. Government Printing Office, Washington, D.C. 208 p.

Environmental Science Services Administration, U.S. Dep. Comm. 1969-1970. Local Climatological Data, Eureka, Calif. Looseleaf n.p.

________. 1970-1971. Local Climatological Data, Eureka, Calif. Looseleaf n.p.

U.S. Geol. Surv. Water Supply Paper 1866-8. 1970. Floods of December 1964 and January 1965 in the Far western States, Part 2, Streamflow and Sediment Data. p.400.

Inter-Agency Committee on Water Resources; Sub-committee on Sedimentation. 1963. Report No. 14, Determination of Fluvial Sediment Discharge. U.S. Govt. Printing Office, Washington, D.C. pp.23-42, 116-139.

Wilson, Lee. 1971. Comments on 'Possible Effects of Precipitation Modification on Stream Channel Geometry and Sediment Yield' by A. Rango. In: Water Resources Research. 7(5): 1365.

APPENDIX

MINOR SAMPLING POINTS

Symbol explanations are: T, temperature; Q, discharge; SSS, suspended sediment sample.

Last Fork 3: NW/4, SW/4, Section 32, T5N, R2E, HBM. This station was located 100 yards downstream from the junction of Last Fork 1 (L.F. 1) and Last Fork 2 (L.F. 2). Acting on advice from my committee, this station was abandoned in February, as no new or desirable evidence was being procured.
Q, T, SSS.

Last Bridge A: NE/4, NE/4, Section 31, T5N, R2E, HBM. This sampling station collects data from a 1.95 square mile drainage unit which, like L.F. 1 and 2 has a history of logging. Limited information was obtained at this point.

Dirt Bridge: SE/4, SE/4, Section 30, T5N, R2E, HBM. This tributary slopes from the north and is located betw-en L.B. and Gaging Sta.

Up Slide and Down Slide: NW/4, SW/4, Section 24, T5N, R1E, HBM. It was decided to collect data both up and down stream from this tremendous gravel and mud slide when inspection indicated this as a major source of sediment productivity during high flows.

Quarry Bridge: SW/4, NW/4, Section 24, T5N, R1E, HBM. This is the last major tributary cascading southward into the main stream channel. It is located just downstream from the slide area.

Smart Property: SE/4, SW/4, Section 11, T5N, R1E, HBM. Located at the junction of Kirkpatrick-Quarry Road and Jacoby Creek, Smart Property is midway between Gaging Sta. and Highway 101.
Q, T, SSS.

DEPARTMENT OF THE ARMY
SAN FRANCISCO DISTRICT, CORPS OF ENGINEERS
100 McALLISTER STREET
SAN FRANCISCO, CALIFORNIA 94102

SPNCO-OW

11 May 1971

Mr. Norman H. Pillsbury
School of Natural Resources
Humboldt State College
Arcata, California 95521

Dear Mr. Pillsbury:

Reference is made to your letter of 20 April 1971 requesting dredging costs and volumes within Humboldt Bay for the past few years. The following table reflects only the work conducted by the Corps and is listed by fiscal year:

CofE Dredging Within Humboldt Bay

Fiscal Year	Quantity (Cubic Yards)	Cost
1971	51,300	$ 81,500
1970	73,500	70,000
1969	139,200	139,500
1968	127,230	156,500
1967	257,340	241,500

Sincerely yours,

CHARLES R. ROBERTS
Colonel, CE
District Engineer

VINTON L. RATHBURN
LTC CE
Deputy District Engineer

LAST FORK 1 STATION DATA

Date (1971)	Water Turbidity (ppm)	Suspended Sediment Concentration (mg/1)	Water Discharge (cfs)	Antecedent Precipitation Index (Pa in inches)	Sediment Discharge (lbs/hr/sq.mi.)
Jan.23	7.00	0.00	9.40	0.05	0.00
Feb.20	3.00	0.00	4.37	0.50	0.00
Feb.24	35.00	48.33	3.11	1.43	32.79
Mar. 5	11.00	8.43	12.90	0.93	23.72
Mar. 6	7.00	24.71	8.30	0.69	44.75
Mar.12	51.00	355.66	27.57	3.00	2139.37
Mar.13	23.50	62.23	20.64	2.50	280.24
Mar.20	6.00	0.00	5.99	1.34	0.00
Mar.22 11:15 a.m.	7.00	14.29	10.47	1.41	32.64
Mar.22 3:55 p.m.	26.00	30.57	15.42	2.23	102.85
Mar.22 8:30 p.m.	33.00	48.91	18.58	3.38	198.27
Mar.23 10:00 a.m.	12.00	39.58	13.58	2.21	117.27
Mar.23 3:25 p.m.	135.00	236.70	25.34	2.40	1308.64
Mar.23-4 11:00 p.m.	30.00	77.63	15.95	2.42	270.15
Mar.24 12:25 p.m.	21.00	49.11	14.76	1.91	158.15
Mar.24 4:10 p.m.	16.50	47.80	16.88	1.87	176.04
Mar.27	20.00	8.62	14.63	2.32	126.11
Apr. 3	7.50	30.07	12.99	0.89	85.22

LAST FORK 2 STATION DATA

Date (1971)	Water Turbidity (ppm)	Suspended Sediment Concentration (mg/l)	Water Discharge (cfs)	Antecedent Precipitation Index (Pa in inches)	Sediment Discharge (lbs/hr/sq.mi.)
Feb.20	5.00	0.00	2.47	0.50	0.00
Feb.24	39.00	53.94	2.63	1.43	40.87
Mar. 5	16.50	16.22	14.29	0.93	66.78
Mar. 6	5.00	32.94	9.10	0.69	86.36
Mar.12	31.00	62.84	32.23	3.00	583.52
Mar.13	21.00	34.73	16.47	2.50	572.00
Mar.20	8.00	0.00	2.96	1.34	0.00
Mar.22 11:25 a.m.	5.00	7.61	3.65	1.41	27.78
Mar.22 4:05 p.m.	222.00	240.45	39.67	2.23	2748.18
Mar.22 8:35 p.m.	35.00	40.85	13.37	3.38	157.36
Mar.23 10:05 a.m.	12.00	60.27	13.45	2.21	233.55
Mar.23 3:30 p.m.	310.00	585.07	39.69	2.40	6690.33
Mar.23-4 11:05 p.m.	29.00	83.48	21.17	2.42	509.17
Mar.24 12:30 p.m.	19.00	54.46	15.04	1.91	235.98
Mar.24 4:15 p.m.	15.00	53.26	19.96	1.87	306.28
Mar.27	18.50	0.00	14.73	2.32	0.00
Apr. 3	7.50	11.51	7.98	0.89	26.46

LAST BRIDGE STATION DATA

Date (1971)	Water Turbidity (ppm)	Suspended Sediment Concentration (mg/1)	Water Discharge (cfs)	Antecedent Precipitation Index (Pa in inches)	Sediment Discharge (lbs/hr/sq.mi.)
Jan.23	7.50	18.96	14.87	0.05	16.04
Feb. 7	3.00	0.00	12.33	0.50	0.00
Feb.20	4.00	0.00	11.17	0.50	0.00
Feb.24	40.00	72.39	51.37	1.42	211.56
Mar. 5	14.50	22.64	48.25	0.92	62.16
Mar.12	65.00	185.84	116.72	2.98	1234.02
Mar.13	29.00	68.04	53.47	2.48	206.97
Mar.20	9.50	0.00	16.15	1.33	0.00
Mar.22 11:40 a.m.	18.50	8.43	15.54	1.40	7.45
Mar.22 4:05 p.m.	114.00	159.19	182.49*	2.21	1652.69
Mar.22 9:00 p.m.	75.00	99.12	63.29	3.35	356.89
Mar.23 10:20 a.m.	23.50	49.49	45.13	2.19	127.06
Mar.23 3:45 p.m.	135.00	390.07	124.36	2.38	2759.68
Mar.23-4 11:15 p.m.	36.00	100.54	64.10	2.40	366.63
Mar.24 12:35 p.m.	26.00	57.59	48.92	1.89	160.28
Mar.24 4:30 p.m.	25.00	52.98	47.40	1.86	142.87
Mar.27	30.00	9.67	54.99	2.30	30.25
Apr. 3	8.00	31.02	24.60	0.88	43.41

*Predicted values.

GAGING STATION DATA

Date (1971)	Water Turbidity (ppm)	Suspended Sediment Concentration (mg/1)	Water Discharge (cfs)	Antecedent Precipitation Index (Pa in inches)	Sediment Discharge (lbs/hr/sq.mi)	Stage Height (in ft.)
Jan.31	2.00	0.01	14.05	0.03	0.00	F 1.27
Feb.13	2.50	0.01	11.90	0.14	0.00	F 1.19
Feb.20	5.00	8.18	11.20	0.49	3.27	F 1.32
Feb.24	39.00	88.48	86.98	1.40	274.90	R 2.05
Mar. 5	13.00	17.73	51.60	0.91	32.68	F 1.84
Mar. 6	4.00	32.41	45.56	0.67	52.74	F 1.66
Mar.12	153.00	328.97	172.48*	2.96	2026.78	R 2.48
Mar.13	35.00	105.44	80.52	2.46	303.26	F 2.14
Mar.20	7.50	10.60	23.26	1.31	8.81	F 1.47
Mar.22 12:05 p.m.	8.00	15.53	18.56	1.38	10.29	F 1.46
Mar.22 4:30 p.m.	90.00	124.45	212.73*	2.18	945.66	R 1.68
Mar.22 9:25 p.m.	65.00	114.76	87.47	3.31	358.56	R 1.99
Mar.23 10:30 a.m.	25.00	71.06	51.08	2.17	129.65	F 1.87
Mar.23 4:00 p.m.	155.00	326.83	160.44	2.35	1873.04	R 2.35
Mar.23-4 1:30 a.m.	51.00	120.84	75.74	2.36	326.92	F 2.10
Mar.24 12:25 p.m.	28.00	85.64	53.93	1.87	164.98	F 2.02
Mar.24 4:45 p.m.	26.00	54.61	87.35	1.84	170.39	R 1.98
Mar.27	29.00	85.04	64.87	2.28	197.05	R 2.08
Apr. 3	9.50	30.78	36.38	0.87	40.00	F 1.35

*Predicted values.
F Falling stage.
R Rising stage.

MORRISON GULCH STATION DATA

Date (1971)	Water Turbidity (ppm)	Suspended Sediment Concentration (mg/l)	Water Discharge (cfs)	Antecedent Precipitation Index (Pa in inches)	Sediment Discharge (lbs/hr/sq.mi.)
Jan.31	7.00	7.97	1.75	0.02	3.13
Feb. 7	8.00	0.00	2.27	0.37	0.00
Feb.13	7.00	0.00	1.46	0.10	0.00
Feb.20	7.00	0.00	2.23	0.34	0.00
Feb.24	43.50	67.19	11.40	0.96	172.14
Mar. 5	10.00	23.85	5.01	0.62	26.85
Mar.12	34.00	80.69	27.14	2.02	492.14
Mar.20	9.50	0.00	3.80	0.89	0.00
Mar.22 12:35 p.m.	17.00	31.10	10.83	0.95	75.69
Mar.22 10:20 p.m.	79.00	164.07	42.59	2.27	1570.36
Mar.23 11:00 a.m.	37.00	64.96	29.66	1.46	432.99
Mar.23 4:20 p.m.	28.00	68.49	21.18	1.61	326.00
Mar.23-4 1:45 a.m.	27.00	66.68	20.24	1.62	303.30
Mar.24 1:15 p.m.	20.00	58.23	13.65	1.28	178.62
Mar.24 5:20 p.m.	20.00	59.20	13.65	1.18	181.60
Mar.27	26.00	70.65	19.30	1.55	306.43
Apr. 3	10.00	38.69	4.24	0.60	36.86

HIGHWAY 101 STATION DATA

Date (1971)	Water Turbidity (ppm)	Suspended Sediment Concentration (mg/1)	Water Discharge (cfs)	Antecedent Precipitation Index (Pa in inches)	Sediment Discharge (lbs/hr/sq.mi.)
Jan.31	4.00	0.00	20.21	0.02	0.00
Feb. 7	8.00	0.00	31.34	0.33	0.00
Feb.13	6.00	20.03	13.15	0.09	3.41
Feb.20	11.00	32.00	28.94	0.31	12.00
Feb.24	192.00	461.66	439.84*	0.88	2631.61
Mar. 5	36.00	118.87	111.67	0.57	172.03
Mar. 6	21.00	55.91	71.83	0.42	52.05
Mar.12	130.50	671.93	303.18*	1.85	2640.16
Mar.13	143.50	273.49	332.06*	1.55	1176.96
Mar.20	13.50	16.05	43.57	0.82	9.06
Mar.22 1:15 p.m.	12.00	31.04	42.47	0.87	17.08
Mar.22 5:10 p.m.	138.00	174.05	779.84*	1.37	1759.08
Mar.22 10:30 p.m.	165.00	1075.85	429.84*	2.08	5993.27
Mar.23 11:15 a.m.	80.00	191.68	260.97	1.34	648.29
Mar.23 5:40 p.m.	510.00	881.81	1146.47*	1.48	13102.15
Mar.23-4 2:00 a.m.	210.00	289.35	479.84*	1.49	1799.39
Mar.24 1:30 p.m.	80.00	175.09	190.97	1.18	433.34
Mar.24 5:50 p.m.	77.50	161.20	175.35	1.06	366.33
Mar.27 12:00 noon	65.00	164.92	257.63	1.43	550.65
Apr. 3	15.00	39.04	46.53	0.55	23.54

*Predicted values.