STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

Central District

SEDIMENT STUDY

ALTERNATIVE DELTA WATER FACILITIES

Peripheral Canal Plan

APRIL, 1977

CONVERSION FACTORS

English to Metric System of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)	25.4	millimetres (mm)
		.0254	metres (m)
	feet (ft)	.3048	metres (m)
	miles (mi)	1.6093	kilometres (km)
Area	square inches (in^2)	6.4516×10^{-4}	square metres (m^2)
	square feet (ft^2)	.092903	square metres (m^2)
	acres	4046.9	square metres (m^2)
		.40469	hectares (ha)
		.40469	square hectometres (hm^2)
		.0040469	square kilometres (km^2)
	square miles (mi^2)	2.590	square kilometres (km^2)
Volume	gallons (gal)	3.7854	litres (l)
		.0037854	cubic metres (m^3)
	million gallons (10^6 gal)	3785.4	cubic metres (m^3)
	cubic feet (ft^3)	.028317	cubic metres (m^3)
	cubic yards (yd^3)	.76455	cubic metres (m^3)
	acre-feet (ac-ft)	1233.5	cubic metres (m^3)
		.0012335	cubic hectometres (hm^3)
		1.233×10^{-6}	cubic kilometres (km^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
		.028317	cubic metres per second (m^3/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
		6.309×10^{-5}	cubic metres per second (m^3/s)
	million gallons per day (mgd)	.043813	cubic metres per second (m^3/s)
Mass	pounds (lb)	.45359	kilograms (kg)
	tons (short, 2,000 lb)	.90718	tonne (t)
		907.18	kilograms (kg)
Power	horsepower (hp)	0.7460	kilowatts (kW)
Pressure	pounds per square inch (psi)	6894.8	pascal (Pa)
Temperature	Degrees Fahrenheit (°F)	$\frac{tF - 32}{1.8} = tC$	Degrees Celsius (°C)

C—041830

STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

Central District

SEDIMENT STUDY

ALTERNATIVE DELTA WATER FACILITIES

Peripheral Canal Plan

APRIL, 1977

FOREWORD

The purpose of this study is to estimate the present and future sediment yields of the Sacramento River at the Peripheral Canal intake, estimate the quantity of sediment that would be diverted from the river into the Peripheral Canal, determine the need for and size requirements of a settling basin near the Canal intake, estimate the sediment transport capability of the Canal and sediment deposition in Clifton Court Forebay, and to determine the effect of Peripheral Canal diversions on sediment transport and deposition in the Sacramento River downstream from the Canal. A Canal operation concept is discussed which would result in minimizing the amount of sediment which would enter the Canal. Information is also provided on the relationship between suspended sediment concentration and turbidity in the Sacramento River.

The Department of Water Resources is currently reevaluating the Peripheral Canal and alternatives to the Canal. Information in this report on sediment yields and transport rates in the Sacramento River upstream of Hood is applicable to all of the Delta Water Facility alternatives. Information on sediment intake into the facility, the effect of the facility on settling basin sizing criteria, and sediment projections in Clifton Court Forebay is only applicable to the Peripheral Canal.

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Wayne MacRostie, Chief
Central District

State of California
EDMUND G. BROWN, JR., Governor

The Resources Agency
CLAIRE T. DEDRICK, Secretary for Resources

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CONCLUSIONS AND RECOMMENDATIONS

The purposes of this study were to: (1) estimate the present and future sediment yield of the Sacramento River near Hood; (2) estimate the quantity of sediment that would be diverted from the Sacramento River into the Peripheral Canal; (3) determine the need for and size requirements of a sediment basin near the Peripheral Canal intake; (4) estimate the sediment transport capacity within the Peripheral Canal and sediment deposition in the Canal and Clifton Court Forebay; (5) estimate the effect of Peripheral Canal diversions on sediment transport, deposition and turbidity in the Sacramento River downstream from the Canal intake.

Conclusions

The conclusions reached as a result of this study are:

1. The present average annual measured sediment load of the Sacramento River at Sacramento is about 2.7 million tons (2.45 million t).

The sediment load is exhibiting a decreasing trend which indicates that under the 2020 level of development the average annual sediment yield will be about 2 million tons (1.8 million t) with or without construction of the Peripheral Canal. Whether these trends are due to the effect of upstream water resource developments or if the river is still undergoing alterations of its regime as a result of hydraulic mining in the nineteenth century, or both, cannot be identified.

2. The characteristics of Sacramento River sediments have changed since the mid-1960s. Bed material is becoming somewhat finer and the operation of upstream reservoirs has had some effect on the monthly distribution of flows and sediment loads.

3. The Peripheral Canal would divert approximately 48 percent of the 2 million tons per year (1.8 million t/year)

of the Sacramento River sediment yield at the 2020 level of development.

4. Due to the possible criteria for the protection of fish, a low velocity, very wide Canal intake section may be required. Because of this, a considerable amount of the 993,000 tons (990 000 t) of sediment diverted by the Canal, will settle in the Canal intake.

5. A settling basin approximately 5,300 feet long (1 600 m) should be provided to accommodate an average annual amount of material in the order of 500,000 tons (460 000 t), including a 50 percent sediment overload factor to account for above average runoff years. The width and depth of the basin to provide this dead storage volume will need to be sized accordingly.

6. Suspended material not trapped in the intake settling basin will be transported through the Canal to Clifton Court Forebay, although some deposition may occur in siphons and in planned recreation lagoon areas.

7. Under present operation, Clifton Court Forebay is losing approximately 97 acre-feet (120 000 m^3) of storage space annually due to sediment accumulation. This loss of storage space will increase to about 396 acre-feet annually (490 000 m^3) if the Peripheral Canal becomes operational.

8. Due to the reduced flows in the Sacramento River downstream of the Canal intake, approximately 159 000 tons (145 000 t) of sediment will deposit annually between Hood and Walnut Grove due to Canal operation during an average year at full development. Deposition downstream of the intake during above normal and critically dry years would be about 340,000 tons (310 000 t) and 60,000 tons (55 000 t) respectively.

9. Annual dredging and disposal will be required at the Canal intake settling basin. Periodic dredging will be required at Clifton Court Forebay, at siphons, in recreation lagoons, and in the Sacramento River from Hood to Walnut Grove (if sediment deposition encroaches on navigational depths or impairs the flow capacity of the river).

10. By selectively operating the intake gates in response to the river hydrograph, a considerable portion of the total annual amount of material that would settle in the basin can be retained in the river, where it will remain in suspension.

11. Operation of the Peripheral Canal will reduce turbidity duration in the Sacramento River downstream of the Canal intake.

Recommendations

The following recommendations are made:

1. The effects of alternative intake and fish screen facilities on sediment diversions were not included in this report. These effects should be evaluated in the model under construction at the University of California at Davis.

2. Point sediment sampling should be conducted in the Sacramento River at Hood to determine the vertical distribution of sediment at the intake site. Such a program, which could be conducted in cooperation with the USGS*, would provide better information on the size of particles that would be diverted into the Canal.

3. The collection and evaluation of data on turbidity, organic material, and inorganic sediments, under the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary and the Department's Sacramento River Debris Distribution and Occurrence Study, should continue to determine how these factors affect the ecology of the estuary.

4. The trap efficiency of Clifton Court Forebay should be more accurately determined from measurements of sediment inflow at the control structure and outflow from the Delta Pumping Plant for low and high export rates and at different times of the year, especially during the winter when concentration of sediment is high in the surrounding Delta channels.

5. If the Peripheral Canal is not chosen as the Delta Facility, the sedimentation aspects of the alternative facility should be evaluated.

---

* U.S. Geological Survey

CHAPTER I

INTRODUCTION

Importance of Sedimentation

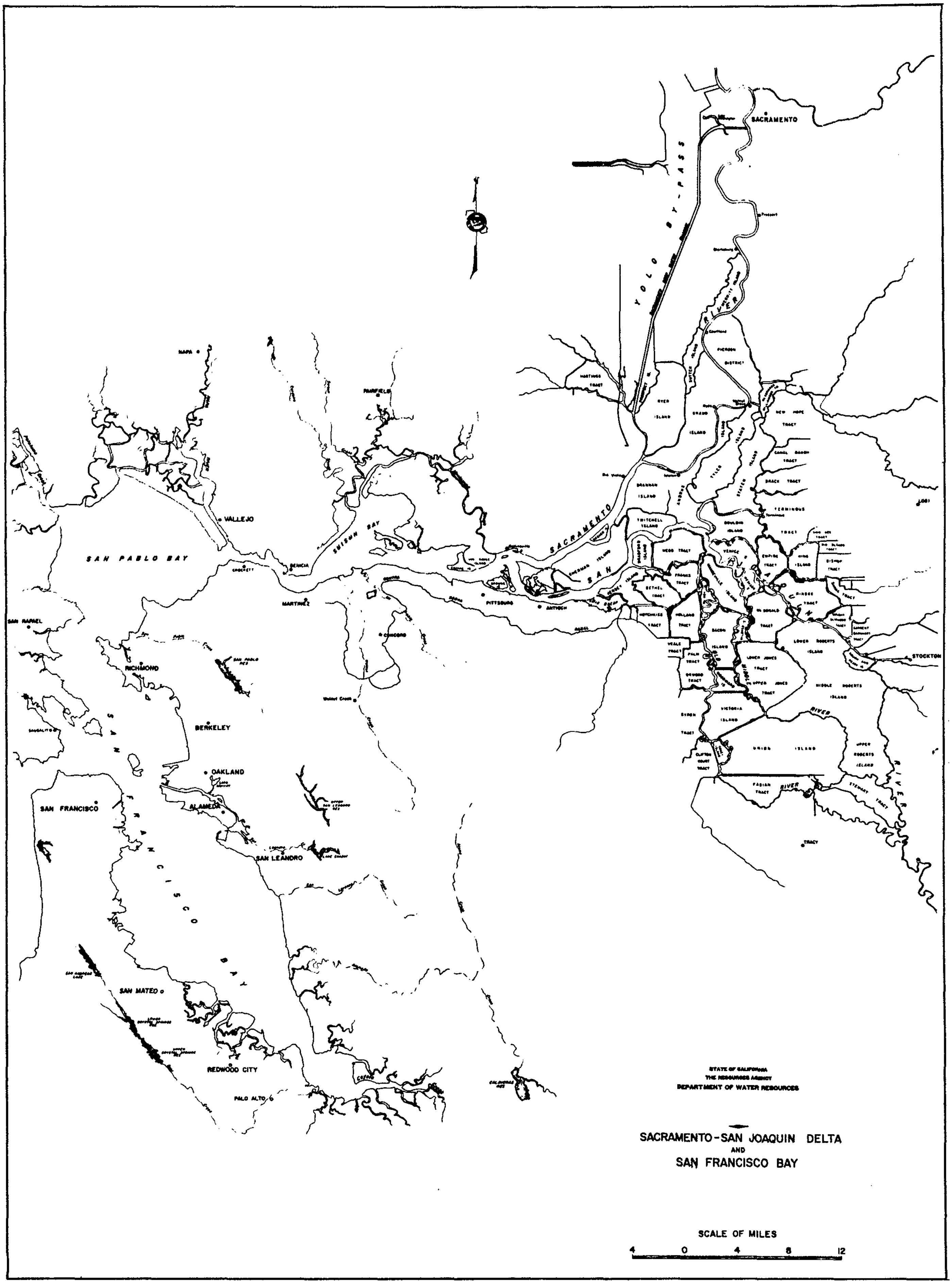
The reader is probably familiar with the most visual impacts of sedimentation -- erosion of hillsides and flood plain deposition. Less obvious are some of the sediment transport and deposition problems that can result from the construction and operation of large scale water projects; the decline of sand supply to coastal beaches, deposition in project reservoirs that may reduce the operating flexibility and the capacity of the system, sediment accumulation at canal bends, siphons and other structures in the project, damage to turbine and pump parts, and deposition of silts in agricultural irrigation canals.

Sediments are also a major factor in water quality problems. Chemicals, pesticides, bacteria, viruses, radioactive material and other wastes are assimilated and transported by sediment particles. Turbidity, caused by sediments in water, has resulted in changes in fish species occurring in streams and a resultant impact on recreation use. Decreased turbidity due to removal of sediments may stimulate algae and aquatic plant growth [25]*.

Source of Sediments Entering the Bay-Delta System

Water-borne sediments entering the Sacramento-San Joaquin Delta and San Francisco Bay system (Figure 1) originate within the Central Valley drainage basin which encompasses an area of more than 60,000 square miles (155 000 km^2) or nearly 40 percent of the land surface of California. Two major rivers, the Sacramento and the San Joaquin, join to form the Sacramento-San Joaquin Delta, then flow westerly into San Francisco Bay. Although the drainage area of the Sacramento River upstream of Sacramento is only slightly greater than one-third of the Central Valley drainage area, the Sacramento and its

* See Bibliography - Appendix B



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tributaries supply an estimated 80 to 94 percent of the sediment load entering the Bay system [6, 9]; the remainder is contributed from the San Joaquin River and a number of minor streams entering the Delta. The drainage areas of the Central Valley are shown on Figure 2.

Delta Water Facility Alternatives

Water transfer facilities are needed to correct adverse environmental conditions in the Delta associated with the present method of conveying water through the Delta for the State Water Project (SWP) and federal Central Valley Project (CVP), and to help meet the export requirements of the projects.

The Department of Water Resources (DWR) adopted the Peripheral Canal as the Delta Water Facility in 1966 as a result of the Interagency Delta Committee studies [31]. However, comments received on the 1974 draft Environmental Impact Report on the Peripheral Canal raised numerous technical, legal, and policy issues. Some of the issues raised indicated a need to reanalyze the Delta requirements including the need for and timing of physical facilities. Accordingly, the Department proceeded with a review to reexamine alternative Delta facilities and to resolve certain environmental concerns. Many plans were reviewed, and after lengthy public hearings, the proposed Delta water transfer facilities have been narrowed to three alternatives: (1) New Hope Cross Channel with an enlarged Clifton Court Forebay (Figure 3); (2) The New Hope Cross Channel with a Southern Delta Intake Channel (Figure 4); and the Peripheral Canal (Figures 5 and 6).

1. New Hope Cross Channel - Enlarged Clifton Court Forebay Plan. This alternative would involve the construction of a new channel from Hood on the Sacramento River to Beaver Slough (the New Hope Cross Channel). This channel would be 12 miles (19 km) long. Another channel 1-1/2 miles (2.5 km) long would be constructed across Staten Island to cross-connect the two forks of the Mokelumne River. Fish screens and flood gates would be required at the intake. Enlarging

FIGURE 2

DRAINAGE AREAS OF THE CENTRAL VALLEY

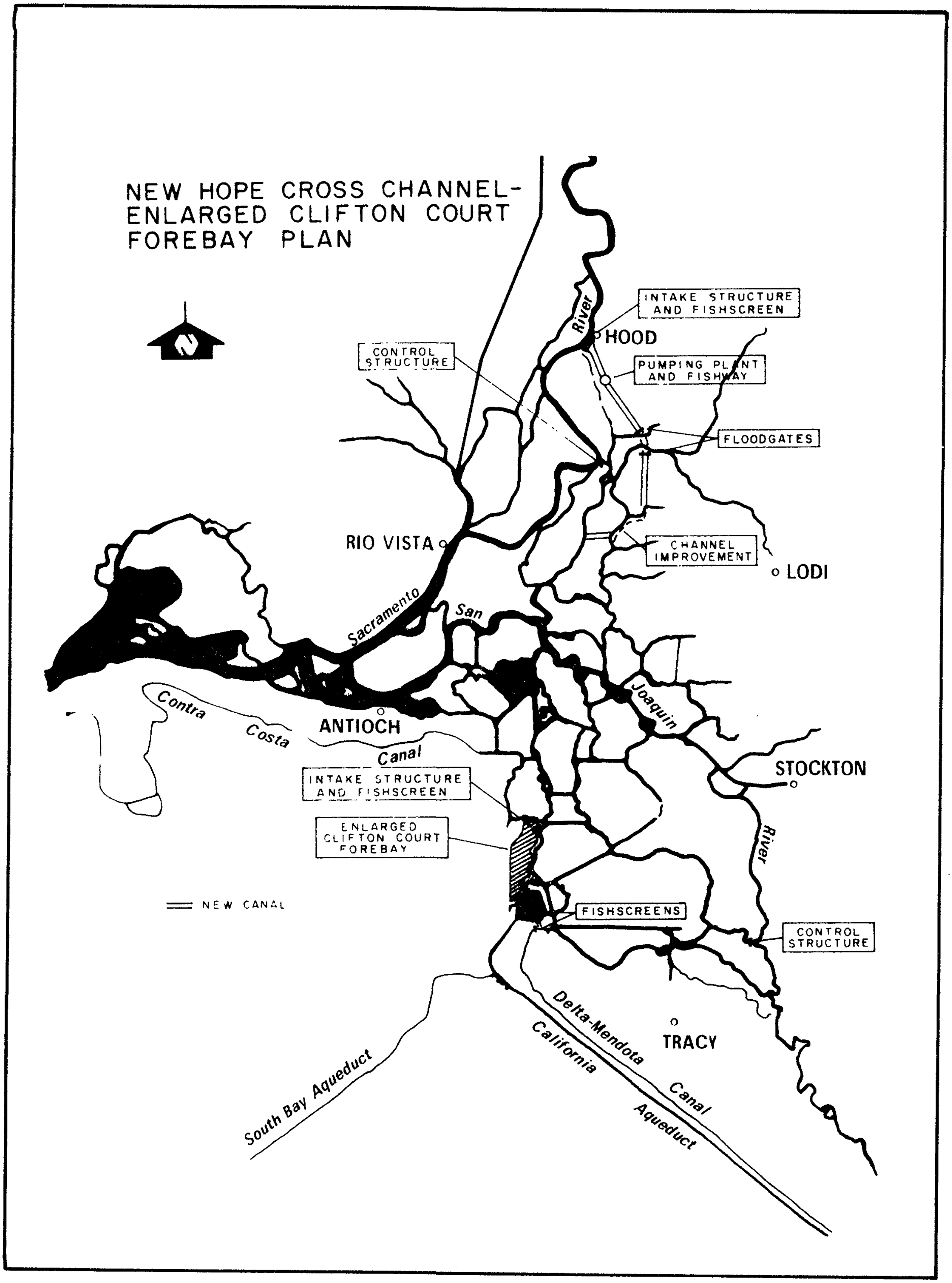
SCALE OF MILES

80 0 80

LEGEND

DRAINAGE AREA UPSTREAM OF SACRAMENTO

SAN FRANCISCO BAY, DELTA AND SAN JOAQUIN VALLEY DRAINAGE AREA



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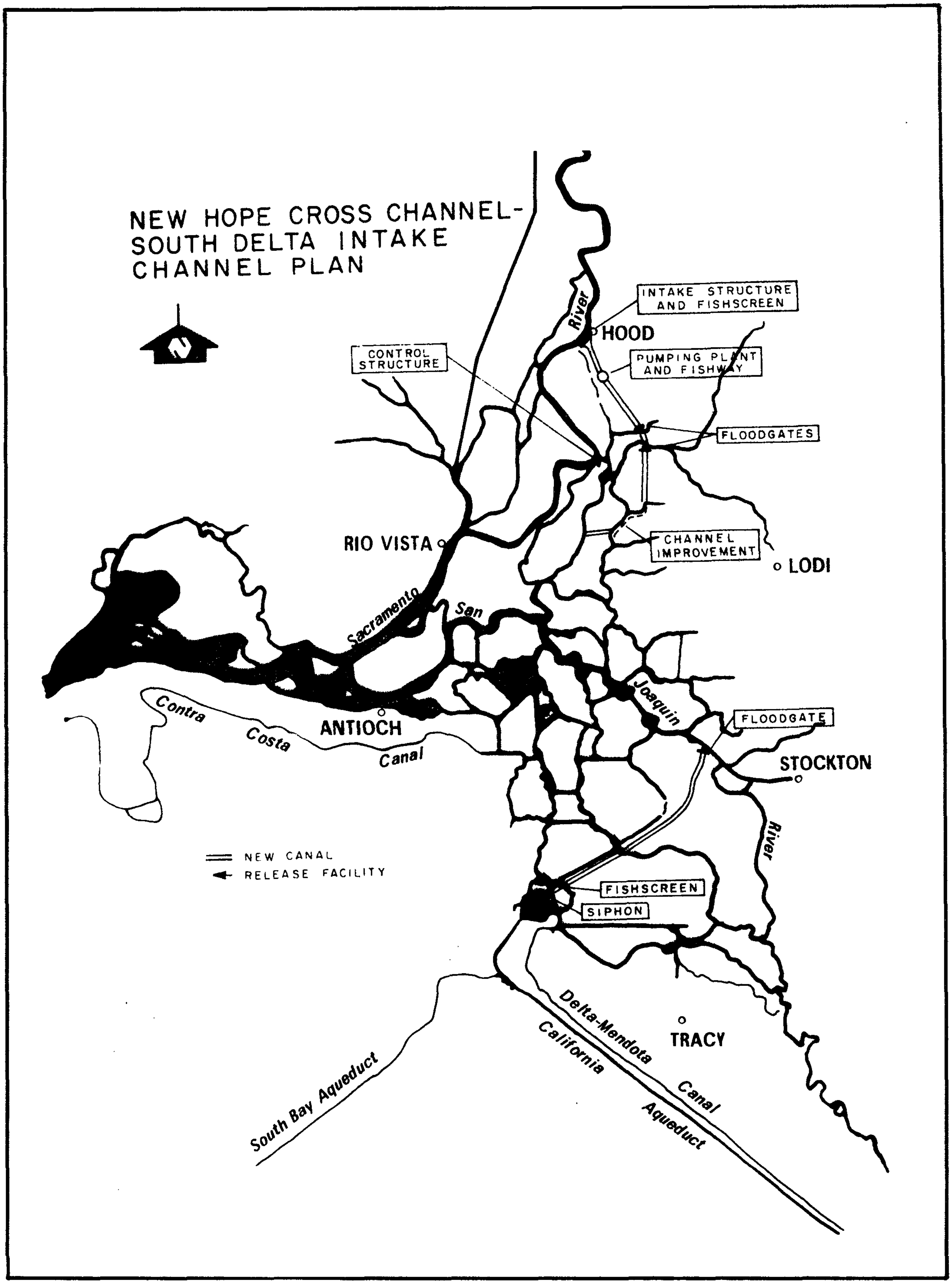
NEW HOPE CROSS CHANNEL-
SOUTH DELTA INTAKE
CHANNEL PLAN
INTAKE STRUCTURE AND FISHSCREEN
HOOD
River
CONTROL STRUCTURE
PUMPING PLANT AND FISHWAY
FLOODGATES
RIO VISTA
CHANNEL IMPROVEMENT
LODI
Sacramento
San
Joaquin
FLOODGATE
STOCKTON
River
Contra
Costa
ANTIOCH
Canal
NEW CANAL
RELEASE FACILITY
FISHSCREEN
SIPHON
Delta-Mendota
California
TRACY
Canal
Aqueduct
South Bay Aqueduct

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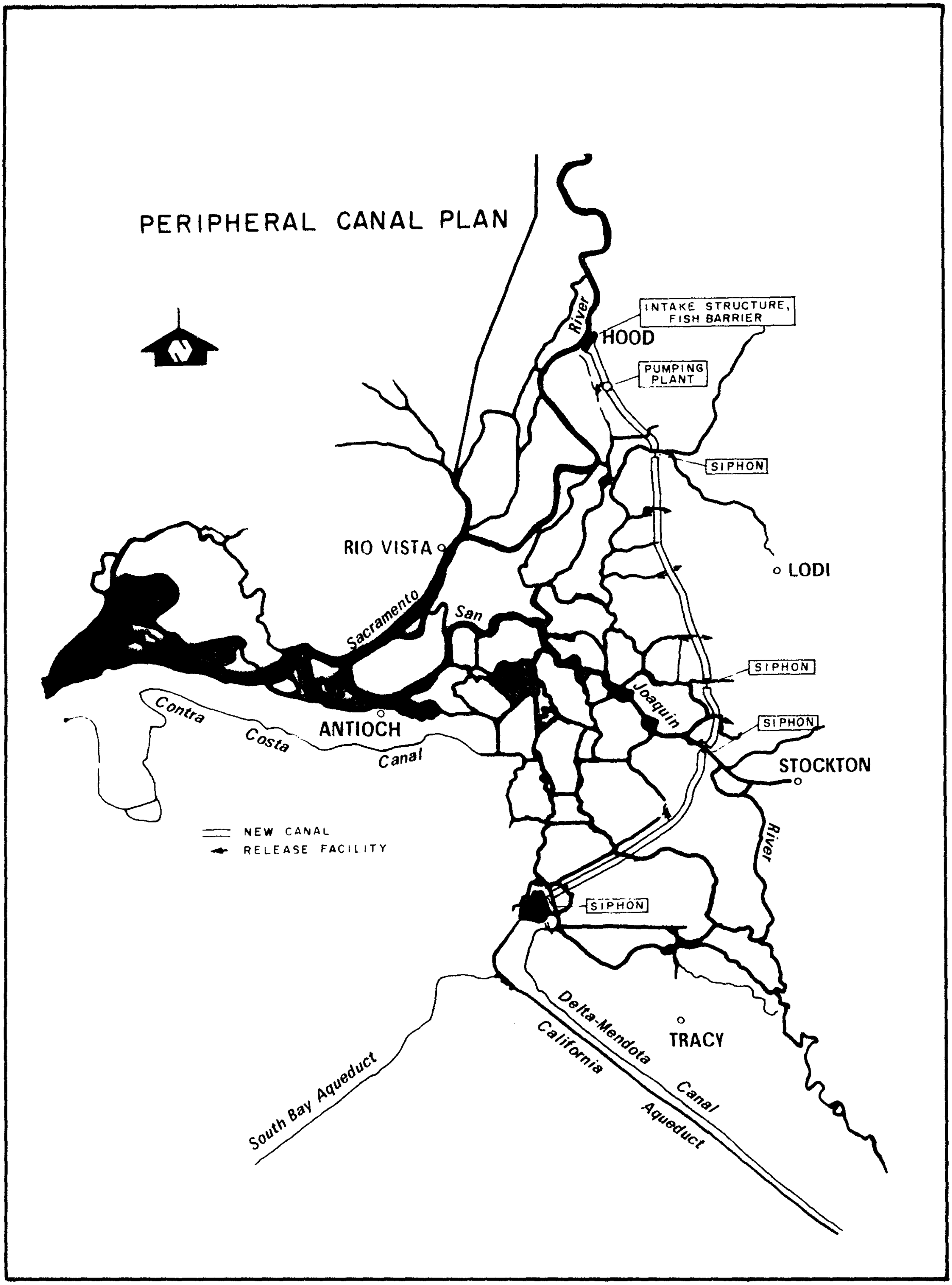
PERIPHERAL CANAL PLAN
INTAKE STRUCTURE, FISH BARRIER
HOOD
PUMPING PLANT
River
SIPHON
RIO VISTA
LODI
Sacramento
San
SIPHON
Joaquin
SIPHON
STOCKTON
River
Contra
Costa
Canal
ANTIOCH
NEW CANAL
RELEASE FACILITY
SIPHON
TRACY
Delta-Mendota
Canal
California
Aqueduct
South Bay Aqueduct

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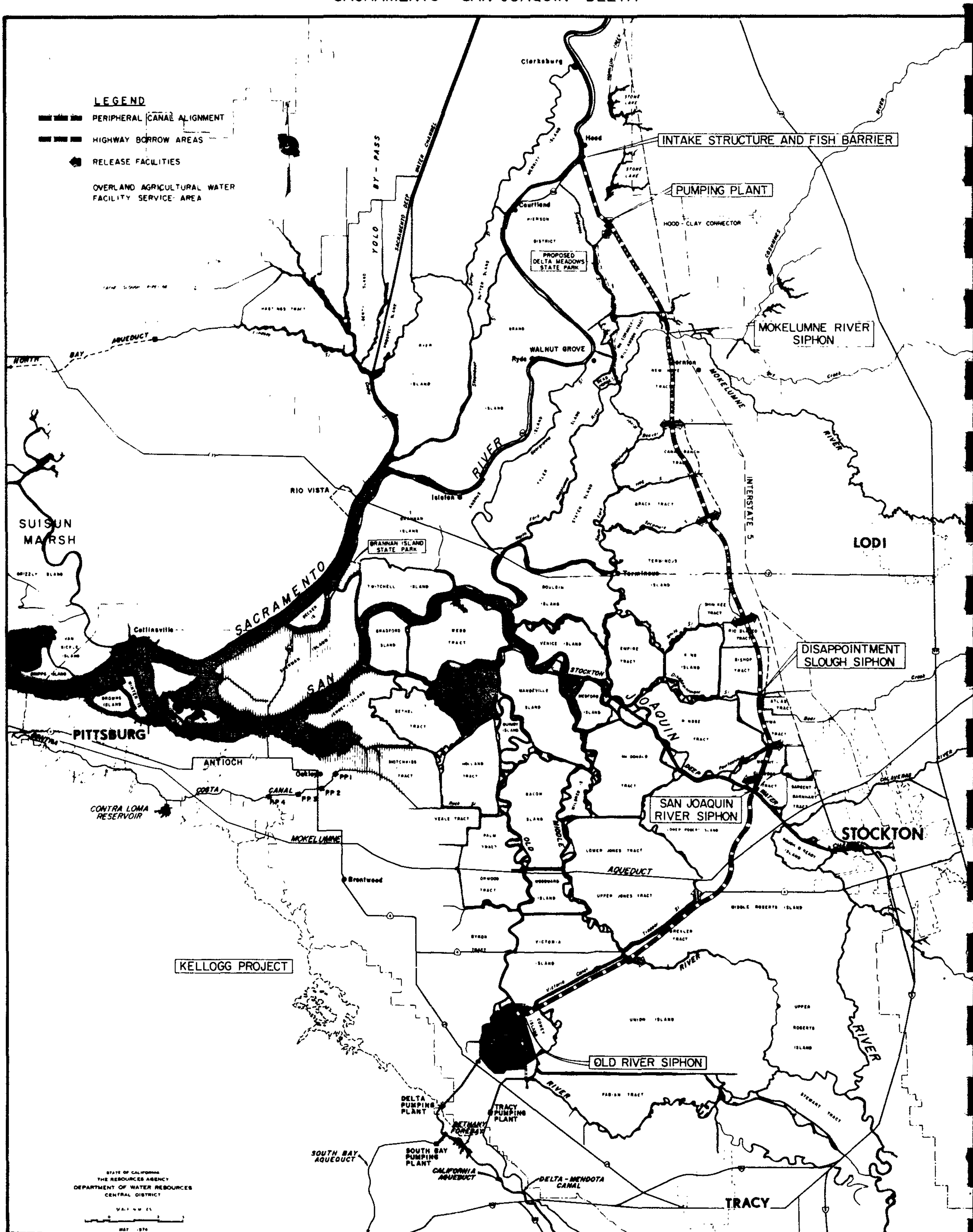
FIGURE 6

PERIPHERAL CANAL PLAN

SACRAMENTO – SAN JOAQUIN DELTA



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the Forebay to double the existing capacity would allow more water to be diverted at high tide, which would increase the average sustained rate of export without causing excessive scour or low water problems in the southern Delta. It would not, however, correct flow reversal and fishery problems in Old and Middle Rivers.

This alternative would eliminate reverse flow around Sherman Island, reduce damage to the striped bass spawning and nursery area in the western Delta, reduce damage to salmon and shad, and permit conservation of water that is now required for salinity control.

2. New Hope Cross Channel - South Delta Intake Channel Plan. This alternative is the same in the northern Delta as the previous alternative. The New Hope Cross Channel and the Staten Island Cross Channel would be constructed and Beaver Slough would be enlarged. Its accomplishments would also be similar.

A South Delta Intake Channel would be constructed from the San Joaquin River just west of Stockton to the existing Clifton Court Forebay. A fish screen would be needed at the terminous of the South Delta Intake Channel near Clifton Court Forebay.

This alternative would allow diversion of more water without scour or low water problems. In addition, positive flow would be provided for fish in Middle and Old Rivers.

3. Peripheral Canal Plan. This alternative would involve the construction of the Peripheral Canal which would divert CVP and SWP water from the Sacramento River near Hood and transport it around the easterly perimeter of the Sacramento-San Joaquin Delta to the existing export pumping plants near Tracy (Figure 6). The intake capacity of the Canal would be 23,300 cfs (650 m^3/s) which would include 1,500 cfs (40 m^3/s) for the federally proposed Hood-Clay connection to the Folsom-South Canal. The 42-mile long (68 km) earth-lined Peripheral

Canal would have a water surface width of about 400 feet (120 m) or more and a maximum depth of about 30 feet (9 m).

The Canal would be siphoned under the Mokelumne River, Disappointment Slough, San Joaquin River and Old River.

release structures would be located along the length of the Canal to distribute fresh water into existing Delta channels. Hydraulically isolated from the Delta channels, the Peripheral Canal would correct virtually all the reverse flow problems in the Delta.

A typical cross-section of the canal is shown in Figure 7a. Lagoon areas are being proposed for recreation purposes at several locations along the Canal. A typical lagoon area is shown in Figure 7b.

Alternative Intake Configurations

All three of the alternatives would divert water from the Sacramento River near the community of Hood, approximately 22 miles (35 km) south of the City of Sacramento. The intake structure would include trashracks, floodgates, and fish screening facilities.

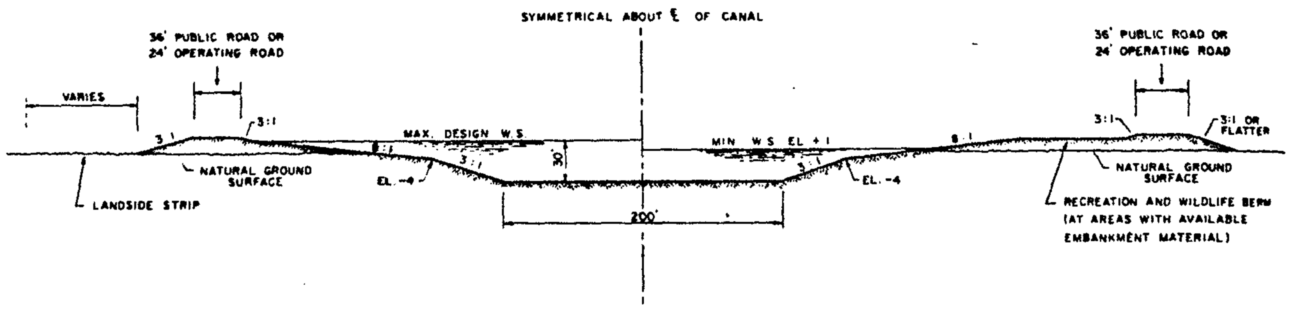
Two alternative intake concepts - on-river and off-river - are being studied. These are shown in Figures 8 and 9.

Scope of Report

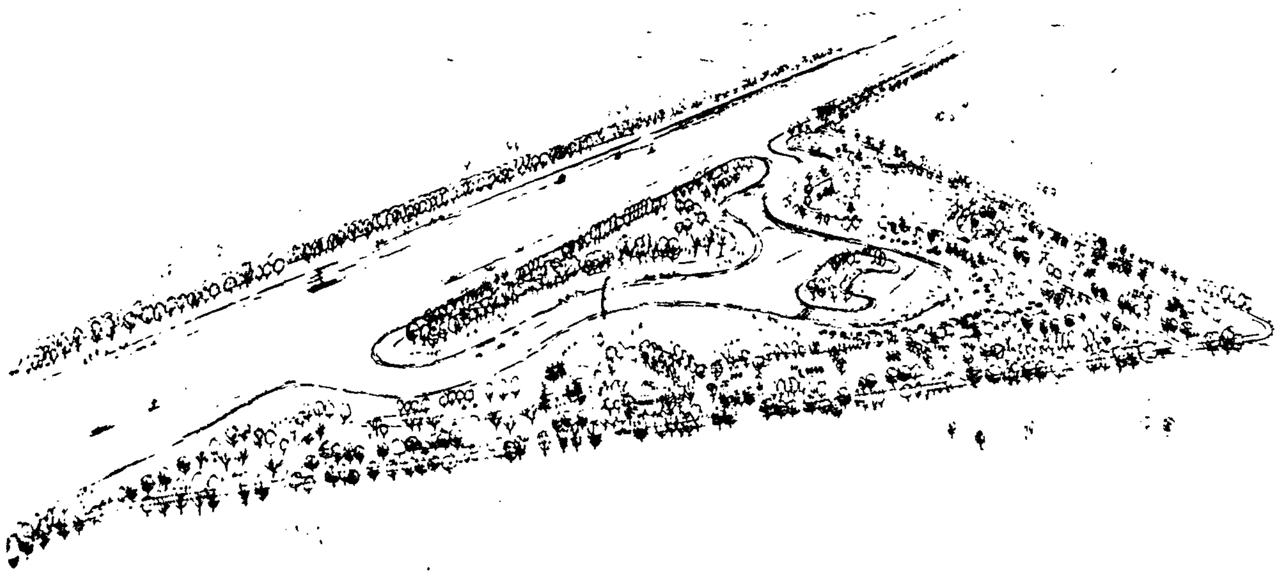
Information in this report on sediment loads and transport rates in the Sacramento River upstream of Hood is applicable to all three of the Delta water facility alternatives. Information on sediment intake into the facility, the effect of the facility on sediment basin sizing criteria, and sediment projections in Clifton Court Forebay are applicable only to the Peripheral Canal.

The two alternatives that include New Hope Cross Channel are not hydraulically isolated from Delta channels as is the Peripheral Canal. Therefore, the effect of tides on flow depth, velocity, discharge, flow distribution and sediment transport both within the facility and in the Delta channels would need to be studied for

PERIPHERAL CANAL PLAN
TYPICAL CROSS SECTION AND
PROPOSED RECREATION AREA



7A TYPICAL CROSS SECTION



7B PROPOSED RECREATION AREA

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FIGURE 8

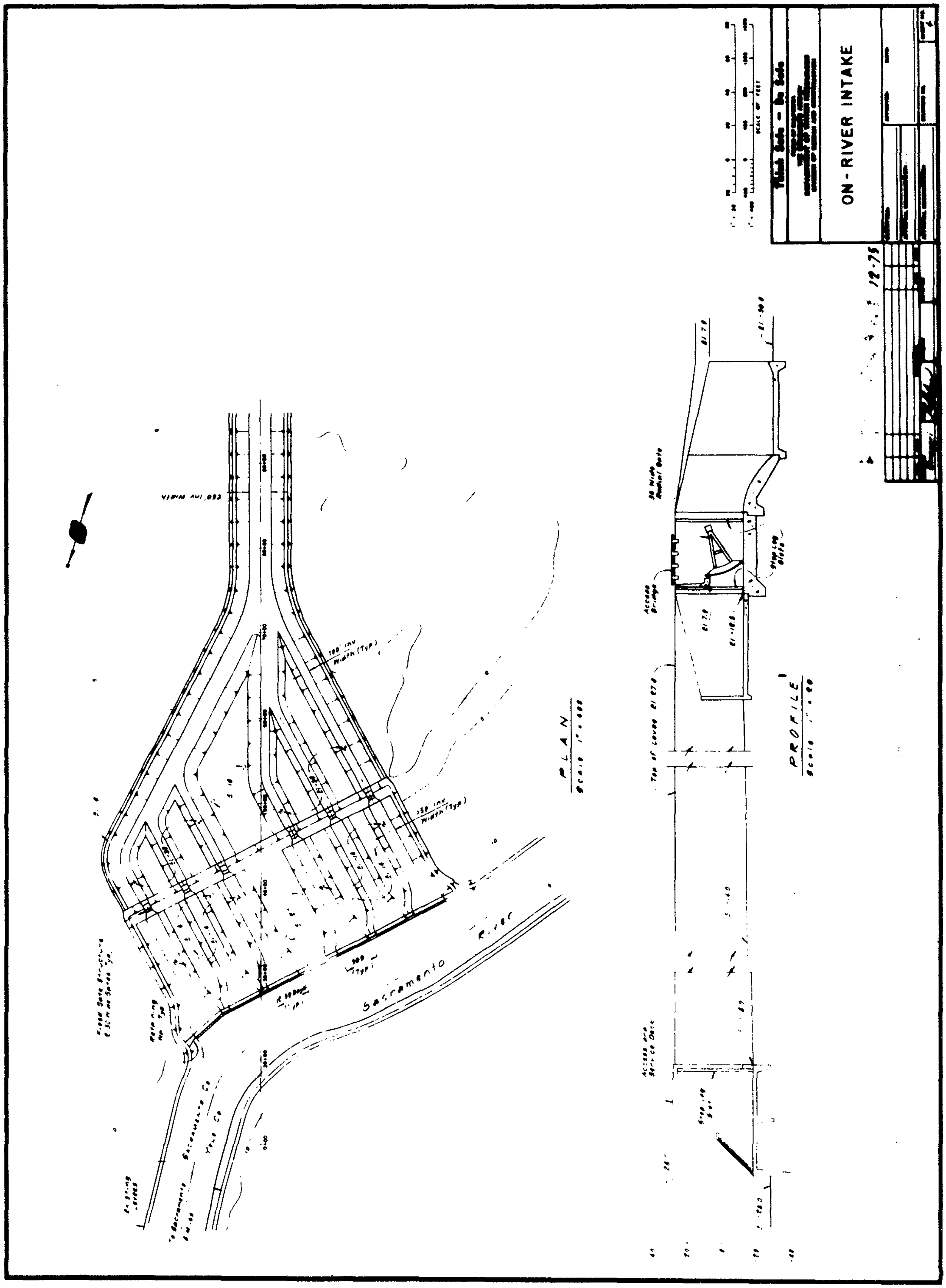
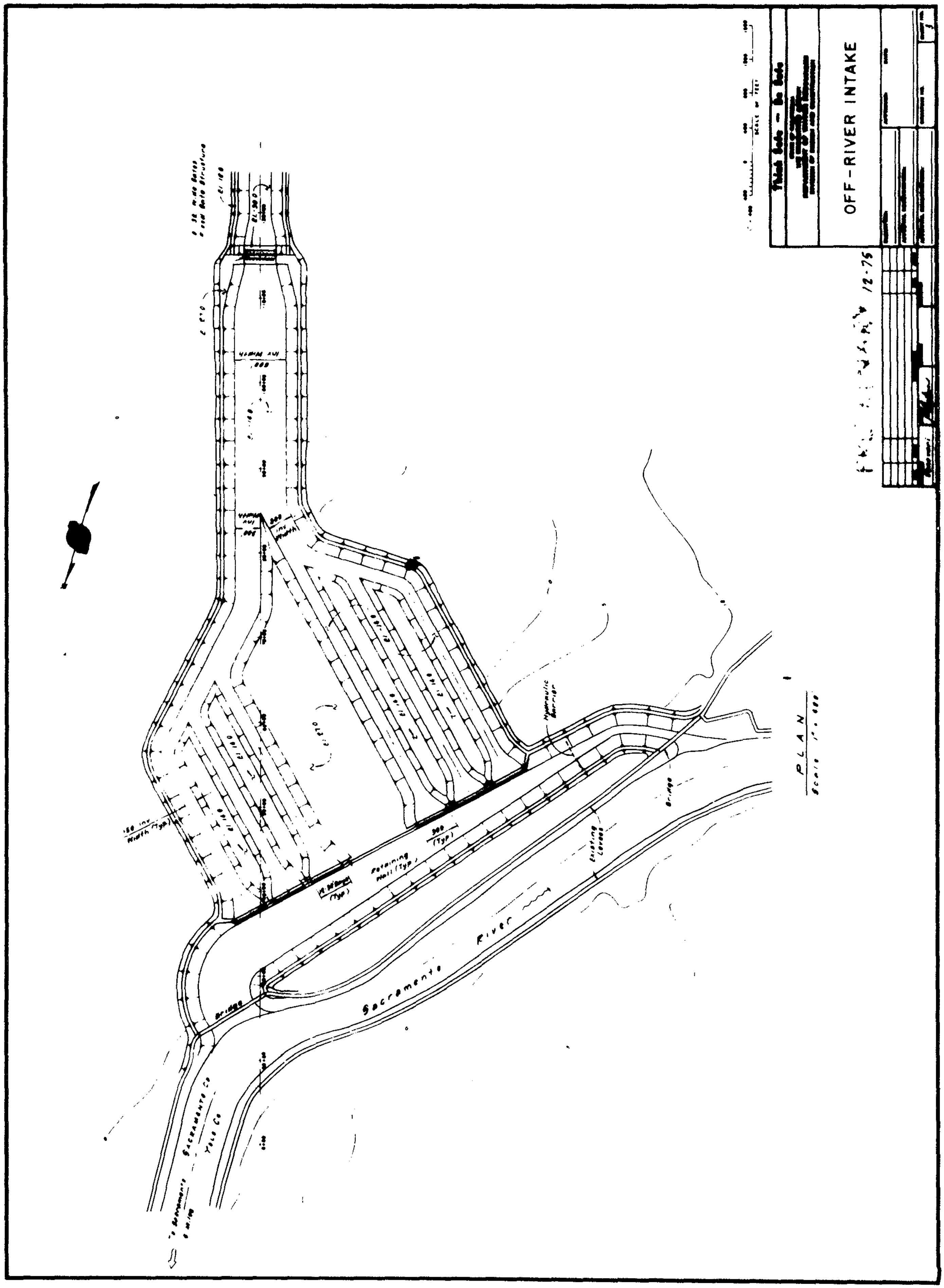


FIGURE 9


OFF-RIVER INTAKE
PLAN
Bridge
Existing Levees
Hydraulic Barrier
Retaining Wall (Typ)
Sacramento River
Sacramento Co
Yolo Co
12-75

these two alternatives. If either of these two alternatives are selected, a sediment study similar to this one will be required. However, such a study also would require consideration of sediment inflows to the Delta from other streams such as the San Joaquin River, Mokelumne River, and Cosumnes River, along with analysis of transport capacity and deposition in existing Delta channels.

CHAPTER II

SEDIMENT TRANSPORT MECHANICS

Terminology

In this report the term "sediment" refers to the sand, silt and clay particles that result from weathering and erosion of inorganic material. Organic debris (leaves, algae, etc.) are not considered as sediment.

The following descriptions of sediment motion, bed configuration and classification of sediment loads have been taken from the ASCE Manual on Sedimentation Engineering [25].

> Description of Sediment Motion. "To define the terms to be used in considering sediment movement, it is convenient to describe the motion of grains caused by water flowing over a bed of sediment that was first flattened artificially. At very low velocities no sediment will move, but at some higher velocity individual grains will roll and slide intermittently along the bed. The material so moved is defined as the contact load of the stream. At a still higher velocity, some grains will make short jumps, leaving the bed for short instants of time and returning either to come to rest or to continue in motion on the bed or by executing further jumps. The material moved in this manner is said to saltate and is called the saltation load of the stream. If now, the flow velocity is raised gradually, the jumps executed by the grains will occur more frequently and some of the grains will be swept into the main body of the flow by the upward components of the turbulence and kept in suspension for appreciable lengths of time. Sediment that is carried in suspension in this manner is known as the suspended load of a stream.
>
> Bed Configuration. "Under certain flow conditions with relatively low sediment-transport rates, the sediment bed will deform into wavelike forms with small slopes on their upstream faces, a sharp crest, and steep downstream faces. At higher velocities and depths, the length of these forms may increase many fold, still keeping the sharp crest. These forms move downstream at velocities that are small compared to the flow velocity. Sharp-crested forms of this kind with wave lengths less than approximately 1 foot are called dunes. At some higher velocity, the ripples or dunes, or both, disappear and the bed becomes flat. At some still higher velocity, a wave of sinusoidal shape develops, which usually moves upstream

and is accompanied by waves on the water surface. Sand waves of the latter type are known as antidunes. Antidunes are always accompanied by waves on the water surface that are called surface waves or sand waves. Surface waves are often unsteady; they usually move upstream slowly, increase in amplitude until they become unstable, then break by curling over in the upstream direction, and disappear only to form again and repeat the cycle.

Classification of Sediment Load. "While material is transported in suspension, saltation and rolling and sliding on the bed is also occurring, so that all three modes of transportation occur simultaneously. Apparently then, the different modes of transportation are closely related and it is difficult, if not impossible, to separate them completely. The borderline between contact load and saltation load is certainly not well defined, because it is indeed hard to imagine a particle rolling on the bed without at some time losing contact with the bed and executing short jumps, and, according to definition, becoming saltation load. In a similar manner, the distinction between saltation and suspension is also not definite.

"These difficulties are avoided in a practical way by introducing the term "bed load", which is defined as material moving on or near the bed so that the total load is now made up of the bed load and suspended load. In addition, the total load is divided into "bed sediment load" and "wash load", which are defined as being, respectively, of particle sizes found in appreciable quantities and in very small quantities in the shifting portions of the bed. Obviously, both the bed sediment load and the wash load may move partially as bed load and partially as suspended load, although by definition, practically all the wash load is carried in suspension.

"Finally, it is convenient to introduce the term "sediment discharge", which is defined as the quantity of sediment per unit time carried past any cross section of a stream. The term should be qualified. For example, one may refer to the bed load discharge, the bed sediment discharge, or the total sediment discharge."

The term "load" is usually used in a qualitative manner to refer to the material that is being transported, while the term "sediment discharge" refers to the rate of transport of the material. In this report, the two terms are used interchangeably.

Measurement of Sediment Discharge

U. S. Government agencies have developed and accepted procedures for measuring suspended sediment loads in streams and rivers. In a technique similar to stream gaging, a number of water samples are obtained and from the concentration of sediment in the samples, a "measured suspended sediment" load of the stream is calculated based on the water discharge [10]. Because of physical limitations of the sampling equipment, it is not possible to measure down close to the streambed. The U. S. Geological Survey (USGS) estimates that 75 to 95 percent of the total sediment load of a stream can be measured. Sediment transported close to the bed, usually within 0.5 feet (0.15 m) of the bed, is below the zone of measurement and is referred to as "unmeasured sediment load". If an estimate of the unmeasured load is required, it is usually determined mathematically from bed load equations. To date, no method has been developed that is successful in measuring the bed load discharge, although Serr [27] reports that the USGS is investigating an experimental bed load sampler (Helley-Smith) that is reportedly successful under certain conditions.

Factors Affecting Sediment Transport

Many factors are involved in sediment transport -- precipitation, soil saturation, vegetative cover, watershed changes, stream channel configuration and geometry, flow velocities, water quality, characteristics of the sediments, and many more. The determination of sediment transport rates is extremely complex because many of the variables cannot be determined or must be expressed graphically.

> "The variables relate not only to available supply of the sediment but also to sizes, shapes, and densities of the particles; velocities of flow; channel widths, depths, and slopes; bank roughness and bed configuration; and density, temperature, and at times even chemical composition of the water. An average particle size or mean velocity may be an inadequate measure, respectively, of particle sizes of a sediment or of velocity at a cross section, because the distribution about the average has significant effects. Most factors affecting sediment discharge change not only with time and with distance along a channel but also with depth and with lateral distance at an individual cross section"[1].

The mechanics of sediment transport in either saline or tidally affected streams, such as the lower Sacramento River and the Delta, is even more complex than in fresh water streams.

> "The changes in tide affect the place of deposition of the stream sediments. A stream transporting some sediment sizes at its full ability will begin to deposit some particles of these sizes where the stream is first slowed by the effect of the ocean level. The place of this first deposition may vary several miles and depends on whether the flow is affected by high or low tide. Thus, along an appreciable reach of tidal stream, sediment deposition may be intermittent. Also, some sediment deposited at high tides may be eroded from the stream-bed at low tides. Farther downstream, sediment may deposit slowly at low tide and much faster at high tide. Of course, the amount and place of deposition of sediment also vary with the discharge of the stream. If the stream-flow is low, some fine sediment may even be carried back upstream while the tide is rising and be deposited before downstream flow begins again. Especially during floods, some fine sediment may be carried far out into the ocean or bay by the stream current.
>
> "The fine sediments usually flocculate readily when they meet the saline water near the mouth of a stream that enters an ocean or a salt-water bay. The flocculated particles then settle faster with respect to the flow than less flocculated particles of the same discrete sizes. The upstream extent of the salt water intrusion in a river or estuary varies within each tidal cycle and with the flow of the stream and the slope of the channel.
>
> "The water-sediment mixture that enters salt water from a river is practically always less dense than the salt water, and hence the mixture may spread out over the salt water but probably seldom moves under it in the form of a density current that might carry large amounts of fine sediment far from the river mouth. Also, the effects of the tide may help to mix saline water with the river water and increase the amount of flocculation of the fine sediment.
>
> "These facts do not mean that vast tonnages of fine sediment are not carried beyond the mouths of tidal rivers, but they do mean that the proportion thus transported would probably be far greater if the stream entered a fresh water reservoir [1].

Data Used

Data on flows, sediment discharge and particle size analysis of suspended and bed material for this report were taken from USGS published records. The nearest measurement station to the Delta water facility intake located near Hood is the Sacramento River at Sacramento, some 22 miles (35.4 km) upstream. Soundings of the river in the vicinity of Hood were taken by the Department during high and low flows in 1973 and 1974 for the construction of a physical model of the canal intake by the University of California at Davis. No significant deposition or scour occurred in the riverbed between high and low flows, although the accuracy of soundings may not be adequate to detect small changes in the bed elevation. Since no major diversions from or accretions to the river occur between Sacramento and Hood, the sediment and flow data for the Sacramento River at Sacramento were considered also to be valid for the vicinity of the Canal intake site at Hood. Records of daily flows and measured suspended sediment discharge for water years 1957 through 1973 were collected for analysis, along with periodic analysis of particle size distribution of suspended and bed material.

Records of daily high, low, and mean water surface stages from 1957 through 1970 were obtained from DWR publications for stations at Sacramento, Freeport, Snodgrass Slough, and Walnut Grove.

Monthly runoff and measured suspended sediment loads for the 1957 through 1973 water years are tabulated and shown graphically in Appendix C.

Logarithmic plots of daily discharge and measured suspended sediment load for Sacramento River at Sacramento for the 1957 through 1970 water years are shown in Appendix D.

CHAPTER III

PRESENT SEDIMENT CONDITIONS

Effects of Hydraulic Mining

The major cause of sediment related problems in the Central Valley resulted from mining activities during the gold rush of the nineteenth century.

> "Extensive hydraulic placer-mining operations on the west slopes of the Sierra Nevada Mountains in Northern California, between 1849 and 1914, dumped over a billion and a half cubic yards of sediment into the Sacramento River and its tributaries" [12].

Millions of cubic yards of sand were disgorged into the streams annually, obliterating some of the channels and covering the river bottomlands with sand up to several miles in width. As the river channels were filled with sand, normal water levels rose drastically and frequent flooding occurred. Subsequently, fertile farm lands were destroyed by sediment deposits that often filled farm homes up to the window tops [11].

While some hydraulic mining was carried on in the tributaries of the San Joaquin River, by far the greatest sediment loads were produced in three tributaries of the Sacramento, namely the Feather, Yuba, and American Rivers.

During the gold rush, which began in 1849 and lasted into the 1870s, and until after the turn of the century, when debris catchment dams were constructed, the average sediment load reaching San Francisco Bay was about 18 million cubic yards (14 million m^3) compared to the present average of about 4 million cubic yards (3 million m^3). The average annual amount of material washed out of the hydraulic mining areas was estimated to be about 28 million cubic yards (21 million m^3) [8]. Approximately half of this material reached the bays; the rest remained in the Sierra Nevada foothills in piedmont fan deposits, in river channels, or in flood plain deposits.

Estimates of the historic annual sediment inflow to San Francisco Bay are presented in Table 1. Much of the information shown for years prior to 1957 was predicted based

TABLE I

ANNUAL SEDIMENT INFLOW TO BAY SYSTEM
FROM CENTRAL VALLEY DRAINAGE AREA

PERIOD	ANNUAL SEDIMENT INFLOW - CUBIC YARDS	
	Total drainage area	Sacramento River 5/
Prior to 1849	2,000,000 1/	1,900,000 2/
1849 to 1914	18,000,000 1/	17,100,000 2/
Future Estimate with 1914 Controls 4/	8,000,000 1/	7,600,000 2/
1931	5,750,000 1/	5,461,000 2/
1955	4,000,000 1/	3,800,000 2/
1957 to 1963	4,045,000	3,843,000 3/
1964 to 1970	4,445,000	4,223,000 3/
1971 to 1973	3,454,000	3,281,000 3/

1/ From Reference 9.

2/ Inflow from Sacramento River estimated at 95 percent of total Delta inflow.

3/ USGS Records for measured sediment of Sacramento River at Sacramento, assuming a density of 100 pounds per cubic foot.

4/ Based on river control works (dams, reservoirs, levees, etc) that existed in 1914.

5/ Sacramento River sediment yield estimated to be 95 percent of total drainage area sediment yield.

on visual estimates of land erosion in the watershed. Estimates after 1957 are based on river sediment measurements.

As the mining activities abated, channel depths increased as the river eroded the bed deposits. The deposits were gradually washed farther downstream each year, much like a huge sand wave.

Jones [8] compiled data from many sources to develop the annual low water elevation of the Yuba River at Marysville and the Sacramento River at Sacramento (see Figure 10). The hypothesis indicated by this plot is that the passage of mining sediment at these two river locations is directly related to the low water elvations, and it can be seen that the data from Table 1 follow the same general trend.

> "Inspection of the graphs indicates that the apex of the debris flood, which left the mines prior to 1883, passed the junction of the Feather and Yuba Rivers about 1905, and had been eroding and passing downstream at a fairly uniform rate until it reached its original elevation about 1955. The stream of debris from the Yuba River was joined in the Feather River by a smaller stream from the Bear River and in Sacramento River by a stream of debris from the American River.
>
> "The low water graph at Sacramento indicates that due to the debris wave from the American River having a much shorter course, its apex reached the Sacramento River about 1897 and erosion and reduction of the river deposit continued at a fairly uniform rate until it reached its original elevation about 1930.
>
> "Apparently the debris wave from the Yuba River was so arrested, flattened and extended, in its long journey from Marysville that its influence could not be detected at Sacramento. A large volume of the sediments from Feather River have been permanently deposited in the lower eight miles of Sutter Bypass with which that river is coincident and a large secondary delta has been built up at the northerly end of this eight mile section of the bypass west of Nicholaus" [8].

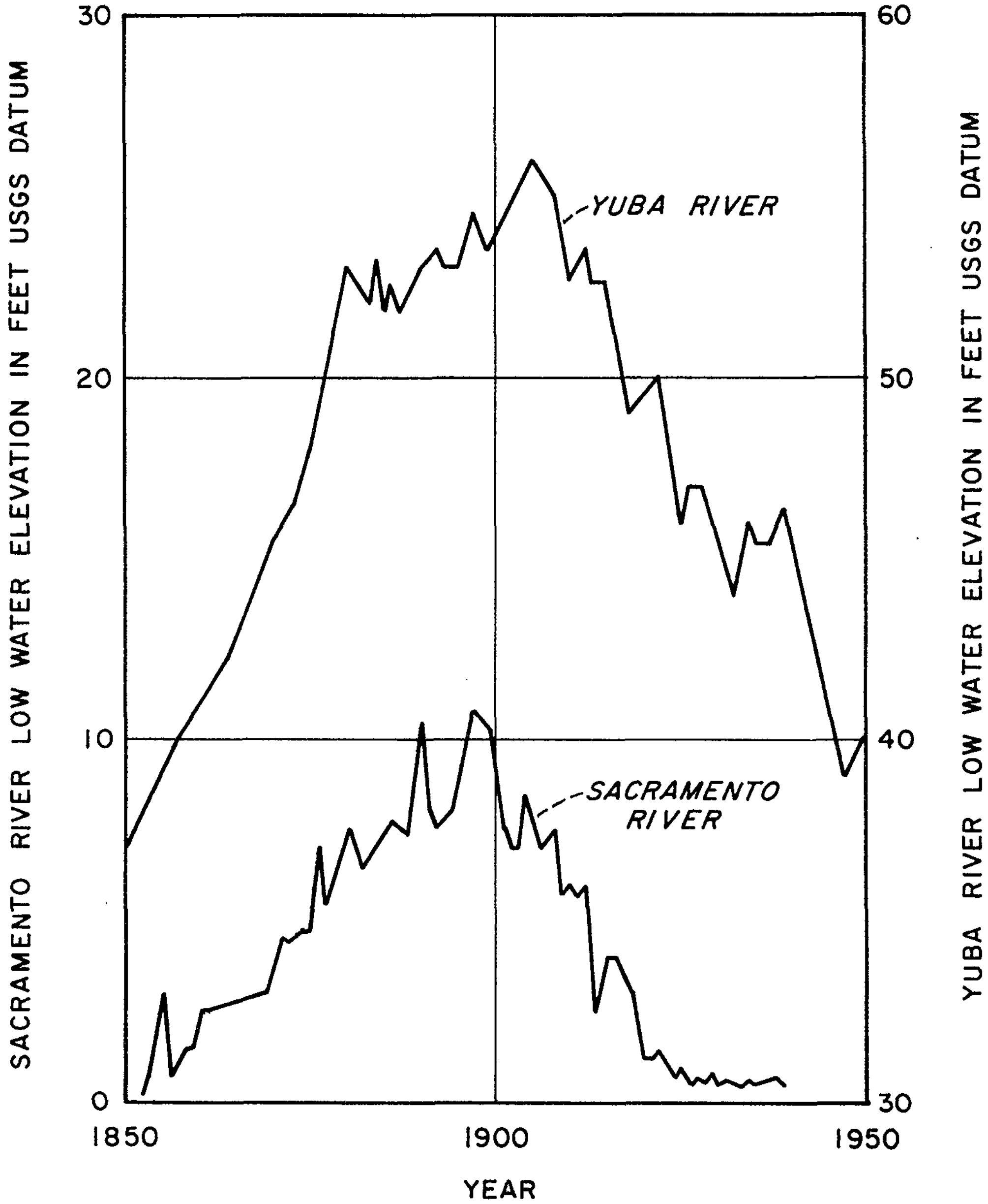
Effects of Stream Channel Bank Erosion

During the high runoff winters of 1954-55, 1962-63, and 1964-65, serious bank erosion occurred on the Feather River near its confluence with the Sutter Bypass [13]. The peak mean daily flow at Sacramento reached 94,400 cfs (2 700 m^3/s) on

ANNUAL LOW WATER ELEVATIONS

YUBA RIVER AT MARYSVILLE AND SACRAMENTO RIVER AT SACRAMENTO

1850 TO 1950



February 2, 1963. The USGS record of suspended sediment was 229,000 tons (208 000t) on that day which amounted to 6 percent of the total annual sediment load. From December 23 to 25, 1964, the mean daily flow at Sacramento averaged 97,400 cfs (2 800 m^3/s), and during this three-day period 1,261,000 tons (1 150 000 t) of sediment passed Sacramento which amounted to 22 percent of the total annual sediment load. Since 1965, the flow still gets above 90,000 cfs (2 500 m^3/s) in some winters; however, the peak daily sediment load has been 100,000 tons (91 000 t) or less except for one day when it reached 132,000 tons (120 000 t).

With continued levee stabilization and flow regulation, sediment contribution from bank erosion will be diminished in both magnitude and frequency in the future.

Effects of Channel Dredging

Presently, the Corps of Engineers dredges two reaches of the Sacramento River to maintain navigation depths [15]. Approximately 300,000 cubic yards (230 000 m^3) of sand are removed annually in the reach between Rio Vista and Isleton to maintain navigation access to the Sacramento Deep Water Channel. The Sacramento River is also dredged from the Sacramento-Yolo Port barge locks to the Sacramento Weir. The recent annual dredging in this reach of the river has been:

Year	Annual Dredging Sacramento-Yolo Port to Sacramento Weir 1 000 cubic yards	 1 000 m^3
1969	500	382
1970	326	249
1971	258	197
1972-74	0	0

The reasons for the decrease are:

(1) In recent years water-borne commerce has decreased and shallower draft vessels are using the river, thus reducing the need to maintain a deeper channel [15].

(2) The supply of sand from the Feather River has decreased due to flow regulation and borrow operations in the riverbed.

(3) Between 1968 and 1970, Caltrans excavated approximately 2 million cubic yards (1.6 million m^3) of sand from the Sacramento River upstream of Sacramento for fill in constructing the Elkhorn Bridge on Interstate 80 and Bryte Bend Bridge on Interstate 880 [19].

This last factor, the most important, has left a huge depression in the bed of the river. Sand movement from upstream will have to fill this depression before any significant amount of material will be deposited below this reach of the river. The Corps estimates that once equilibrium is reached (about 1980), the average annual dredging requirement between Sacramento and the Yolo Port will be about 200,000 cubic yards (153 000 m^3) [15].

Present Sediment-Discharge Relationships of the Sacramento River at Sacramento

To estimate the amount of sediment that would be diverted into the Peripheral Canal, it was initially decided to use the 1957 through 1970 water year sediment and flow data from USGS records and apply Peripheral Canal diversions to this hydrologic series, assuming that the data would represent an average repetitive series of future events. However, the runoff of this series would be modified by upstream water development projects that have become operational since 1970 or that will be put into operation between now and the time the Peripheral Canal reaches full operational capability. Therefore, an average sediment-discharge relationship was developed from existing data and modified to account for future hydraulic conditions under full project development.

In developing a sediment-discharge formula for the Sacramento River, it was initially assumed that a relationship might exist between the mean daily water discharge, and the mean daily measured sediment load. Data on the daily discharge and measured sediment load were analyzed for the 14-year period from 1957 to 1970. A plot of daily discharge versus measured suspended sediment load for the Sacramento River at Sacramento for the 1969-70 water year is shown in Figure 11. Figure 12 shows the 1969-70 data plotted for the individual months. These figures show the variability in the data that is typical of all years. Data for the 14-year period from 1957 to 1970 is shown in Appendix C, and Appendix D.

An equation of the type

$$Q_s = a(Q_w)^b \qquad \text{Eqn 1}$$

was found by regression analysis to yield the curve of best fit, where:

Q_s = Daily sediment load in tons

Q_w = Daily water discharge in cfs

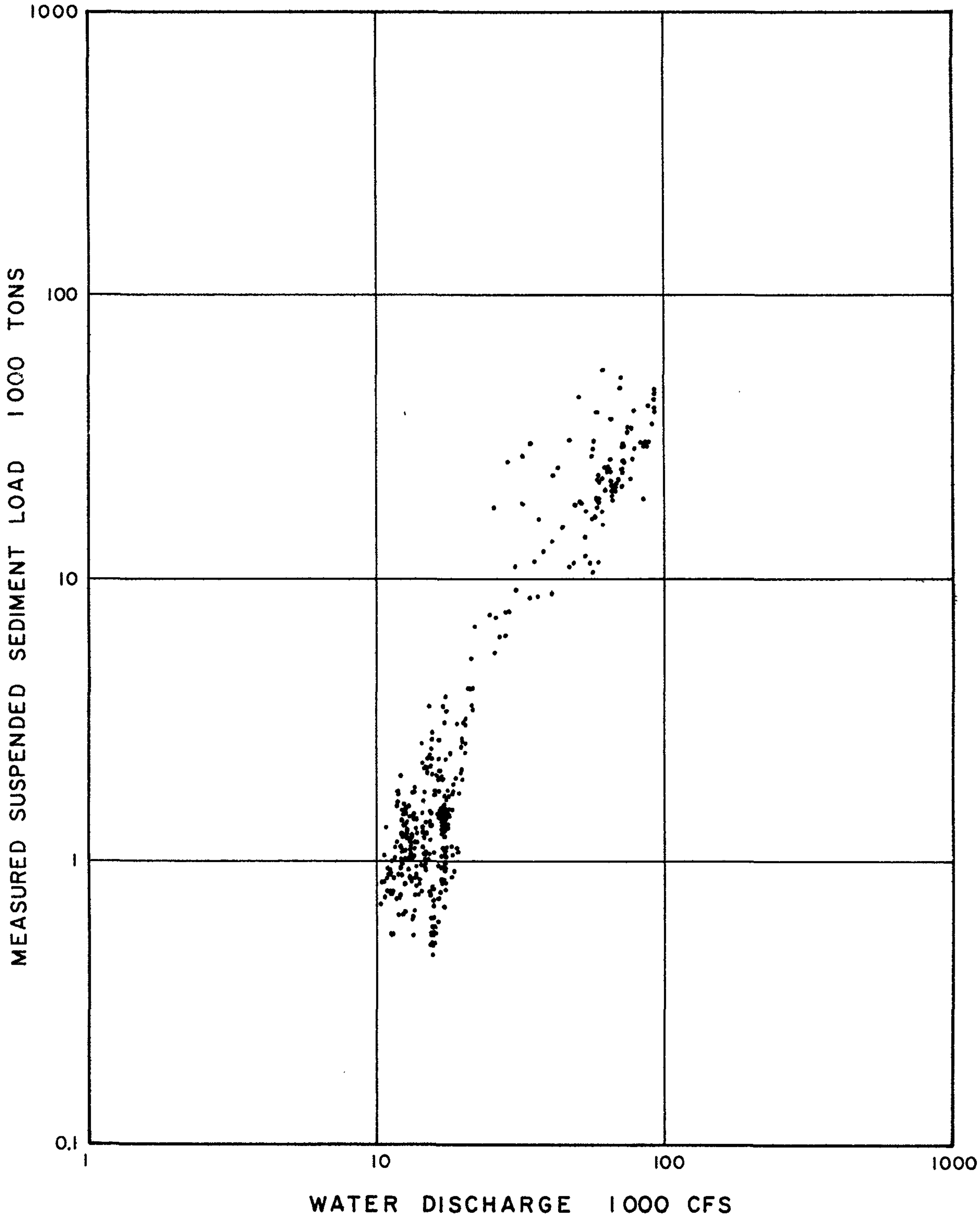
a, b = Constants

An equation was derived for the 14-year period and then used to recalculate daily sediment loads using the known daily hydrology. The calculated load was compared to the known load and probability analysis was used to determine the accuracy of the formula to predict sediment loads (assuming, of course, that future flows could be predicted). The results were discouraging. The equation tended to greatly underestimate peak sediment loads during winter months and overestimate the spring and summer sediment loads.

To eliminate the variability in the daily data (as shown in Figure 11), a similar procedure was used on a monthly

FIGURE 11

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1969-70 WATER YEAR



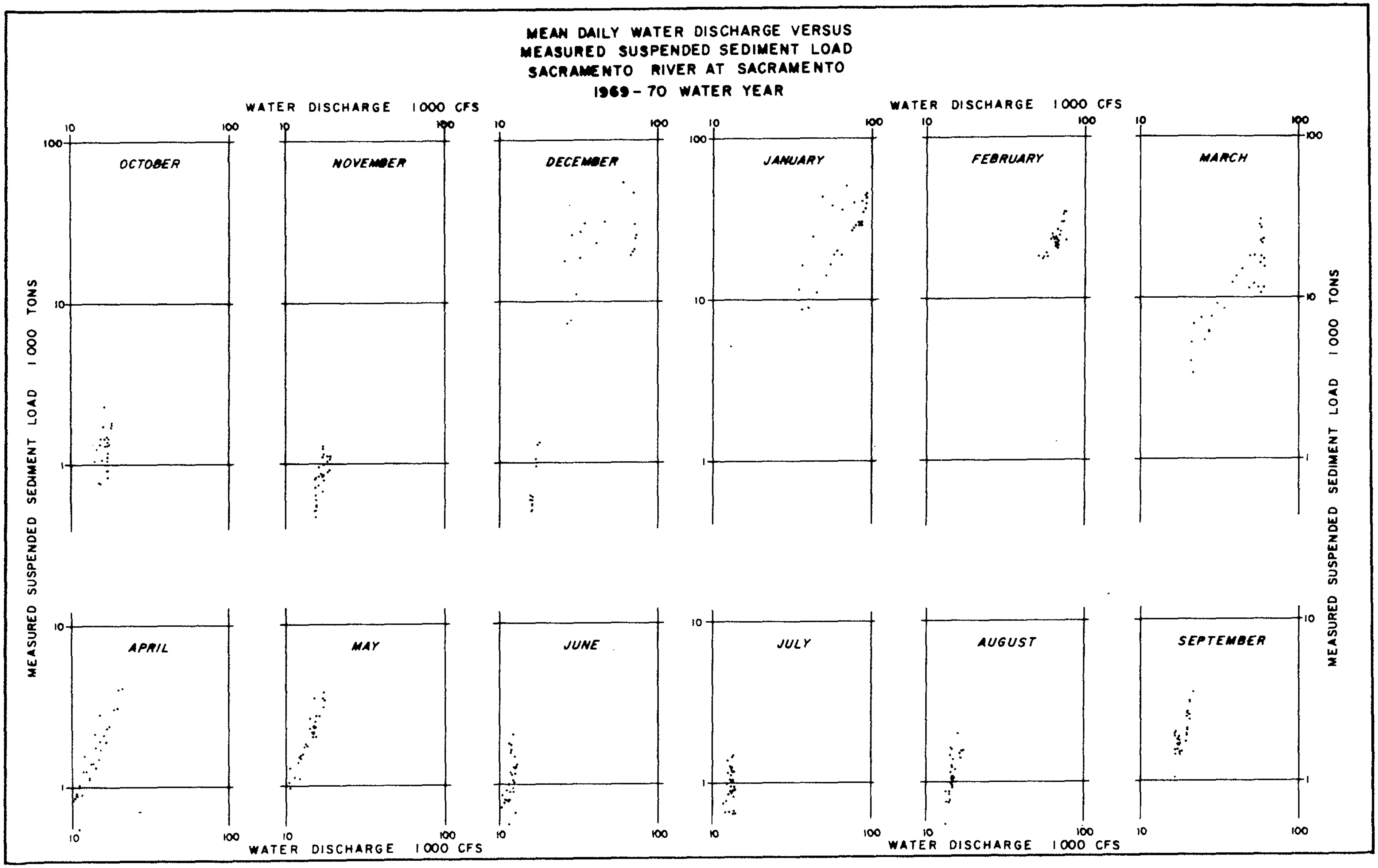

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1969 - 70 WATER YEAR
WATER DISCHARGE 1000 CFS
MEASURED SUSPENDED SEDIMENT LOAD 1000 TONS
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
10
100
1

FIGURE 12

basis and equations of the above type were determined for each month. The results were better, but the set of equations developed was still not sufficiently accurate to predict peak daily sediment loads.

Since no reliable simple relationship could be found between daily discharge and daily suspended sediment load, the average mean monthly runoff and the average mean monthly sediment load for the 1957 to 1970 period were plotted logarithmically. The equation of best fit was found to be:

$$S_{mm} = \left(2.1 \times 10^{-8}\right)\left(MAF\right)^{2.1} \qquad \text{Eqn 2}$$

where

S_{mm} = Mean monthly sediment load in tons

MAF = Mean monthly runoff in million acre-feet

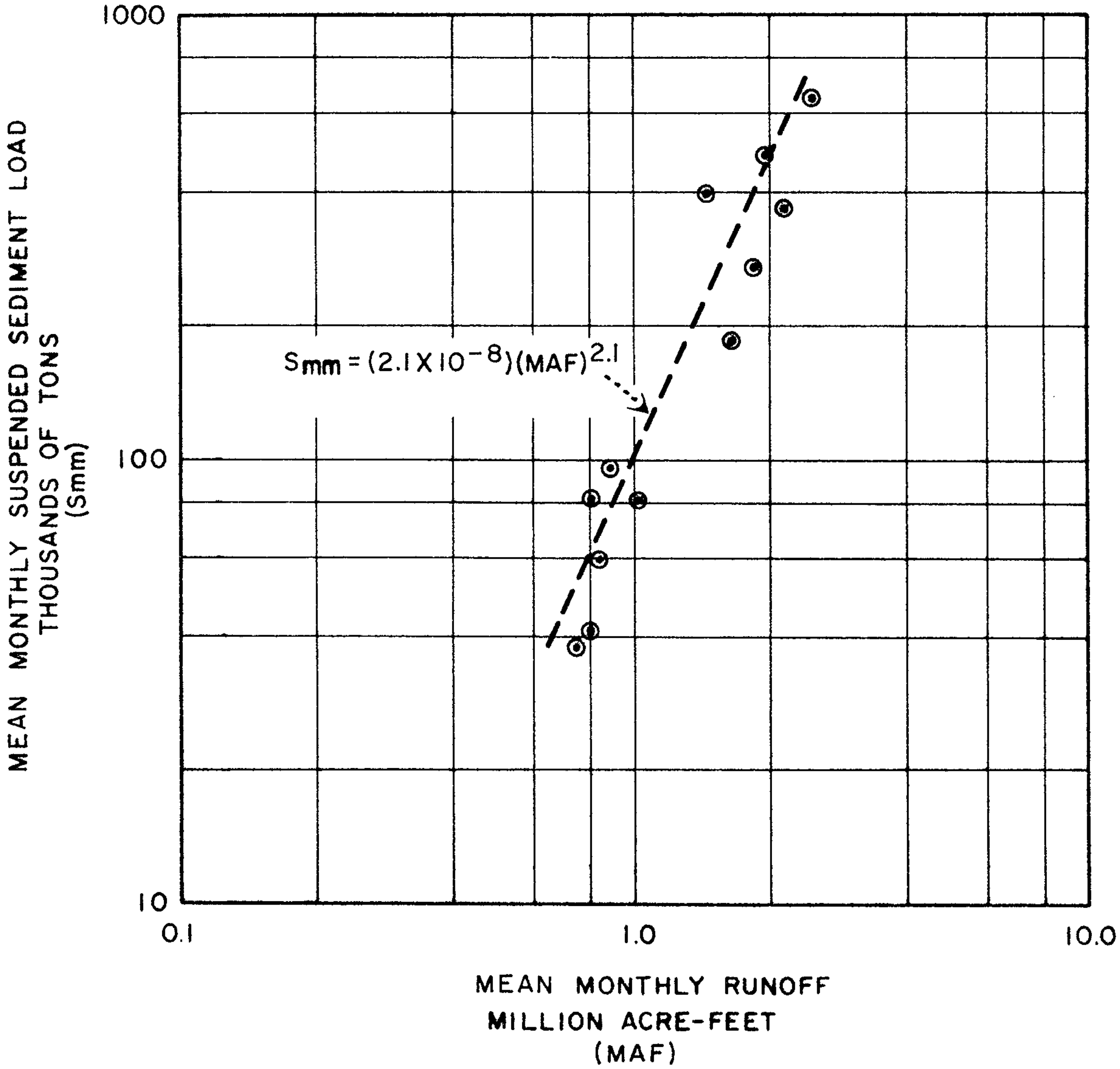
This equation more closely fitted the data. Figure 13 shows Equation 2 fitted to the plot of this data. Consequently, if the mean monthly runoff were known, Equation 2 could be used to estimate the mean monthly sediment loads more accurately than equations based on daily relationships.

To explain the scatter in the data of Figure 13, seasonal effects upon the data were investigated. Figure 14 shows the plot of Figure 13 with the months indicated. This plot is quite similar to the hysteresis, or loop-rating curve, effect quite commonly found in stage-discharge relationships during the passage of floods [14]. Thus, Equation 2 should not be used to estimate sediment loads since the same runoff does not produce equal sediment loads during different times of the year. Since there were obviously seasonal effects to consider, the role of upstream water projects upon any changes in the seasonal pattern of runoff and sediment load would also have to be considered. The separation of the data into monthly or seasonal groups for analysis may account for some of the variability between the sediment-runoff relationship.

LOG-LOG RELATIONSHIP BETWEEN SUSPENDED SEDIMENT AND RUNOFF SACRAMENTO RIVER AT SACRAMENTO

AVERAGE FOR 1957 TO 1970

MONTHLY DATA



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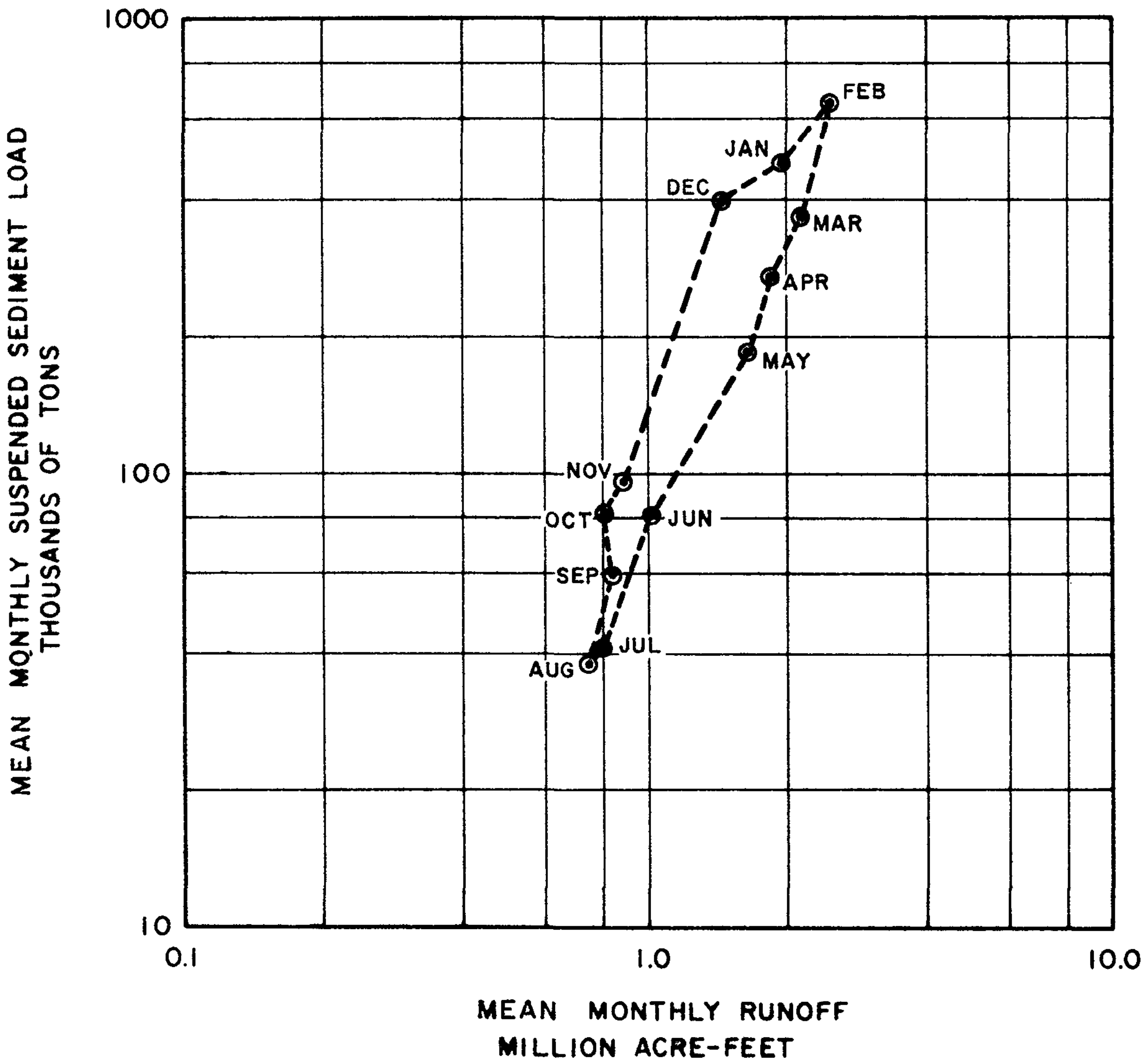
MONTHLY RELATIONSHIP BETWEEN SUSPENDED SEDIMENT AND RUNOFF SACRAMENTO RIVER AT SACRAMENTO

AVERAGE FOR 1957 TO 1970



From 1957 to 1970, the major development that might have affected runoff and sediment yield was the beginning of operation of Oroville Dam and reservoir on the Feather River, which effectively began to store sediment in the mid-1960s. Therefore, data was separated into two 7-year periods: (1) pre-Oroville (1957 to 1963); and, (2) post-Oroville (1964 to 1970). Table 2 and Figure 15 show the changes in the pattern of runoff and sediment yield that have occurred in these two periods.

The data was then reanalyzed using daily and monthly groupings for both the pre-Oroville and post-Oroville periods. The resulting equations showed a slight, but insignificant, improvement in the ability to reproduce the historic daily sediment loads.

The post-Oroville mean annual runoff at Sacramento increased 18 percent over the pre-Oroville runoff while the annual sediment yield increased only 10 percent above the pre-Oroville yield. The data was further examined to see if the smaller increase in sediment yield could be attributed to some temporal factors (i.e., if as earlier assumed mean annual runoff was an indicator of sediment yield, an 18 percent increase in runoff should have resulted in roughly an 18 percent increase in annual sediment yield).

One method of determining temporal changes in data is to plot the accumulated variable in question against time. A break in the slope of the curve will indicate the time occurrence of a change. Another method of determining temporal changes that can be used when two variables are being examined (i.e., runoff and sediment yield) is the double-mass relationship constructed by plotting one accumulated variable against the other and indicating time on the curve itself. Usually the variables will plot as a relatively straight line when the two variables are proportional. Breaks in the slope of the line represent changes in the relationship between the variables. This type of plot often magnifies such changes more dramatically than the previous method.

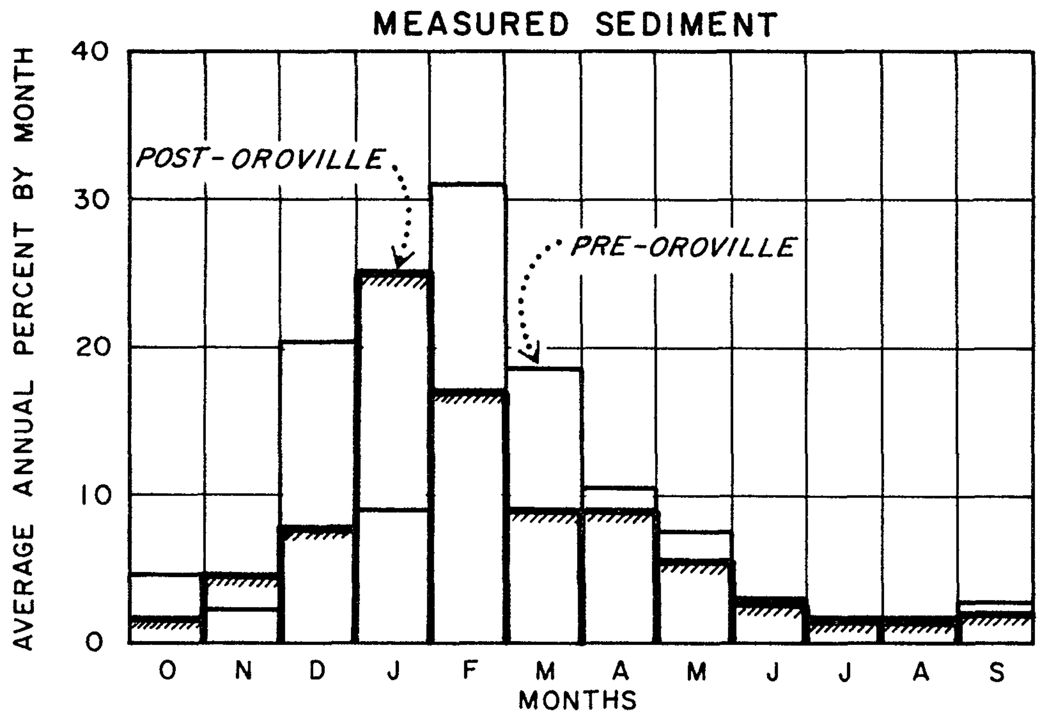
TABLE 2

AVERAGE MONTHLY DISTRIBUTION
OF RUNOFF AND MEASURED SEDIMENT
SACRAMENTO RIVER AT SACRAMENTO

MONTH	AVERAGE MONTHLY PERCENT OF ANNUAL TOTAL			
	PRE-OROVILLE 1957 to 1963		POST-OROVILLE 1964 to 1970	
	RUNOFF	SEDIMENT	RUNOFF	SEDIMENT
Oct.	5.5	4.8	4.5	3.0
Nov.	5.1	2.3	5.7	3.4
Dec.	7.0	7.6	9.9	14.3
Jan.	7.5	8.9	15.3	17.5
Feb.	15.9	31.1	14.4	23.6
Mar.	15.1	18.5	11.4	13.5
Apr.	12.9	10.5	9.5	9.8
May	10.8	7.7	8.7	6.7
Jun.	6.3	3.1	6.0	2.9
Jul.	4.5	1.4	4.6	1.4
Aug.	4.6	1.5	4.9	1.6
Sept.	4.8	2.6	5.1	2.3
TOTAL	100.0	100.0	100.0	100.0

PRE-OROVILLE AND POST-OROVILLE AVERAGE MONTHLY DISTRIBUTION OF MEASURED SEDIMENT AND RUNOFF

SACRAMENTO RIVER AT SACRAMENTO 1957 TO 1970



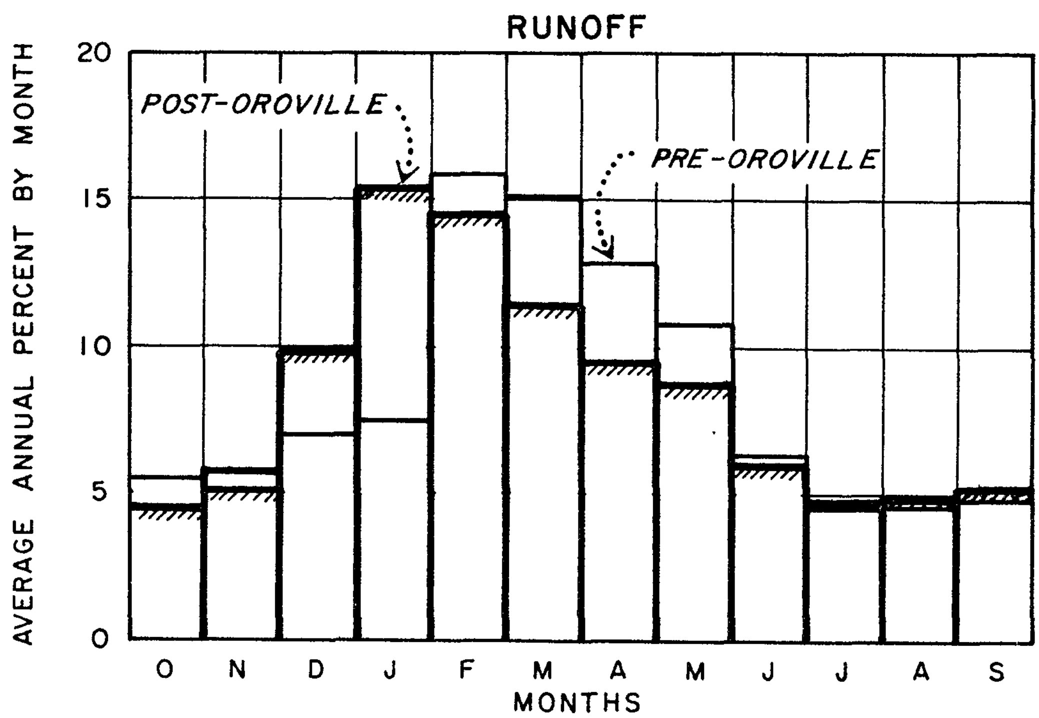


Table 3 shows the annual runoff and measured sediment yield of the Sacramento River at Sacramento for the 1957 to 1974 water years. Data for the 1971 to 1974 water years were included to determine if New Bullards Bar Reservoir, completed on the Yuba River in 1970, would show some effect on the sediment yield at Sacramento. Table 4 and Figure 16 show the accumulated runoff and sediment yield.

Figure 16 indicates that some decreasing trend has occurred in the sediment yield at Sacramento. Since accumulated runoff exhibited a fairly smooth curve, a curve with the same smooth shape was fitted to the accumulated sediment data from 1957 to about 1965, and extrapolated from 1965 to 1975 (Figure 17). The difference between the extrapolated limb of the curve and the plot of actual sediment yield from 1965 to 1975 indicates that the average annual sediment yield has apparently decreased by about 500,000 tons (454 000 t) since construction of Oroville Dam and New Bullards Bar Reservoir. Figure 18 shows the double-mass relationship between accumulated runoff and accumulated sediment yield.

Variation in Sacramento River Sediment Size Characteristics

Bed load equations used to compute bed load transport capacity of a stream incorporates sediment particle size diameter as a variable that is descriptive of the bed material. The sediment particle size generally used in these equations is the size for which 35, 50, or 65 percent of the bed material sample is finer (by weight) than the total sample. Bed load equations will be used to determine the effect the Peripheral Canal will have on sediment transport capacity of the Sacramento River downstream of the Canal intake (Chapter IV).

To determine whether the bed sediment size characteristics of the Sacramento River at Sacramento vary between low and extremely high flows, the median (50 percent finer) bed material size was determined graphically from USGS records from 1957 to 1970, and plotted against discharge. No significant variation was found. However, variation was found when the data were

TABLE 3

ANNUAL RUNOFF AND MEASURED
SUSPENDED SEDIMENT
SACRAMENTO RIVER AT SACRAMENTO
1957 TO 1974

WATER YEAR	MEASURED SEDIMENT 1 000 TONS	RUNOFF 1000 AC-FT
1956-57	1,669	13,186
1957-58	5,000	25,877
1958-59	1,857	11,975
1959-60	1,756	10,722
1960-61	1,943	11,389
1961-62	2,006	12,678
1962-63	3,946	20,278
1963-64	1,069	11,625
1964-65	5,684	19,921
1965-66	2,065	13,381
1966-67	3,312	24,162
1967-68	1,602	13,384
1968-69	3,454	23,211
1969-70	2,790	20,365
1970-71	3,214	22,870
1971-72	839	12,520
1972-73	2,598	20,650
1973-74	1/	30,660

1/ Sediment Data Unavailable

Average		
1957-63	2,597	15,158
1964-70	2,854	18,007
1964-73	2,662	21.275
1957-73	2,636	16,952

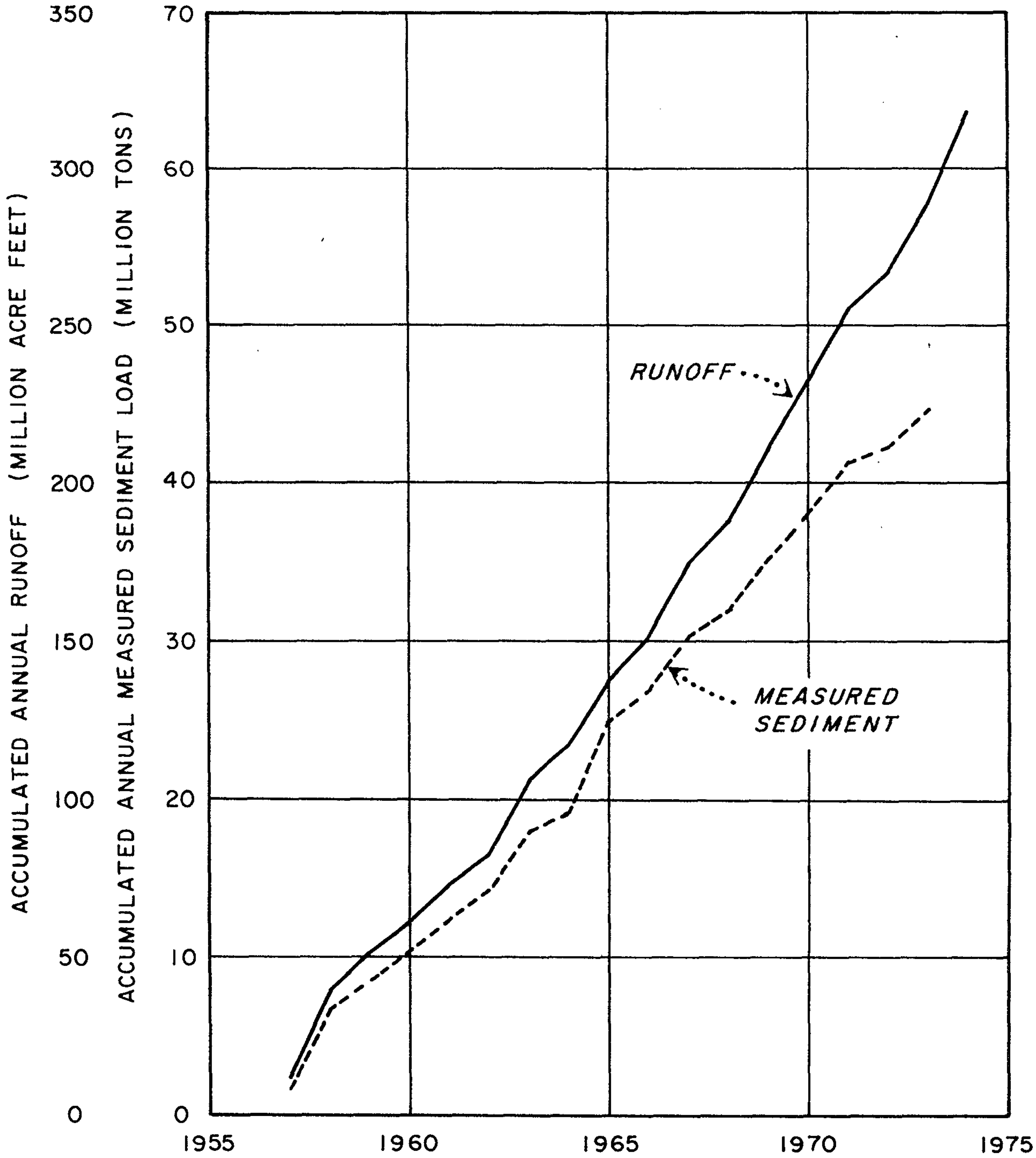
TABLE 4

ACCUMULATED ANNUAL RUNOFF
AND MEASURED SEDIMENT
SACRAMENTO RIVER AT SACRAMENTO
1957 to 1974

WATER YEAR	ACCUMULATED RUNOFF 1000 AC-FT	ACCUMULATED SEDIMENT 1000 TONS
1956-57	13,186	1,669
1957-58	39,073	6,669
1958-59	51,038	8,526
1959-60	61,760	10,291
1960-61	73,149	12,234
1961-62	85,827	14,240
1962-63	106,105	18,186
1963-64	117,730	19,255
1964-65	137,651	24,939
1965-66	151,032	27,004
1966-67	175,194	30,316
1967-68	188,578	31,918
1968-69	211,789	35,372
1969-70	232,154	38,162
1970-71	255,024	41,376
1971-72	267,544	42,215
1972-73	288,194	44,813
1973-74	318,854	1/

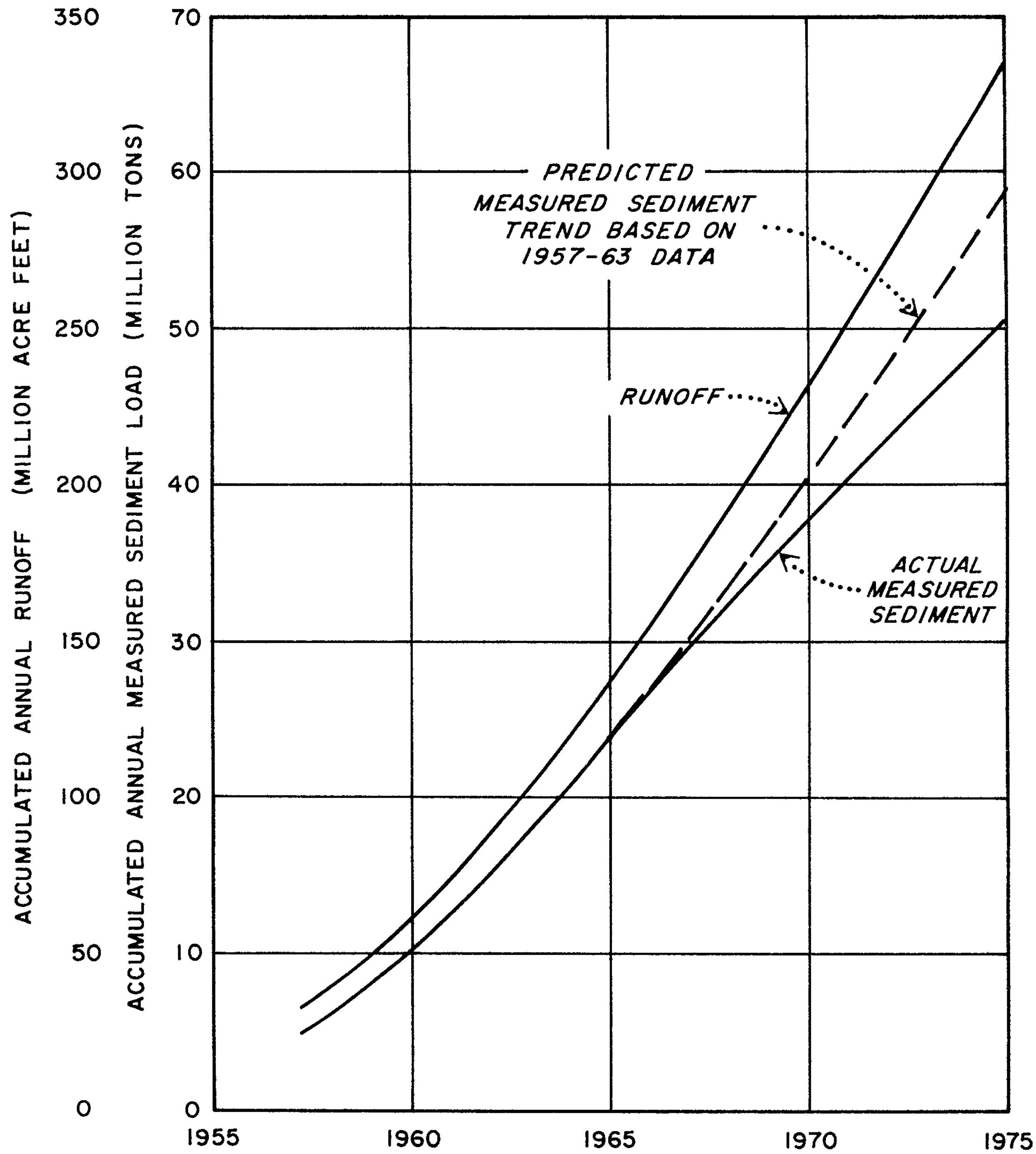
1/ Sediment data unavailable.

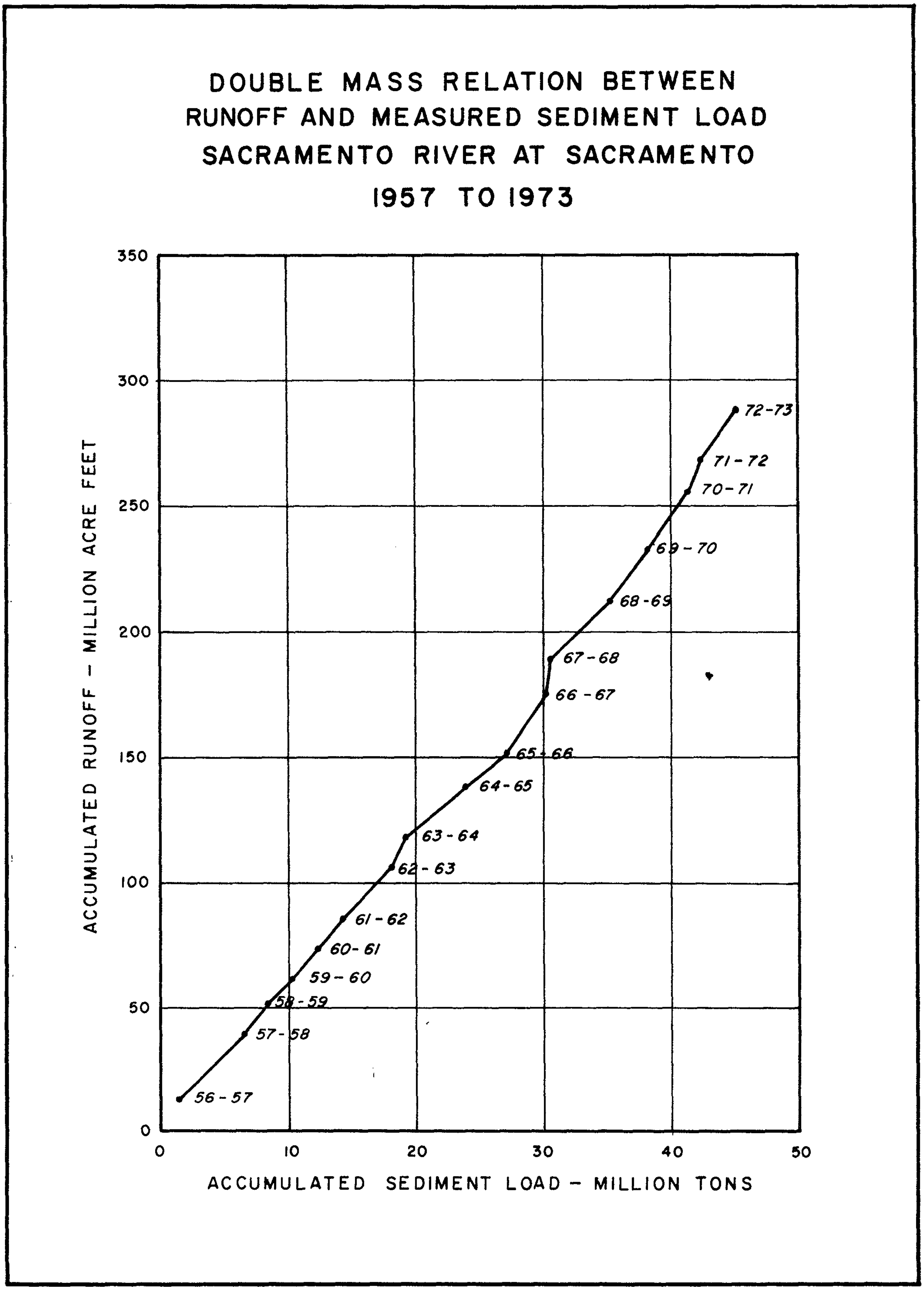
ACCUMULATED ANNUAL RUNOFF AND MEASURED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1957 TO 1973



REDUCTION IN ANNUAL MEASURED SEDIMENT LOAD SACRAMENTO RIVER AT SACRAMENTO

PREDICTED TRENDS





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grouped into pre-Oroville and post-Oroville periods (i.e., 1957 to 1963 and 1964 to 1970 respectively - see Figure 19). The 35 and 65 percent sizes also showed a similar pattern. It was concluded from this figure that a significant change had occurred in the size distribution of bed material since construction of Oroville Dam.

Figure 19 shows that the bed material is significantly finer for the post-Oroville period. The Kalinske bed load equation (see Eqn. 9, Chapter IV) states that the bed load transport rate of a stream is inversely proportional to the sediment particle size diameter. Bed load transport computations for the Sacramento River are based on this equation in this report. Based on this equation, the bed load discharge for the post-Oroville period is greater than the bed load discharge for the pre-Oroville period. However, on a long-term basis the average annual total sediment load is decreasing. Therefore, for the post-Oroville period, the amount of bed material and that portion of the bed material carried in suspension should constitute a slightly greater portion of the total sediment load than the pre-Oroville period.

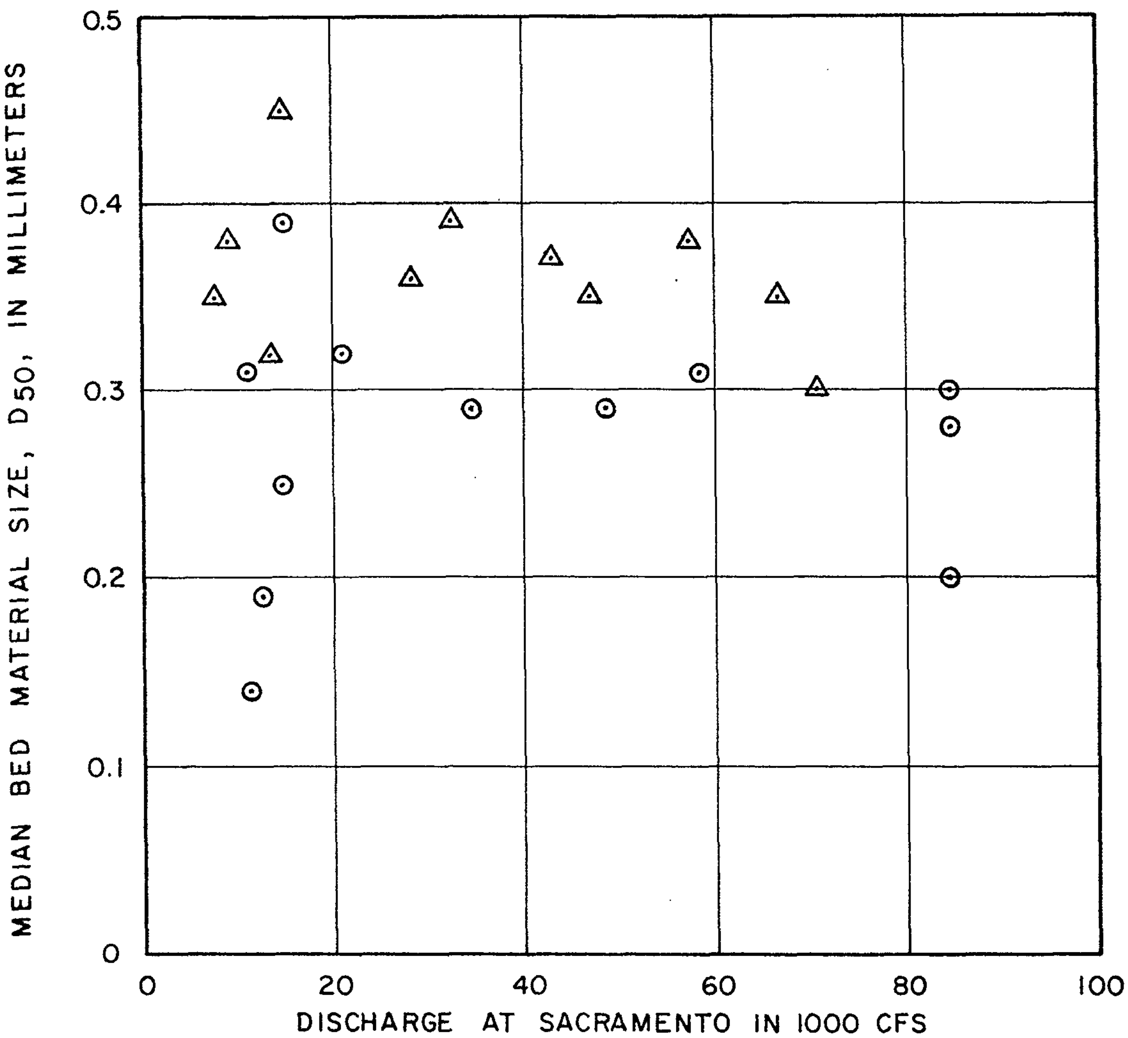
If the above is true, then the particle size distribution of measured suspended sediment for the post-Oroville period should show a decrease in the percent of fine material (less than about .062mm) compared to the pre-Oroville period, and an increase in the percent of material coarser than about .062mm. Figure 20 shows this to be true, and is consistent with the hypothesis of reduced bank erosion (a source of fine material) resulting from regulation of peak flows by reservoir flood control operation. The post-Oroville particle size distribution of bed material will be used in bed load transport computations under Peripheral Canal project conditions.

Present Sedimentation in Clifton Court Forebay

When Clifton Court Forebay was constructed, accurate surveys of the ground surface were not conducted prior to filling the reservoir. Consequently, accurate dead-storage volumes and sediment deposition rates cannot be determined.

VARIATION IN MEDIAN BED MATERIAL SIZE SACRAMENTO RIVER AT SACRAMENTO

(FROM U.S.G.S. RECORDS 1957 TO 1970)



△ - MEASUREMENTS MADE FROM 1957 TO 1963

⊙ - MEASUREMENTS MADE FROM 1964 TO 1970

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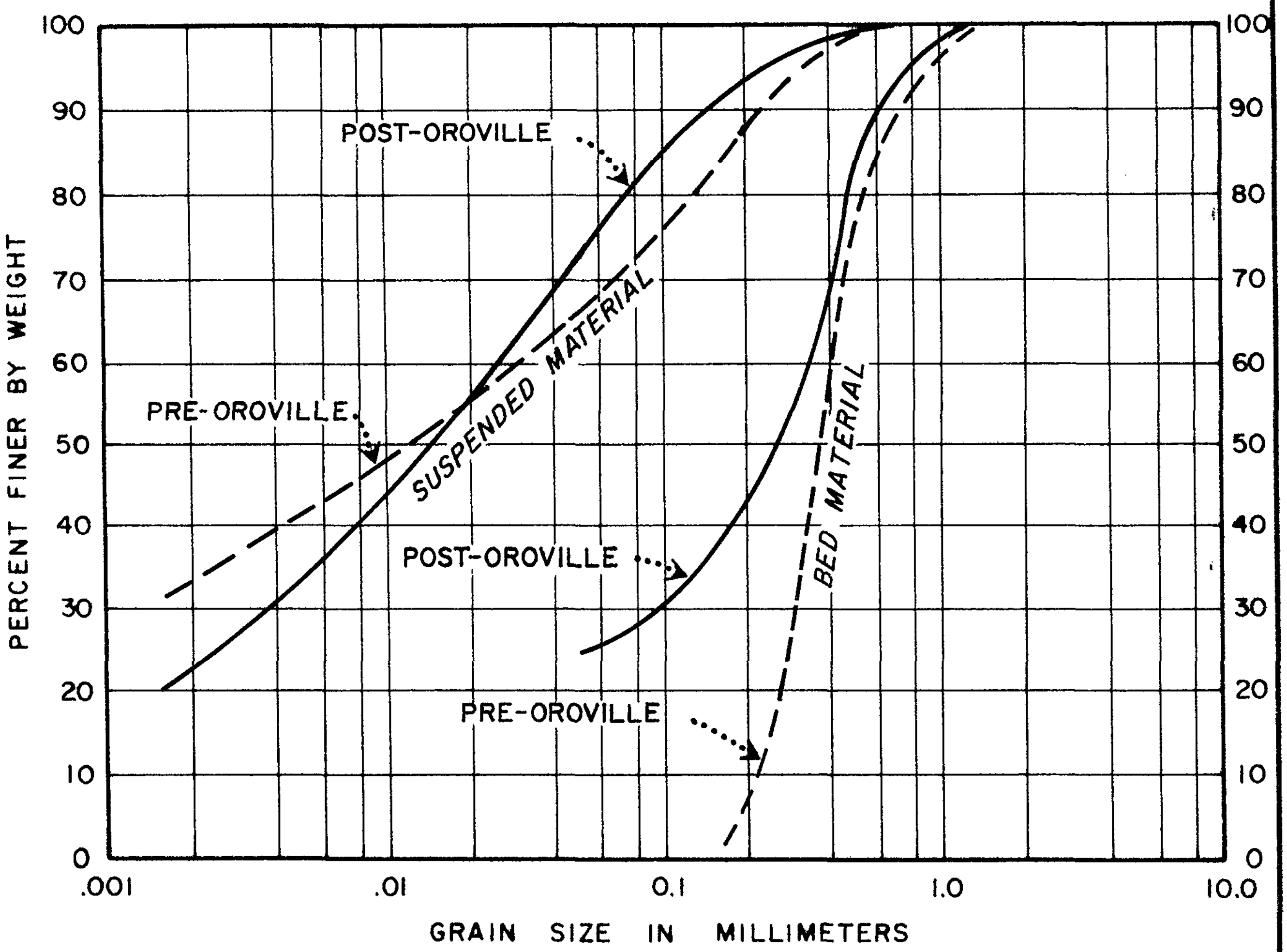
PARTICLE SIZE ANALYSIS
SUSPENDED MATERIAL AND BED MATERIAL
SACRAMENTO RIVER AT SACRAMENTO

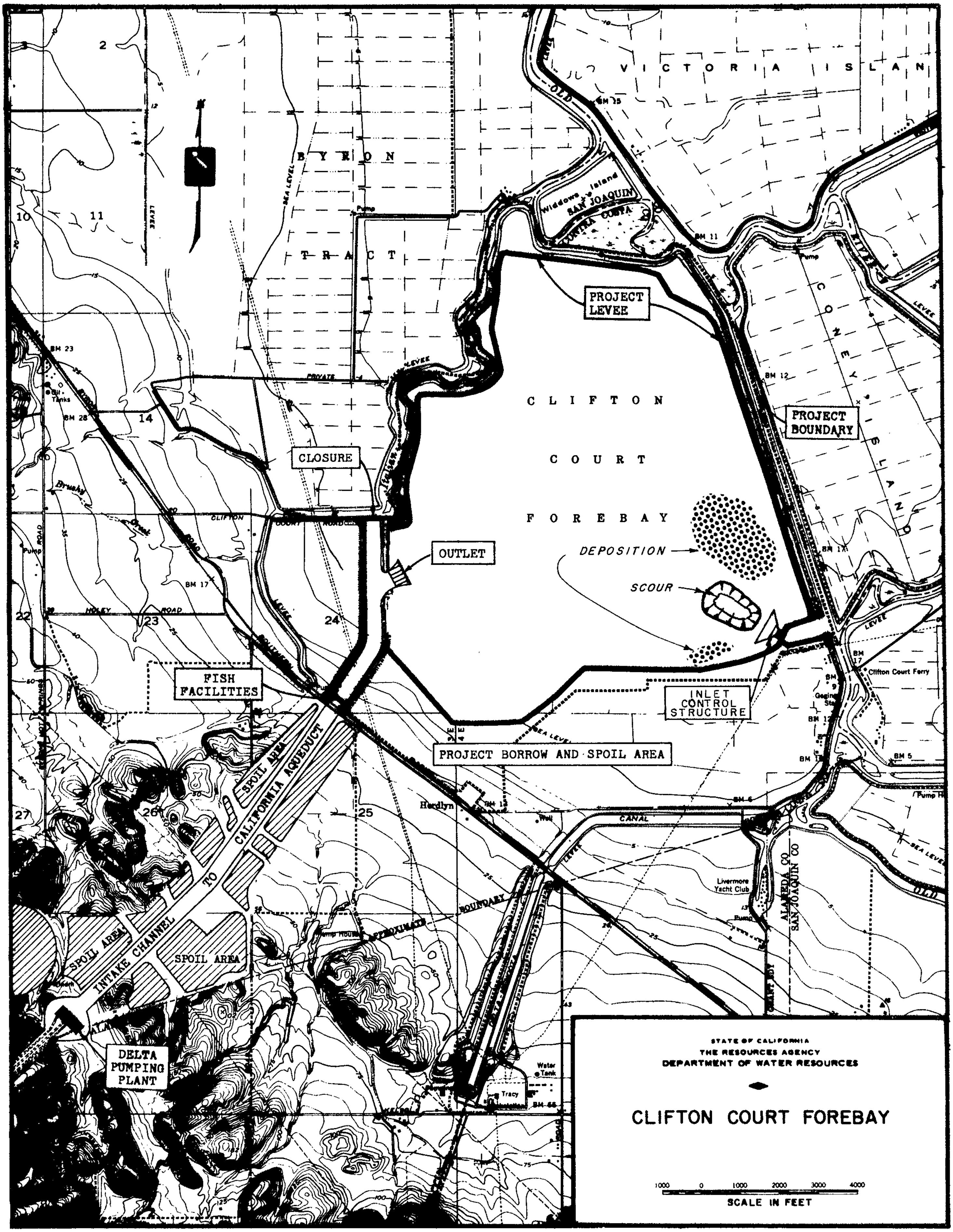
(U.S.G.S. MEASUREMENTS 1957 TO 1970 WATER YEARS)



During October 1973, the U. S. Bureau of Reclamation conducted sediment sampling within Clifton Court Forebay [18]. During the 15-day sampling period the average daily sediment inflow into the Forebay was about 180 tons (98 t) and the average daily water export was 1,491 acre-feet (1.8 million m^3). Approximately 30 percent of the sediment inflow was transported through the Delta Pumping Plant, indicating the reservoir has a trap efficiency of about 70 percent, based on data taken during a period of low export diversion. The trap efficiency was assumed to be the same during the winter when the amount of sediment carried by the Delta channels is much higher.

A trap efficiency of 70 percent indicates that approximately 77 tons per day (70 t/day) settlement is occurring within the Forebay, or an average annual decrease in capacity of about 97 acre-feet (120 000 m^3).

In addition to the above depositon, which can be assumed to be mostly washload from diversions from the southern Delta channels, localized deposition is occurring in the reservoir in the vicinity of the existing inlet control structure (see Figure 21). However, information from the Department's Scour Monitoring Program indicates that this may be due to operation of the inlet gates, since an approximately equal amount of scour is also occurring below the inlet structure.


VICTORIA ISLAND
BYRON TRACT
PROJECT LEVEE
CLIFTON COURT FOREBAY
PROJECT BOUNDARY
CLOSURE
CONEY ISLAND
OUTLET
DEPOSITION
SCOUR
FISH FACILITIES
INLET CONTROL STRUCTURE
PROJECT BORROW AND SPOIL AREA
CALIFORNIA AQUEDUCT
TO CALIFORNIA AQUEDUCT
INTAKE CHANNEL
SPOIL AREA
DELTA PUMPING PLANT
Widdows Island
SAN JOAQUIN
CONTRA COSTA
ALAMEDA CO
SAN JOAQUIN CO
Clifton Court Ferry
Livermore Yacht Club
Herdlyn
Tracy
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
CLIFTON COURT FOREBAY
1000 0 1000 2000 3000 4000
SCALE IN FEET

CHAPTER IV

PERIPHERAL CANAL EFFECTS ON SEDIMENT TRANSPORT OF SACRAMENTO RIVER

In addition to diverting a portion of the suspended sediment from the Sacramento River, the reduced flows downstream of the Peripheral Canal intake will affect the bed load transport capacity of the river. Before discussing the effect the Peripheral Canal might have on sediment transport of the Sacramento River, it is appropriate to examine how flow rates affect sediment transport.

Effect of Flow Rates on Sediment Particle Movement

There is some flow below which no sediment can be transported. As the flow increases, a point is reached where the energy becomes sufficient to move a particle along the streambed. This point is called the threshold of sediment motion. If the energy of flow is increased still further, the particle, instead of moving along the bed, will become suspended.

In the 1930s, A. Shields devoted considerable effort to investigating the threshold of movement of sediment particles. Both the Kalinske [14] [16] and Einstein bed load functions [17] are based on the results of Shield's work, although Kalinske independently arrived at somewhat the same results.

Shield's work consisted of determining a relationship between a sediment particle Reynolds number and a particle Froude number at the beginning of motion, where the relationships between the Froude number and Reynolds number are defined by:

$$F_s = \frac{V^{*2}}{(S_s - 1)gd} \qquad \text{Eqn 3}$$

$$R_e^* = \frac{V^* d}{\nu} \qquad \text{Eqn 4}$$

The shear velocity is given by:

$$V^* = \sqrt{\tau_0/\rho_f} = \sqrt{gRS_f} \qquad \text{Eqn 5}$$

where:

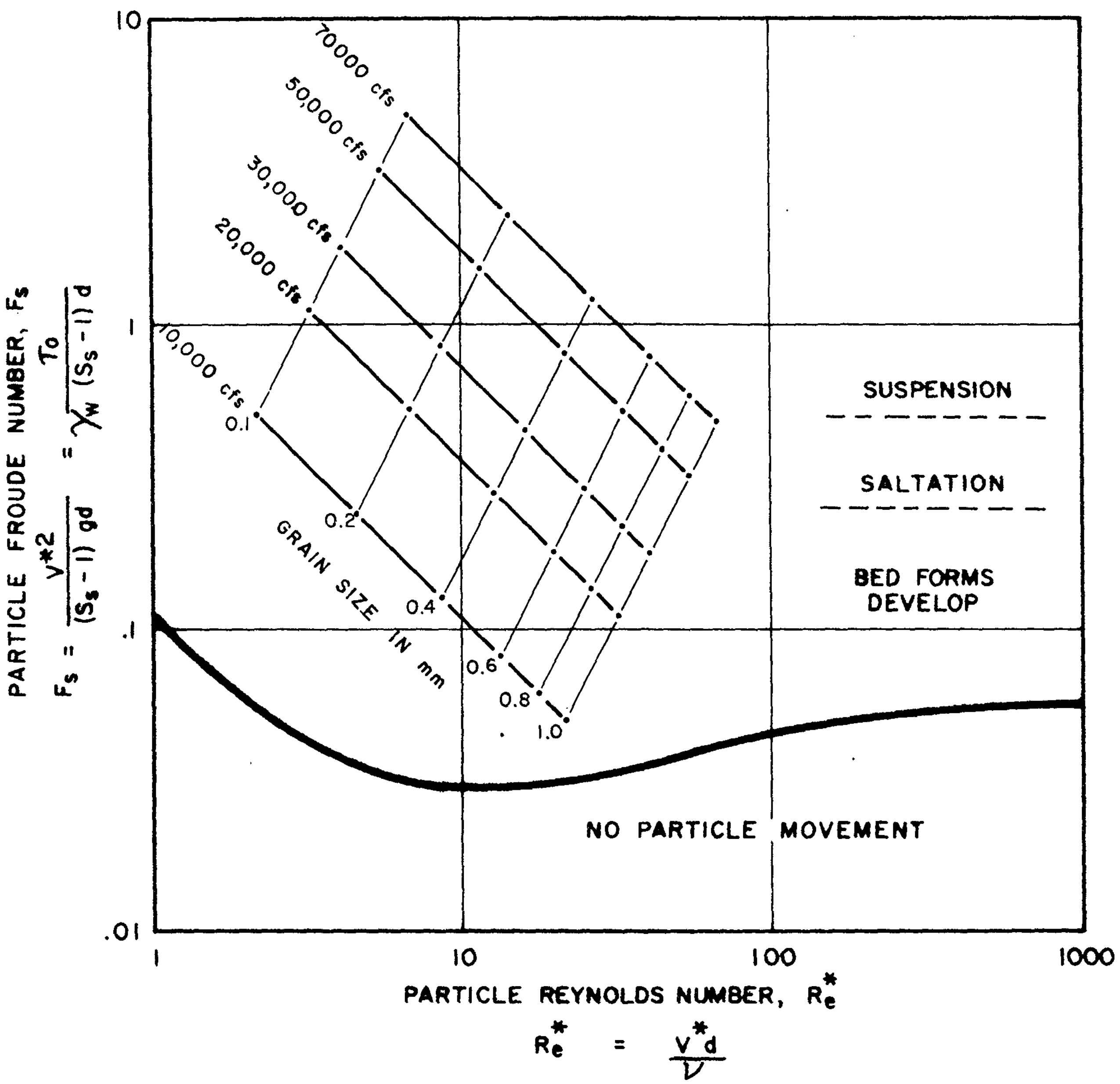
F_s^* = Particle Froude number
R_e^* = Particle Reynolds number
V^* = Shear velocity
S_s = Specific gravity of sediment
g = Acceleration due to gravity
d = Particle size
ν = Kinematic viscosity of water
τ_0 = Shear stress at the bed
ρ_f = Fluid density
R = Hydraulic radius
S_f = Channel friction slope

If the particle Froude number is below some critical value (depending on the value of the Reynolds number), no particle movement takes place. Ripples, bars, or other bed forms develop until the Froude number reaches a value of about 0.25. Bed material movement in the form of saltation, occurs when the Froude number is between about 0.25 and 0.50. Above a Froude number of about 0.50 the material is carried in suspension.

Figure 22 shows the relationship between particle Froude number and Reynolds number for various discharges in the Sacramento River between Freeport and Hood. This diagram was developed for sediment sizes ranging from 0.1 to 1.0 mm (the approximate range of bed material in this reach).

The effect of decreased river velocities downstream of the intake due to Canal diversions is important. As an example, consider a sediment particle 1.0 mm in size with an initial flow upstream from the Canal intake of 60,000 cfs (1 700 m^3/s). Figure 22 indicates that the flow would transport this particle as bed load by saltation. With a 20,000 cfs

SHIELDS DIAGRAM FOR INITIATION OF SEDIMENT MOVEMENT SACRAMENTO RIVER FREEPORT TO HOOD



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diversion (570 m^3/s), the river flow downstream from the intake would be 40,000 cfs (1 130 m^3/s), but the energy would still be sufficient to transport the particle as bed load. However if the flow upstream of the diversion were 40,000 cfs (1 130 m^3/s), the flow downstream would only be 20,000 cfs (570 m^3/s), and the particle would change from the lower limit of a regime of saltation in the upstream reach to one of bed formation in the downstream reach and settlement would take place.

Sediment Yield of Sacramento River Under Full Project Development

If the decreasing trend in the sediment yield of the Sacramento River continues, the amount of sediment diverted by the Peripheral Canal would have to be based on an estimate of the future sediment yield of the river and not on past data. Therefore, Canal diversions were based on the 2020 level of development (or at full development). It was also necessary to estimate the average annual sediment yield of the Sacramento River at the 2020 level of development. Two mathematiaal relationships were fitted to the data of Table 3, expressing the time-dependent trend. In both relationships:

S_{ma} = Annual sediment load

T = Time in years, A.D.

1. Exponential relationship:

$$S_{ma} = ae^{bT} \qquad \text{Eqn 6}$$

where:

$a = 2.11934 \times 10^9$

$b = -0.003465$

e = Base of natural logarithms

2. Power Relationship:

$$S_{ma} = aT^b \qquad \text{Eqn 7}$$

where:

$a = 2.61517 \times 10^{28}$

$b = -6.69476$

The annual 2020 Sacramento River sediment load, estimated using both Equations 6 and 7, is about 1.9 million tons (1.7 million t).

A statistical t-distribution test was applied to the historic annual sediment yields to determine if the calculated future sediment yield could be explained by random chance, or if a trend in the data existed. Assuming that the annual sediment loads from 1957 to 1973 represent a random sample drawn from a much larger group of sediment loads that has an unknown true mean, then by using the t-distribution test, it can be stated that the true mean (or average) of the group of sediment loads lie within the range:

$$\mu = \bar{S}_{ma} \pm \frac{k\sigma}{\sqrt{n}} \qquad \text{Eqn 8}$$

Where:

μ = The true mean sediment yield

$\bar{S}_{ma}$ = The mean annual sediment yield from the known sample

σ = The standard deviation of the known sediment sample

k = A tolerance factor which varies from about 2 to 5 depending on the sample size and the confidence level

n = The number of years in the sample

Using the 1957-73 data, it was determined with 90 percent confidence, that the true mean annual sediment yield for the Sacramento River lies within the range of 2.0 to 3.8 million tons (1.6 to 3.5 million t). Also, extrapolation using Equations 6 and 7 indicates the sediment yield at 2020 to be approximately 2 million tons, which is the lower limit of the range determined by the t-distribution test. On the basis of the lower limit of the t-distribution test and the extrapolations based on Equations 6 and 7 (also shown graphically in Figures 16, 17 and 18) a decreasing trend in annual sediment is probably occurring at the Sacramento River at Sacramento. Thus, a projected estimate of 2.0 million tons (1.8 million t) was assumed as the mean annual sediment yield at the year 2020. Note that this projected sediment yield is in agreement with the estimate of annual sediment yield that existed prior to hydraulic mining (Table 1, Chapter III).

Hydrologic Assumptions

To estimate the effects diversions into the Peripheral Canal will have on sedimentation in the Sacramento River below the intake, an operation study estimating Canal diversions is required. The operation study for the 2020 level of development used in the Peripheral Canal Draft Environmental Impact Report [22] was used for this purpose. That study assumes: (1) additional water will be provided when needed for summer export, although no specific projects are assumed; (2) State Water Resources Control Board Decision 1379 striped bass and neomysis criteria in dry and critical years are relaxed; and (3) certain reservoirs currently under construction, namely--Hidden, Buchanan, New Melones, Auburn, and Indian Valley, are in operation (but not the authorized Marysville Reservoir on the Yuba River). The 45-year long-term average monthly flows for the Sacramento River at Sacramento and Courtland, and the Peripheral Canal diversions at the 2020 level of development taken from that study, are shown in Table 5.

A fairly accurate estimate of the long-term average annual amount of suspended sediment diverted by the Peripheral Canal could be made by using the projected Sacramento River sediment yield of 2 million tons (1.8 million t) and the average monthly flows from Table 5. However, this method would not properly assess the effects of velocity reductions on bed load movement downstream of the intake due to Canal diversions. To accomplish that, an average daily hydrograph would be required to incorporate bed load transport during peak flow periods.

A synthetic daily hydrograph was extracted from USGS records of discharge for the 1957 to 1973 water years (see Figure 23). Months were selected that had an average monthly flow at Sacramento equivalent to those shown in Table 5. Suspended sediment loads were chosen that had the same monthly distribution of annual sediment load as in the post-Oroville period of record. When summed, these monthly sediment

TABLE 5

AVERAGE MONTHLY FLOWS AND DIVERSIONS
SACRAMENTO RIVER AND PERIPHERAL CANAL
2020 LEVEL OF DEVELOPMENT

MONTH	AVERAGE MONTHLY FLOW IN CFS		
	SACRAMENTO RIVER AT SACRAMENTO	PERIPHERAL CANAL DIVERSIONS	SACRAMENTO RIVER AT COURTLAND 1/
Oct.	12,128	9,537	2,596
Nov.	11,872	9,306	2,579
Dec.	17,521	11,236	6,290
Jan.	26,201	13,259	12,945
Feb.	32,038	13,884	18,161
Mar.	24,326	12,855	11,471
Apr.	21,135	11,548	9,620
May	19,100	6,472	12,630
Jun.	19,636	16,198	3,456
Jul.	18,103	15,564	2,559
Aug.	17,134	14,685	2,450
Sept.	13,317	9,418	3,903

1/ Includes channel depletion.

SYNTHETIC HYDROGRAPH OF MEAN DAILY DISCHARGE AND DAILY SUSPENDED SEDIMENT LOAD OF THE SACRAMENTO RIVER AT SACRAMENTO FOR AVERAGE YEAR WITH PERIPHERAL CANAL AND 2020 LEVEL OF DEVELOPMENT

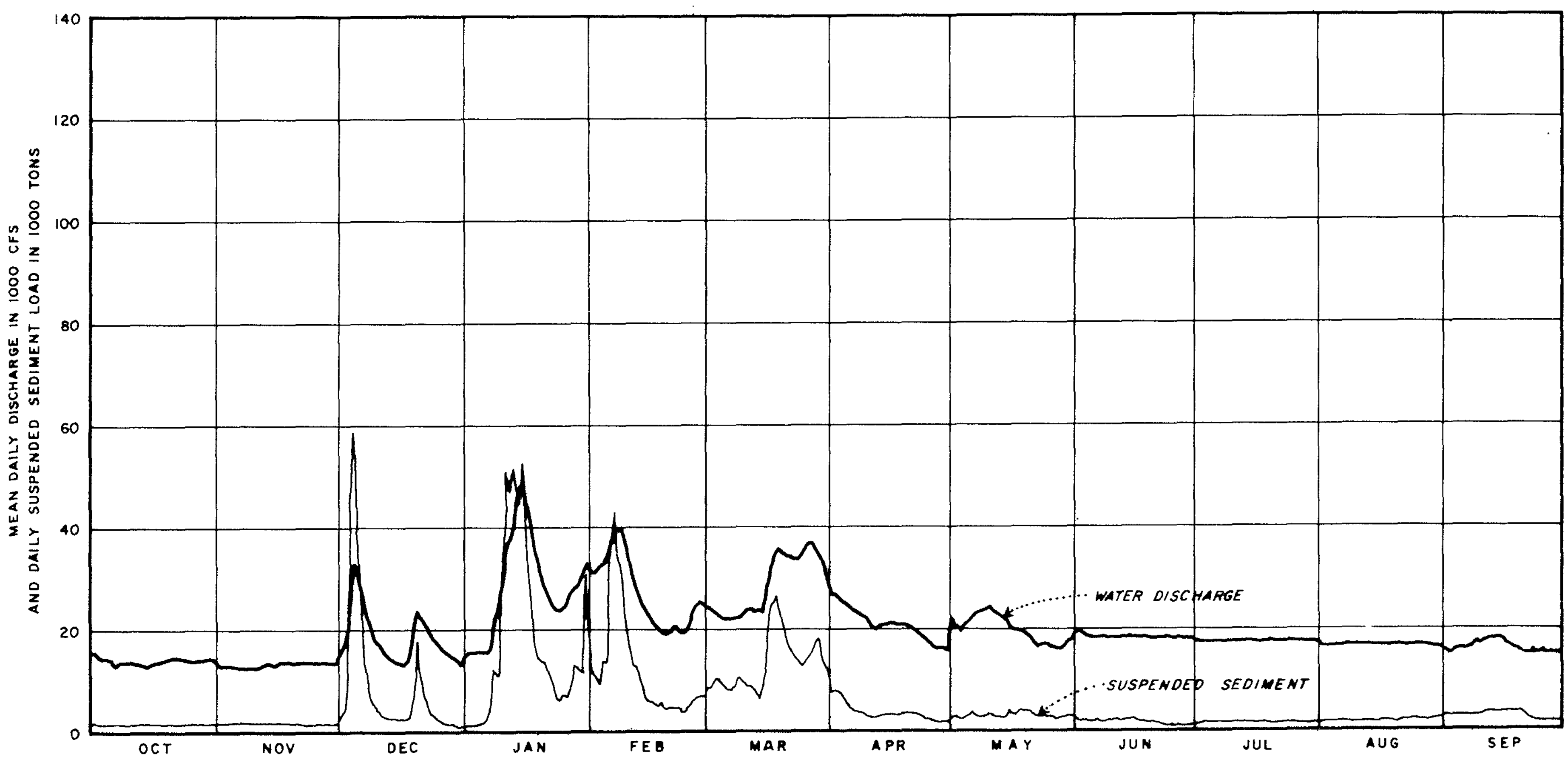

FIGURE 23

loads would produce an annual suspended sediment load of about 2 million tons (1.8 million t). Figure 24 shows the logarithmic suspended sediment-discharge relationship for this synthetic average year.

Suspended Sediment Diversions by the Canal

Suspended sediment was assumed to be diverted into the Canal in the same proportion as water diverted into the Canal. Based on the synthetic daily hydrograph and the flows from the canal operation study (shown in Table 5), it was calculated that the Peripheral Canal would divert approximately 993,000 tons (900 000t) of the average annual suspended sediment yield of the Sacramento River at the 2020 level of development. Table 6 shows the monthly summary of these calculations.

Effect of Canal on Bed Load Transport

With the Peripheral Canal in operation, the reach of the river downstream from the Canal intake will have a reduced capability to transport bed load due to the reduction in flows. A modification of the Kalinske bed load equation [16] was used to estimate the effect of Canal operation on bed load transport. The Kalinske bed load equation can be stated as:

$$g_s = 10 d_{50} \left[\frac{\tau_0}{\gamma_w (S_s - 1) g d_{50}} \right]^2 \sqrt{g R S_f} \qquad \text{Eqn 9}$$

where:

g_s = total bed load transport rate in tons per day per foot of channel width

d_{50} = median (50 percent finer) sediment size

γ_w = specific weight of water

S_s = specific gravity of sediment

g = acceleration due to gravity

R = channel hydraulic radius

S_f = friction slope

τ_0 = shear stress at the bed

From river stage information collected at Freeport and at Snodgrass Slough, stage-discharge curves were constructed for the Sacramento River at Freeport and Hood. The Delta Cross

MEAN DAILY WATER DISCHARGE VERSUS SUSPENDED SEDIMENT LOAD SACRAMENTO RIVER AT SACRAMENTO AVERAGE YEAR AT 2020 LEVEL OF DEVELOPMENT

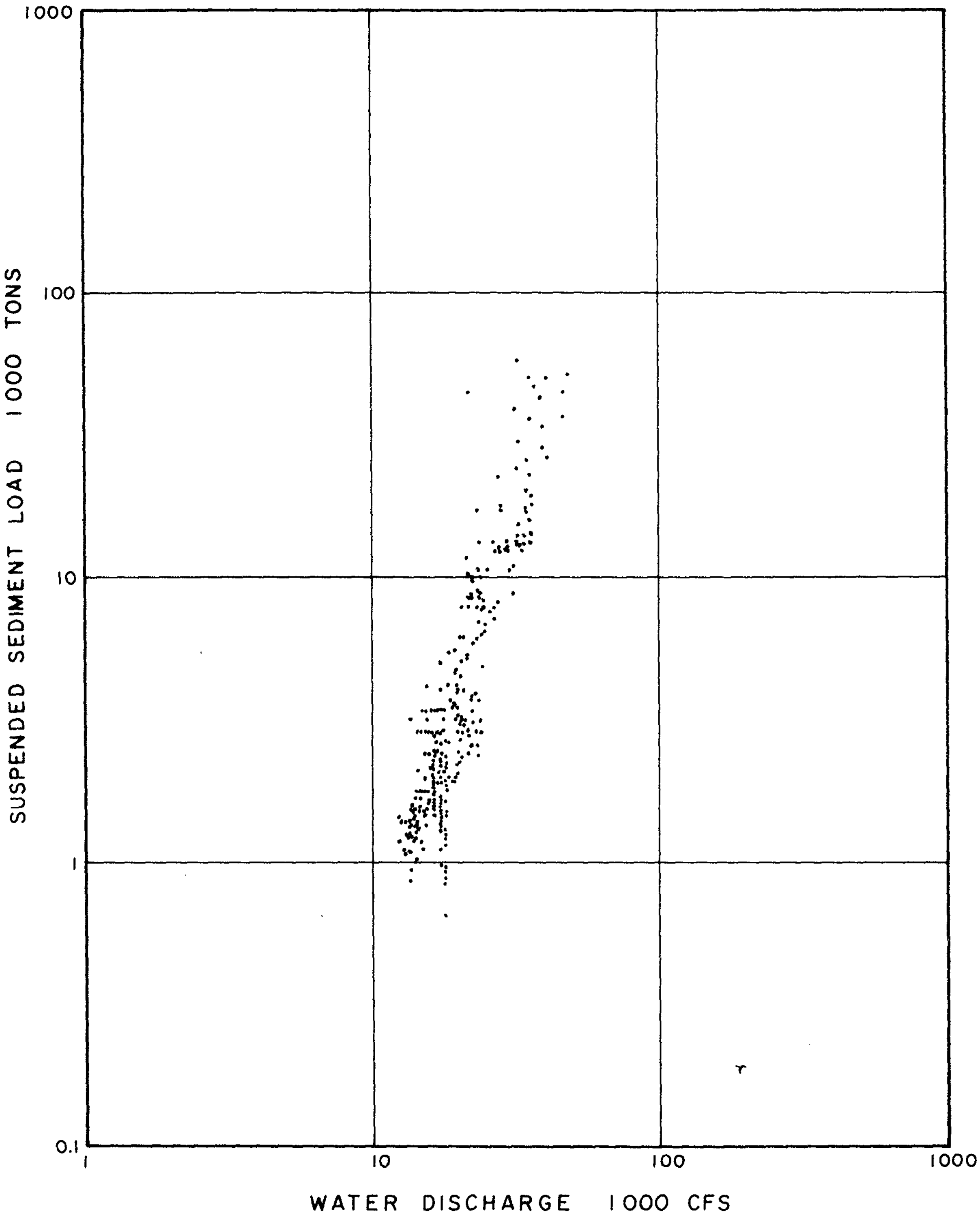

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TABLE 6

SEDIMENT DIVERSIONS
2020 LEVEL OF DEVELOPMENT 1/

MONTH	FREEPORT TO HOOD			CANAL DIVERSIONS		HOOD TO WALNUT GROVE		
	FLOW	SEDIMENT		FLOW	SEDIMENT	FLOW	BED SEDIMENT	
		SUSPENDED	BED		SUSPENDED		CAPACITY	DEPOSITION
	1000 CFS DAY	1000 TONS	1000 TONS	1000 CFS DAY	1000 TONS	1000 CFS DAY	1000 TONS	1000 TONS
Oct	432	44	8.7	296	30	136	0.8	7.9
Nov	392	40	7.4	279	28	113	0.5	6.9
Dec	574	273	16.9	348	131	226	3.4	13.5
Jan	869	547	45.5	411	196	458	15.7	29.8
Feb	756	338	34.2	389	154	367	9.2	25.0
Mar	882	404	41.1	399	178	483	12.8	28.3
Apr	620	103	7.4	346	55	274	1.6	5.8
May	612	86	6.9	201	29	411	1.3	5.6
Jun	543	48	14.6	496	43	47	.1	14.5
Jul	538	48	13.8	482	45	56	.1	13.7
Aug	513	62	4.8	455	56	58	.1	4.7
Sep	478	81	4.3	285	48	196	.7	3.6
TOTAL	7209	2074	205.6	4385	993	2824	46.3	159.3

1/ Summary of computations of daily data from synthetic hydrograph, Figure 23.

Channel was assumed to be closed and its effect and that of the Peripheral Canal on river stages were assumed to be minimal. Analysis of the stage-discharge data yielded the following expression for the Freeport to Hood reach of the river:

$$RS_f = (3.092 \times 10^{-10})(Q_w)^{.40719} \qquad \text{Eqn 10}$$

where:

Q_w = mean daily river flow in cfs

Assuming an average channel bottom width of 450 feet (137 m) for the Sacramento River in this reach, a median sediment particle size of 0.24 mm, and a sediment specific gravity of 2.67, Equation 9 was simplified to:

$$G_s = (2.7922 \times 10^{-6})(Q_w)^{2.11079} \qquad \text{Eqn 11}$$

where:

G_s = total bed load transport in tons per day

Assuming an average daily flow of approximately 20,300 cfs (575 m^3/s) (computed from Sacramento River flows at Sacramento -- Table 5) the above equation gives a total annual bed material transport load of about 1.13 million tons (1.02 million t).

However, to determine the effect of Canal operation on sediment deposition in the river below the Canal intake (between Hood and Walnut Grove), an equation is needed that expresses the fractional part of the total load that is in contact with the bed which will settle out under reduced flow. Estimating this fractional part as the amount of bed material dredged in the upstream reach (i.e., 200,000 cubic yards (153 000 m^3) or approximately 243,000 tons (220 000 t)), Equation 11 was multiplied by a factor of 243,000/1,130,000 or 0.21.

The resulting equation,

$$G'_s = (6 \times 10^{-7})(Q_w)^{2.11079} \qquad \text{Eqn 12}$$

was then used to calculate daily contact load rates using the synthetic hydrograph.

Using Equation 12, it was found that the Hood to Walnut Grove reach was capable of transporting only about 25 percent of the contact load from the upstream reach. Approximately 159,000 tons (145 000 t) would be deposited annually downstream from the Canal intake due to operation of the Peripheral Canal at full development. The results of the computations are also shown in Table 6.

The preceding calculations of the amount of deposition downstream of the Canal intake were developed using the average annual hydrograph for the 2020 level of development. Variation in the amount of deposition occurring in the river should be expected. The amount of deposition depends on the magnitude and distribution of the runoff, antecedent water conditions, project reservoir storage, and diversion requirements, For a wet year preceeded by several dry years, which would produce a maximum amount of deposition, the annual deposition downstream of the intake would be about 340,000 tons (310 000 t). During a critical year, when deposition would be at a minumum, annual deposition might amount to only about 60,000 tons (55 000 t). Dredging would be required to remove the accumulated sediment.

CHAPTER V

SEDIMENTATION IN THE PERIPHERAL CANAL

Effect of Intake Configuration and Fish Screens on Sediment Diversions

To prevent fish from entering the Peripheral Canal, a fish screening structure would be located at the head of the diversion channel. Two alternative intake configurations being evaluated are the on-river and off-river concepts shown in Figures 8 and 9 in Chapter I. Both concepts include a perforated plate or mesh screen with holes small enough to prevent juvenile fish from being diverted into the canal.

The allowable approach velocity of water to the screen is being determined from studies on survival of small fish impinged against the screen at various velocities. The operating velocity selected will minimize fish mortality and will probably be less than 1.0 foot per second (0.3 m/s) approaching the screen. Taking into account the need to minimize head loss and the allowable approach velocities, preliminary estimates indicate that a fish screen approximately 4,000 to 6,000 feet (1 200 to 1 800 m) long may be required.

The screen and the low velocities approaching the screen will cause some sediment to accumulate in front of the fish facility. Large amounts of moss, algae, and leaves would also accumulate on the screen and tend to clog the holes, necessitating frequent cleaning. The accumulation of such organic material on the screen would also tend to trap a portion of the inorganic sediment that would be washed away in the cleaning process and consequently not be diverted into the Canal.

Engineering studies are being conducted at the Hood Fish Screen Test Facility on the rate of clogging of perforated plates and screens and measurements of the organic debris load of the river are being conducted as part of the Sacramento River Debris Distribution and Occurrence Study. These studies are being conducted jointly by the Department of Water Resources, Department of Fish and Game, U.S. Bureau of Reclamation, and

U. S. Bureau of Sport Fisheries and Wildlife. These studies will establish the size, configuration, and operating criteria for the Canal intake. Some information on debris occurrence in the Sacramento River near Hood was collected under earlier debris studies conducted by the Department of Water Resources [28].

For the purpose of this report, the effects of intake configuration and fish screens were ignored, and as stated earlier, estimates of the amount of suspended sediment diverted into the Canal were based on the ratio of Canal flow diversion to Sacramento River flow. This assumption would overestimate the sediment diversion into the Canal, provided those effects are significant.

Bed material from the Sacramento River will essentially be prevented from entering the Canal by the planned placement of a 10-foot (3 m) high sill across the invert of the diversion channel. Inspection of Figure 25 shows that the coarser material is typically concentrated close to the bed, indicating that a sill can reduce or eliminate the amount of bed load diversion.

A physical model of the Canal intake and a portion of the river is being constructed by the University of California at Davis, to determine the hydraulic and sediment aspects of the diversion configuration. This model study will provide qualitative information on the amount of sediment deposition occurring in the river below the canal intake. Also, the effectiveness of the sill design and placement can be evaluated with the model.

Settling Basin Sizing Criteria

As stated earlier, the Peripheral Canal would divert an average annual sediment load of about 993,000 tons (900 000 t) from the Sacramento River (Table 6). Table 7 shows the particle size distribution of the diverted sediment load. Approximately 66 percent of this material would be diverted from December through March (based on Table 6).

TYPICAL DISTRIBUTION OF DIFFERENT SEDIMENT SIZES

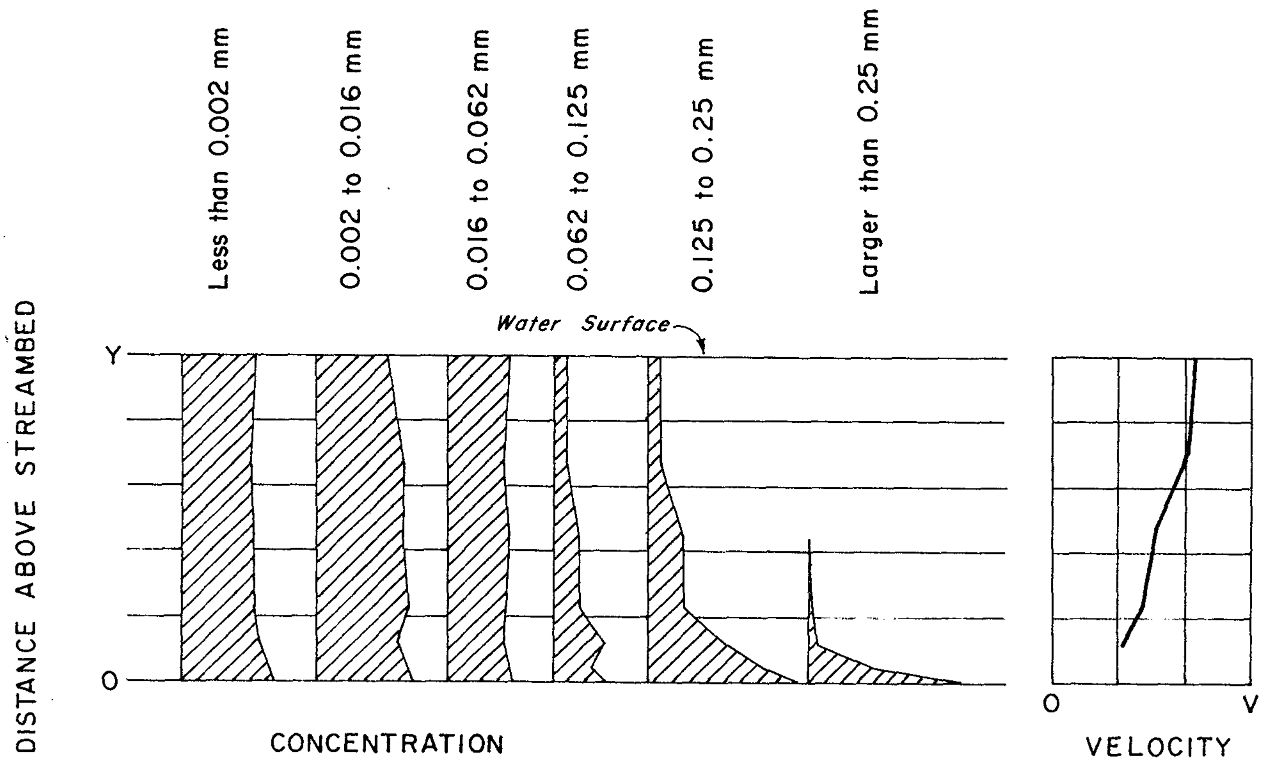

TABLE 7

DISTRIBUTION OF SUSPENDED SEDIMENT
ENTERING THE PERIPHERAL CANAL

PARTICLE SIZE RANGE MM	GEOMETRIC MEAN SIZE MM	SETTLING VELOCITY FPS *	AVERAGE % IN CLASS	SUSPENDED LOAD 1000 TONS
> 0.8	-	-	-	-
0.8 - 0.4	0.57	0.225	2	20
0.4 - 0.15	0.24	0.100	8	79
0.15 -0.062	0.10	0.025	12	120
0.062-0.04	0.05	0.006	10	99
0.04 -0.02	0.03	0.002	13	130
0.02 -0.01	0.014	0.005	11	110
< 0.01	-	-	44	432
			100	990

* From Einstein (17).

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Usually settling basins are designed to remove material coarser than some specified size. In canals, this size is generally taken as the lower limit of the sand classification (.062 mm). Canal velocities are usually high enough to transport silts and clays in suspension, and the minor amount of deposition of this material generally does not present maintenance problems.

Approximately one-third of the average annual sediment load diverted into the Peripheral Canal would be sand size or coarser (larger than .062 mm) and most of this heavier material can be expected to settle out in the Canal intake. The length of an idealized settling basin needed to settle out this material can be expressed by:

$$L = \frac{VY}{V_s} \qquad \text{Eqn 13}$$

where:

- L = required basin length, in feet
- V = velocity through the basin, in feet per second
- V_s = particle settling velocity in feet per second
- Y = depth of flow, in feet

Assuming the maximum velocity through the basin as 1 foot per second (0.3 m/s) at a design flow of 23,300 cubic feet per second (660 m^3/s), and a flow depth of about 30 feet (9.1m), the minimum length required for the basin to settle particles of 0.062 mm is approximately 3,500 feet (1 100 m). Rouse [23] indicates that the length should be about 1.5 times the idealized length computed from equation 13. In practice, this would maintain approximately the same sediment removal ratio as the idealized basin, partly because the particle size distribution of sediment in suspension changes as the material passes through the basin. In the upstream portion of the basin, some finer particles are hindered from settling by collisions with larger particles during the settling process. Therefore, the idealized length is not 100 percent effective in allowing settlement. A 50 percent increase in length would require a basin approximately 5,300 feet (1 500 m) long.

The trap efficiency, or sediment removal ratio of the settling basin, is a function of basin length and unit discharge. In the design of the Imperial Dam and desilting works for the All-American Canal, Vetter [24] found that the trap efficiency ratio could be expressed as:

$$T_e = 1 - e^{-\frac{V_s L}{q_w}} \qquad \text{Eqn 14}$$

Where:

T_e = trap efficiency ratio

q_w = unit discharge in cfs per foot of width

V_s = particle settling velocity, in feet per second

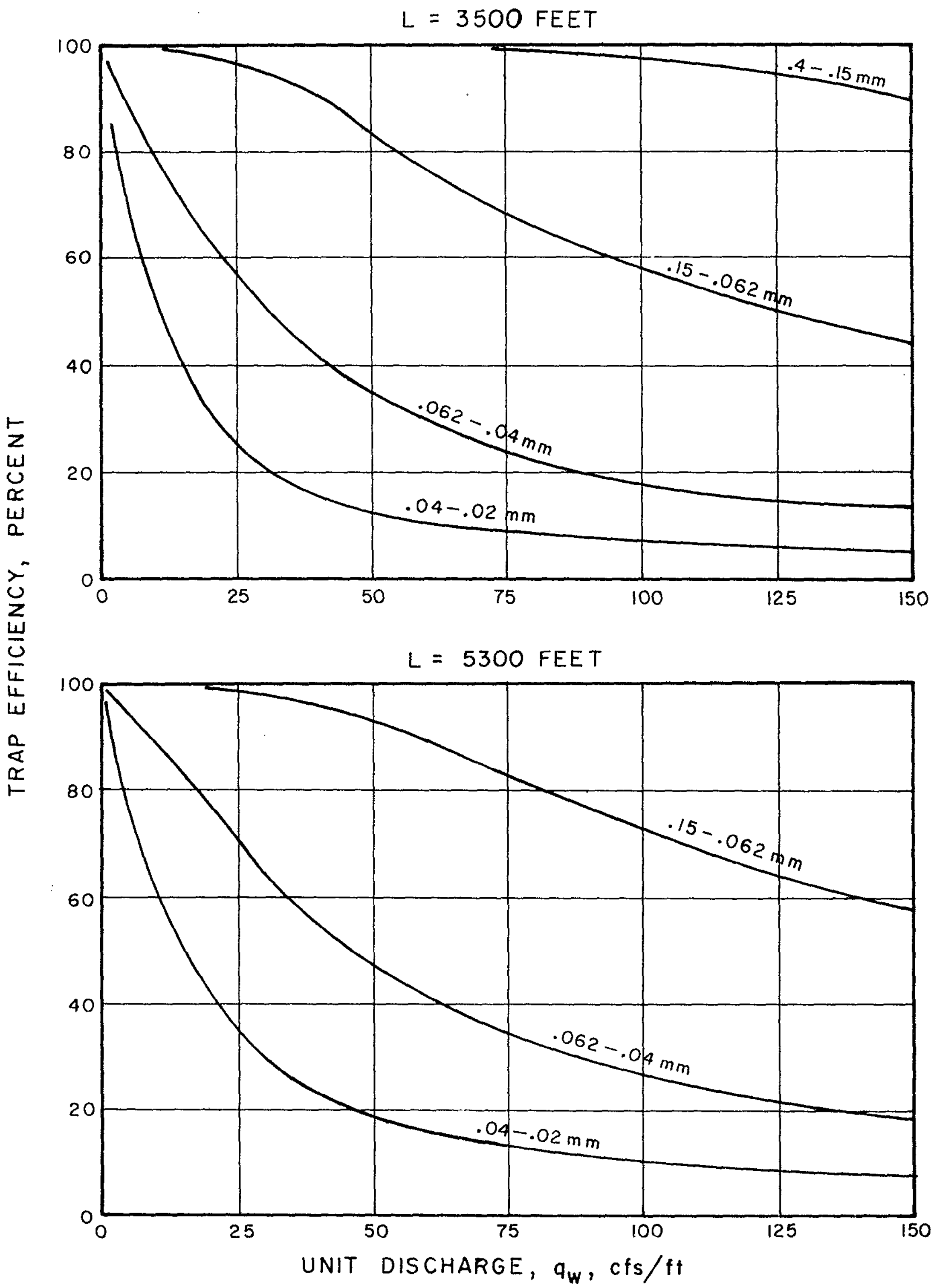
L = basin length, in feet

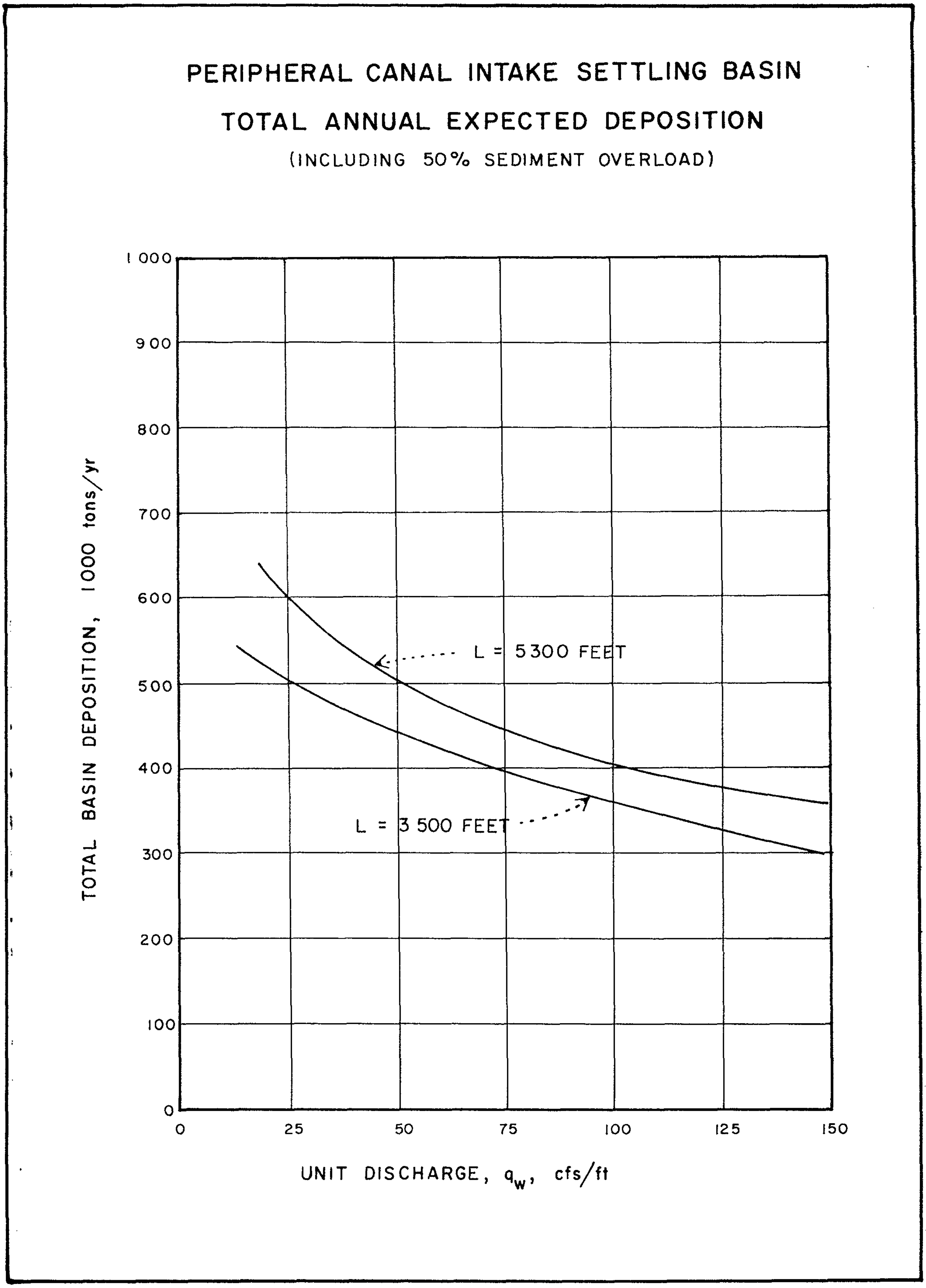
e = base of natural logarithms

Equation 14 can be used to compute the trap efficiency ratio for the Peripheral Canal. With the estimated sediment diversion into the Canal and the trap efficiency ratio, the annual sediment deposition in the Canal settling basin can be computed.

Figure 26 shows the trap efficiency, in percent, for various sediment size classes for settling basin lengths of 3,500 and 5,300 feet (1 100 and 1 600 m) and for unit discharges up to 150 cfs (4.3 m^3/s) per foot of basin width. To account for sediment diversion during years of above average runoff and sediment loads, the amount of dead-storage provided for deposition should be increased by about 50 percent. Figure 27 shows the range of total annual expected deposition in the Peripheral Canal settling basin, including a 50 percent overload factor for settling basins of 3,500 and 5,300 feet (1 100 m and 1 600 m) long, as a function of various unit discharges. Expected deposition for each basin length is higher at the lower unit discharges due to the increased detention time, which results in more efficient settling of the finer particles. Fine material not trapped in the settling basin will be carried through the Canal as washload. Assuming a unit discharge of 50 cfs/ft., the total basin deposition would be about 500,000 tons (460 000 t) annually.

PERIPHERAL CANAL INTAKE SETTLING BASIN
THEORETICAL TRAP EFFICIENCY CURVES
(FOR VARIOUS PARTICLE SIZE CLASSES)




PERIPHERAL CANAL INTAKE SETTLING BASIN
TOTAL ANNUAL EXPECTED DEPOSITION
(INCLUDING 50% SEDIMENT OVERLOAD)
TOTAL BASIN DEPOSITION, 1000 tons/yr
1 000
900
800
700
600
500
400
300
200
100
0
L = 5300 FEET
L = 3 500 FEET
0
25
50
75
100
125
150
UNIT DISCHARGE, q_w, cfs/ft

The sizing of the settling basin must consider other factors such as land costs, construction costs, sediment removal frequency, and costs and methods and costs of handling and disposal of the soil material.

Cost of Sediment Removal

The cost of removing sediment from a settling basin varies with the cleaning frequency, type of equipment used, the amount of material handled, and the method of transportation and disposal of spoil material. Few desilting works of the magnitude of the Peripheral Canal settling basin have been constructed. Therefore, information is limited regarding annual operating costs. The American Society of Civil Engineers (ASCE) [25] has published information on sediment removal costs for a few projects in the United States. In 1972, costs ranged from $0.60 per cubic yard ($0.78 per m^3) for a small settling basin removing 21,000 cubic yards (16 000 m^3) by dragline, bulldozing and rehandling, to $0.35 per cubic yard ($0.46 per m^3) for larger basins removing as much as 170,000 cubic yards (130 000 m^3) by a 10-inch suction dredge. Due to escalation, the ASCE estimates that these costs are doubling every 10 to 15 years.

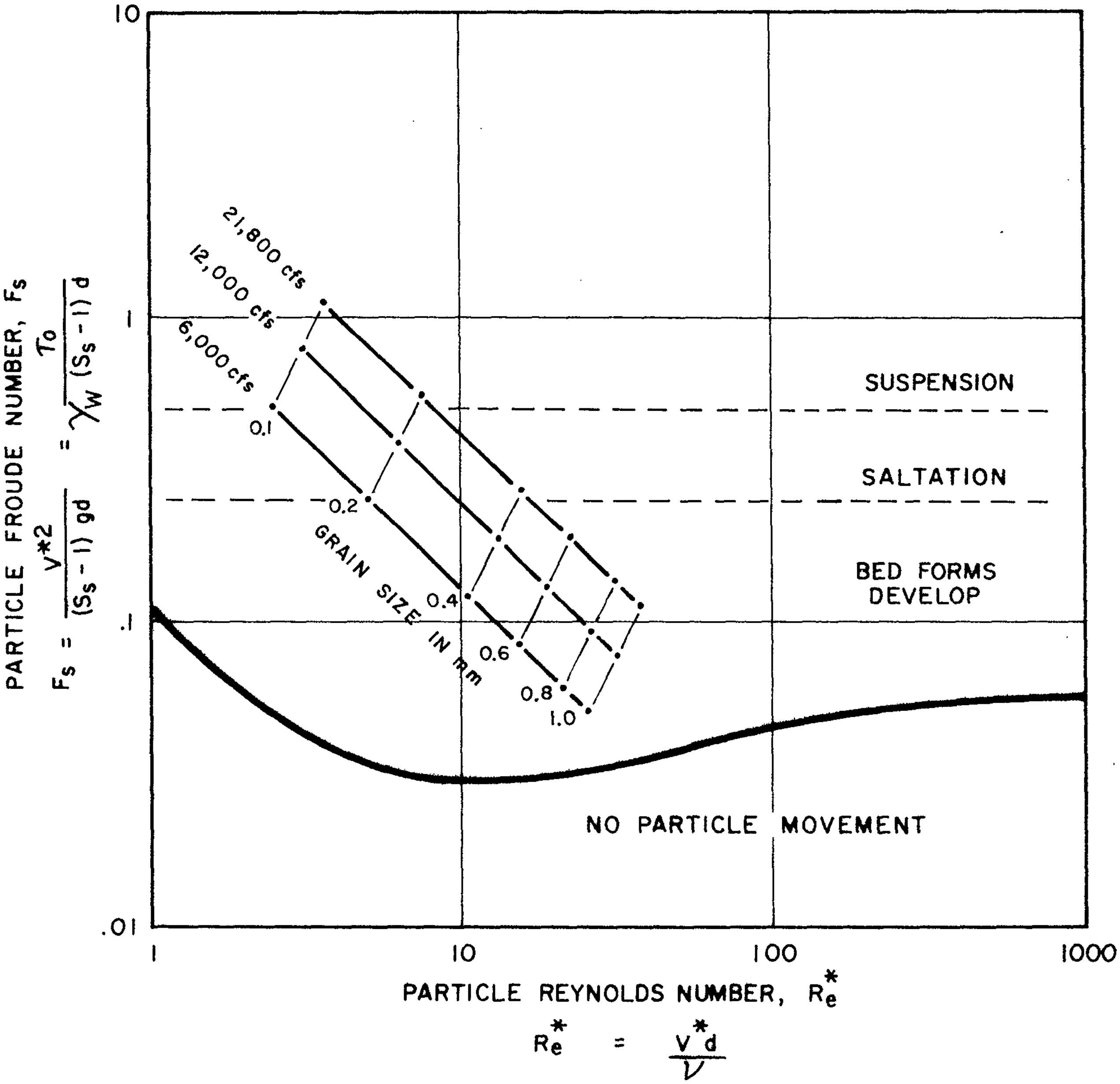
The 1976 cost of clamshell removal, barging, stockpiling, and spreading of sediment in the Delta area is approximately $2 per cubic yard ($2.55 per m^3) [26].

Transport Capacity of the Peripheral Canal

The Peripheral Canal downstream of its pumping plant, is capable of transporting particles between approximately 0.20 and 0.40 mm as bed load depending on the Canal flow rate (see Figure 28). As stated earlier, finer particles not trapped in the settling basin will be carried in suspension through the Canal as wash load.

Overexcavation of various reaches of the Canal prism will be required to obtain sufficient embankment material for constructing the Canal levees and development of several

SHIELDS DIAGRAM FOR INITIATION OF SEDIMENT MOVEMENT PERIPHERAL CANAL (TYPICAL SECTION)



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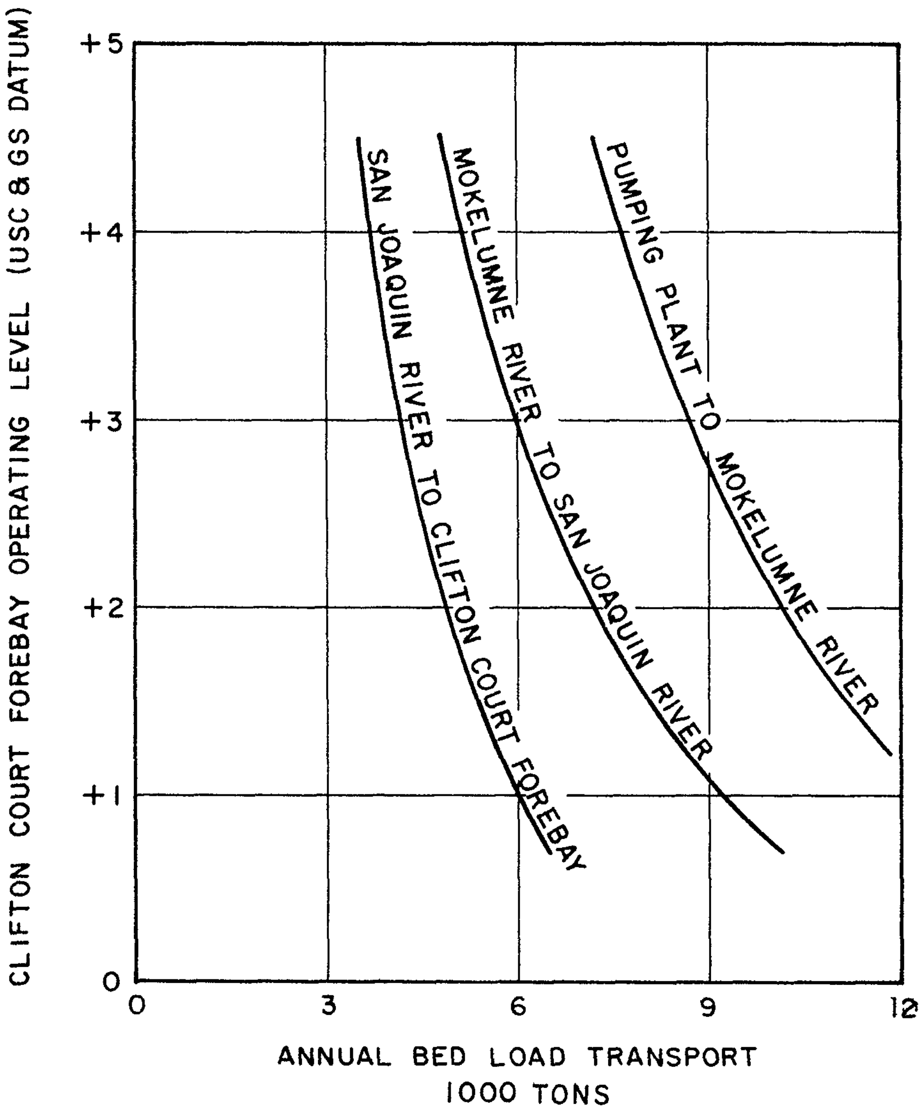
BED LOAD TRANSPORT CAPABILITY
OF THE PERIPHERAL CANAL
(MEAN ANNUAL FLOW OF 12,000 CFS)



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planned recreation and wildlife areas. Since the limits and amounts of overexcavation are not known, the effect of overexcavation on sedimentation was not evaluated. However, overexcavation will both reduce the flow velocity and provide storage capacity for some of the bed load transported along the Canal. Figure 29 shows the annual bed load transport capacity of three reaches of the Peripheral Canal, for a mean annual Canal flow of 12,000 cfs (340 m^3/s), under various water surface elevations at Clifton Court Forebay. These computations were made using the Kalinske bed load formula (Equation 9).

Morrison Creek Sediments

Floodflows from the Morrison Creek stream group would be controlled by the proposed Morrison Creek Flood Control Project under consideration by the Corps of Engineers [29]. This project calls for a large flood retention basin, a flood control reservoir, and some channel improvements. Floodflows from this stream group now transport a very minor amount of silts and clays, much of which settle out in broad floodplain deposits. If the Peripheral Canal is constructed prior to federal authorization of the Corps proposal, the two projects will be integrated, and floodflows from Morrison Creek will be taken into the Peripheral Canal upstream from the Peripheral Canal Pumping Plant. If the Morrison Creek project is constructed, most of the sediment will be retained in the project reservoir and flood retention basin. Thus, for this report, no sediment was assumed to enter the Canal from the Morrison Creek stream group whether or not the flood control project is constructed.

Releases from the Peripheral Canal

Water quality rleeases will be made at 12 locations along the Peripheral Canal to distribute flows at controlled rates into Delta Channels. The largest releases will normally be made during April through September to improve Delta water quality. Sediment diversion into the Canal from the Sacramento River during this 6-month period will only constitute 30 percent of the total annual sediment diversion (Table 6). Fine sands which could deposit in the channels and cause deposition problems, will be removed at the Canal intake settling basin. Suspended sediment in the release flows will be fine silts and clays, and the effect on these Delta tidal channels will be minor.

Sedimentation in Recreation Facilities

A typical proposed recreation lagoon area for the Peripheral Canal is shown in Figure 7-B. The lagoon would consist of a side channel for swimming, fishing, boating access and other activities. Certain sedimentation aspects must be considered for these areas. As has been shown previously, the Peripheral Canal is theoretically capable of transporting a small amount of material as bed load. To prevent this bed load material from depositing in the mouths of the side channels and eventually choking them (unless dredged), the invert elevation of the side channels should be established above the invert elevation of the main Canal trough, keeping bed material movement within the main trough. Some very fine material will settle in the lagoons due to the low velocities through these channels.

Canal Bank Erosion

The general alignment of the Canal makes it susceptible to strong north-south winds. Bank erosion due to wind waves and boat wakes may cause some material to be eroded from the Canal sideslopes. However, erosion will be minimzed by the flattened sideslopes of the upper portion of the cross-section (Figure 7A) and the establishment of vegetative growth.

Canal Maintenance Dredging

Some amount of channel maintenance will have to be performed, possibly dredging within lagoon areas and in the Canal itself, during the lifetime of the project. However, this will not be necessary on an annual basis. Periodic dredging may also have to be performed to maintain the flow capacity of siphons.

Sedimentation in Clifton Court Forebay

The Canal intake settling basin will trap about 450,000 tons (410 000 t) of the average annual Sacramento River sediment diversion of 993,000 tons (900 000 t), based on an average between the curves of Figure 27. The actual amount of deposition will vary depending on the basin length and unit discharge. The remaining material passing through the intake settling basin, 543,000 tons (490 000 t) will be transported as wash load along the Canal and into Clifton Court Forebay.

Assuming an average annual Canal flow of 12,000 cfs (340 m^3/s) and Clifton Court Forebay operating at a water surface of +3.0 feet (0.9 m) USC and GS* datum, the Canal reach from the San Joaquin River to the Forebay is also capable of transporting about 4,000 tons (3 600 t) of bed load material annually. (see Figure 29).

Since the Forebay has no capability of transporting sediment as bed load and no storage volume specifically provided for sediment storage, material transported from the Peripheral Canal that accumulates in the Forebay will reduce the operating capacity of the Forebay. Assuming unit weights of 100 pounds per cubic foot for Canal bed material (sand) and 50 pounds per cubic foot (silts and clays), Forebay trap efficiencies of 100 percent for sand and 70 percent for silts and clays, the average annual deposition in Clifton Court Forebay under full development will reduce the capacity by approximately 396 acre-feet (490 000 m^3) per year.

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* U.S. Coast and Geodetic Survey

CHAPTER VI

CONTROLLING PERIPHERAL CANAL SEDIMENT DIVERSIONS

A method of operating the Peripheral Canal was investigated that would minimize the amount of sediment diverted into the Canal and deposited in the intake settling basin, thus minimizing the annual cost of dredging and disposal.

Table 6 shows that about 66 percent of the total annual sediment diversion occurs from December through March. By closing the intake gates at Hood during peak riverflows within this period, a considerable amount of material would be prevented from entering the Canal and instead be transported downstream by the river. This would also decrease flows that would otherwise enter the Canal and become available for project use. Partial or full compensation for the reduced flows from the Sacramento River might be possible by diverting directly from southern Delta channels into Clifton Court Forebay. Additional structures and/or channel improvements in the southern Delta may also be required to allow these increased diversions to be made.

Assuming that sufficient water would be available in the southern Delta from December through March to meet the Canal export loss from the Sacramento River (if the Hood intake were closed), and also assuming that the Sacramento River peak hydrograph events could be predicted up to a week in advance (an assumption that is reasonable, considering the State and federal flood forecasting capability), the synthetic average annual hydrograph (Figure 23) was used to compute the reduction in sediment diversions into the Canal with the intake gates closed for various periods. Table 8 shows the accumulated reduction in sediment diversion and settling basin deposition that could be expected by selectively operating in this manner for arbitrary periods of up to 13 days during each peak flow event each month from December through March for the hydrograph shown in Figure 23. The reduction in basin deposition was calculated using an average basin trap efficiency of 30 percent. As shown in Table 8, a reduction in intake settling basin

TABLE 8

SEDIMENT INTAKE REDUCTION
BY SELECTIVE OPERATION

(Based on Average Annual Hydrograph)

DAYS AT ZERO DIVERSION * DEC-MAR	REDUCTION IN SEDIMENT DIVERTED INTO PERIPHERAL CANAL (TONS)	REDUCTION IN INTAKE SETTLING BASIN DEPOSITION ** (TONS)
1	55,000	17,000
3	158,000	47,000
5	233,000	70,000
7	293,000	89,000
9	339,000	100,000
11	378,000	115,000
13	413,000	125,000

* Number of days at zero diversion for peak flow event for each month

** Based on average basin trap efficiency of 30 percent deposition for an arbitrary period of 13 days for each peak event each month would be about 125,000 tons (113 000 t) annually. This would constitute a reduction of approximately 28 percent, based on the calculated average annual deposition in the Canal sediment basin of 450,000 tons (410 000 t) from Chapter V.

Operation studies and fish occurrence studies would have to be made to completely evaluate the feasibility of operating in this manner.

CHAPTER VII

EFFECT OF PERIPHERAL CANAL ON SACRAMENTO RIVER TURBIDITY

Sediment-Turbidity Relationships

Diversions of water from Central Valley rivers and streams reduce the sediment input to the Delta and San Francisco Bay. Concern has been expressed that such reduction might reduce turbidity and increase light penetration. That in turn might increase the frequency and severity of phytoplankton blooms and reduce the capacity of the estuary to assimilate certain wastes.

In 1971, the USGS expanded its program to include more stations and numbers of measurements of inorganic suspended solids in the Sacramento River and Yolo Bypass [30]. The overall objectives of this program are to predict future reductions of inorganic sediment and to estimate how such reductions would affect turbidity in the Bay and Delta waters.

Factors that must be considered in predicting concentrations of inorganic suspended solids are the amount of material brought into the estuary by river inflow and the settling and resuspension of the material in the estuary. Settling and resuspension are largely controlled by hydraulic conditions and salinity.

Figure 30 is a plot of the discharge and measured suspended sediment load for the Sacramento River at Sacramento during the 1972-73 water year. The figure also shows turbidity and the percentage of organic material in the flow. Figure 31 shows the logarithmic relationship between discharge and measured suspended sediment at Sacramento for the 1973 water year. Figure 32 shows a relationship between sediment concentration and turbidity, which for the 1972-73 data was:

$$JTU = 0.3819(C)^{0.9780} \qquad \text{Eqn 15}$$

HISTORICAL RECORD OF MEAN DAILY DISCHARGE AND DAILY SUSPENDED SEDIMENT LOAD OF THE SACRAMENTO RIVER AT SACRAMENTO DURING WATER YEAR 1972-1973 (INCLUDING TURBIDITY AND PERCENT ORGANIC MATERIAL)

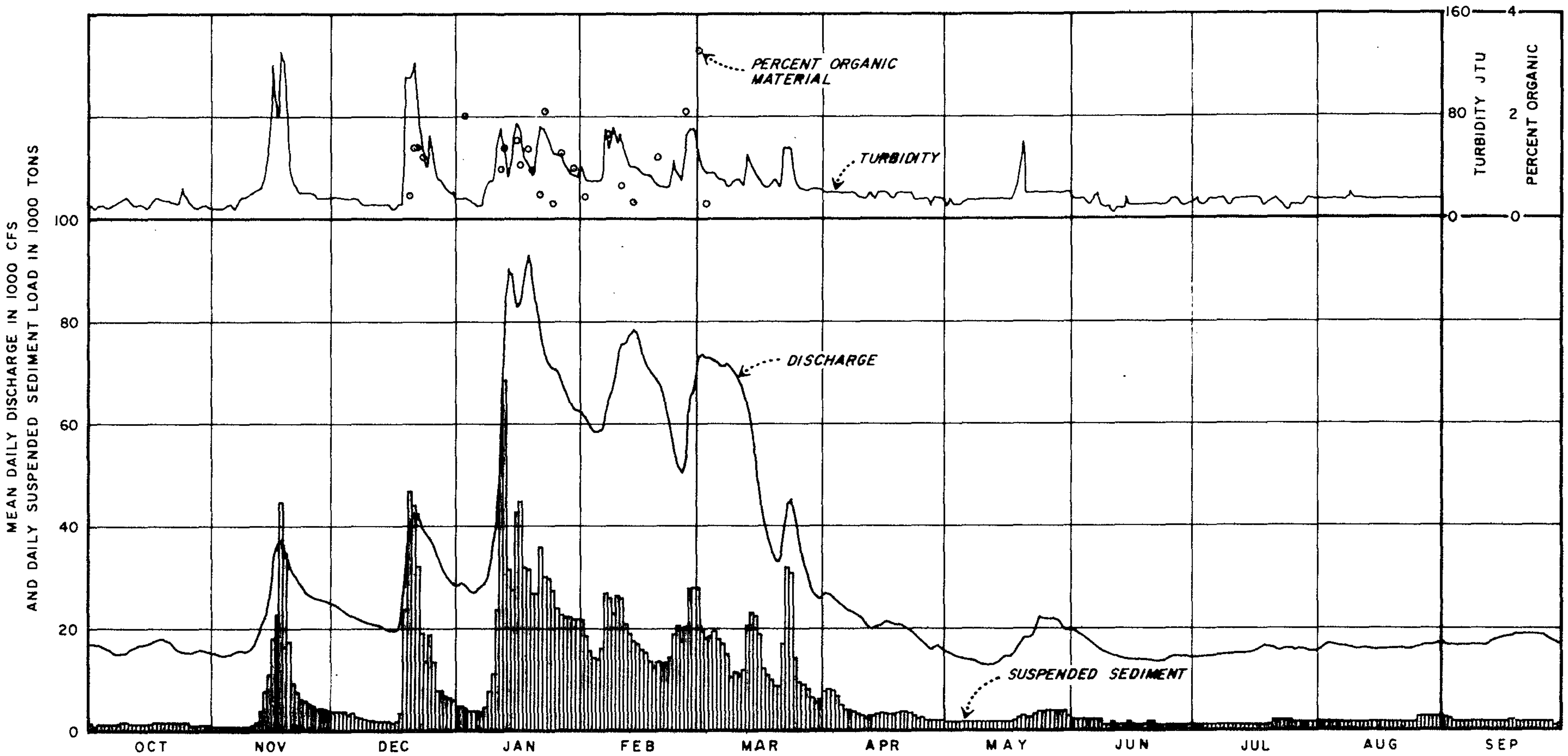
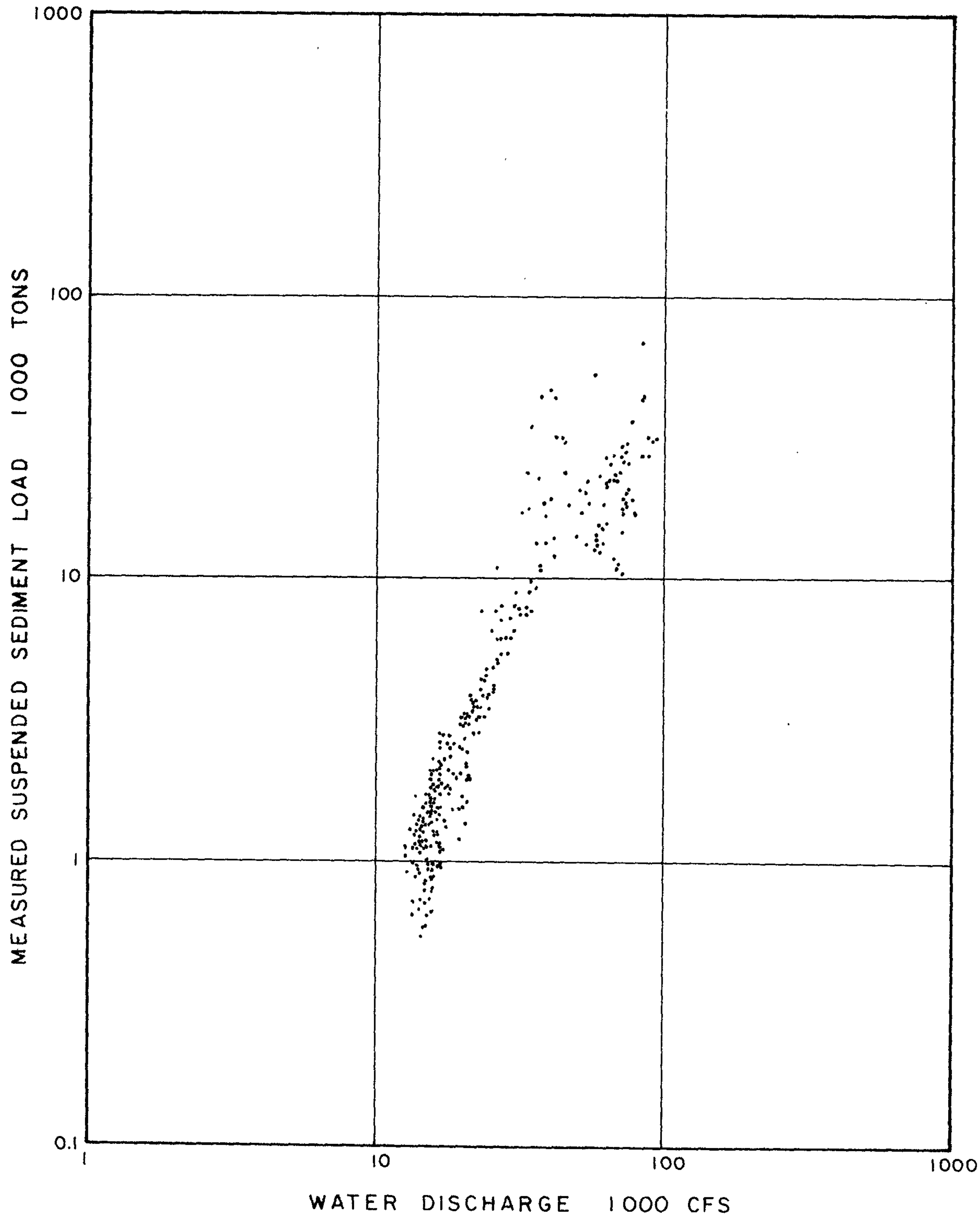
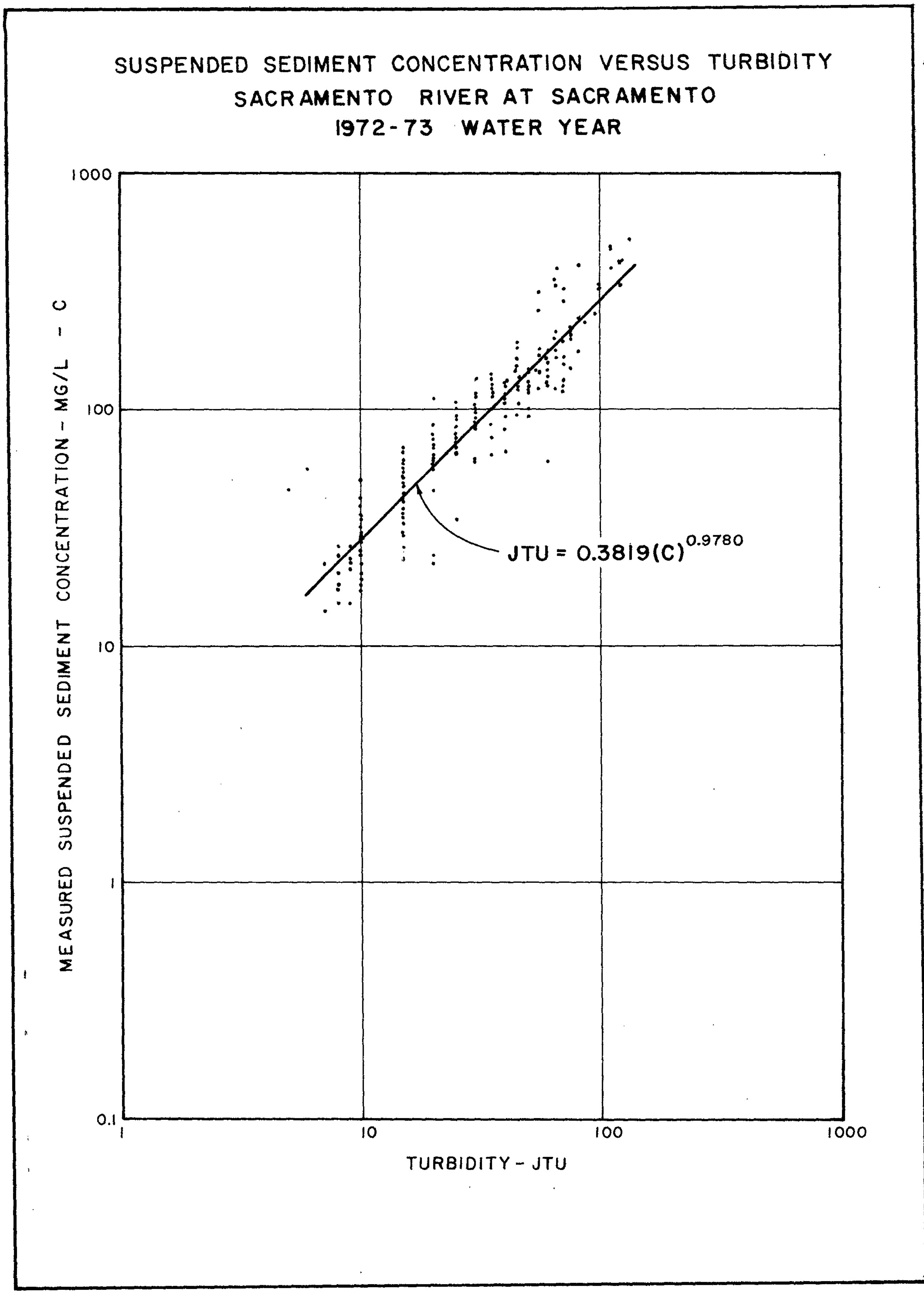


FIGURE 30

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1972-73 WATER YEAR





C-041919

C-041919

Where:

JTU = turbidity in Jackson turbidimeter units

C = suspended sediment concentrations in milligrams per litre

A logarithmic relationship also exists between suspended sediment concentration (load) and discharge (see Figure 31). Therefore, equation 15 can be related in terms of turbidity and discharge in the following equation:

$$JTU = 0.00356(Q_w)^{0.8495} \qquad \text{Eqn 16}$$

Where:

Q_w = Mean daily discharge in cfs

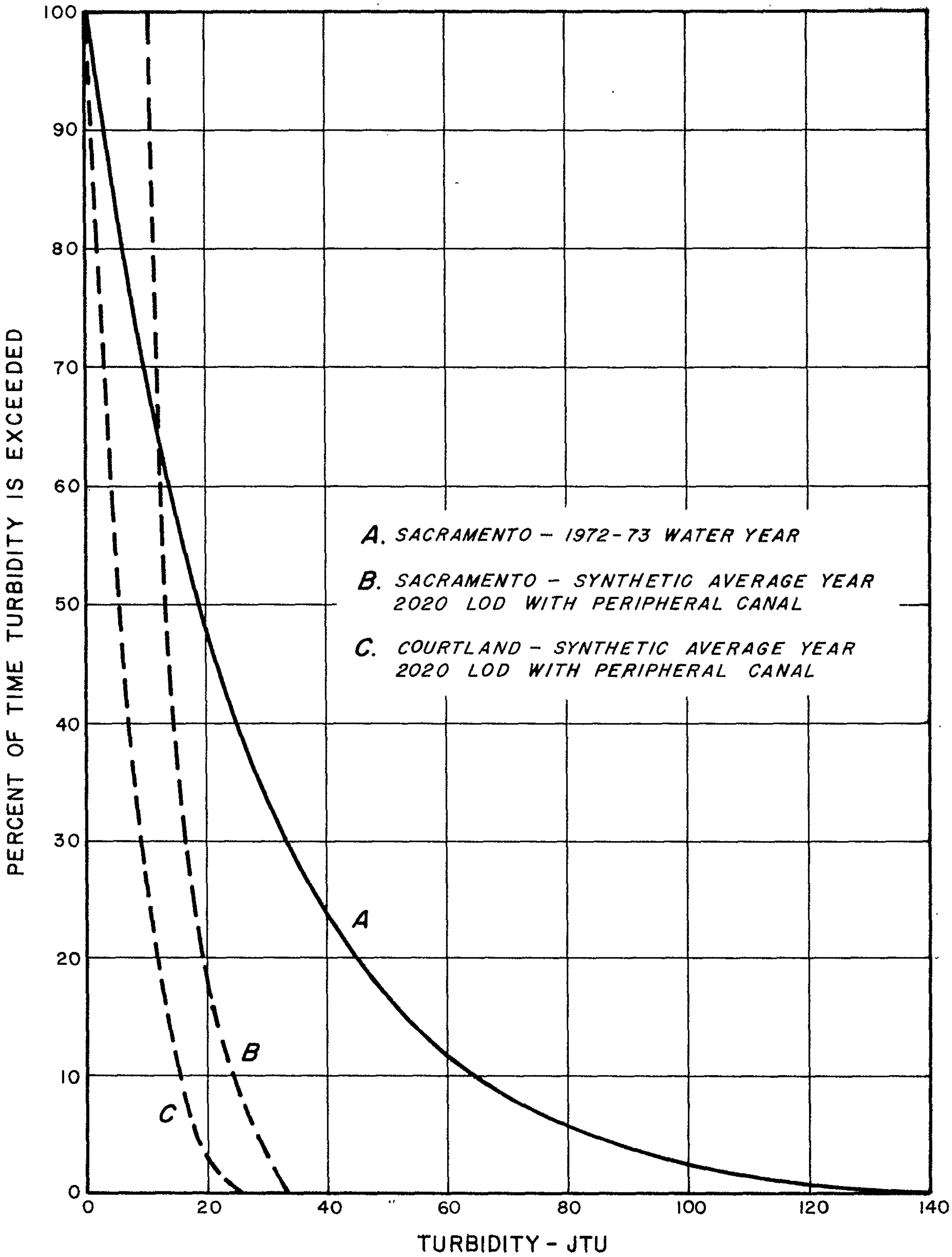
Effect of Peripheral Canal Operation on Turbidity

Using the above discharge-turbidity relationship and the synthetic average annual hydrograph for the Sacramento River at the 2020 level of development (Figure 23), daily turbidities were calculated for Sacramento and Courtland (upstream and downstream from the Peripheral Canal intake at Hood). Figure 33 shows turbidity duration curves developed for Sacramento and Courtland for the 1972-73 water year and for the synthetic annual hydrograph with the Peripheral Canal operational at the 2020 level of development.

Since these curves were developed from only the 1972-73 turbidity-discharge relationship, which may not represent an average relationship, emphasis should not be given to the numerical values of the calculated curves, but rather to the relative differences between upstream and downstream turbidity due to Canal operation. Curves B and C of Figure 33 indicate that the duration of Sacramento River turbidity downstream of Hood will decrease due to Canal operation. This does

FIGURE 33

TURBIDITY DURATION CURVES
SACRAMENTO RIVER



not take into account the operational scheme to minimize sediment intake into the Canal from December to March as discussed in the previous chapter. If such a scheme were implemented, the turbidity and suspended sediment load in the Sacramento River downstream from the Canal intake would be maintained at a higher level during this period.

C-041922

APPENDIX A

MATHEMATICAL SYMBOLS

a, b = Constants

C = Sediment concentration

d = Sediment particle diameter

d_{35}, d_{50}, d_{65} = Sediment particle diameters for which 35, 50, and 65 percent of the material is finer

e = Base of natural logarithms

F_s = Particle Froude number

g = Acceleration of gravity

g_s = Bed material discharge per unit channel width

G_s = Total bed material discharge

G_s' = Bed material contact load

JTU = Turbidity

k = Tolerance factor

L = Channel length

MAF = Runoff in million acre-feet

n = Sample size

Q_s = Mean daily sediment load

q_w = Unit discharge per foot of channel width

Q_w = Mean daily water discharge

R = Hydraulic radius

R_e^* = Particle Reynolds number

S_s = Specific gravity of sediment

S_f = Slope of water surface

S_{ma} = Mean annual sediment load

S_{mm} = Mean monthly sediment load

T = Time, in years, A.D.

T	=	Settling basin trap efficiency ratio
V	=	Average channel velocity
V^*	=	Shear "velocity"
V_s	=	Particle settling velocity
Y	=	Average channel depth
γ_w	=	Specific weight of water
ν	=	Kinematic viscosity of water
ρ	=	Fluid density
τ_0	=	Shear stress at the bed
μ	=	Population mean
σ	=	Standard deviation of sample

APPENDIX B

REFERENCES

Items [2, 3, 5, 6, 10, 20, 21] appearing in the following list were not quoted from or used as reference material in this report. They have been included here since they deal with some aspects of sedimentation in the Delta or are excellent sources on the mechanics of sediment transport.

C-041926

1. Colby, Bruce, R., "Fluvial Sediments-A Summary of Source, Transportation, Deposition, and Measurement of Sediment Discharge": U. S. Geological Survey Bulletin 1181-A, 1963.

2. Smith, Bernard J., "Sedimentation in the San Francisco Bay System", Paper No. 70, Proceedings of the Federal Interagency Sedimentation Conference, Miscellaneous Publication No. 970, U. S. Department of Agriculture, 1963.

3. Krone, R. B., "Predicted Sediment Inflows to the San Francisco Bay System", U. C. Davis, California, 1966.

4. Kennedy, David N., "An Evaluation of the Hydrologic Data and the Methodology Used by Dr. Krone for Predicting Diversion of Sediment from the Sacramento-San Joaquin Delta", State Water Service Contractors Exhibit 505 to the State Water Resources Control Board at Water Right Hearing, USBR Applications 5625, et al., Sacramento-San Joaquin Delta Water Supply, September 1970.

5. Graf, Walter H., "Hydraulics of Sediment Transport", McGraw-Hill Book Company, 1971.

6. Porterfield, G., Hawley, N. C., and Dunnam, C. A., "Fluvial Sediments Transported by Streams Tributary to San Francisco Bay Area", U. S. Geological Survey, Sacramento, California, 1961.

7. Shen Hsieh Wen, (Editor) "River Mechanics", (2 vols.), Fort Collins, Colorado, 1971.

8. Jones, Gerald H., "Alteration of the Regimen of Sacramento River and Tributary Streams Attributable to Engineering Activities During the Past 116 Years", Paper prepared for the historical records of Sacramento Section of American Society of Civil Engineers, 1967.

9. California Division of Water Resources, "Sedimentation-Appendix G of Report to the Water Project Authority of the State of California on Feasibility of Construction by the State of Barriers in the San Francisco Bay System", 1955.

10. Porterfield, George, "Computation of Fluvial Sediment Discharge", Techniques of Water Resources Investigations of the United States Geological Survey, Chapter C3, Book 3, Applications of Hydraulics, 1972.

11. Grunsky, C. E., "Silt Transportation by Sacramento and Colorado Rivers and by the Imperial Canal", Transactions ASCE, August, 1929.

12. "Sediment Transportation Mechanics: Nature of Sedimentation Problems", Task Committee on Preparation of Sedimentation Manual, Proceedings ASCE, No. HY2, March, 1965.

13. "Bank Erosion Investigations-Feather River at Nelson Bend", State of California, Department of Water Resources, May, 1967.

14. Henderson, F. M., "Open Channel Flow", The Macmillan Company, 1966.

15. McBride, James, Corps of Engineers, Sacramento, California. Personal communication.

16. Kalinske, A. A., "Movement of Sediment as Bed Load in Rivers", Transactions, American Geophysical Union, Vol. 28, No. 4, August, 1947.

17. Einstein, H. A., "The Bed Load Function for Sediment Transportation in Open Channel Flows", U. S. Department of Agriculture Technical Bulletin No. 1026, September, 1950.

18. U. S. Bureau of Reclamation, Sacramento, California, "Final Report: California Aqueduct-Delta Mendota Canal Sediment Studies; Final Recommendations", October 4, 1973.

19. McClurg, Darryl, CALTRANS, Marysville, California Personal communication.

20. "Interim Report on Study of Beach Nourishment Along the Southern California Coastline", State of California, Department of Water Resources, Memorandum Report, July, 1969.

21. Colby, Bruce R., "Discharge of Sands and Mean-Velocity Relationships in Sand-Bed Streams": U. S. Geological Survey Professional Paper 462-A, 1964.

22. State of California, Department of Water Resources, "Draft Environmental Impact Report-Peripheral Canal Project", August 1974.

23. Rouse, H., "Engineering Hydraulics", John Wiley and Sons, Inc., 1950.

24. U. S. Bureau of Reclamation, "Boulder Canyon Project Final Reports, Part IV-Design and Construction, Bulletin 6, Imperial Dam and Desilting Works", 1949.

25. ASCE-Manuals and Reports on Engineering Practice, No. 54, "Sedimentation Engineering", 1975.

26. George Peifer, DWR, Sacramento, personal communication.

27. Serr, Eugene F., DWR Staff Sedimentation Specialist, Red Bluff, California. Personal communication.

28. State of California, Department of Water Resources, "The Sacramento River Debris Study", October 1971.

29. Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California, "Draft Review Report for Flood Control on Morrison Creek Stream Group, California", January, 1970.

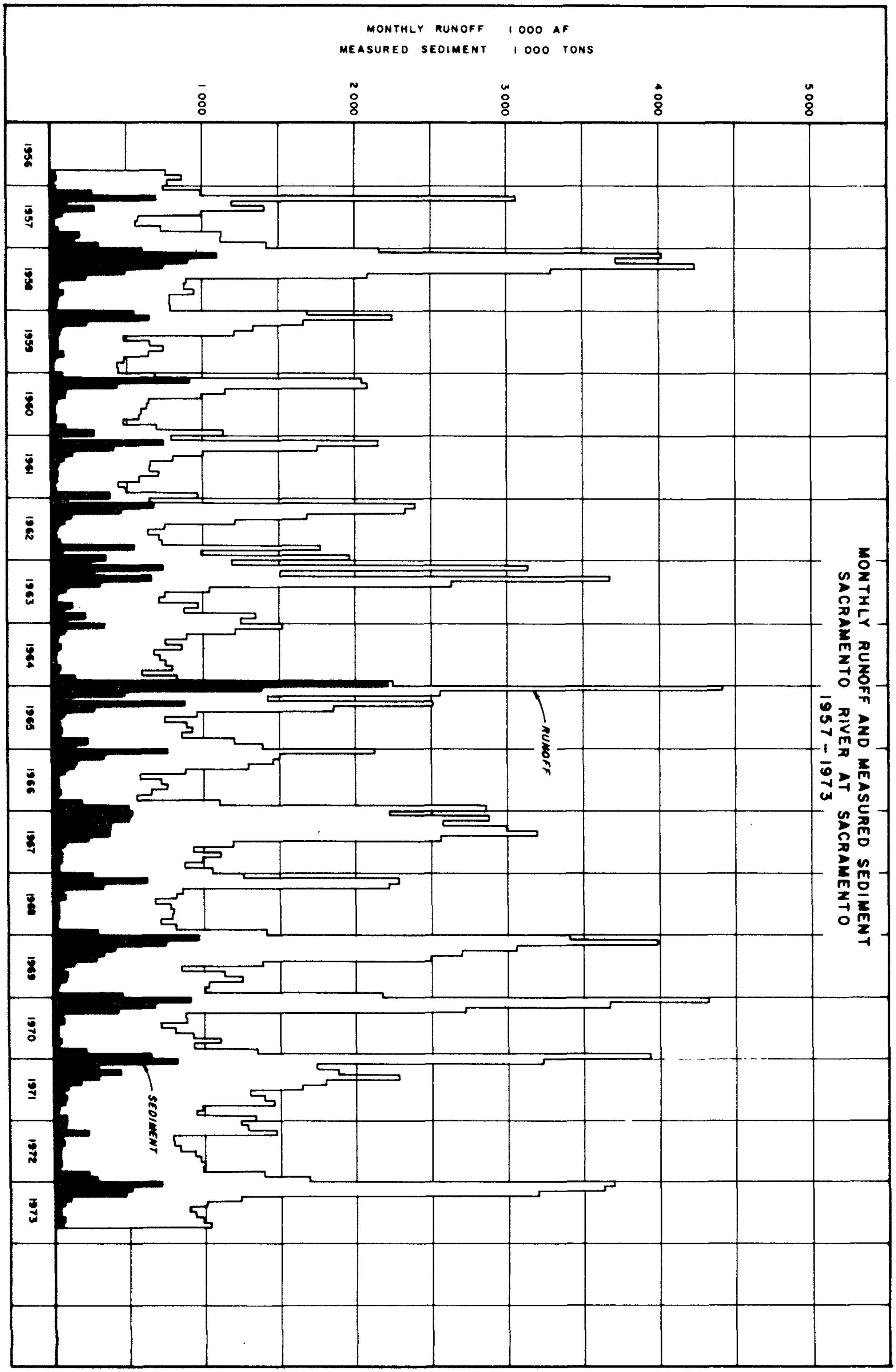
30. "Interagency Ecological Study Program for the Sacramento - San Joaquin Estuary", First Annual Report (1971), March, 1972, a cooperative study by the Calif nia Department of Fish and Game, California Department of Water Resources, U. S. Bureau of Sport Fisheries and Wildlife, and the U. S. Bureau of Reclamation.

31. "Plan of Development, Sacramento-San Joaquin Delta", Prepared by the Interagency Delta Committee as a Recommendation for a Plan of Action to the California Department of Water Resources, U. S. Bureau of Reclamation, U. S. Corps of Engineers, January 1965.

APPENDIX C

HISTORICAL MONTHLY STREAM FLOW AND MEASURED SEDIMENT LOAD SACRAMENTO RIVER AT SACRAMENTO 1957 THROUGH 1973 WATER YEARS

C-041930


MONTHLY RUNOFF 1 000 AF
MEASURED SEDIMENT 1 000 TONS
1 000
2 000
3 000
4 000
5 000
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
RUNOFF
SEDIMENT
MONTHLY RUNOFF AND MEASURED SEDIMENT
SACRAMENTO RIVER AT SACRAMENTO
1957 - 1973

C-041931

Historical Monthly Streamflow and Measured Sediment
Load Sacramento River at Sacarmento

Month	Flow in River 1,000 Af	Flow in River % of Annual	Measured Sediment 1,000 Tons	Measured Sediment % of Annual
		1956-57 Water Year		
October	761	5.8	37	2.2
November	868	6.6	41	2.4
December	769	5.8	18	1.1
January	740	5.6	40	2.4
February	992	7.5	276	16.3
March	3,064	23.3	697	41.2
April	1,189	9.0	100	5.9
May	1,904	14.4	294	17.4
June	999	7.6	77	4.6
July	574	4.4	27	1.6
August	599	4.5	29	1.7
September	727	5.5	54	3.2
Total	13,186	100.0	1,690	100.0

Month	Flow in River 1,000 Af	Flow in River % of Annual	Measured Sediment 1,000 Tons	Measured Sediment % of Annual
		1957-58 Water Year		
October	1,120	4.3	199	4.0
November	1,117	4.3	151	3.0
December	1,420	5.5	308	6.2
January	2,155	8.3	602	12.0
February	4,018	15.6	1,198	23.9
March	3,714	14.4	900	18.0
April	4,245	16.4	735	14.7
May	3,296	12.7	485	9.7
June	2,087	8.1	234	4.7
July	885	3.4	56	1.1
August	873	3.4	54	1.1
September	948	3.7	81	1.6
Total	25,878	100.0	5,003	100.0

Month	Flow in River 1,000 Af	Flow in River % of Annual	Measured Sediment 1,000 Tons	Measured Sediment % of Annual
1958-59 Water Year				
October	779	6.5	45	2.4
November	778	6.5	40	2.2
December	782	6.5	35	1.9
January	1,682	14.0	547	29.5
February	2,248	18.9	642	34.6
March	1,667	13.9	230	12.4
April	829	6.9	65	3.5
May	702	5.9	53	2.9
June	477	4.0	31	1.7
July	649	5.4	44	2.4
August	735	6.1	46	2.5
September	647	5.4	79	4.3
Total	11,975	100.0	1,857	100.0
1959-60 Water Year				
October	487	4.5	20	1.1
November	437	4.1	12	0.7
December	443	4.1	11	0.6
January	682	6.3	66	3.7
February	2,045	19.0	902	51.2
March	2,072	19.3	437	24.8
April	1,145	10.6	92	5.2
May	988	9.2	94	5.3
June	646	6.0	34	1.9
July	639	5.9	29	1.6
August	598	5.6	30	1.7
September	574	5.3	39	2.2
Total	10,756	100.0	1,766	100.0
1960-61 Water Year				
October	473	4.2	21	1.1
November	696	6.1	91	4.7
December	1,137	10.0	273	14.1
January	795	7.0	43	2.2
February	2,150	18.9	736	37.8
March	1,750	15.4	404	20.8
April	1,007	8.8	138	7.1
May	806	7.1	79	4.1
June	651	5.7	48	2.5
July	648	5.7	33	1.7
August	704	6.2	40	2.1
September	576	5.1	38	2.0
Total	11,393	100.0	1,943	100.0

Month	Flow in River 1,000 Af	Flow in River % of Annual	Measured Sediment 1,000 Tons	Measured Sediment % of Annual
		1961-62 Water Year		
October	436	3.4	18	0.9
November	491	3.8	25	1.2
December	965	7.4	381	19.0
January	648	5.0	97	4.8
February	2,388	18.4	668	33.3
March	2,323	17.9	451	22.5
April	1,680	12.9	126	6.3
May	1,214	9.4	86	4.3
June	774	6.0	41	2.0
July	630	4.9	26	1.3
August	710	5.5	33	1.6
September	721	5.6	54	2.7
Total	12,978	100.0	2,006	100.0
		1962-63 Water Year		
October	1,764	8.7	544	13.8
November	994	4.9	60	1.5
December	1,962	9.7	352	8.9
January	1,186	5.8	237	6.0
February	3,114	15.4	1,237	31.3
March	1,502	7.4	258	6.5
April	3,667	18.1	652	16.5
May	2,630	13.0	315	8.0
June	1,047	5.2	96	2.4
July	746	3.7	34	0.9
August	705	3.5	31	0.8
September	965	4.8	130	3.3
Total	20,281	100.0	3,946	100.0
		1963-64 Water Year		
October	871	7.5	60	5.6
November	1,347	11.6	216	20.2
December	1,290	11.1	77	7.2
January	1,520	13.1	345	32.2
February	1,201	10.3	88	8.2
March	884	7.6	44	4.1
April	744	6.4	38	3.6
May	857	7.4	56	5.2
June	661	5.7	33	3.1
July	714	6.1	25	2.3
August	748	6.4	29	2.7
September	788	6.8	59	5.5
Total	11,625	100.0	1,070	100.0

Month	Flow in River 1,000 Af	Flow in River % of Annual	Measured Sediment 1,000 Tons	Measured Sediment % of Annual
		1964-65 Water Year		
October	598	3.0	28	0.5
November	826	4.1	154	2.7
December	2,247	11.3	2,214	38.9
January	4,415	22.2	1,376	24.2
February	2,552	12.8	477	8.4
March	1,418	7.1	111	2.0
April	2,509	12.6	871	15.3
May	1,850	9.3	227	4.0
June	953	4.8	71	1.2
July	746	3.7	42	0.7
August	888	4.5	53	0.9
September	921	4.6	61	1.1
Total	19,924	100.0	5,685	100.0
		1965-66 Water Year		
October	857	6.4	44	2.1
November	1,200	9.0	233	11.3
December	1,390	10.4	142	6.9
January	2,123	15.9	760	36.8
February	1,500	11.2	338	16.4
March	1,456	10.9	154	7.5
April	1,292	9.7	149	7.2
May	873	6.5	77	3.7
June	570	4.3	32	1.6
July	712	5.3	42	2.0
August	756	5.7	41	2.0
September	651	4.9	51	2.5
Total	13,380	100.0	2,063	100.0
		1966-67 Water Year		
October	561	2.3	26	0.8
November	1,106	4.6	197	5.9
December	2,854	11.8	509	15.4
January	2,219	9.2	521	15.7
February	2,873	11.9	505	15.3
March	2,570	10.6	379	11.4
April	2,996	12.4	380	11.5
May	3,192	13.2	378	11.4
June	2,559	10.6	235	7.1
July	1,198	5.0	74	2.2
August	925	3.8	43	1.3
September	1,105	4.6	64	1.9
Total	24,159	100.0	3,311	100.0

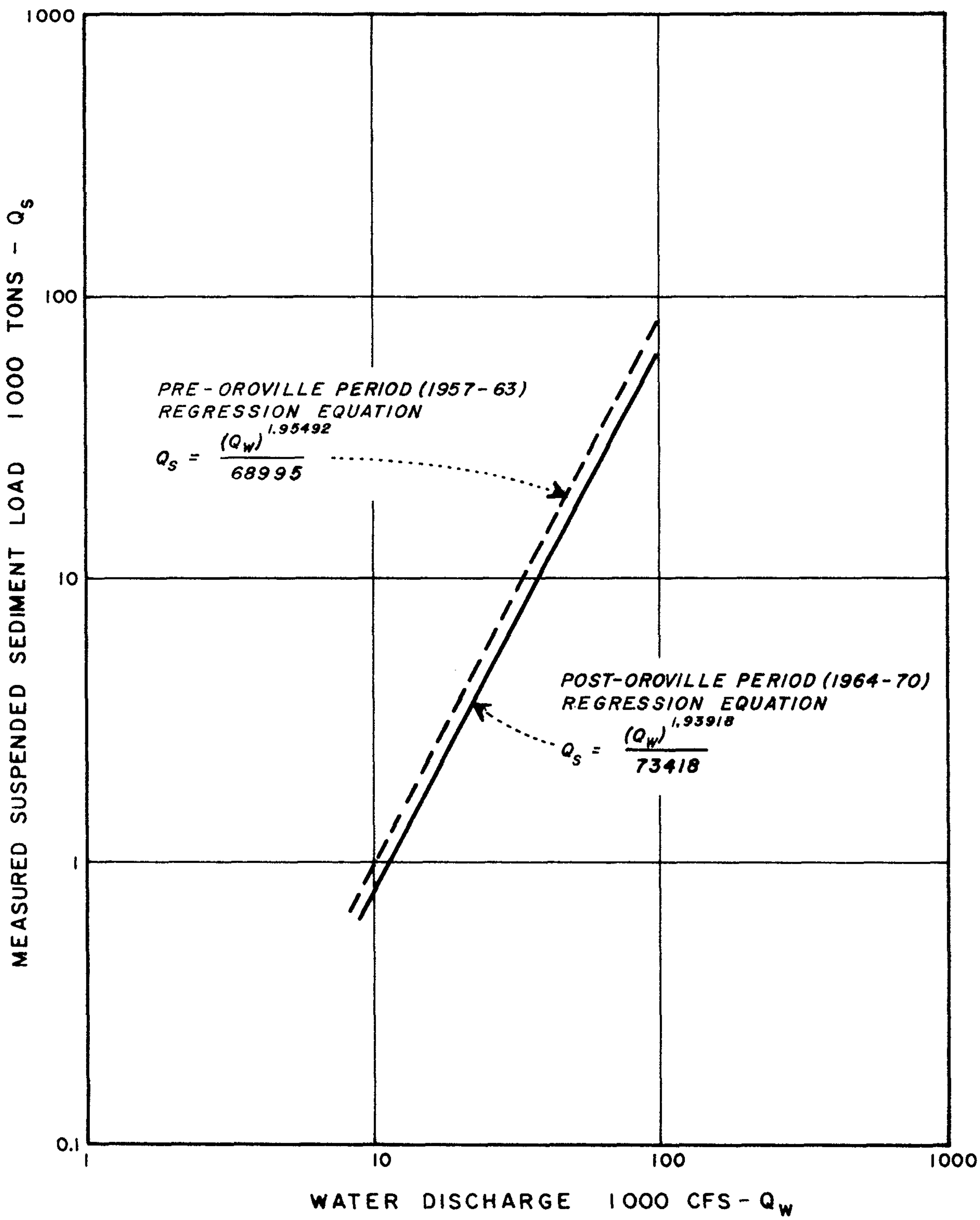
Month	Flow in River 1,000 Af	Flow in River % of Annual	Measured Sediment 1,000 Tons	Measured Sediment % of Annual
		1967-68 Water Year		
October	993	7.4	59	3.7
November	868	6.5	35	2.2
December	1,056	7.9	45	2.8
January	1,259	9.4	258	16.1
February	2,288	17.1	620	38.7
March	2,214	16.5	325	20.3
April	859	6.4	51	3.2
May	819	6.1	79	4.9
June	675	5.0	29	1.8
July	774	5.8	31	1.9
August	799	6.0	33	2.1
September	781	5.8	37	2.3
Total	13,384	100.0	1,602	100.0
		1968-69 Water Year		
October	715	3.1	25	0.7
November	809	3.5	27	0.8
December	1,410	6.1	297	8.6
January	3,406	14.7	955	27.7
February	3,986	17.2	747	21.6
March	3,057	13.2	410	11.9
April	2,698	11.6	326	9.4
May	2,496	10.8	282	8.2
June	1,376	5.9	135	3.9
July	874	3.8	55	1.6
August	1,128	4.9	98	2.8
September	1,250	5.4	95	2.8
Total	23,205	100.0	3,452	100.0
		1969-70 Water Year		
October	1,026	5.1	41	1.5
November	1,008	5.0	26	0.9
December	2,167	10.7	454	16.3
January	4,319	21.4	901	23.3
February	3,668	18.2	665	23.8
March	2,718	13.5	427	15.3
April	870	4.3	53	1.9
May	877	4.3	66	2.4
June	701	3.5	33	1.2
July	810	4.0	31	1.1
August	921	4.6	36	1.3
September	1,101	5.5	58	2.1
Total	20,185	100.0	2,791	100.0

Month	Flow in River 1,000 Af	Flow in River % of Annual	Measured Sediment 1,000 Tons	Measured Sediment % of Annual
		1970-71 Water Year		
October	938	4.1	38	1.2
November	1,340	5.9	211	6.6
December	3,932	17.2	645	20.1
January	3,216	14.1	815	25.4
February	1,732	7.6	282	8.8
March	1,874	8.2	444	13.8
April	2,277	10.0	298	9.3
May	1,794	7.8	177	5.3
June	1,639	7.2	96	3.0
July	1,290	5.6	61	1.9
August	1,381	6.0	78	2.4
September	1,451	6.3	69	2.1
Total	22,864	100.0	3,214	100.0
		1971-72 Water Year		
October	988	7.9	34	4.1
November	943	7.5	28	3.3
December	1,338	10.7	85	10.1
January	1,229	9.8	85	10.1
February	1,272	10.2	78	9.3
March	1,469	11.7	228	27.2
April	781	6.2	55	6.6
May	790	6.3	63	7.5
June	823	6.6	44	5.2
July	922	7.4	44	5.2
August	963	7.7	45	5.4
September	1,000	8.0	50	6.0
Total	12,518	100.0	839	100.0
		1972-73 Water Year		
October	988	4.8	38	1.5
November	1,380	6.7	222	8.5
December	1,686	8.2	287	11.0
January	3,697	17.9	710	27.3
February	3,623	17.5	511	19.6
March	3,190	15.4	468	18.0
April	1,230	6.0	103	4.0
May	1,009	4.9	63	2.4
June	889	4.3	40	1.5
July	932	4.5	44	1.7
August	991	4.8	61	2.3
September	1,040	5.0	54	2.1
Total	20,656	100.0	2,601	100.0

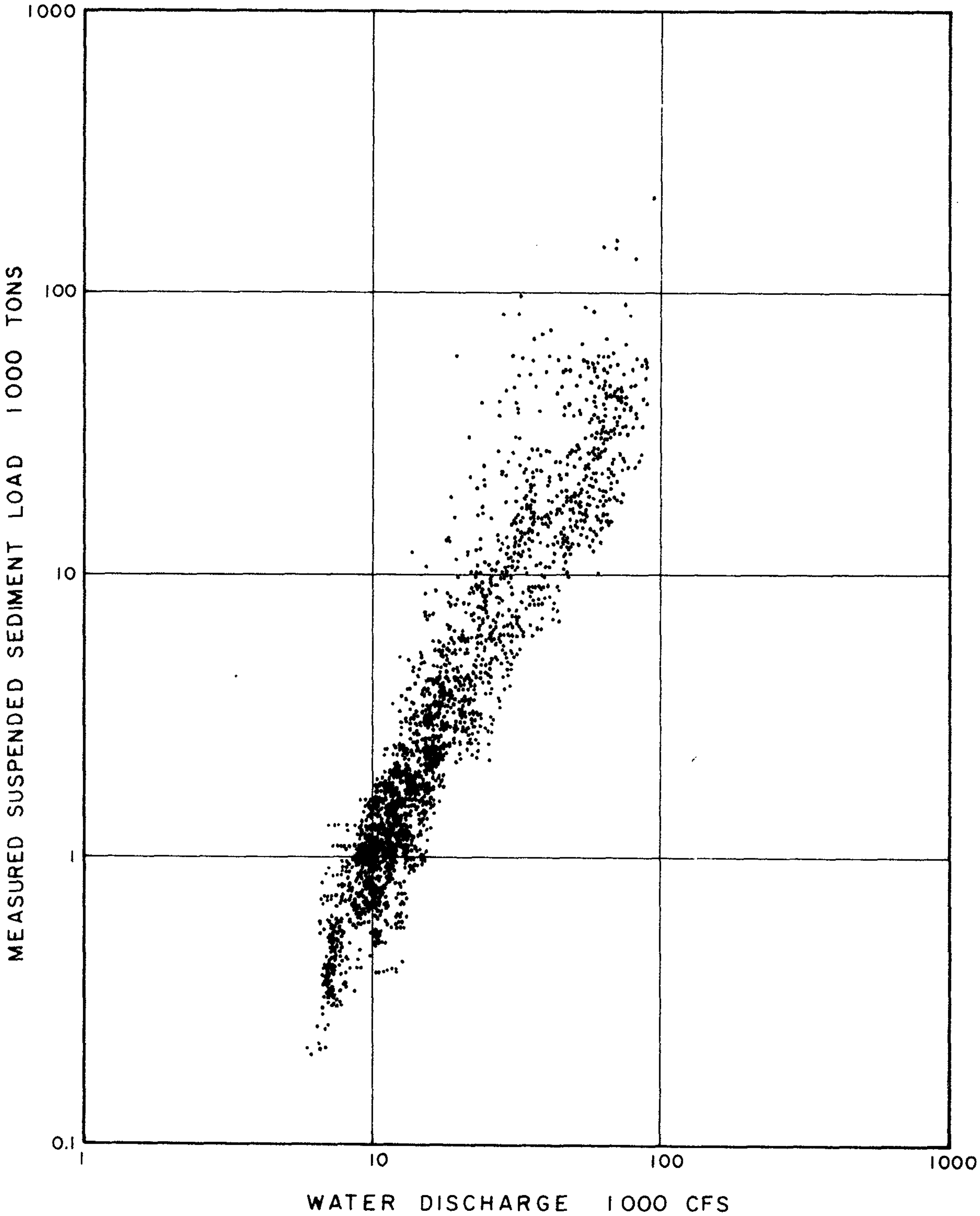
APPENDIX D

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1957 THROUGH 1970 WATER YEARS

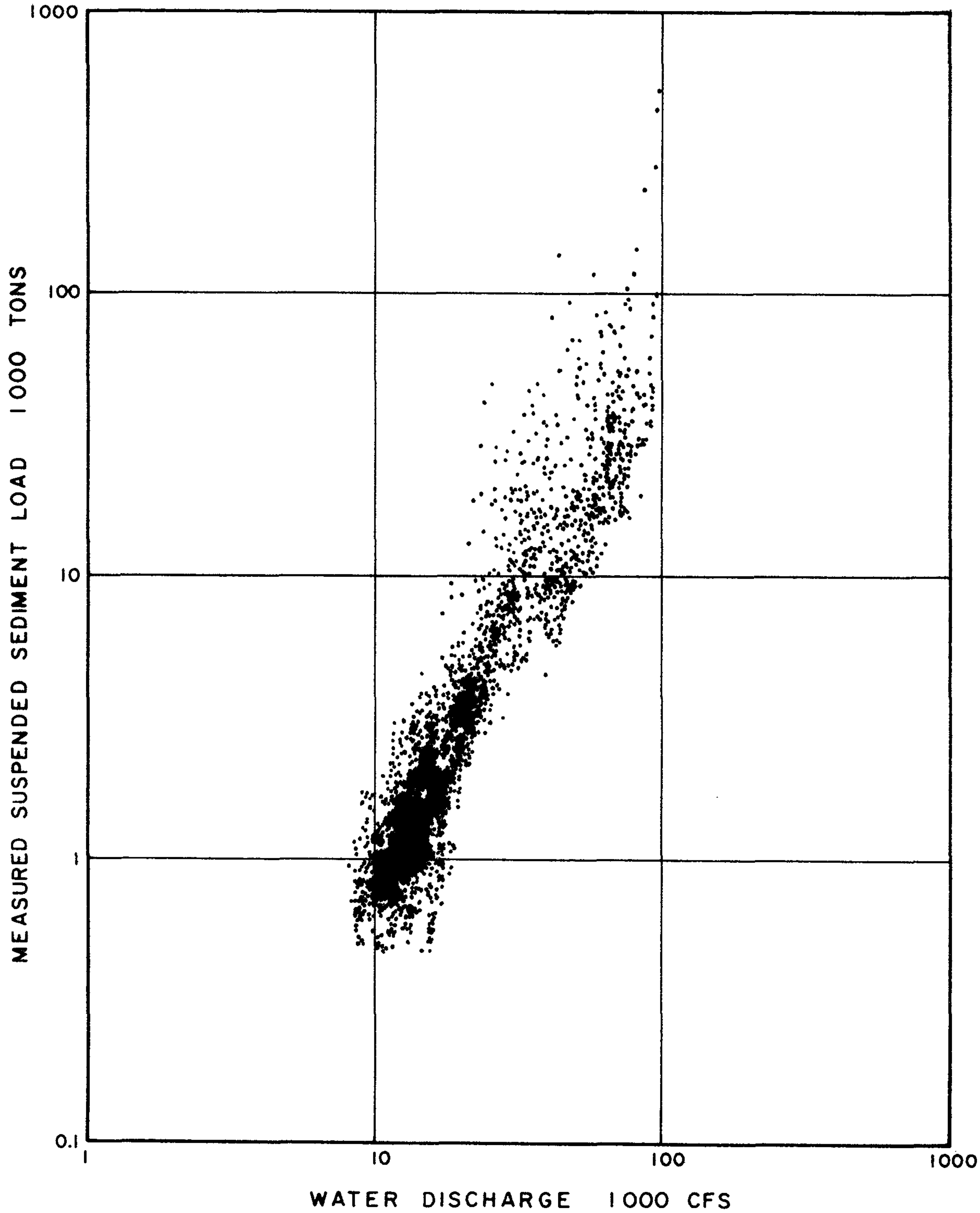
MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1957 - 70 WATER YEARS



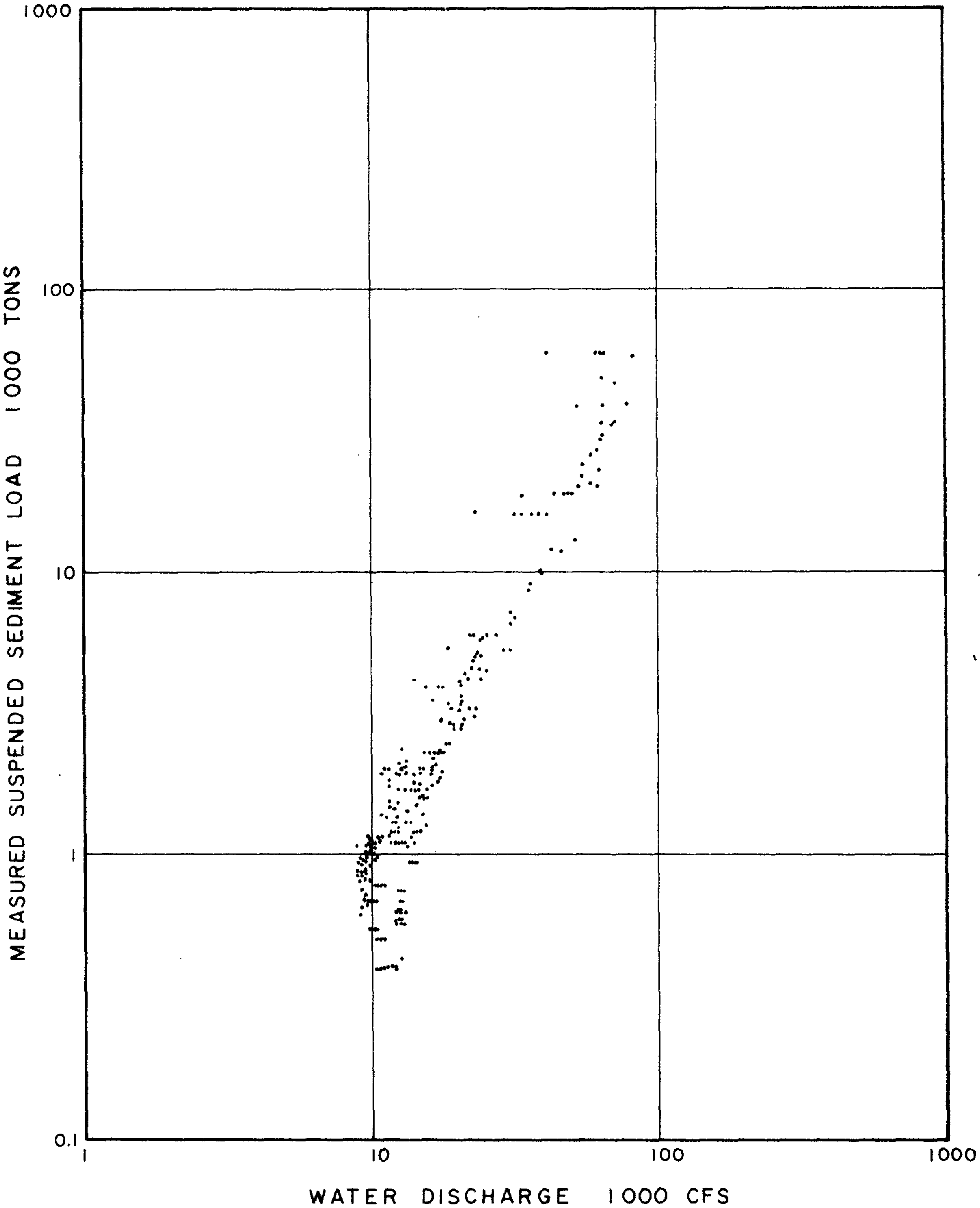
MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
PRE-OROVILLE DISTRIBUTION
1957-1963 WATER YEARS



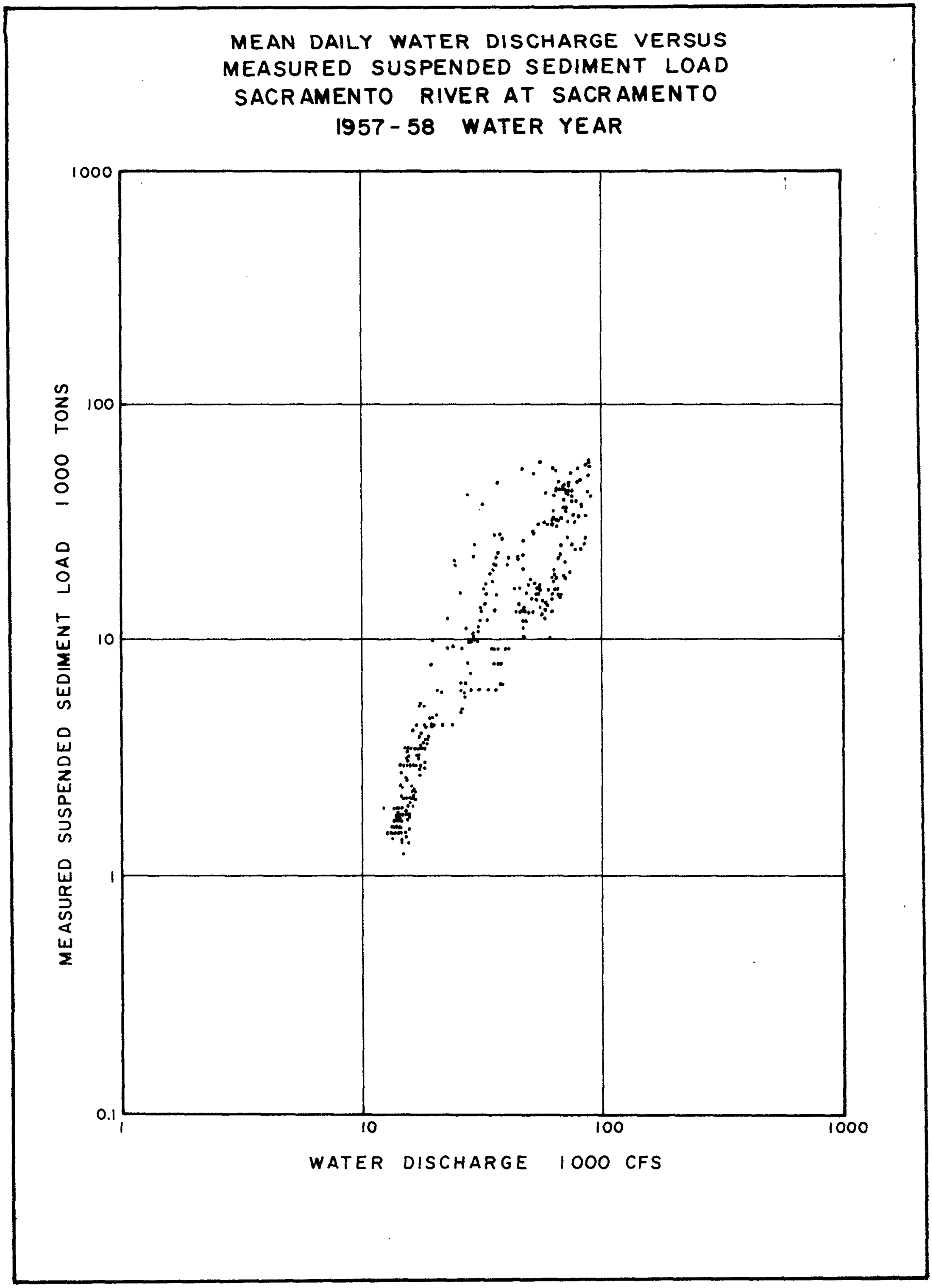
MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
POST-OROVILLE DISTRIBUTION
1964-1970 WATER YEARS



MEAN DAILY WATER DISCHARGE VERSUS MEASURED SUSPENDED SEDIMENT LOAD SACRAMENTO RIVER AT SACRAMENTO 1956-57 WATER YEAR

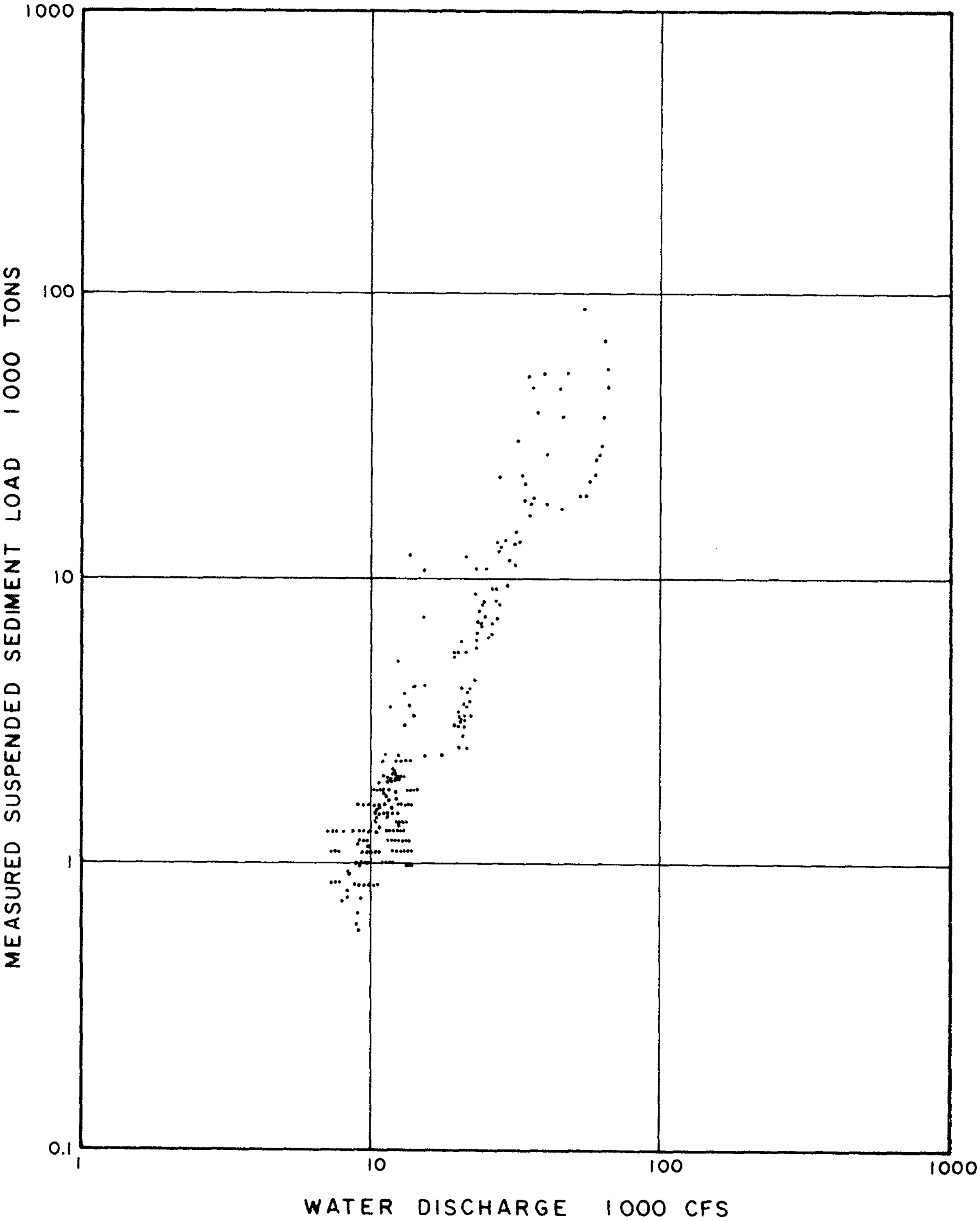


C-041942

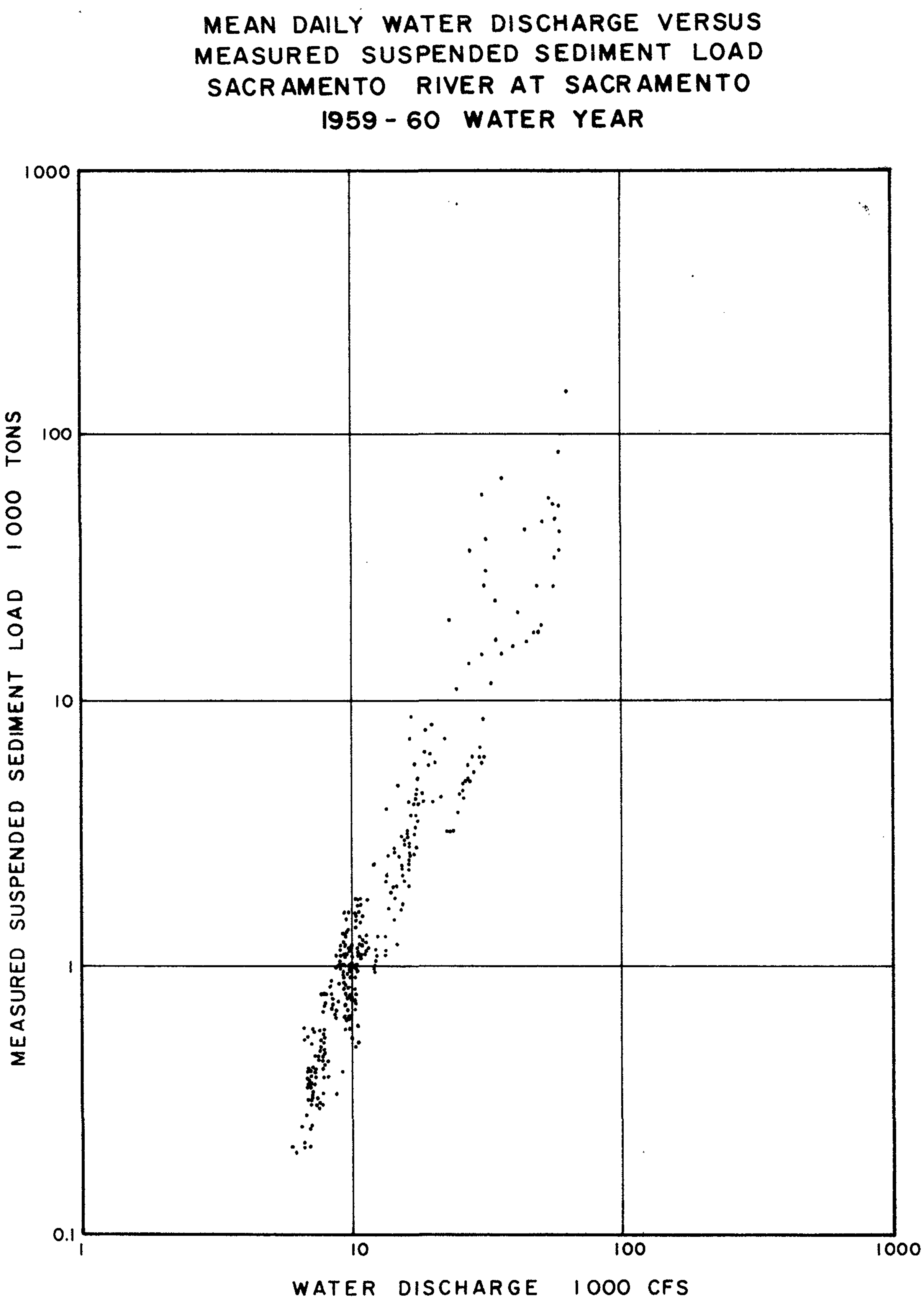

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1957-58 WATER YEAR
1000
100
10
1
0.1
MEASURED SUSPENDED SEDIMENT LOAD 1000 TONS
1
10
100
1000
WATER DISCHARGE 1000 CFS

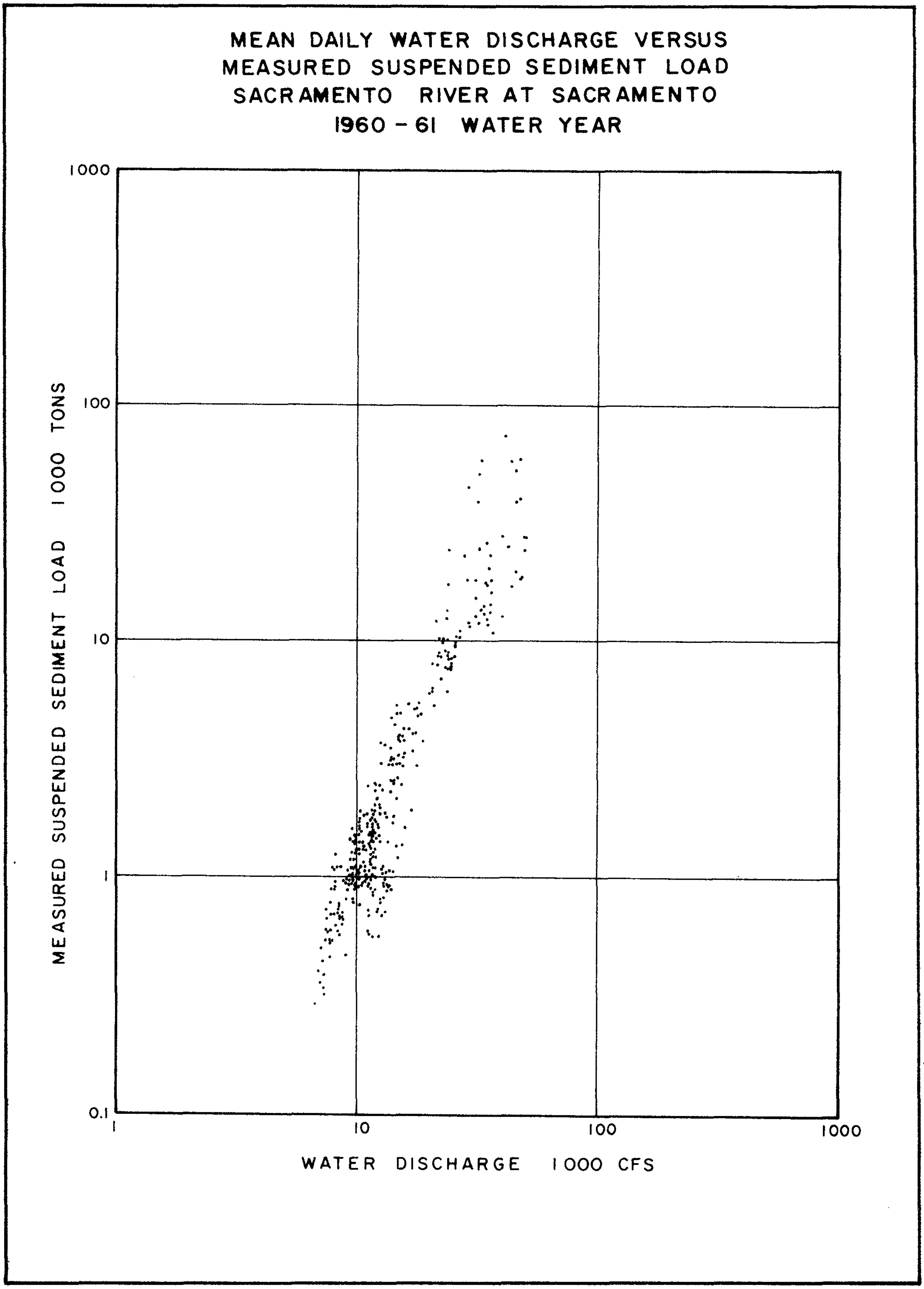
C-041943

MEAN DAILY WATER DISCHARGE VERSUS MEASURED SUSPENDED SEDIMENT LOAD SACRAMENTO RIVER AT SACRAMENTO 1958 - 59 WATER YEAR

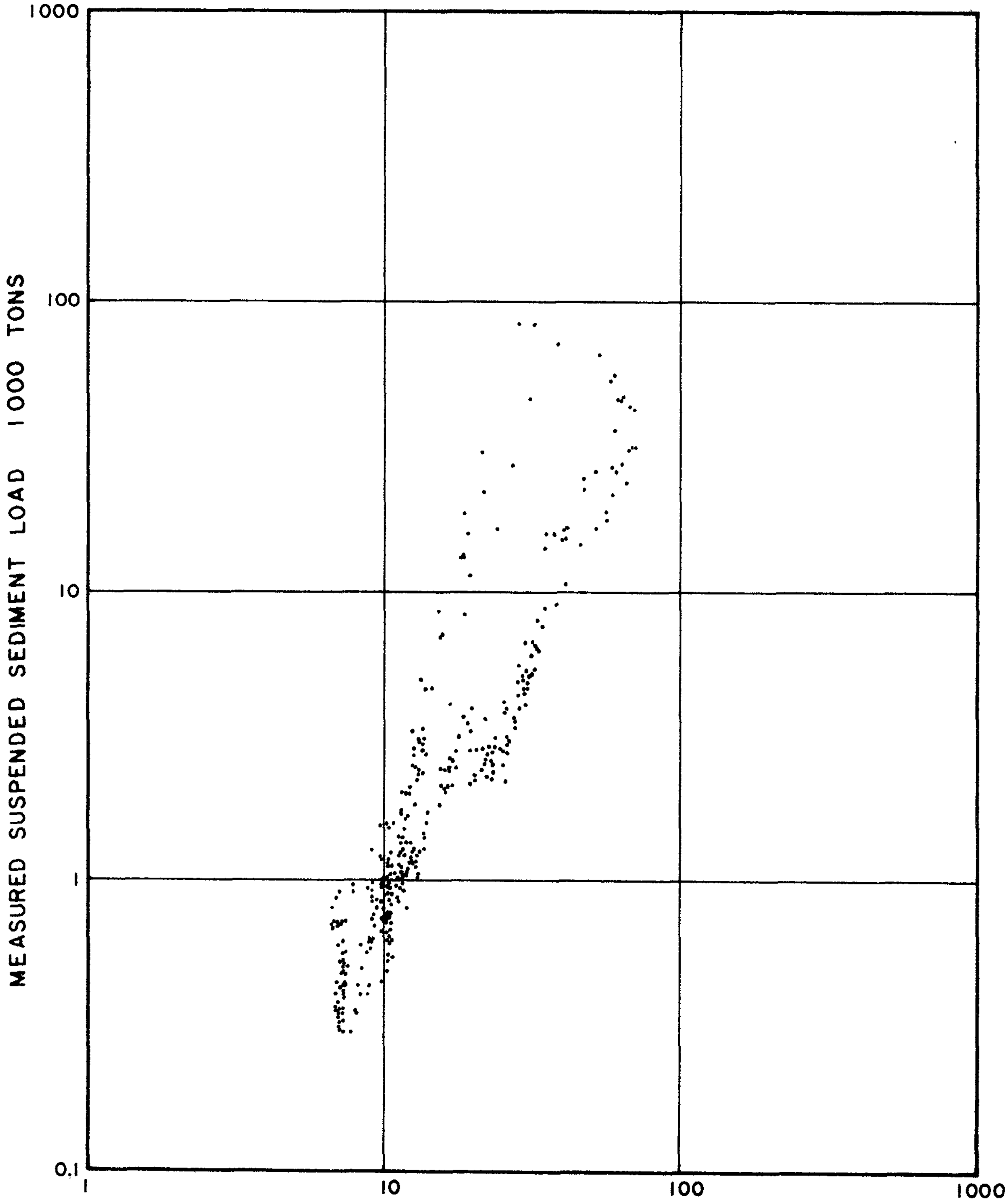


C-041944


MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1959 - 60 WATER YEAR
1000
100
10
1
0.1
MEASURED SUSPENDED SEDIMENT LOAD 1000 TONS
1
10
100
1000
WATER DISCHARGE 1000 CFS

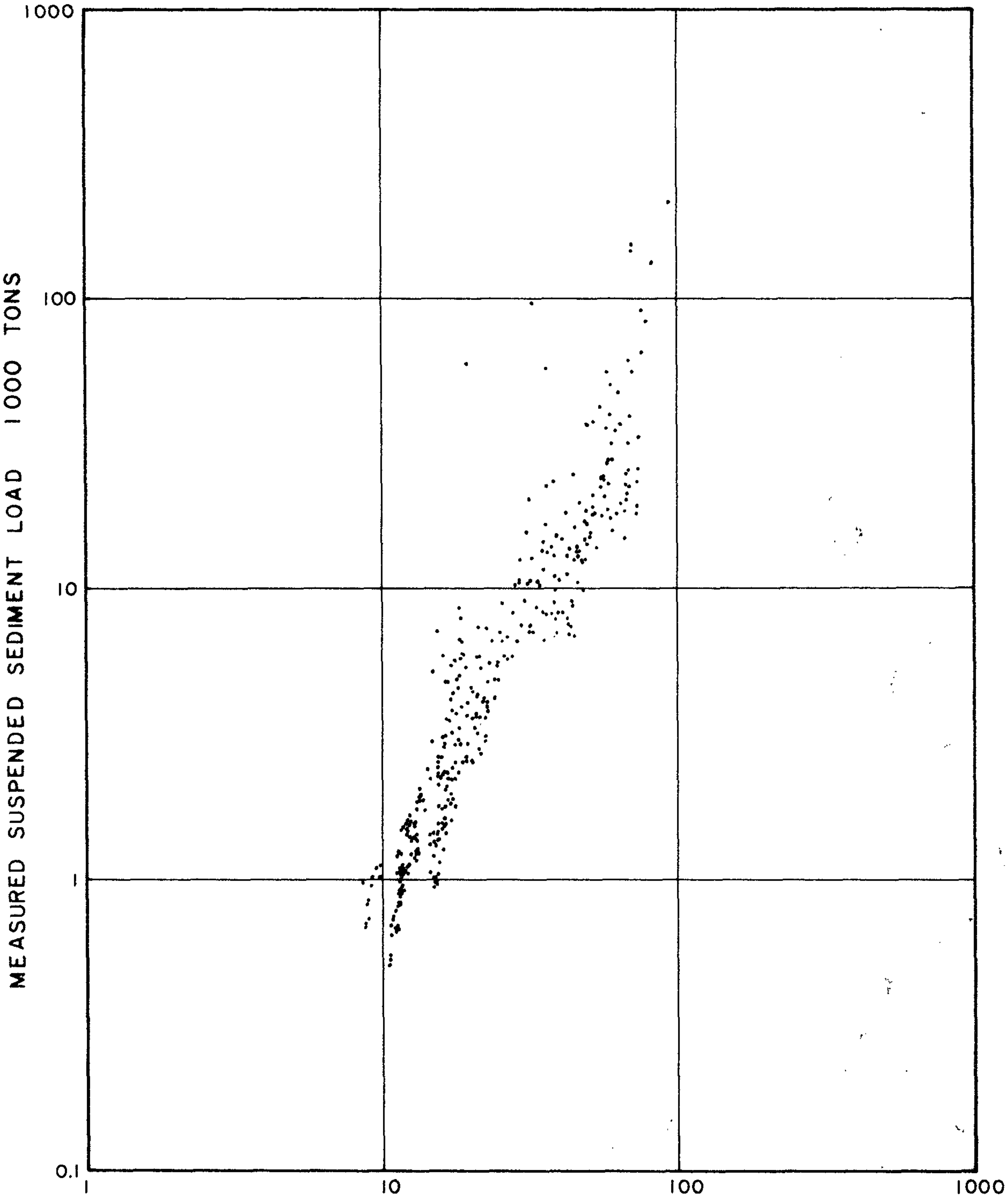

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1960 - 61 WATER YEAR
1000
100
10
1
0.1
MEASURED SUSPENDED SEDIMENT LOAD 1000 TONS
1
10
100
1000
WATER DISCHARGE 1000 CFS

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1961 - 62 WATER YEAR

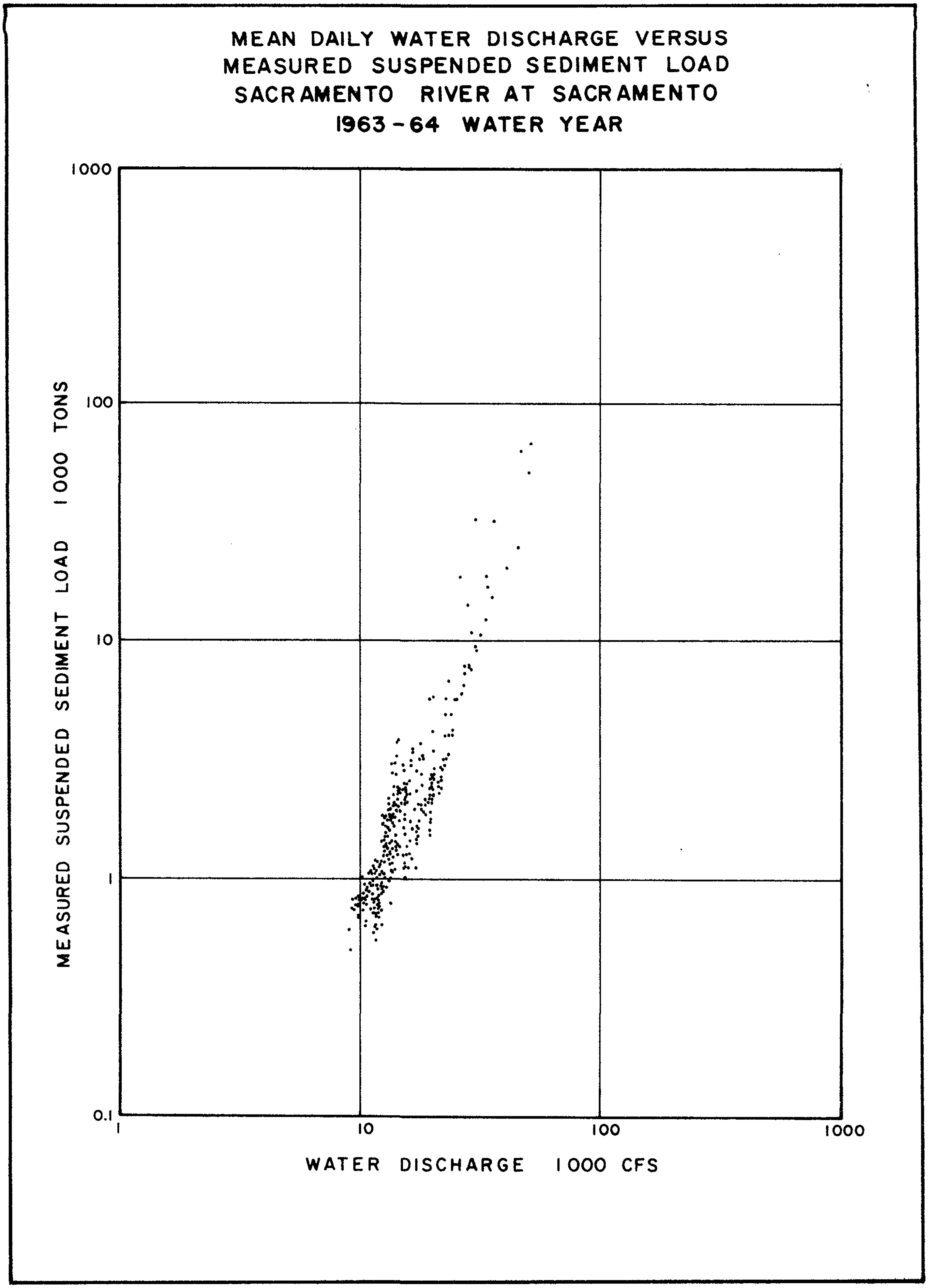


C-041947

MEAN DAILY WATER DISCHARGE VERSUS MEASURED SUSPENDED SEDIMENT LOAD SACRAMENTO RIVER AT SACRAMENTO 1962-63 WATER YEAR



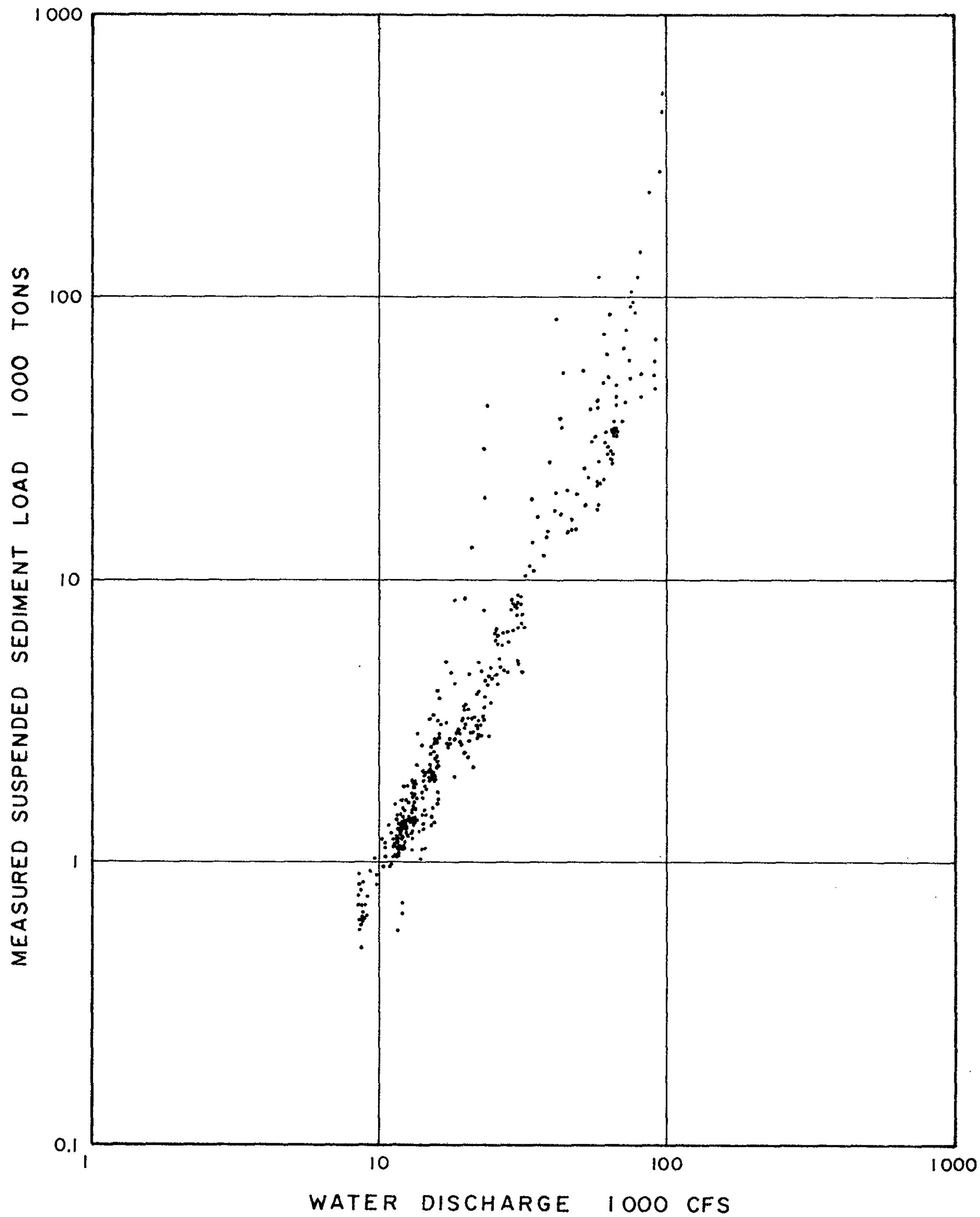
C-041948



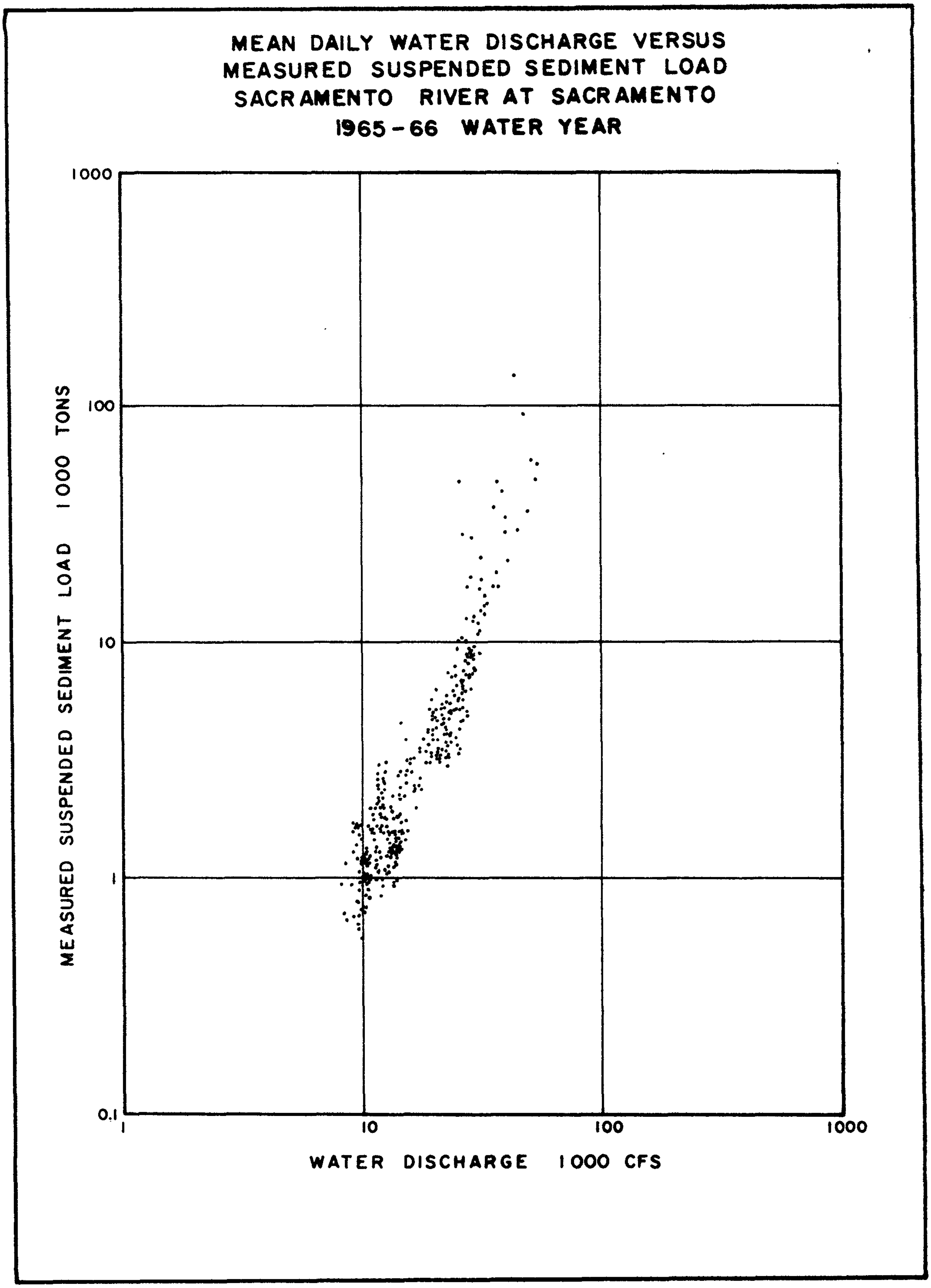
C-041949

C-041949

MEAN DAILY WATER DISCHARGE VERSUS MEASURED SUSPENDED SEDIMENT LOAD SACRAMENTO RIVER AT SACRAMENTO 1964-65 WATER YEAR

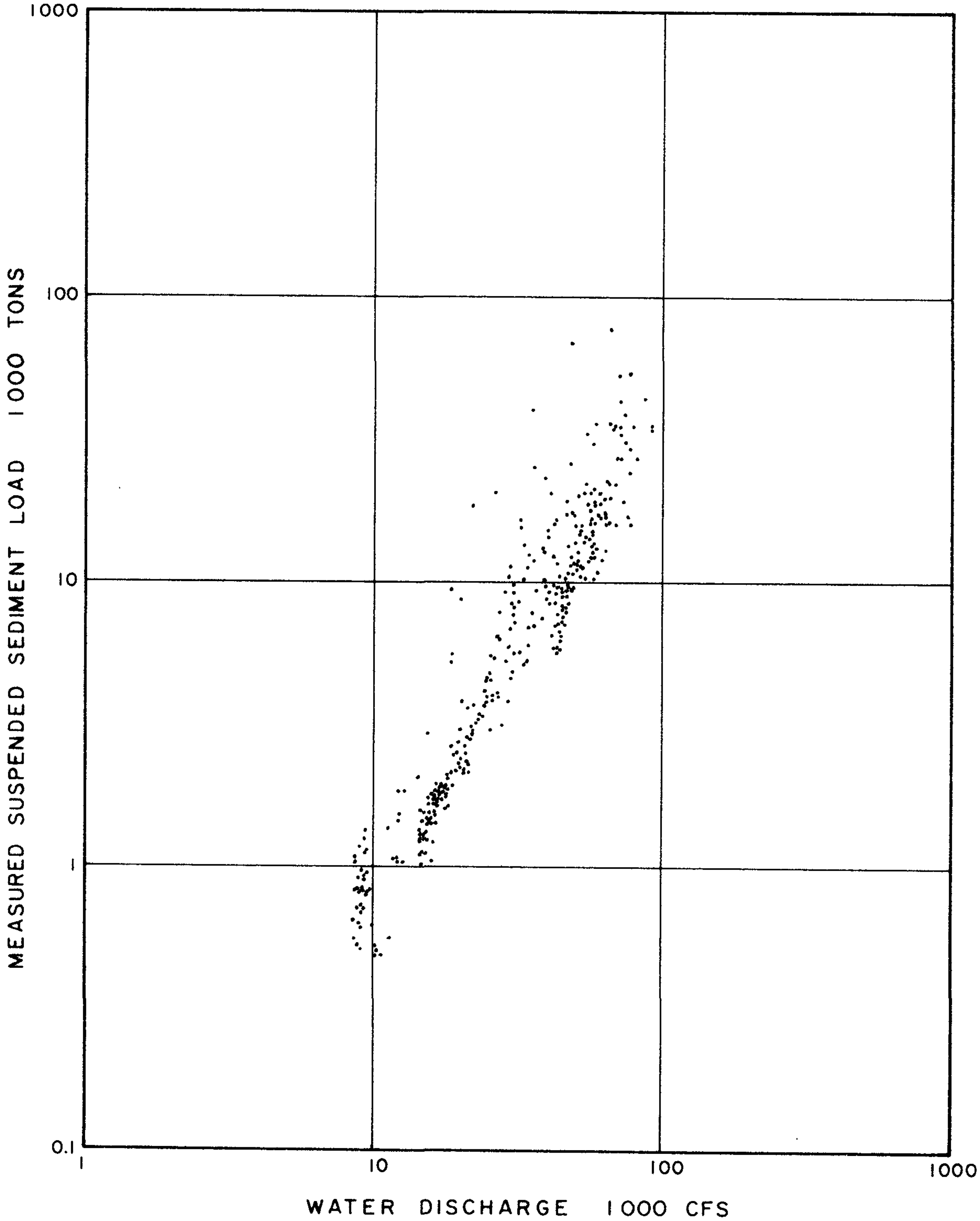


C-041950

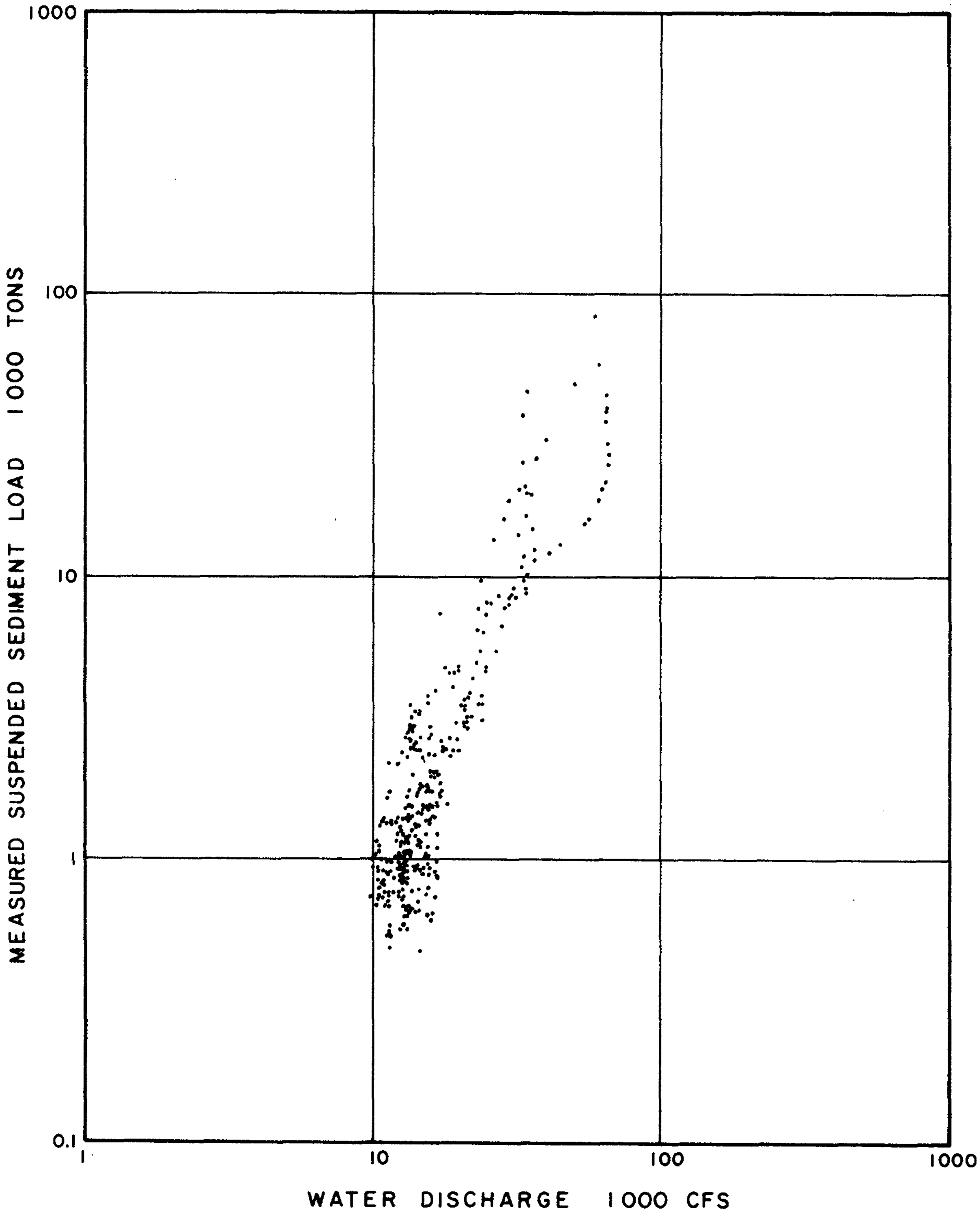

MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1965-66 WATER YEAR
1000
100
10
1
0.1
MEASURED SUSPENDED SEDIMENT LOAD 1000 TONS
1
10
100
1000
WATER DISCHARGE 1000 CFS

C-041951

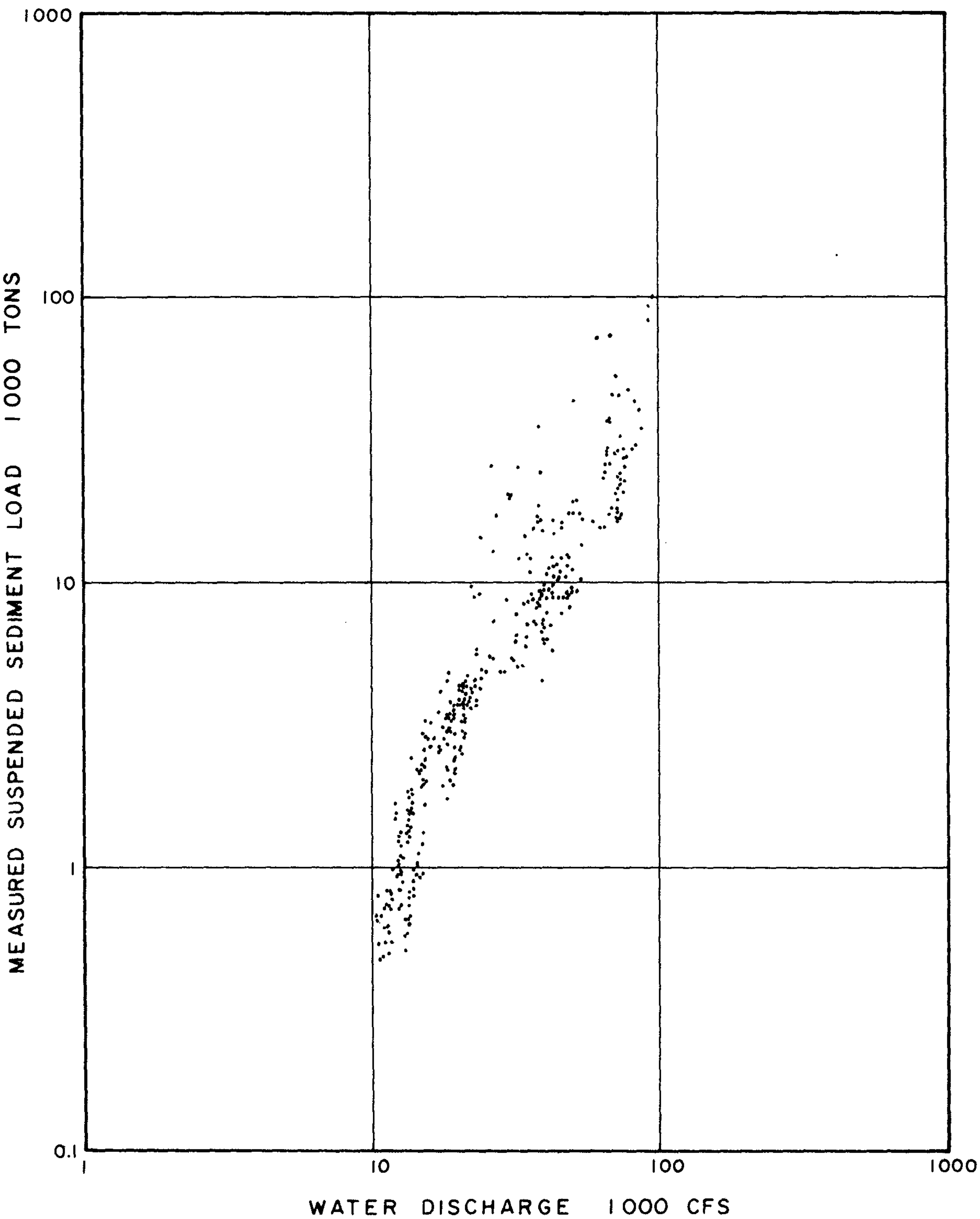
MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1966-67 WATER YEAR



MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1967-68 WATER YEAR



MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1968-69 WATER YEAR



MEAN DAILY WATER DISCHARGE VERSUS
MEASURED SUSPENDED SEDIMENT LOAD
SACRAMENTO RIVER AT SACRAMENTO
1969-70 WATER YEAR