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TURBIDITY AND SUSPENDED-SEDIMENT TRANSPORT IN THE RUSSIAN RIVER BASIN, CALIFORNIA

By

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CONTENTS

ILLUSTRATIONS

TABLES

TURBIDITY AND SUSPENDED-SEDIMENT TRANSPORT IN THE

RUSSIAN RIVER BASIN, CALIFORNIA

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ABSTRACT

The Russian River in north coastal California has a persistent turbidness, which has reportedly caused a decline in the success of the sports fishermen. As a consequence, the number of sports fishermen angling in the river has declined, and industries dependent on their business have suffered. To determine the source of the turbidity and the rate of sediment transport in the basin, a network of sampling stations was established in February 1964 along the river, on some of its tributaries, and near Lake Pillsbury in the upper Eel River basin.

The chief cause of turbid water throughout the Russian River basin was rain which created runoff and erosion. For example, large quantities of sediment made available for fluvial transport by the December 1964 flood were at least partly responsible for the persistence of the turbidity in the basin.

The most persistently turbid water in the Russian River basin was the water diverted from the Eel River into the East Fork Russian River. As long as that water was flowing into Lake Mendocino, the water in the lake remained turbid, and consequently the releases from the lake were turbid. During periods of little or no rain when the lake water was turbid, the river downstream from the lake would be turbid when the releases were high and clearer when the releases were low. Turbidity currents flowing through the lake also influenced the turbidity of the releases. Sand and gravel mining, road construction, flushing of irrigation ditches, and algal blooms also produced turbid water in the Russian River basin.

Turbidity and concentration of suspended sediment, expressed in milligrams per liter, were highly correlative ($r > 0.90$) at almost every sampling station. The correlation differed for each station and varied slightly each year. At stations where flow was regulated, the turbidity was usually higher than the corresponding concentration. At stations where flow was unregulated, concentration was usually higher than turbidity. The difference in correlation between the stations where flow was regulated and those where flow was unregulated seemed to be related to the quantity of sand in the suspended load. Usually little or no sand was transported at stations where flow was regulated, whereas sand constituted a significant part of the suspended sediment transported at stations where flow was unregulated. From these correlations it is concluded that a concentration of particles finer than sand produces a higher turbidity than does an equal concentration of sand. Most of the persistence of turbidity seemed to be produced by particles finer than sand carried in suspension.

The average annual suspended-sediment yield for the basin upstream from Guerneville for the water years 1965-68 was 4,370 tons per square mile. The area of lowest annual yield (1,350 tons per sq mi) and lowest runoff was in the East Fork Russian River basin, where the water was the most persistently turbid because of the diverted Eel River water. The area having the highest annual yield (5,770 tons per sq mi) was the Dry Creek basin, where the water was the least persistently turbid. Dry Creek transported most of its annual suspended load in less than 4 days. In fact, at most stations in the Russian River basin, over half the annual suspended load was transported in 6 days or less.

INTRODUCTION

Turbid water in recent years has been blamed for a decline of successful sport fishing along the Russian River in northwestern California, especially from December through March when the major steelhead migration occurs. The tourist-oriented resort area near Guerneville (fig. 1) has reportedly suffered a consequential decline in trade during winter months. A particular target of many accusations about the cause of the turbid water has been Coyote Dam, which impounds Lake Mendocino on the East Fork (fig. 1). Coyote Dam is a multipurpose flood-control and water-supply project built by the U.S. Army Corps of Engineers in cooperation with Sonoma and Mendocino Counties.

Turbidity commonly is a problem when it becomes excessive. Fishing conditions usually are considered poor during periods of highly turbid water; however, in some streams they are considered best when the water is slightly turbid--probably about 20 mg/l (milligrams per liter). Besides its effects on fishing and the esthetics of a stream, turbidity may affect life in the stream. Turbidity excludes sunlight and thus restricts the growth of both planktonic and benthic algae, which are important to the food chain in the stream. An extremely low turbidity is required for drinking water and for some industrial uses in which turbid water may adversely affect machinery and processes.

"Clear" or "muddy" water is difficult to define in describing turbid conditions of a stream. Geological Survey observers were instructed to note their visual impressions of the clarity of the water. Table 1 shows that the observers reported turbidity in three categories. The visual observations probably were influenced by the depth of flow, prior turbidity, turbulence, type and size of sediment transported, quantity of phytoplankton, and cloud cover. Generally, the turbidity of clear water is less than 20 mg/l. This report is concerned mainly with turbid water or water having a measured turbidity of more than 20 mg/l.

TABLE 1.--*Classification of turbidity in the Russian River basin on the basis of visual observations and measurements*

Station	Turbidity, in milligrams per liter		
	Clear	Murky or cloudy	Muddy
Potter Valley powerhouse tailrace	0-15	12-65	>25
Russian River near Cloverdale	0-30	10-60	>45
Dry Creek near Geyserville	0-20	10-85	>15

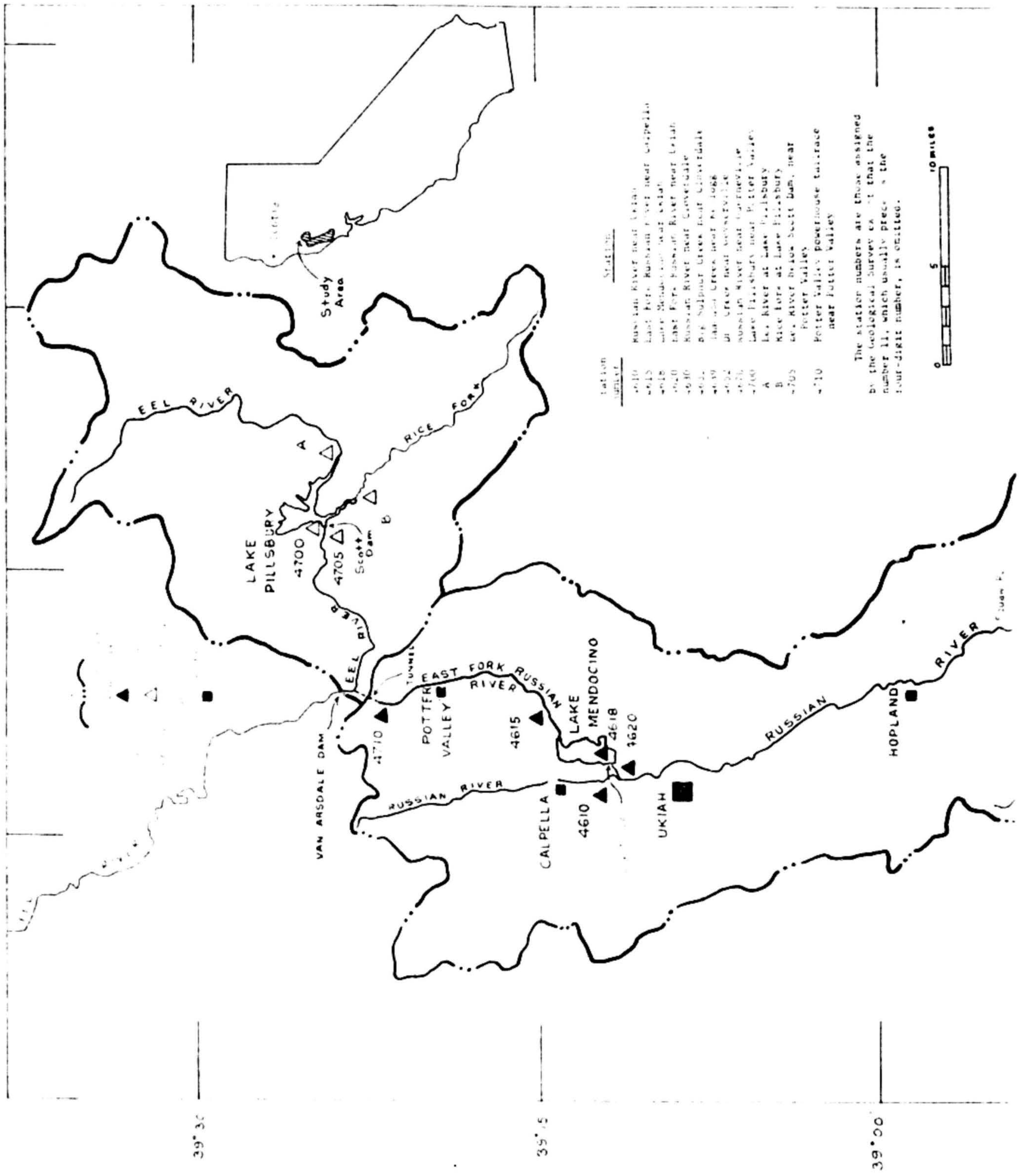
39°30'
39°15'
39°00'
LAKE PILLSBURY
4700
4705
Scott Dam
A
B
EEL RIVER
RICE FORK
VAN ARSDALE DAM
TUNNEL
4710
POTTER VALLEY
EAST FORK RUSSIAN RIVER
RUSSIAN RIVER
4615
CALPELLA
LAKE MENDOCINO
4610
4618
4620
UKIAH
RUSSIAN RIVER
HOPLAND
Study Area
Station
A Eel River at Lake Pillsbury
B Rice Fork at Lake Pillsbury
Potter Valley powerhouse tailrace near Potter Valley
0 5 10 MILES

FIGURE 1.--Map of study area.

Purpose and Scope

This study was proposed after many meetings, called by the Corps of Engineers, and attended by several Federal, State, and county agencies. The purpose of those meetings and subsequent ones was to discuss the turbidity problem and its causes in the Russian River basin.

At the meetings the following possible causes for turbid water in the basin were suggested:

1. The turbid water was caused by erosion during rainstorms in the Russian River basin.
2. The water diverted from the Eel River into the East Fork Russian River was persistently turbid and, therefore, caused turbidity downstream in the Russian River.
3. The water in Lake Mendocino remained turbid for long periods of time because of slow settling of suspended material, and consequently the releases from the lake remained turbid when the rest of the water in the basin was clear.
4. Increased discharge resulting from releases from Lake Mendocino, eroded sediment from the bed and banks of the stream and became turbid as it moved downstream.
5. Mining of sand and gravel along the Russian River and its tributaries created turbidity.
6. Road construction, logging, and other activities of man in the basin caused erosion.
7. Algal blooms created a turbid condition in the water.

The purpose of this report is to describe conditions of turbidity on the Russian River from 1964 to 1968, to explain the causes and origins of turbid water in the Russian River basin, and to determine the quantity and character of suspended sediment transported by the river. Emphasis in this report is placed on the relation between suspended-sediment concentration and turbidity, on the effects of upstream impoundments on the turbidity of downstream water, on the suspended-sediment loads in the basin, and on the persistence of turbid water at several sites. The effects of the turbidity of the water diverted from the Eel River into the East Fork Russian River was of particular interest to the study, and was examined in detail.

The study was conducted from February 1964 to September 1968 by the U.S. Geological Survey in cooperation with the Corps of Engineers.

The study was made under the general supervision of R. Stanley Lord, district chief in charge of U.S. Geological Survey water-resources investigations in California, W. W. Dean, chief of the Sacramento subdistrict office, and L. E. Young, chief of the Menlo Park subdistrict office. George Porterfield began the project and was the report advisor. The manuscript benefited from the criticism of D. M. Culbertson, W. L. Haushild, and K. M. Scott.

Previous Investigations

Measurements of turbidity and concentration of suspended sediment made in 1908 at the Russian River 2 miles north of Ukiah were summarized by Van Winkle and Eaton (1910) in a water-supply paper on the quality of surface waters in California. Reports on the water resources of the Russian River basin published by the Geological Survey include two water-supply papers by Cardwell (1958, 1965) on the ground-water resources of parts of the basin, a water-supply paper by Rantz and Thompson (1967) on the surface-water hydrology, and a hydrologic atlas by Rantz (1968) on the precipitation and runoff in the basin. The California Department of Water Resources (1964, 1965) published reports on the land and water use in the Russian River hydrographic unit and on the water resources and future water requirements of north coastal California. The department, in 1966, published a report on turbidity in north coastal California, including the Russian River, and in 1968 published a report on the water quality of the Russian River basin.

Definition of Terms

Many terms relating to fluvial sediment are not completely standardized, but the generally accepted terminology used in this report is based on the following definitions:

Algae are primitive plants in which the body shows little or no differentiation of vegetative organs.

Bedload or sediment discharged as bedload includes both the sediment that moves along in continuous contact with the streambed and the material that bounces along the bed in short skips or leaps.

Concentration of suspended sediment is the ratio of the dry weight of the suspended sediment to the volume of the mixture of water and suspended sediment and is expressed as milligrams per liter.

Diatoms are unicellular algae characterized by a siliceous cell wall.

Erosion is the process or processes which initiate movement of earth material.

Fluvial sediment is sediment that is transported by, suspended in, or deposited by streams.

Observers are local residents who assist the Geological Survey in collecting water samples.

Phytoplankton comprises all floating plants.

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

Sediment is material, both mineral and organic, that is transported by, suspended in, or deposited by water, air, ice, gravity, organisms, or combinations thereof.

Sediment discharge is the dry weight of sediment that passes a cross section of a stream in a unit time and is generally expressed as tons per day.

Sediment sample is a quantity of water-sediment mixture that is collected to determine the concentration or the particle-size distribution of suspended sediment.

Suspended sediment is sediment that is moved in suspension in water and is maintained in suspension by the upward components of turbulent currents or by colloidal suspension.

Sediment-transport curve is a graph in which suspended-sediment discharge is related to water discharge (see fig. 8).

Turbidity, according to Rainwater and Thatcher (1960, p. 289), is the optical property of a suspension with reference to the extent to which the penetration of light is inhibited by the presence of insoluble material and, in this report, is expressed in milligrams of silica per liter. A less precise but perhaps more understandable definition is the one agreed upon by those Federal, State, and county agencies concerned with the turbid water in the Russian River basin; they defined turbidity as an unclear condition of water. In this report, 20 mg/l is used as the separation between clear and unclear water (p. 3).

Water discharge or discharge is the quantity of water passing through a cross section of a stream in unit time and is generally expressed as cubic feet per second.

Water year is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends.

PHYSICAL SETTING

Physiography and Drainage

The Russian River was named after a Russian colony at Fort Ross from 1812 to 1841, although the Russians themselves called the river Slavianka (Slav woman). The Spanish called it San Ignacio and Rio Ruso, but the most colorful names for the river were given by the Indians, who named it Shabaikai or Misallaaka, meaning long snake. The present name has been used since American occupation (Gudde, 1965).

The Russian River basin has an area of 1,485 square miles and is 12 to 32 miles wide and about 80 miles long. The river flows southward for 90 miles from its headwaters north of Ukiah (fig. 1), it turns southwestward near Healdsburg and continues southwestward 20 miles to the Pacific Ocean at Jenner, which is about 60 miles north of San Francisco. Most of its southward course is through alluvial valleys that are separated by mountain gorges (fig. 2), whereas most of its southwestward course is through a canyon in the Coast Ranges (fig. 3).

Altitudes in the basin range from sea level to about 4,500 feet near Cobb Mountain. Stream gradients range from about 2 feet per mile in the lower part of the Russian River to several hundred feet per mile in the upper part. The slopes of the Russian River and some of its principal tributaries are shown in figure 4.

FIGURE 2.--Russian River at Squaw Rock. Coarse bed material is typical in the reach of the river near Squaw Rock.

FIGURE 3.--Russian River at Guerneville. Recreation is a major industry in this area.

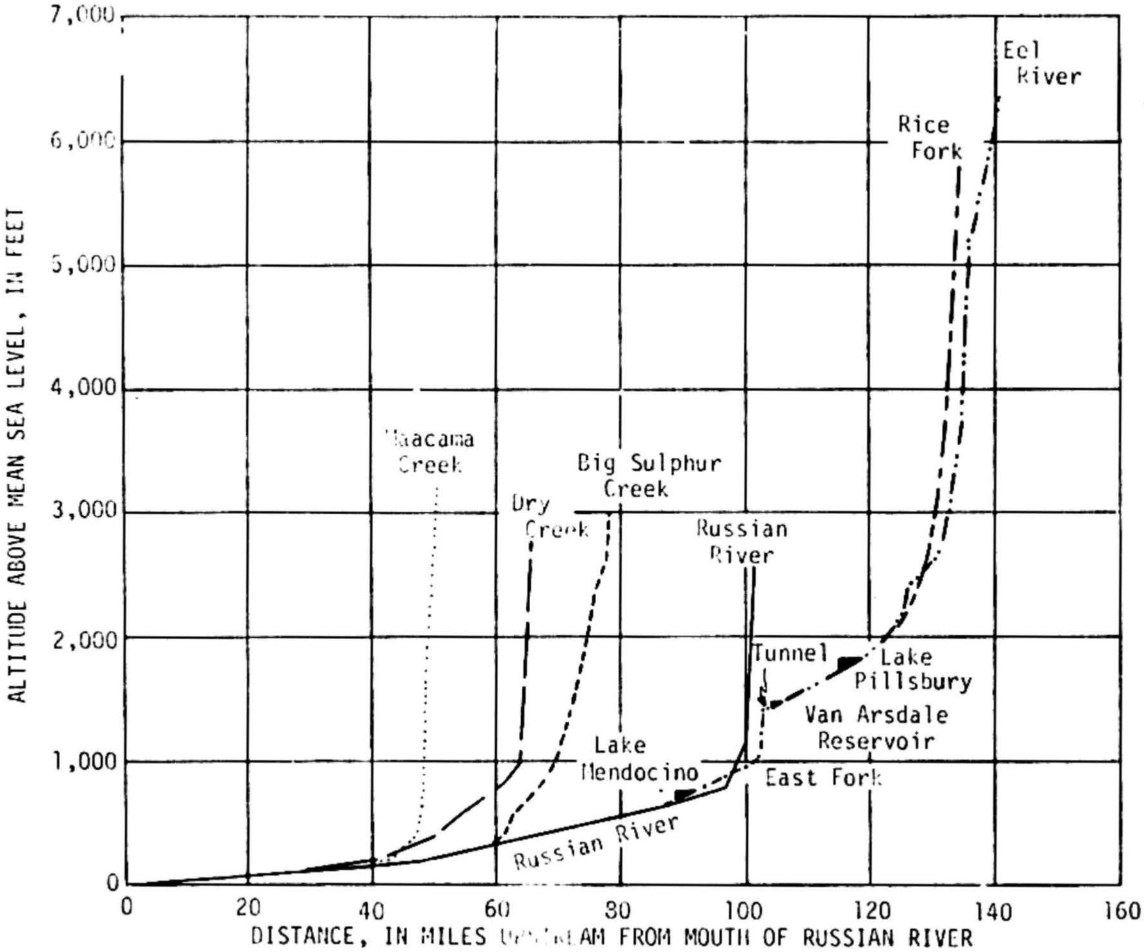

FIGURE 4.--Slopes of streams referred to in this report.

Dams and Diversions

Three main developments divert or store water in the basin. The oldest development diverts water from the Eel River into Potter Valley. In 1908 the Snow Mountain Water and Power Company began diverting water from the Eel River through a tunnel near Van Arsdale Dam to a powerhouse at Potter Valley. From the powerhouse the water was discharged through a tailrace into the East Fork Russian River. In 1922 Scott Dam, which impounds water in Lake Pillsbury, was completed on the Eel River upstream from Van Arsdale Dam. Scott Dam is 105 feet high, and the storage capacity of the lake is 86,780 acre-feet (Porterfield and Dunnam, 1964, p. EE45). The storage of water behind Scott Dam stabilized and increased the diversion into the East Fork Russian River. In 1930 the Pacific Gas and Electric Company acquired Snow Mountain Water and Power Company and its Potter Valley system. The average discharge through the powerhouse from 1910 to 1968 was 199 cfs (cubic feet per second) and the maximum daily discharge was 348 cfs.

Also on the East Fork near Ukiah is Coyote Dam, completed in 1958 by the U.S. Army Engineer District, San Francisco, Corps of Engineers. Coyote Dam rises about 160 feet above the streambed. The invert of the single-level outlet is near the bottom of the reservoir. Lake Mendocino, impounded by Coyote Dam, has a storage capacity of 122,500 acre-feet. Of this capacity, the flood control pool is 48,000, the conservation pool is 70,000, and the space for sediment storage is 4,500 acre-feet. During the study period the contents of the reservoir ranged from 35,100 acre-feet on October 6, 1964, to 128,700 acre-feet on December 24, 1964, a day when the reservoir was spilling. The water level rose 57 feet between October 6 and December 24. Usually the yearly range of water level is about 20 feet. Release and storage of water in Lake Mendocino help control floods and provide water for urban, agricultural, and recreational uses during the summer.

The Sonoma County Flood Control and Water Conservation District built pumping plants (fig. 5) in 1959 at a site between Guerneville and Healdsburg. The plants are designed to pump water at a rate of 62 cfs from a gallery 60 feet below the streambed of the Russian River. The water is used as a municipal supply by Santa Rosa and Forestville in the Russian River basin and by several communities outside the basin.

Other dams will be constructed in the basin in the future. Knights Valley Dam on Maacama and Franz Creeks has been authorized, and Warm Springs Dam on Dry Creek is under construction. The Warm Springs Dam will impound 381,000 acre-feet of water or more than triple the 122,500 acre-feet of water impounded by Coyote Dam.

FIGURE 5.--Pumping plants between Healdsburg and Guerneville that divert Russian River water for municipal purposes.

Industries and Principal Cities

The Russian River basin is noted for its agriculture upon which much of the economy of the region is based. Pear and prune orchards are common and vineyards and wineries are scattered throughout the basin.

Other principal industries include lumber and recreation. Logging and the manufacture of lumber products are economically important in the northern half of the basin, whereas along the lower reaches of the Russian River (fig. 3) the resort industry is a large source of income. Swimming, boating, and fishing facilities make the lower reaches a popular recreational area.

Important mineral deposits are cinnabar and sand and gravel. A large mercury mine is about 3 miles northeast of Guerneville, and there are several large sand and gravel plants along the Russian River and Dry Creek.

The largest cities in the basin are Santa Rosa (population, 48,450 in 1968), and Ukiah (population, 10,350 in 1964). Other cities having populations of more than 2,500 are Cloverdale, Healdsburg, and Sebastopol.

Climate and Runoff

The Russian River basin has a Mediterranean climate characterized by warm dry summers and cool wet winters. About 80 percent of the annual precipitation occurs from November through March with maximums usually occurring in December and January. Figure 6 shows the mean annual precipitation throughout the basin and that part of the Eel River basin upstream from the diversion into Potter Valley. Mean annual precipitation ranges from more than 80 inches in the mountains southeast of Cloverdale to about 30 inches in the valley near Santa Rosa. Snow falls at higher altitudes in the basin but seldom remains more than a few days.

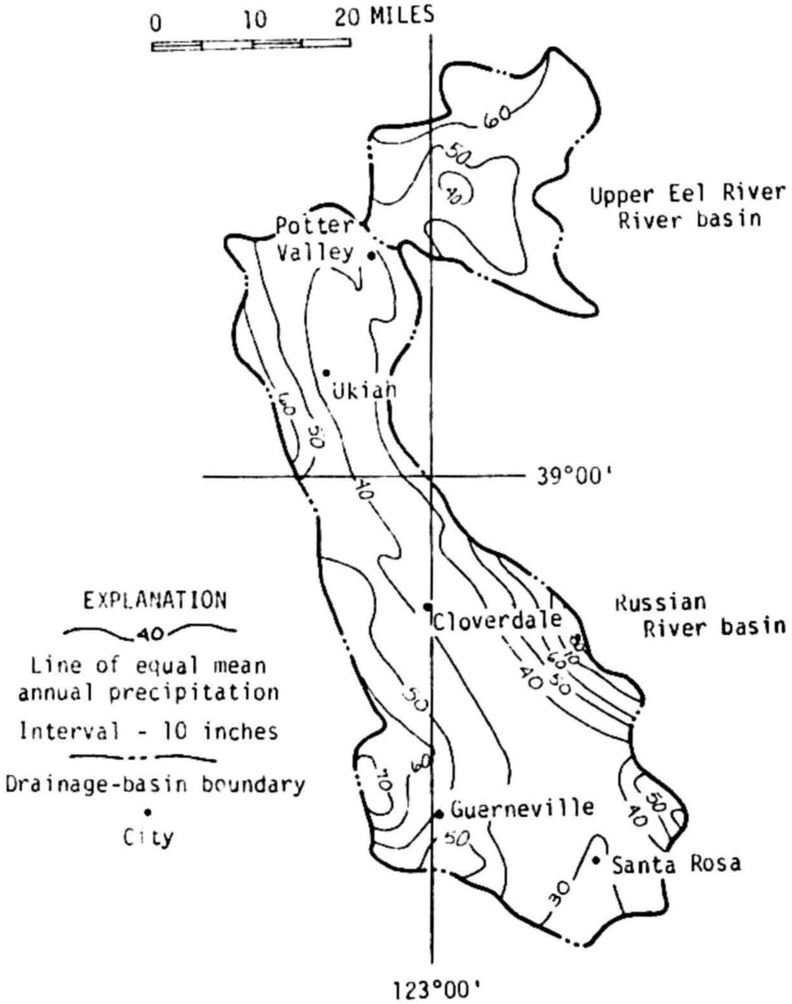

FIGURE 6.--Mean annual precipitation in the Russian River basin and the upper Eel River basin (modified from Rantz, 1968).

Temperatures are generally mild; the mean monthly temperature ranges from about 7°C (45°F) in January to about 21°C (70°F) in July. The highest temperature observed in the basin was 46°C (115°F); the lowest, -10°C (12°F).

During the study period, annual precipitation was lowest in the 1964 water year and highest in the 1965 and 1967 water years (table 2). Sediment transport along the north coast of California, however, is not affected as much by the annual quantity of rainfall as it is by the intensity and duration of each rainstorm. For example, the sediment transported at Russian River near Cloverdale during 1965 was 4 times the load transported during 1967 even though the precipitation of both years was about the same at the Weather Bureau station near Cloverdale.

TABLE 2.--*Precipitation data from selected U.S. Weather Bureau stations in the Russian River basin*

Station	Altitude (feet)	Years of record	Normal annual precipitation (inches)	Precipitation (inches)				
				Water year				
				1964	1965	1966	1967	1968
Santa Rosa	167	80	29.25	20.29	31.46	25.09	41.93	26.64
Healdsburg	102	92	39.81	26.50	47.97	39.75	57.55	35.50
Ukiah	623	91	35.94	25.10	51.06	35.32	42.75	34.33
Cloverdale	320	71	40.50	31.25	56.07	47.55	59.75	38.59
Potter Valley	1,015	57	44.05	32.22	57.37	39.23	52.87	39.12

The mean annual runoff in the Russian River basin upstream from Guerneville was about 19 inches for the period 1931-63 (Rantz and Thompson, 1967, p. 37). Runoff was adjusted to natural conditions by subtracting the quantity of water imported from the Eel River. The mean annual runoff ranged from 15.6 inches in the East Fork Russian River basin to 48.3 inches in the Big Austin Creek basin. Water loss (the difference between precipitation and runoff) ranged from 22 inches in the Big Austin Creek basin to 31 inches in the Maacama Creek basin.

About 80 percent of the runoff occurs from December through March (Rantz and Thompson, 1967, p. 17). The November rains often fall on dry ground and produce little runoff. Although snow sometimes falls in the higher altitudes of the basin, the quantity is so small that runoff from snowmelt is usually insignificant.

Geology

Geology may affect the sediment yield of an area. For example, Colby and others (1956, p. 85) showed a relation between sediment yield and the type of underlying rock in the Wind River basin in Wyoming. No such interpretation is attempted in this report because the geology in the Russian River basin is complex. The basin is underlain mostly by the Franciscan Formation and other rocks of Jurassic-Cretaceous age, but outcrops of ultrabasic rocks of Mesozoic age and many volcanic rocks of Pliocene age are scattered throughout the basin. In the valleys, sedimentary deposits of Quaternary age are dominant.

A good brief geologic history and description of the Russian River basin was written by Cardwell (1965), and maps of the general geology were prepared by Koenig (1963) and Jennings and Strand (1960). The geology of the lower reach of the Russian River is thoroughly discussed by Higgins (1952).

Land Use and Vegetation

Investigators, such as Wallis (1965), have shown that sediment yield may be related to land use and vegetation. Although a study of those relations in the Russian River basin is beyond the scope of this report, it is recognized that the background information on land use and vegetation may be pertinent to sediment yield and transport.

The California Department of Water Resources (1964) estimated that in 1964 in the Russian River basin irrigated lands or all-agricultural lands to which water is applied, comprise 36,316 acres. Lands supporting vegetation by utilizing water from a naturally high water table covered only 756 acres. Dry farmed lands, those lands that are normally planted for crops but do not receive applied water, comprised 60,877 acres. Urban lands had a total area of 29,966 acres and recreational lands covered 3,180 acres. The remaining 819,415 acres, which is 86 percent of the basin, had a cover of native vegetation or was largely in a native state. Those remaining lands, however, were used for quarrying, commercial timber production, and livestock range.

The highest parts of the basin are moderately to heavily wooded, whereas the valleys are commonly covered with grass and orchards. The principal trees are coastal redwood, Douglas-fir, and live oak. Manzanita and chaparral are also widespread.

METHODS

Sampling stations (fig. 1) were established in the Russian River basin and the Lake Pillsbury area to determine the duration and magnitude of turbidity in the surface waters and to determine the quantity of suspended sediment being transported in the streams. At some stations, the sampling frequency was usually daily, and during storms, more frequently; at others, the sampling was monthly. The streams were sampled mostly at gaging stations.

Methods of measurement and analysis of sediment, as used in this study, are given in Report No. 14 of the U.S. Inter-Agency Committee on Water Resources (1963) and reports by Guy (1969) and Guy and Norman (1970). Procedures for the measurement of water discharge are described in detail in Water-Supply Paper 888 (Corbett and others, 1943).

The water-sediment mixture in a stream vertical was sampled with a depth-integrating sampler for analysis of suspended-sediment concentrations. Suspended-sediment and turbidity samples at Lake Mendocino and Lake Pillsbury were obtained at 10-foot intervals of depth with a Foerst sampler. Samples were collected daily at Lake Mendocino during 1964 and 1965 and weekly during 1966-68. They were collected from the outlet tower, which is on the upstream face of the dam. The deepest samples collected there at each sampling were not representative of conditions at the bottom of the reservoir because they were taken at the face of the dam many feet above the bottom of the reservoir. Monthly samples were collected at sites in Lake Mendocino and Lake Pillsbury, and at the inflows of Eel River and Rice Fork to Lake Pillsbury.

The turbidity of one sample from each set of stream samples and the turbidity of each lake sample were measured. In the early part of the study, turbidity was measured both in the field and in the laboratory to determine whether the turbidity changed during transportation and storage of the samples. The field measurement was discontinued after several months because the field and laboratory turbidities were not significantly different. Until July 1966 turbidity was measured in the laboratory with a Hellige turbidimeter after the sample had been shaken for a few minutes. After July 1966, a model 1860 Hach turbidimeter was used. Measurements of turbidity are not easily reproduced even on the same instrument, and observed turbidities of a sample may differ if they are measured on different instruments.

After the concentration of suspended sediment was determined, slides of the suspended sediment were made so that the percentage of algae in the sediment could be estimated. The sediment was resuspended and, with a pipet, was placed on a slide, the preparation of which, with a few minor adaptions, followed the standard technique outlined in Krumbein and Pettijohn (1938, p. 360-361). The estimation was made visually on the basis of the area of the slide covered by algae versus the area covered by sediment and algae.

TRANSPORTATION OF SUSPENDED SEDIMENT

Most of the suspended sediment carried by streams in the Russian River basin is transported during November through March when most of the rain and runoff occurs. Suspended-sediment discharge in the summer and early autumn, when little or no precipitation falls, is extremely low. Figure 7 shows the monthly suspended-sediment discharges during the 1966 water year. As in many years, most of the suspended sediment in 1966 was transported in 1 month, in this case January.

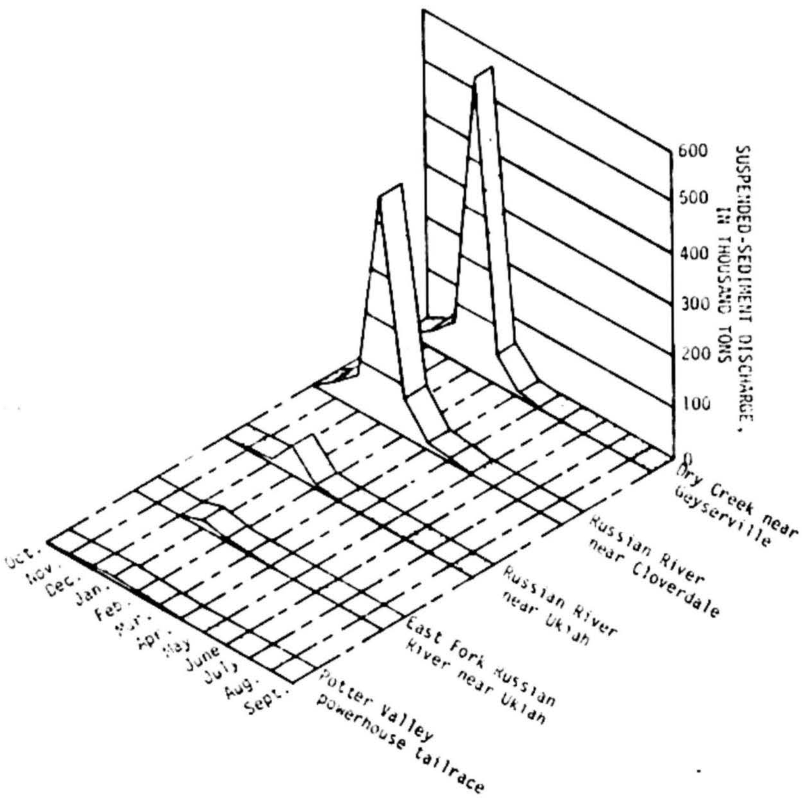

FIGURE 7.--Monthly suspended-sediment discharges at selected sampling stations in the Russian River basin, October 1965 to September 1966. Stations are in order of downstream location from Potter Valley powerhouse tailrace.

The Flood of December 1964

Despite the flood control of the East Fork by Coyote Dam, record or near-record floods occurred in the Russian River basin during Christmas week, 1964 (table 3). The flood created widespread destruction throughout the basin, especially at Guerneville and nearby areas, where 500 people were left homeless and 1,000 summer homes were damaged or destroyed. The business district of Guerneville was flooded to depths of 4 feet. In the upper basin most of the damage was done to agricultural lands (Rantz and Moore, 1965).

The quantity of suspended sediment transported by streams during the flood was tremendous. In the Russian River basin, as well as in other basins in north coastal California, more suspended sediment was transported during 2 days of the flood than during each succeeding year from 1966 to 1968. Moreover, the flood probably made large quantities of sediment available for transport in subsequent years.

TABLE 3.--*Flood stages and discharges at several gaging stations in the Russian River basin (data from Young and Cruff, 1967, and Rantz and Moore, 1965)*

Station number	Station	Period of record	Drainage area (square miles)	Maximum floods		
				Date	Gage height (feet)	Discharge (cfs)
4610	Russian River near Ukiah	1911-13	99.7			
		1952-67		Dec. 22, 1964	19.44	17,900
				Dec. 21, 1955	21.0	18,900
4615	East Fork Russian River near Calpella	[1]1941-67	92.2	Dec. 22, 1964	20.21	18,700
				Jan. 5, 1965	17.19	14,400
				Dec. 21, 1955	[2]15.06	13,300
4620	East Fork Russian River near Ukiah	1958-67	105	Dec. 30, 1964	10.82	[3]6,780
4625	Russian River near Hopland	1939-67	362	Dec. 22, 1964	26.01	41,500
				Dec. 22, 1955	27.00	45,000
4630	Russian River near Cloverdale	1951-67	502	Dec. 22, 1964	31.60	55,200
				Dec. 22, 1955	30.09	53,000
4632	Big Sulphur Creek near Cloverdale	1957-67	82.3	Dec. 22, 1964	15.08	15,700
				Dec. 22, 1955	16.8	20,000
4639	Maacama Creek near Kellogg	1958-67	43.4	Dec. 22, 1964	17.56	8,920
				Feb. 24, 1958	[2]20.06	8,100
4652	Dry Creek near Geyserville	1959-67	162	Dec. 22, 1964	17.04	31,800
				Jan. 31, 1963	17.5	32,400
4670	Russian River near Guerneville	1939-67	1,340	Dec. 23, 1964	49.6	93,400
				Dec. 23, 1955	49.7	90,100

[1]Prior to May 28, 1957, at site 0.9 mile downstream at different datum.
[2]Site and/or datum then in use.
[3]Release after flood to empty the flood control pool.

Not enough data were collected in the Russian River basin prior to the flood to determine if the sediment-transport curve had changed after the 1964 flood; however, after the 1964 flood, the suspended-sediment discharges of streams in the Eel River basin were at least twice as great as those transported by an equal water discharge before the flood (Brown and Ritter, 1970, and fig. 8). How long the postflood relation between water discharge and suspended-sediment discharge will remain unchanged before returning to the preflood relation is unknown. It is assumed that the flood may have similarly affected the transport of suspended sediment in the Russian River basin. However, there are two basic differences in the Russian and Eel River basins.

1. The Eel River basin is noted for the size and number of landslides within its boundaries. The erosion of the landslides increases sediment loads, and during the 1964 flood many landslides were produced. Landslides are not as numerous in the Russian River basin as in the Eel River basin.

2. The flow of the Eel River is unregulated except for Lake Pillsbury and Van Arsdale Reservoir in the headwaters. The flow of the Russian River is affected by Lake Mendocino and the diversion from the Eel River. Storage of water in Lake Mendocino substantially reduced the peak flow downstream during the 1964 flood. For example, the peak discharge of the Russian River at Hopland during the flood was 41,500 cfs and that discharge probably would have reached about 57,000 cfs if Coyote Dam had not been built (Rantz and Moore, 1965).

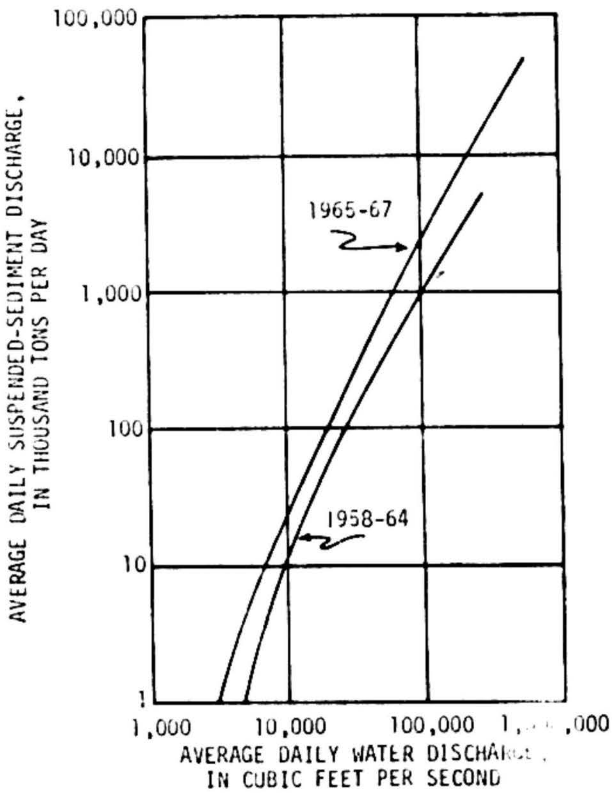

FIGURE 8.--Sediment transport curves for Eel River at Scotia (inset, fig. 1) showing the increase in sediment transport subsequent to the flood of December 1964 (Brown and Ritter, 1970).

Because of these two differences between the basins, suspended-sediment transport by streams in the Russian River basin probably was not affected as greatly by the aftereffects of the 1964 flood as was that in the Eel River basin; however, the flood may have caused the sediment loads for the study period (1964-68) to be higher than normal. The possible influence of the flood on turbidity in streams and lakes in the Russian River basin is discussed later.

The East Fork Russian River is the only place in the Russian River basin where suspended-sediment transport before and after the 1964 flood can be compared. In the 1953-55 water years sediment-transport data were collected at a now-inundated station, East Fork Russian River near Ukiah, about 4 miles downstream from the station at East Fork near Calpella (fig. 9). The inundated station, now covered by Lake Mendocino, was 1 mile upstream from the present station of the same name. The drainage area upstream from the old station near Ukiah was 12 square miles more than the drainage area of the Calpella station. Because the data collected in 1953-55 were not affected by Lake Mendocino, then nonexistent, and because the difference in drainage areas upstream from the 1953-55 and 1964-68 stations was not too great, the suspended loads and sediment-transport curves at each station were compared to determine if the suspended-sediment yields had changed.

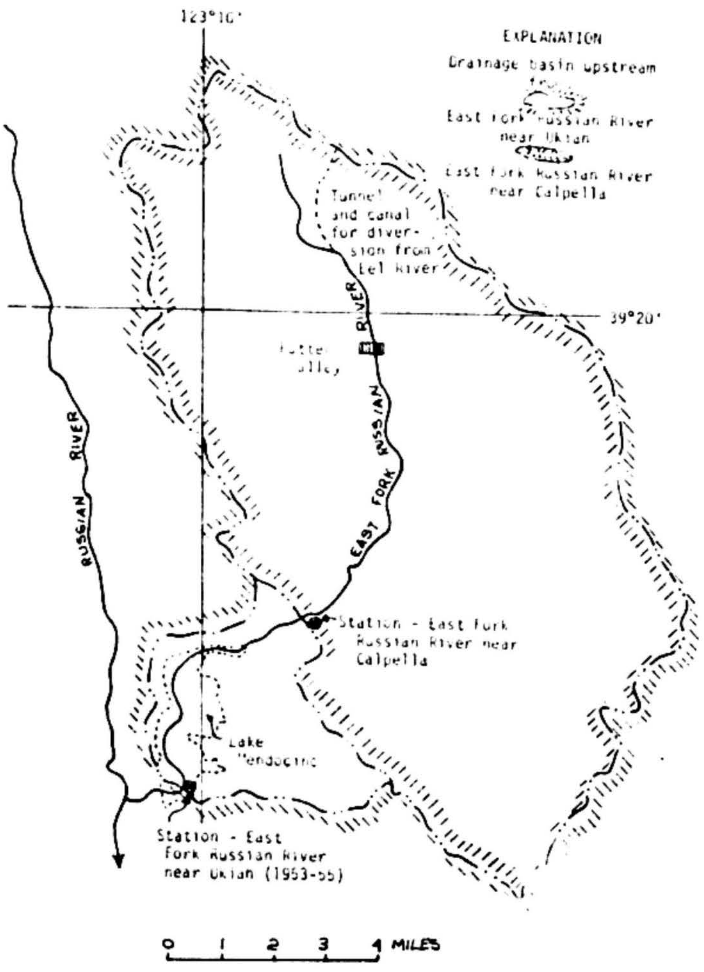

FIGURE 9.--Map of East Fork Russian River showing the stations on the East Fork Russian River near Calpella and near Ukiah (1953-55).

Of the years 1953-55, only 1954 had a complete record of daily suspended-sediment discharge. Because no samples were collected from October 1 to December 10, 1952, and from April 1 to September 30, 1955, the suspended-sediment discharges for those periods were estimated to determine annual suspended-sediment discharges for the 1953 and 1955 water years. Figure 10 shows that during those years the estimated yearly suspended-sediment discharge ranged from 15,000 to 186,000 tons, whereas the water discharge ranged only from 205,600 to 295,900 acre-feet. The diversion from the Eel River ranged from 182,900 to 196,300 acre-feet and kept the annual flow at the station fairly uniform. In 1955, a very dry year, the suspended-sediment discharge was extremely small owing to the lack of erosion from runoff; in fact, the 1955 suspended-sediment discharge was only one-twelfth the 1953 suspended discharge. If the water discharge through the Potter Valley powerhouse tailrace is subtracted from the discharge at East Fork Russian River near Ukiah, then the yearly runoff at the East Fork station was 105,300, 71,000, and 22,700 acre-feet for 1953, 1954, and 1955, respectively.

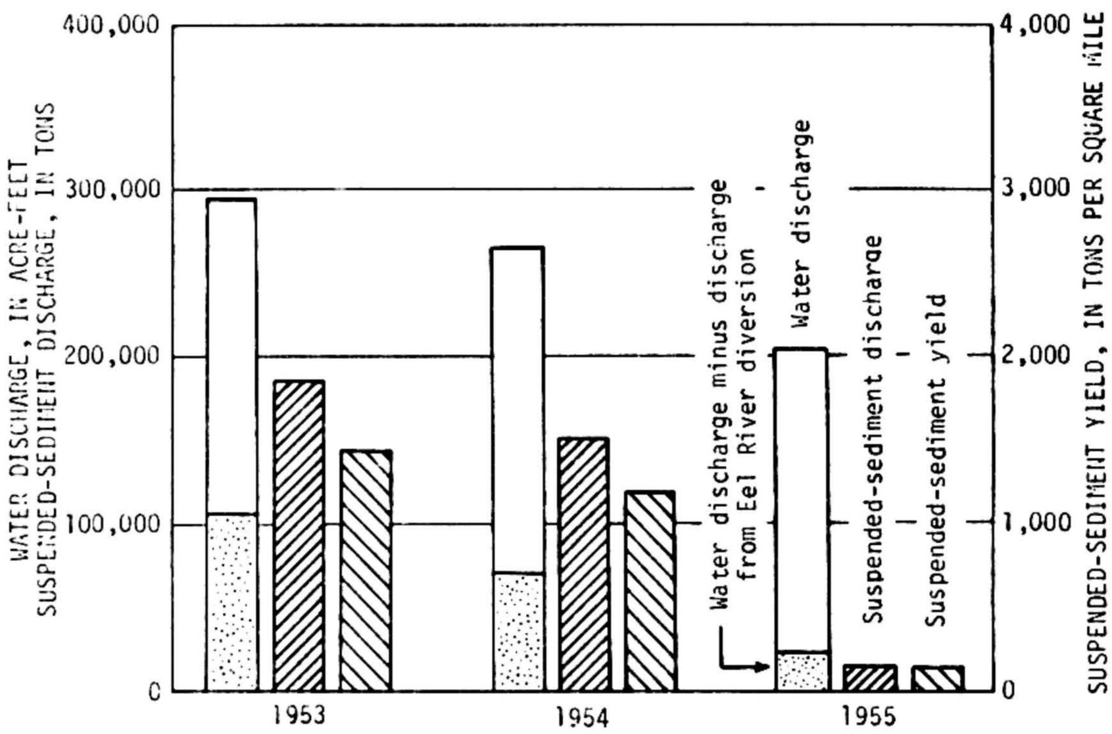

FIGURE 10.--Water discharge and suspended-sediment discharge and yield at East Fork Russian River near Ukiah (1953-55). Suspended-sediment yield was calculated by dividing 80 percent of the annual suspended-sediment discharge by the drainage area of 104 square miles. The annual suspended-sediment discharge diverted through Potter Valley powerhouse was estimated to be 20 percent of the annual suspended-sediment discharge at East Fork Russian River near Ukiah.

At East Fork Russian River near Calpella, the annual suspended-sediment discharge for 1965-68 ranged from 33,200 to 451,000 tons (table 4). Figure 11 shows that the sediment-transport curves fitted by eye for 1953-54 and 1965 and 1967 are fairly similar. Any differences in the curves possibly can be attributed to the difference in the locations of the sampling stations or errors in estimating sediment discharges. The effects of the 1964 flood on the relation between water discharge and suspended-sediment discharge in the East Fork, probably were not significant; however, because the East Fork is the area of lowest sediment yield and runoff in the Russian River basin (table 4), it may not have been affected as much as areas with higher yields. Even so, the quantity of sediment transported by the flood is impressive. For example, the suspended-sediment discharge of the day of the peak of the flood at Calpella--an estimated 220,000 tons--was greater than the discharge for any year of record on the East Fork.

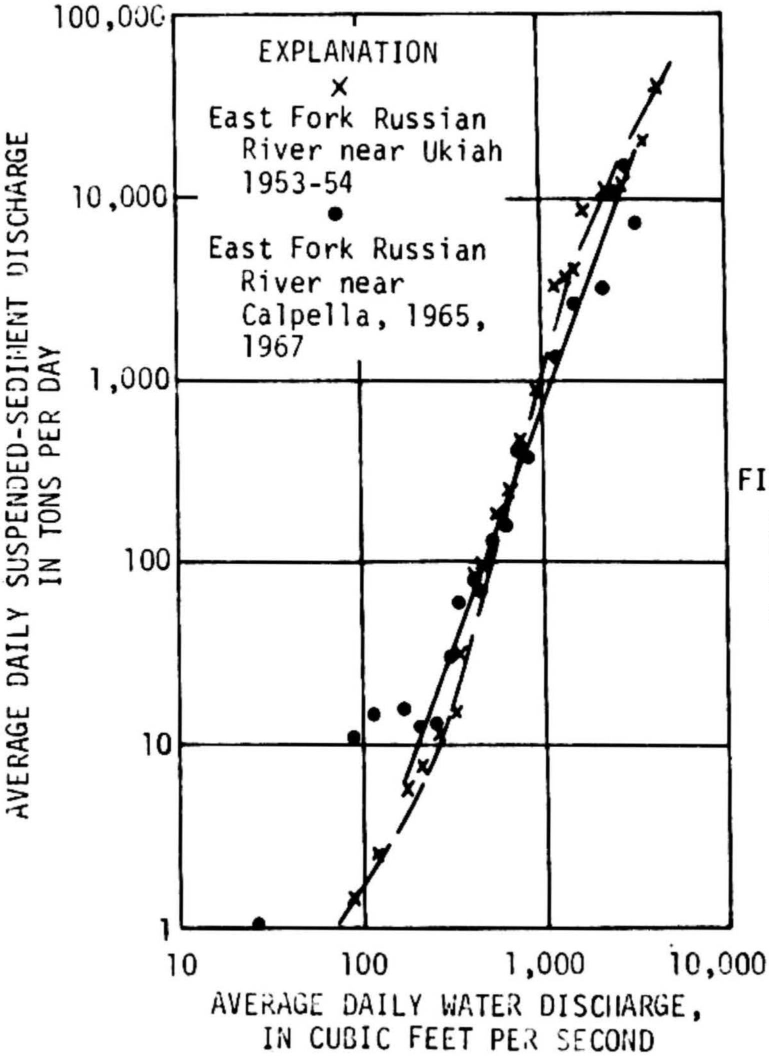

FIGURE 11.--Sediment-transport curves for East Fork Russian River near Ukiah, 1953-54, and East Fork Russian River near Calpella, 1965-67.

Suspended-Sediment Discharge

A summary of the annual suspended-sediment discharge and corresponding yield per square mile for each station is given in table 4. The water year having the highest annual suspended-sediment yield at every station was 1965, which included the flood of Christmas 1964. The water year having the lowest annual suspended-sediment yield at every station was 1968, the driest study year.

For the period 1965-68 the combined suspended-sediment discharge at the three stations, Big Sulphur Creek near Cloverdale, Dry Creek near Geyserville, and Russian River near Cloverdale was 41 percent of the suspended-sediment discharge at Russian River near Guerneville. Therefore, 59 percent of the suspended sediment transported at the Guerneville station must have been eroded from that part of the basin downstream from those three stations.

TABLE 4.--*Summary of annual suspended-sediment and water discharge in the Russian River basin, October 1964 to September 1968*

Water year	Water discharge (acre-feet)	Suspended-sediment discharge (tons)	Suspended-sediment yield (tons per square mile)	Percent of discharge at Guerneville	
				Water	Suspended sediment
		4710 Potter Valley powerhouse tailrace			
1965	155,9[illegible]	38,[illegible]	-	-	-
1966	174,700	15,080	-	-	-
1967	[illegible]	21,140	-	-	-
1968	159,[illegible]	[1]13,500	-	-	-
Average	187,200	22,500	-	-	-
		4615 East Fork Russian River near Calpella (drainage area - 92.2 sq mi)			
1965	329,400	[2]392,000	[5]3,800	-	-
1966	240,500	[2]77,000	[5]670	-	-
1967	329,100	[4]84,000	[5]660	-	-
1968	210,100	33,200	[5]190	-	-
Average	275,[illegible]	147,000	[5]1,350	-	-
		4620 East Fork Russian River near Ukiah (drainage area - 105 sq mi)			
1965	290,800	109,800	-	13.4	1.0
1966	213,800	15,060	-	14.9	.3
1967	296,100	16,800	-	13.2	.3
1968	211,100	7,420	-	18.0	.6
Average	258,000	37,300	-	14.4	.7
		4610 Russian River near Ukiah (drainage area - 99.7 sq mi)			
1965	203,100	792,900	7,950	9.4	7.2
1966	97,250	65,850	660	6.2	1.4
1967	135,[illegible]	149,200	1,500	6.0	3.0
1968	[illegible]	44,140	450	6.2	3.8
Average	127,[illegible]	263,000	2,640	6.8	4.8

Water year	Water discharge (acre-feet)	Suspended-sediment discharge (tons)	Suspended-sediment yield (tons per square mile)	Percent of discharge at Guerneville	
				Water	Suspended sediment
		4630 Russian River near Cloverdale (drainage area - 502 sq mi)			
1965	950,400	2,111,000	[7]5,040	44.0	19.2
1966	630,100	622,900	[7]1,530	40.3	13.4
1967	818,200	[6]537,000	[7]1,350	37.3	10.9
1968	491,800	345,000	[7]850	41.8	30.8
Average	729,900	904,000	[7]2,180	40.9	16.6
		4632 Big Sulphur Creek near Cloverdale (drainage area - 82.3 sq mi)			
1965	194,200	[3]656,000	10,400	9.0	7.8
1966	118,500	[3]260,000	3,160	7.6	5.6
1967	188,600	295,000	3,580	8.4	6.0
1968	[illegible],760	103,400	1,260	8.3	9.0
Average	149,700	379,000	4,600	8.4	7.0
		4652 Dry Creek near Geyserville (drainage area - 162 sq mi)			
1965	316,000	2,283,000	14,100	14.6	20.8
1966	212,100	717,000	4,430	13.5	15.4
1967	294,200	554,700	3,420	13.1	11.3
1968	159,000	186,700	1,150	13.5	16.3
Average	245,300	935,400	5,770	13.7	17.2
		4670 Russian River near Guerneville (drainage area - 1,340 sq mi)			
1965	2,164,000	[3]11,000,000	[7]8,820	-	-
1966	1,564,000	[3]4,660,000	[7]3,760	-	-
1967	2,242,000	[3]4,910,000	3,960	-	-
1968	1,175,000	1,147,000	[7]920	-	-
Average	1,786,000	5,430,000	[7]4,370	-	-

[1]Suspended-sediment discharge for June through September was estimated.
[2]Suspended-sediment discharge for December, January, and September was estimated.
[3]Suspended-sediment discharge for whole year was estimated from flow-duration and sediment-transport curve.
[4]Suspended-sediment discharge for November and December was estimated.
[5]Suspended-sediment yield was calculated by subtracting the suspended-sediment discharge of Potter Valley powerhouse tailrace from the suspended-sediment discharge at East Fork Russian River near Calpella and dividing by 92.2 square miles.
[6]Suspended-sediment discharge for October-December was estimated.
[7]Suspended-sediment yield was calculated by subtracting the suspended-sediment discharge of East Fork Russian River near Ukiah from the suspended-sediment discharge of this station and dividing by the drainage area upstream from this station minus the drainage area of East Fork Russian River near Ukiah.

The relation of water discharge to sediment discharge for each of the five stations having the smallest drainage areas (East Fork Russian River near Calpella, Russian River near Ukiah, Big Sulphur Creek near Cloverdale, Dry Creek near Geyserville, and Maacama Creek near Kellogg) is similar as shown in figures 11, 12A, 12C, and 13A. The coordinates of the points used to define the sediment-transport curves in figure 12 were averages for selected intervals of water discharge and the corresponding averages of sediment discharge computed for that interval. In many cases, the few water and sediment discharges that were available to define upper ends of the curves were estimated or computed rather than measured directly.

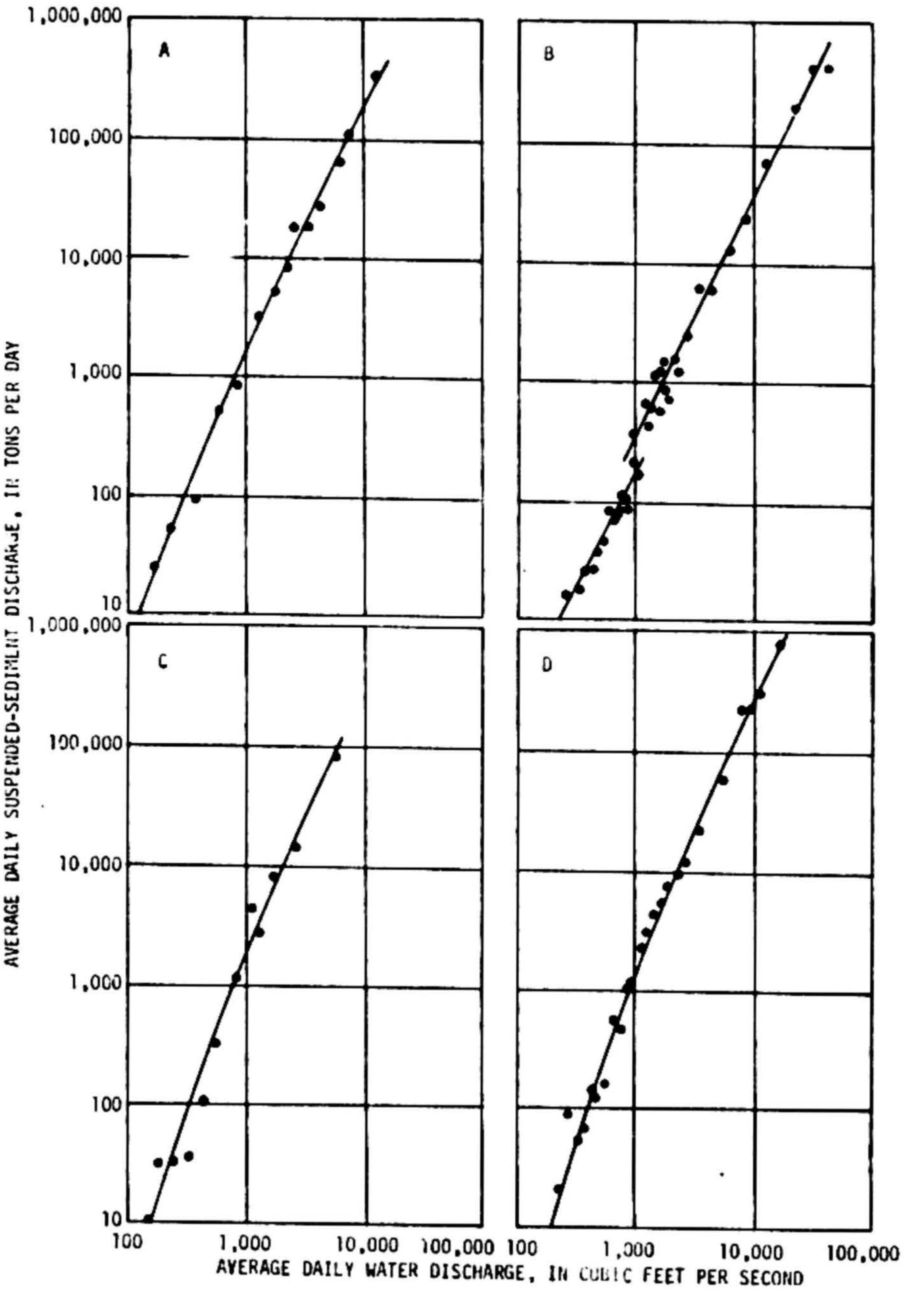

FIGURE 12.--Sediment-transport curves for: A. Russian River near Ukiah, 1965-67, B. Russian River near Cloverdale, 1965-67, C. Big Sulphur Creek near Cloverdale, 1967, and D. Dry Creek near Geyserville, 1965-67.

The curves for Russian River near Cloverdale and Russian River near Guerneville (figs. 12B and 13B) are different from the smaller basins and each other. Part of the difference between the curves of the two stations may be because the Cloverdale curve is based on average daily measurements and the Guerneville curve on instantaneous measurements, which, in this report, are assumed equivalent to those based on average daily measurements. Sediment-transport curves could not be drawn for Potter Valley powerhouse tailrace and East Fork Russian River near Ukiah because no relation between water discharge and suspended-sediment discharge existed at those stations. The plotted points at the lower ends of the curves for East Fork Russian River near Calpella and Russian River near Cloverdale (figs. 11 and 12B) are inconsistent with the trend of the upper part of each curve and reflect the effects of the water released through Potter Valley powerhouse and Coyote Dam.

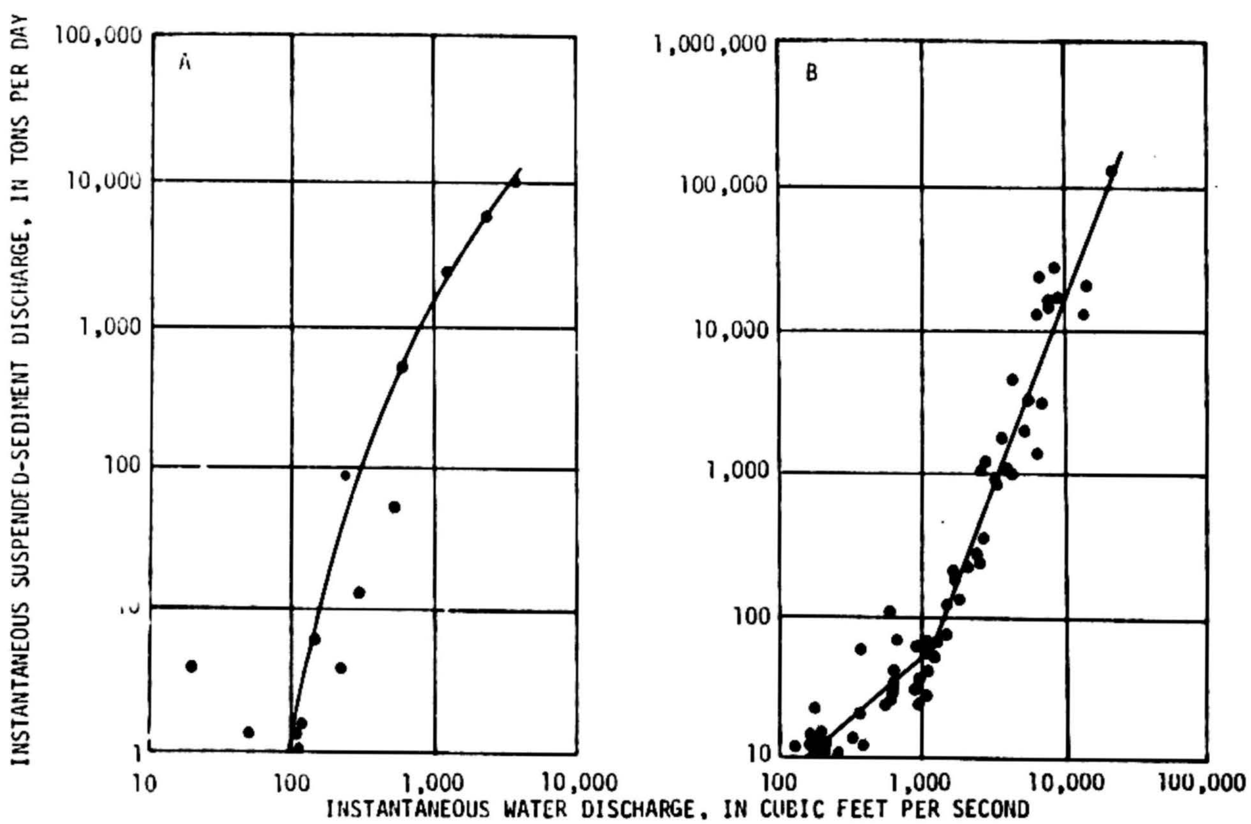

FIGURE 13.--Sediment-transport curves for A. Maacama Creek near Kellogg and B. Russian River near Guerneville.

The effects of reservoirs on suspended-sediment transport are further shown by the number of days required to transport 50, 75, and 90 percent of the suspended load at each station during 1965-68 (table 5). Because of the controlled discharge and a persistent level of concentration of suspended sediment, many more days were required to transport a given percentage of the load at the stations on regulated streams than at stations on unregulated streams. Most of the suspended sediment transported annually by streams unaffected by regulation by dams, such as by the Russian River near Ukiah and Dry Creek near Geyserville, was transported in a very few days, usually during periods of intense rainfall. The number of days that were required to transport the given percentages of the annual suspended-sediment load at each of the stations on unregulated streams was about the same. The time required to transport the load at the stations on regulated streams depended on the degree of the effect of the upstream dams on flow. East Fork Russian River near Ukiah was usually less affected by regulation than Potter Valley powerhouse tailrace possibly because turbidity currents passed through Lake Mendocino after most storms.

TABLE 5.--*Number of days required for transporting 50, 75, and 90 percent of the annual suspended-sediment load at selected stations*

Station	Number of days required to transport given percent of annual suspended load											
	1965			1966			1967			1968		
	50	75	90	50	75	90	50	75	90	50	75	90
Potter Valley powerhouse tailrace[1]	17	54	121	33	82	139	35	88	143	[4]23	[4]60	[4]100
East Fork Russian River near Calpella[2]	[4]1	[4]4	[4]10	-	-	-	[4]5	[4]15	[4]87	6	27	77
East Fork Russian River near Ukiah[1]	5	11	21	6	21	97	14	35	90	15	74	166
Russian River near Ukiah[3]	2	4	8	2	2	9	5	9	14	3	6	11
Russian River near Cloverdale[2]	3	7	16	2	9	21	[4]6	[4]14	[4]26	4	9	20
Big Sulphur Creek near Cloverdale[3]	-	-	-	-	-	-	3	7	15	2	6	13
Dry Creek near Geyserville[3]	2	4	7	2	3	11	4	9	17	5	10	19

[1]Regulated.
[2]Partly regulated.
[3]Unregulated.
[4]Estimated.

Suspended-Sediment Yield

The suspended-sediment yield in basins downstream from Russian River near Cloverdale was more than 4,300 tons per square mile per year; in fact, the average suspended-sediment yield from the basin between Cloverdale and Guerneville excluding the Dry Creek basin upstream from Dry Creek near Geyserville was about 5,400 tons per square mile. The yield in the basins upstream from Russian River near Cloverdale was less than 2,700 tons per square mile per year. This downstream increase in sediment yield was also evident in the Eel River basin (Brown and Ritter, 1970). The lowest suspended-sediment yield was in the East Fork basin upstream from the station near Calpella where the average was less than 1,400 tons per square mile per year (table 4). That basin had the lowest runoff in the Russian River basin, which may be responsible for the low yield.

The highest average suspended-sediment yield in the Russian River basin (5,770 tons per sq mi per yr) was from the Dry Creek basin above the station near Geyserville. More suspended sediment passed this station than passed Russian River near Cloverdale, even though the drainage area upstream from the Russian River station is more than twice the drainage area upstream from the Dry Creek station (table 4). Whether the rate of suspended-sediment yield in Dry Creek basin is exceptionally high because of the flood of Christmas 1964 cannot be determined from only 4 years of record. That rate, however, is comparable with the rate computed for the Eel River basin on the basis of 10 years of record (Brown and Ritter, 1970).

According to the U.S. Department of Agriculture (1966) the high sediment-transport rate resulted from accelerated erosion caused by land-use practices coupled with the generally steep terrain of the Dry Creek watershed. About 80 percent of the land has slopes ranging from 30 to 80 percent. Prior to settlement in the midnineteenth century, about one-half the watershed was covered by Douglas-fir and redwood forests. At present, about 40 percent of the forested land has been cleared and is grazed. The U.S. Department of Agriculture (1966, p. 31) estimated that 42 percent of the annual sediment yield was from slope erosion of land used primarily for grazing and 43 percent was from channel erosion. Logging, landslides, wildfire, and road building were other direct or indirect causes of erosion in the basin.

The large quantity of sediment carried by Dry Creek was a major concern in the design of Warm Springs Dam presently under construction by the U.S. Army Engineer District, San Francisco, Corps of Engineers. Useful storage could be depleted considerably by deposition of sediment stripped from this highly erodible basin. For this reason a sediment storage of 26,000 acre-feet is provided. Total capacity of the reservoir is 381,000 acre-feet including the sediment storage.

Particle Size

Particle-size analyses of suspended sediment were made from samples collected at every streamflow station in the study area. Table 6 summarizes the percentage composition by weight of clay (less than 0.004 mm), silt (0.004-0.062 mm), and sand (0.062-2.0 mm) of samples of suspended sediment.

The suspended sediment in transport immediately downstream from dams or diversions, such as East Fork Russian River near Ukiah and Potter Valley powerhouse tailrace, contained mostly clay and almost no sand. The suspended sediment in unregulated streams or streams partly regulated by dams, contained significant percentages of sand and on the average contained about equal quantities of silt and clay.

The relation of water discharge to the size of particles transported in suspension is indicated for three stations (fig. 14). At high water discharges there was a higher percentage of sand in the suspended sediment and a lower percentage of clay than at low water discharges; the percentage of silt remained almost constant. For very low flows (not shown in fig. 14) the suspended sediment is mostly clay because the sand and silt has deposited.

TABLE 6.--*Particle-size data for suspended-sediment stations in the Russian River and upper Eel River basins, 1964-68*

Station number	Station	Water discharge			Clay		Silt		Sand	
		Average[1] (cfs)	Range for particle-size analyses (cfs)	Number of analyses	Range (percent)	Average (percent)	Range (percent)	Average (percent)	Range (percent)	Average (percent)
4610	Russian River near Ukiah	160	290-9,600	21	21-77	38	23-59	45	0-42	16
4615	East Fork Russian River near Calpella	332	85-2,440	8	40-87	62	10-52	30	3-18	8
4620	East Fork Russian River near Ukiah	332	16-1,960	8	67-94	82	4-33	17	0-2	1
4630	Russian River near Cloverdale	965	744-26,500	25	24-56	38	29-52	39	3-47	23
4632	Big Sulphur Creek near Cloverdale	185	70-9,750	15	19-85	37	14-59	40	1-49	23
4639	Maacama Creek near Kellogg	81.8	160-2,460	5					6-84	40
4652	Dry Creek near Geyserville	285	330-18,900	22	12-69	30	22-49	40	4-66	31
4670	Russian River near Guerneville	2,221	89-23,600	7	27-79	41	21-61	46	0-33	12
4705	Eel River below Scott Dam near Potter Valley	528	226-4,790	7					0-4	1
4710	Potter Valley powerhouse tailrace near Potter Valley	199	82-312	7	57-92	69	8-33	26	0-10	5

[1]For period of record through 1968.

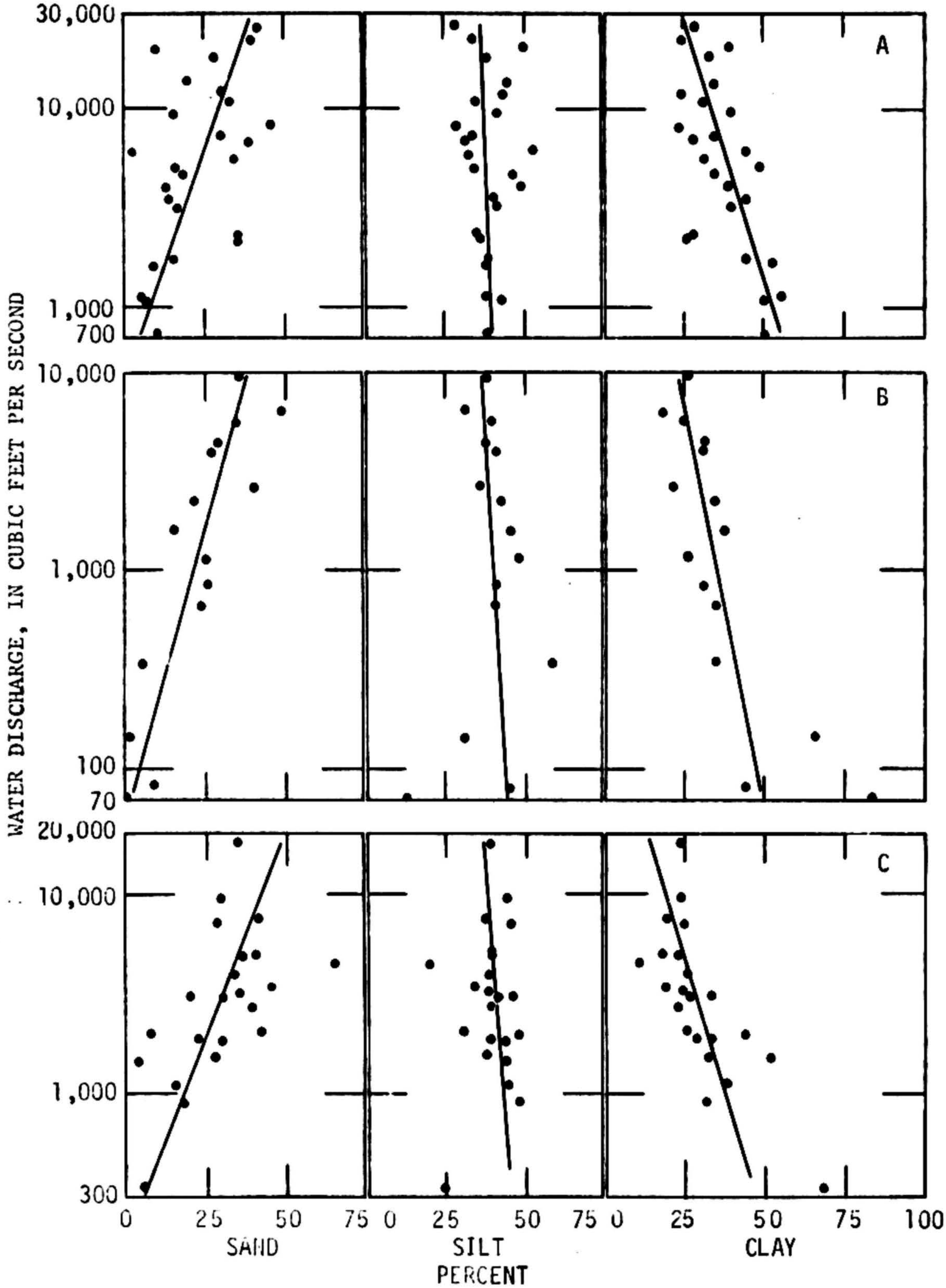

FIGURE 14.--Relation of sand, silt, and clay content of suspended sediment to water discharge at A. Russian River near Cloverdale, B. Big Sulphur Creek near Cloverdale, and C. Dry Creek near Geyserville.

SUSPENDED SEDIMENT AND TEMPERATURE IN RESERVOIRS

Lake Mendocino

Besides the daily or weekly samples of suspended sediment collected at the outlet tower, monthly samples were collected at 10-foot intervals of depth at three sites in the lake (fig. 15). Vertical distributions of suspended-sediment concentrations at site A, about 50 feet upstream from the outlet tower, were typical of vertical distributions at each sampling site. As shown in figure 16, the suspended-sediment concentrations at site A generally increased with depth. In winter, the increase of concentration near the bottom was particularly pronounced. When sediment-laden water flowed into Lake Mendocino, its density was greater than the density of the water in the lake, and it moved along the bottom of the lake as a density or turbidity current. In summer, the increase of concentration with depth was small. The summer increase possibly could be attributed to the low concentrations of suspended sediment transported into the lake by its tributaries and to the effect of water temperature on the settling velocity of suspended material. The rate of settling of particles in the colder and denser bottom water would be much slower than the settling rate in the warmer and less dense surface water, and the particles would become more concentrated in the denser water. Thus, in a lake, such as Lake Mendocino, with a summer thermocline the concentration of particles settling from the surface would tend to become greater with depth. At times, for example September 1968, the suspended sediment seems to be stratified into two or more layers. The stratification may be due to phytoplankton blooms, wind-blown material, differences in water temperature, density of the inflowing water, and turbidity currents. Some of the periods of no stratification or when the suspended sediment is well mixed (such as April 1968) may have occurred during periods of overturn. Overturns occur when denser water replaces the lighter bottom water, which moves upward toward the surface.

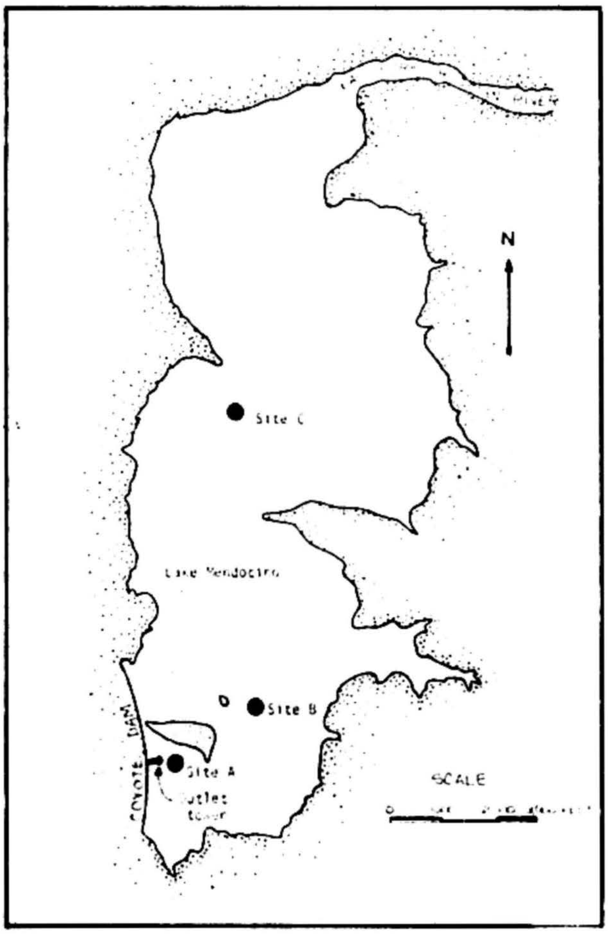

FIGURE 15.--Sampling sites on Lake Mendocino.

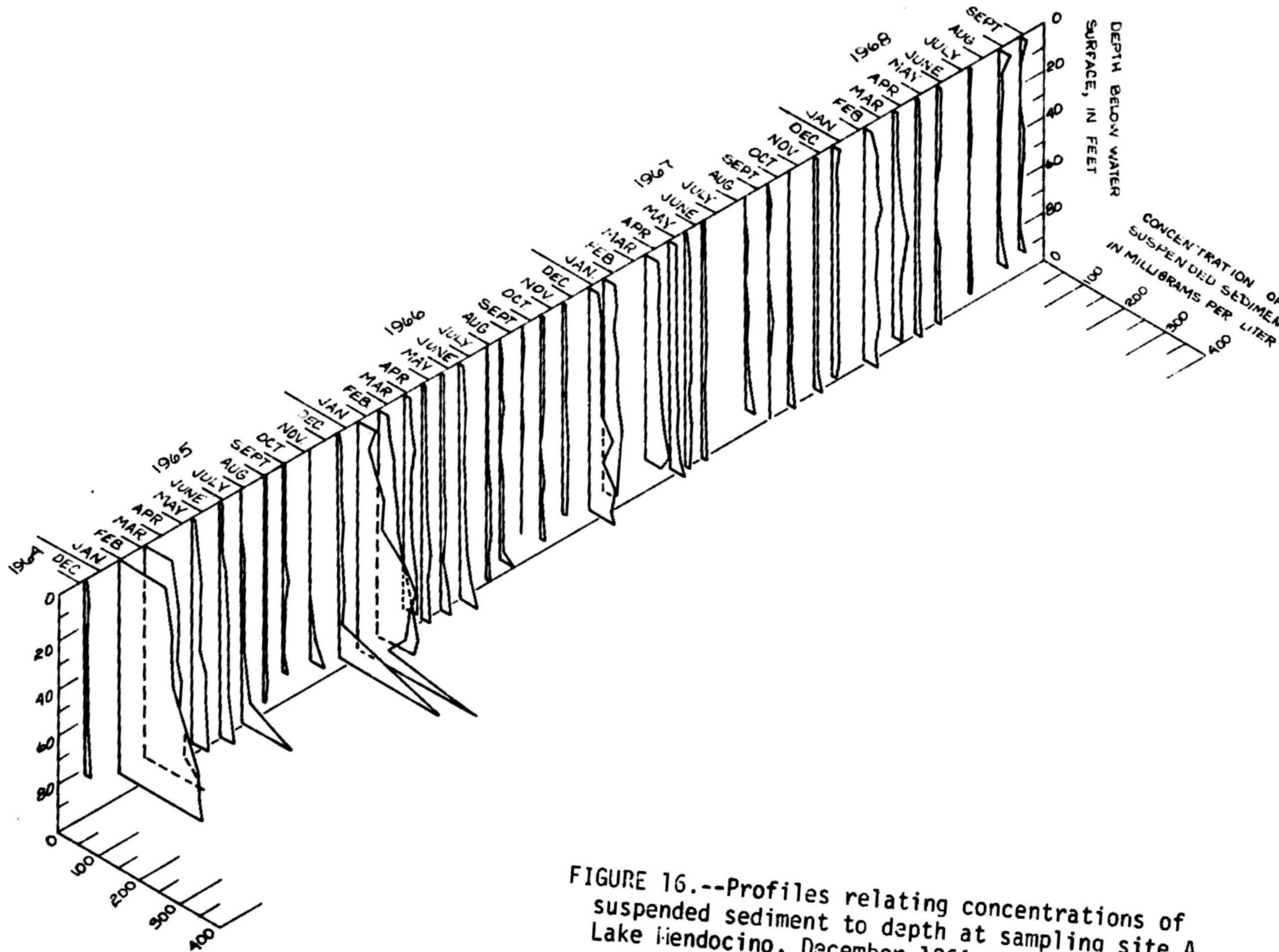

FIGURE 16.--Profiles relating concentrations of suspended sediment to depth at sampling site A, Lake Mendocino, December 1964 to September 1968.

In 1965-68, the East Fork Russian River near Calpella transported about 590,000 tons of suspended sediment. The intermediate drainage basin tributary to Lake Mendocino between East Fork near Calpella and East Fork near Ukiah is 13 square miles. If the annual sediment yield of the intermediate basin was about 1,350 tons per square mile[1] from 1965 to 1968, then about 70,000 tons of sediment entered Lake Mendocino from that source. About 150,000 tons of the total quantity of suspended sediment (660,000 tons) transported into the lake during that period was discharged through the outlet. Based on this assumption, the net deposition was about 510,000 tons of suspended sediment, and about 77 percent of the suspended sediment entering the lake was trapped there. Assuming that the specific weight of the deposited sediment was 60 pounds per cubic foot, then about 400 acre-feet of sediment was deposited in the reservoir.

Temperature at several depths also was measured at the outlet tower and at sites A, B, and C. During the summer when a thermocline is present, the range of temperatures in the reservoir at a given time may be more than 14°C; during the winter when a thermocline is absent, the range of temperatures may be less than 2°C (fig. 17). In general, the water slowly warmed in the spring and cooled more rapidly in the fall. Temperatures of the water in the reservoir ranged from about 6°C to 28°C during the period of measurement.

In December 1965 a recording thermograph was installed at sampling site A at a depth of about 2 feet. The surface temperatures ranged from about 7°C to 28°C (fig. 18). The lowest temperatures each year occurred in January or February; the highest in July or August. In the winter the diurnal range in temperature is rarely more than 1°C, but in the summer the diurnal range may be as much as 3°C.

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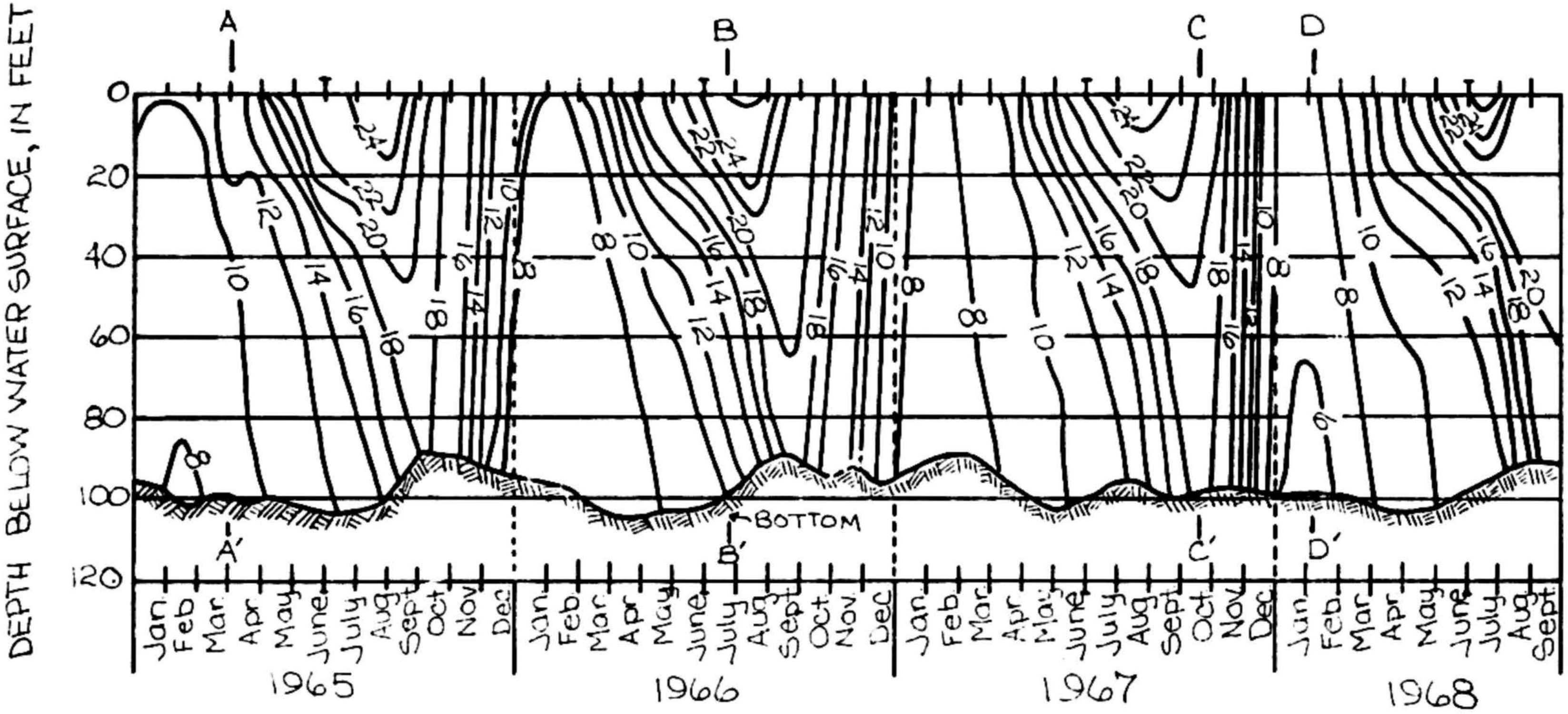
[1]The average annual yield of the basin upstream from East Fork Russian River near Calpella (table 4).



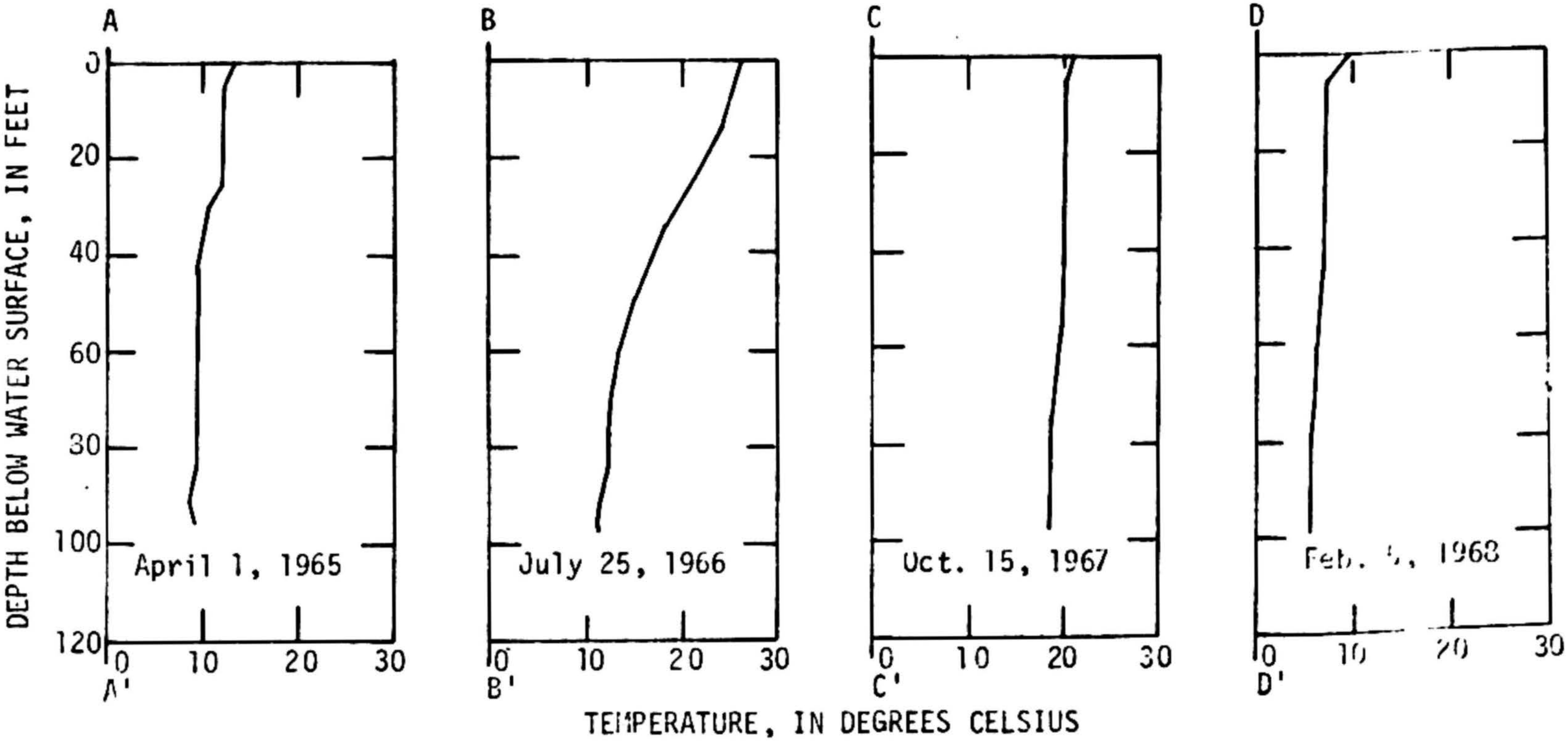
A

EXPLANATION

—— 14 ——

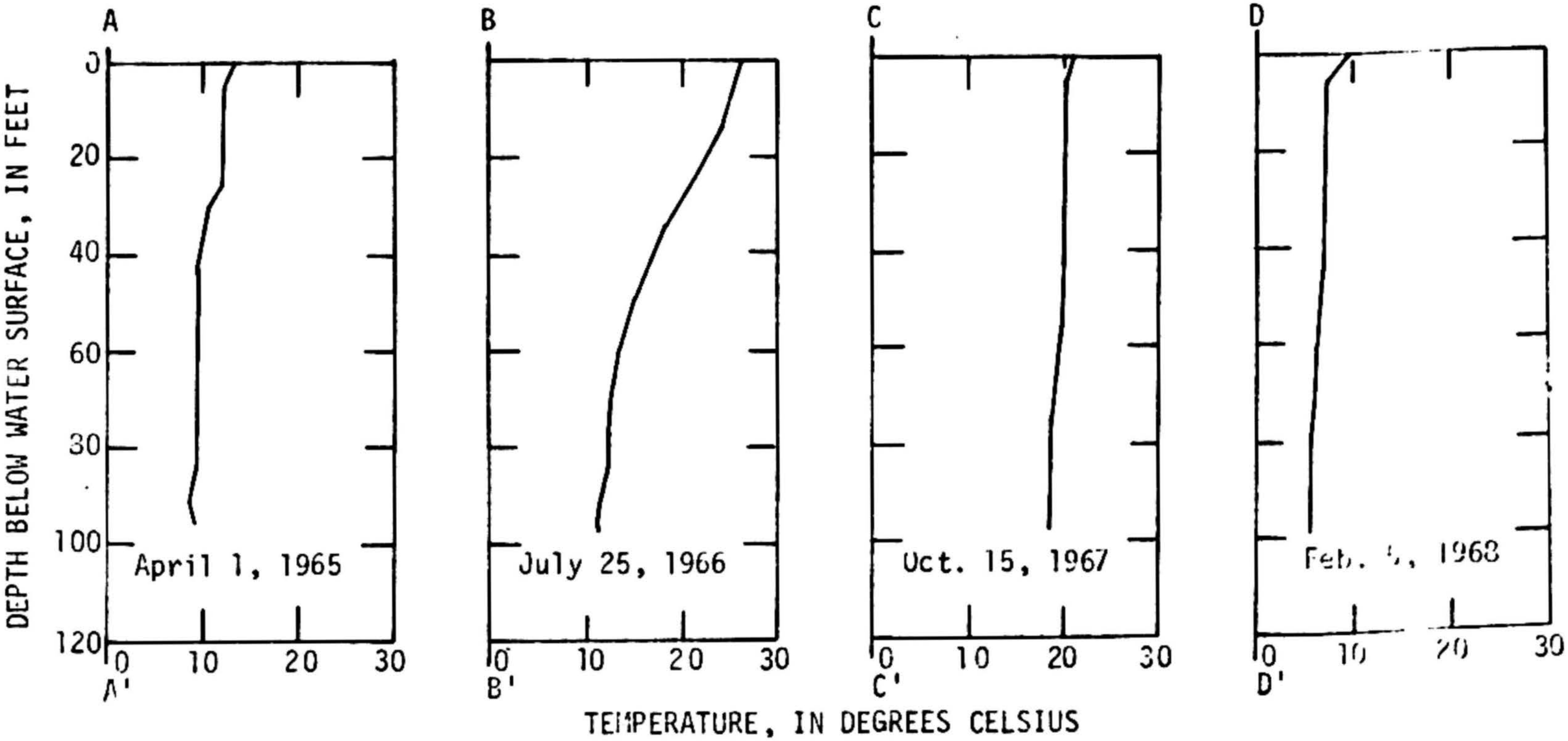
Line of equal water temperature
Interval 2 degrees Celsius

FIGURE 17.--A. Seasonal variation in temperature at sampling site A, Lake Mendocino, January 1965 to September 1968. The variation in the bottom depth is due to variation in the lake level. B. Profiles of seasonal temperatures shown in A.



B

FIGURE 17.--Continued.



B

FIGURE 17.--Continued.

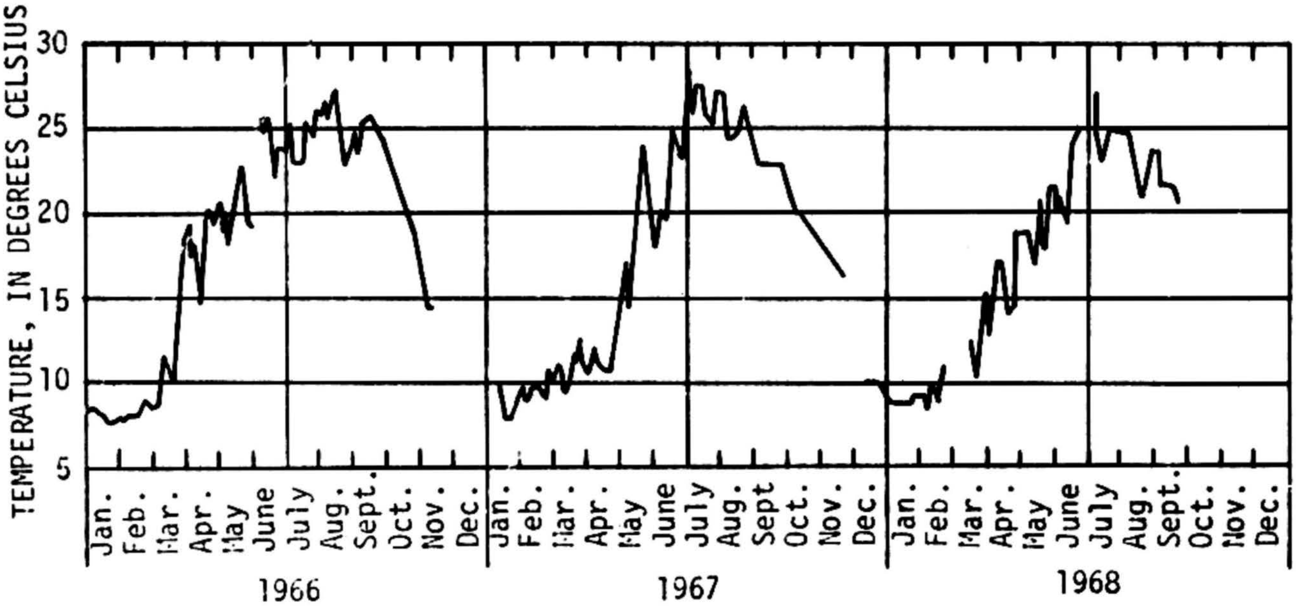


FIGURE 18.--Maximum daily temperatures of water near the surface of Lake Mendocino at sampling site A, January 1966 to September 1968.

Lake Pillsbury

Suspended-sediment samples were collected monthly about 50 feet upstream from Scott Dam and at the inflows to the lake from the Eel River and the Rice Fork (fig. 1). Water discharge was not measured. Figure 19 shows that near the dam concentration of suspended sediment generally increased with depth especially during the winter, but as in Lake Mendocino, stratification of suspended sediment sometimes was observed.

The highest measured concentrations for the tributaries (as much as 28,400 mg/l at Eel River on Nov. 10, 1965) consistently occurred in the autumn when the reservoir was at its lowest level. At that time the discharge of the tributaries was low, and the extremely high concentrations possibly were caused by the erosion of the exposed deltas of the tributaries. High concentrations in the lake and its outflow occurred in the winter during months of storms and were not correlative with the highest measured concentrations of the tributaries. The low concentrations in the tributaries occurred in early summer as did the low concentrations in the lake and its outflow.

Temperatures were taken at 10-foot intervals of depth near the dam about once a month (fig. 20). The temperature pattern is similar to the pattern at Lake Mendocino. The water warms slowly from winter to summer and cools rapidly from summer to winter. Also, a thermocline forms in the summer and is absent in the winter. The temperatures ranged from about 6°C to 27°C.

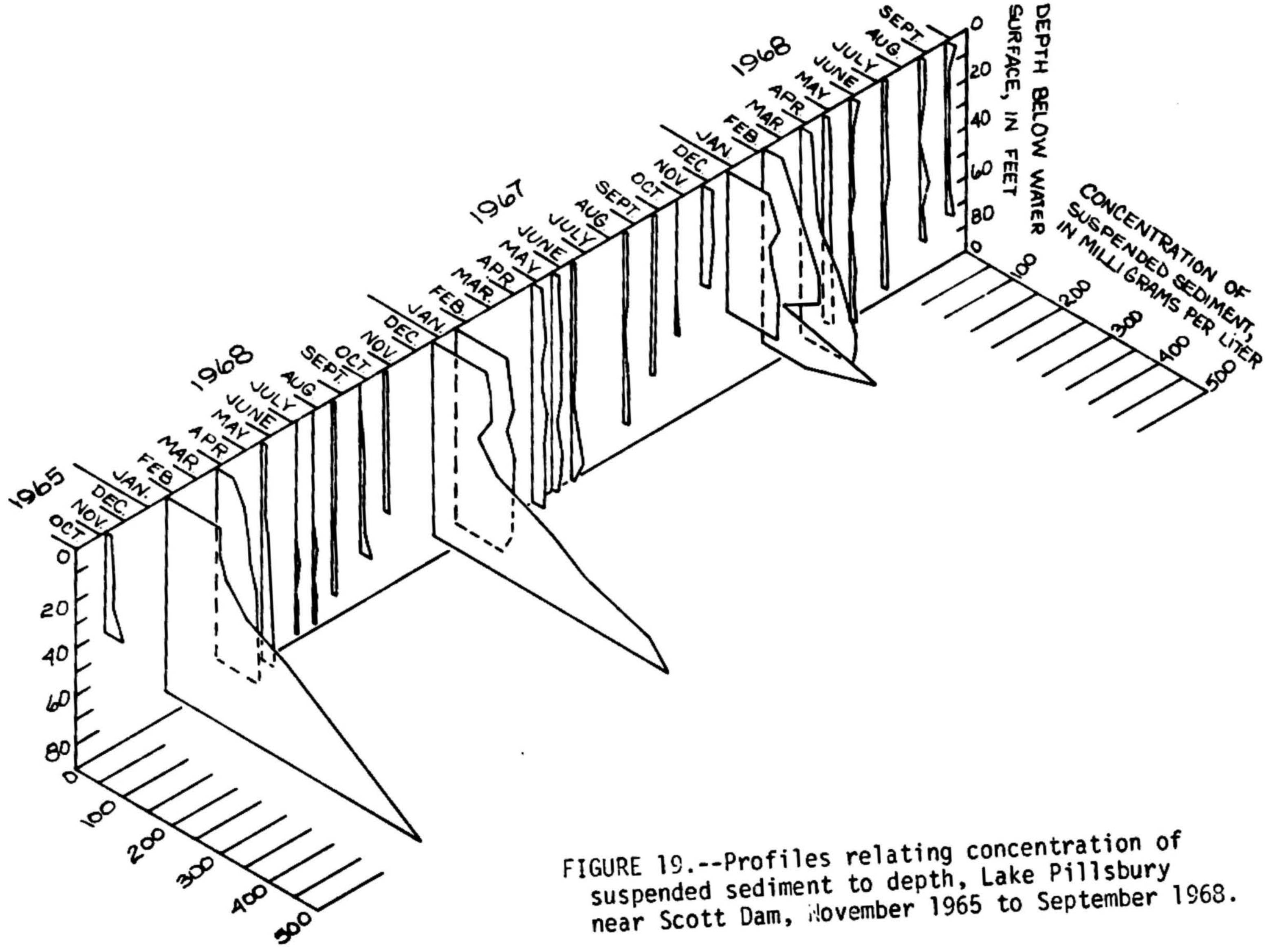
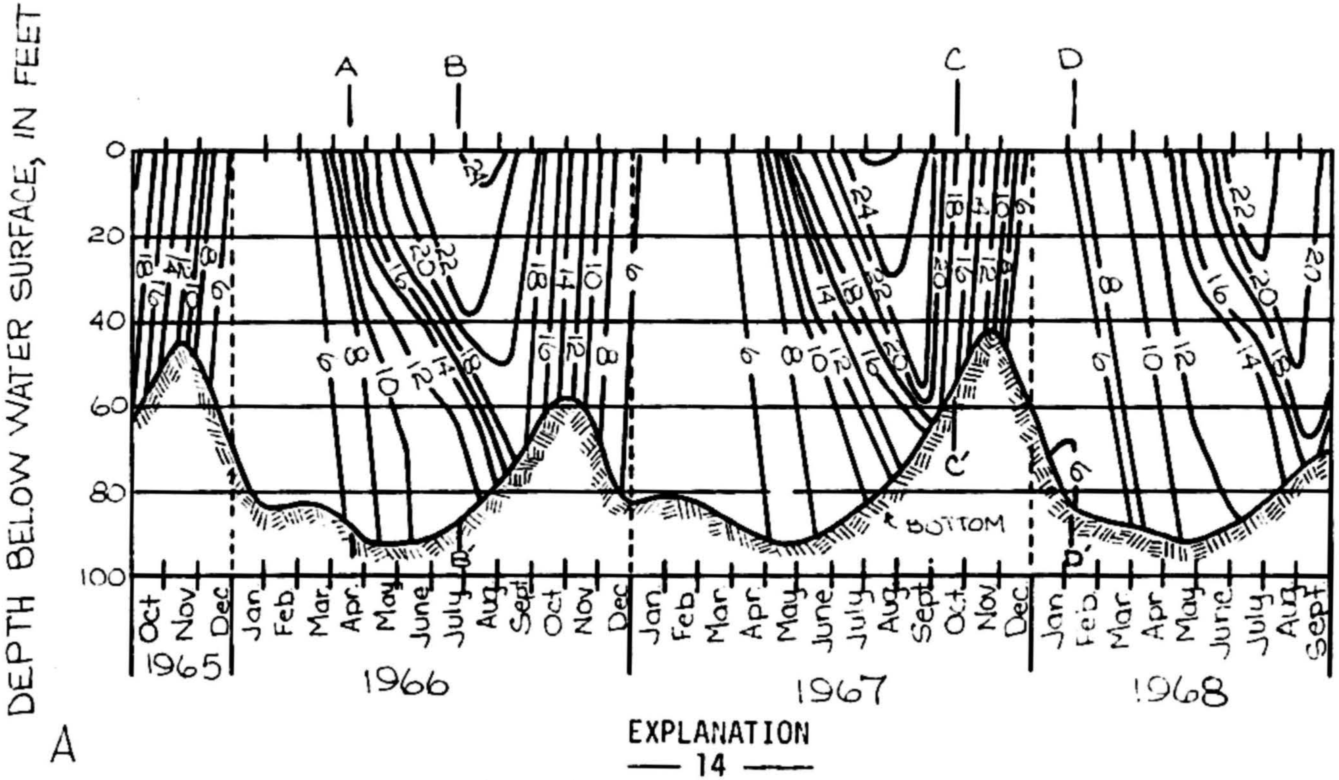


FIGURE 19.--Profiles relating concentration of suspended sediment to depth, Lake Pillsbury near Scott Dam, November 1965 to September 1968.

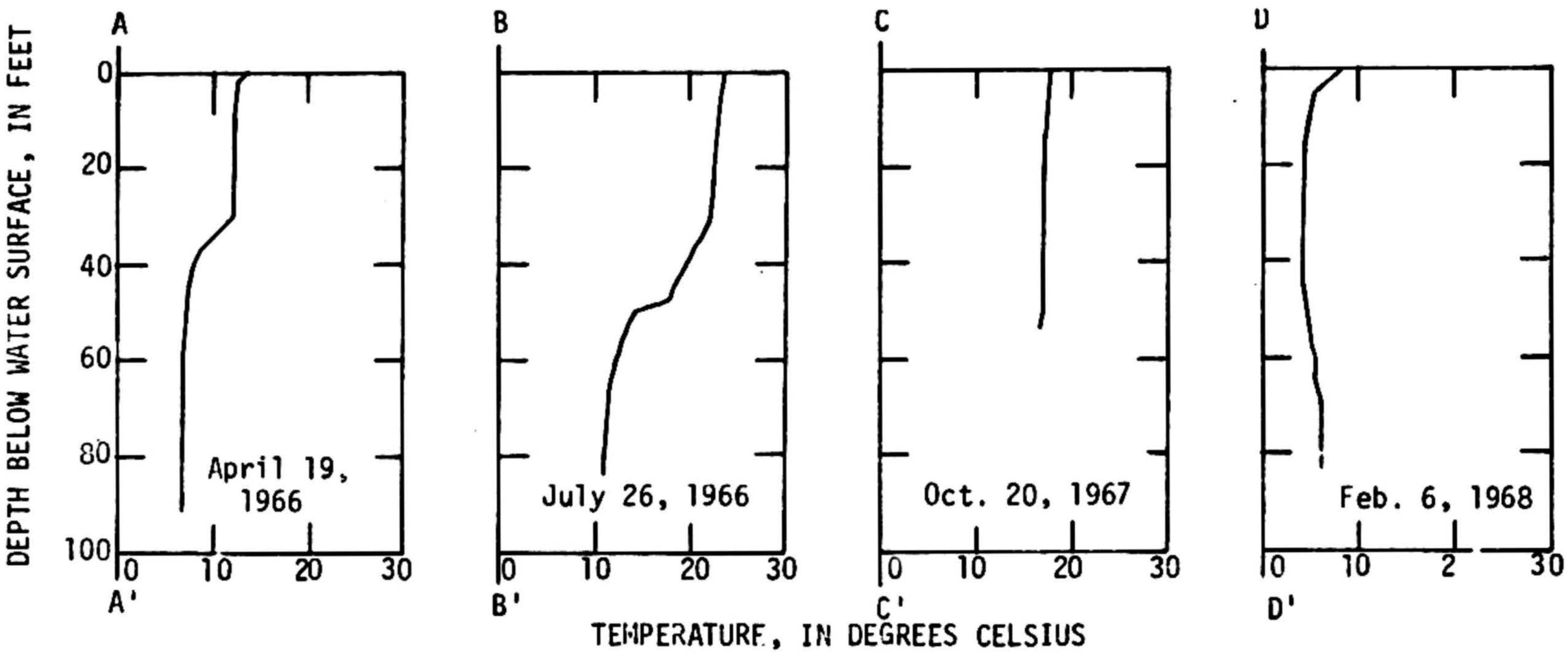


EXPLANATION

—— 14 ——

Line of equal water temperature
Interval 2 degrees Celsius

FIGURE 20.--A. Seasonal variations in temperature at Lake Pillsbury, October 1965 to September 1968. The variation in the bottom depth is due to variation in the lake level. B. Profiles of seasonal temperatures shown in A.



B

FIGURE 20.--Continued.

Temperatures near the surface of Lake Pillsbury were continuously recorded near the dam (fig. 21) from January 1966 to September 1968 and a range of 5°C to 27°C was noted. The water was warmest in July and August and the coldest in December and January. In the winter the diurnal range in temperature is rarely more than 1°C, but in the summer the range is often as much as 3°C.

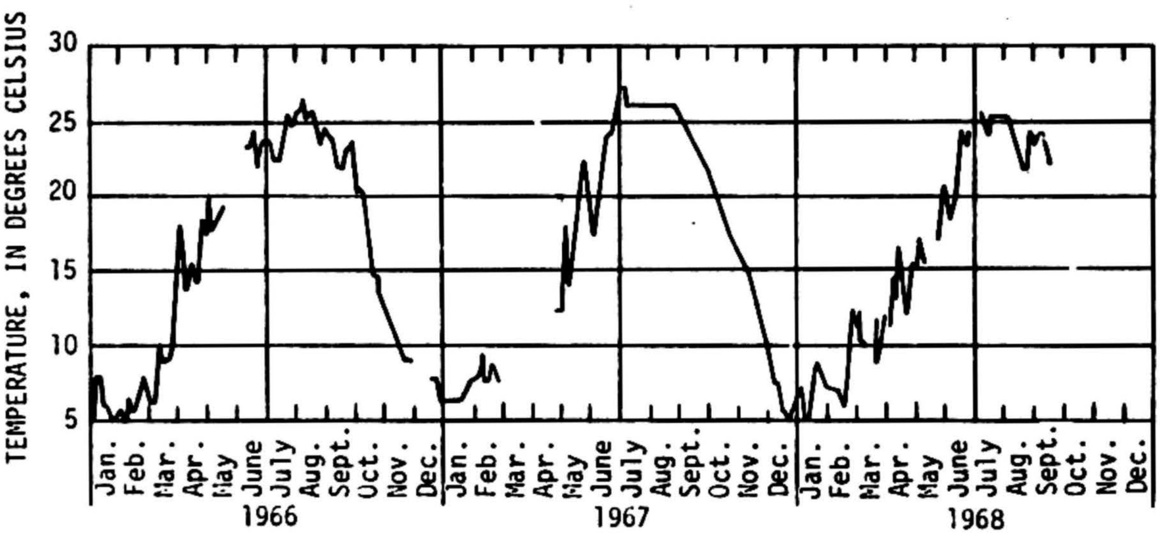


FIGURE 21.--Maximum daily temperatures of water near the surface of Lake Pillsbury, January 1966 to September 1968.

TURBIDITY

Factors Related to Turbidity

Turbidity, like suspended-sediment discharge in a stream, can usually be correlated with water discharge. In general, turbidity increases as water discharge increases in unregulated streams; however, because much of the discharge in the Russian River basin is regulated by Coyote Dam and the diversion at Potter Valley, the relation between discharge and turbidity is very poor. Instead of discharge, periods of rainstorms or precipitation were correlated with periods of turbid water in the section on the persistence of turbidity (p. 46-95).

Phytoplankton (fig.22), especially algae, can cause turbidity at times of low flow and no rainfall. An algal bloom during low flow can make the water turbid, but highly turbid water reduces reproduction by shutting out sunlight essential to the existence of phytoplankton. Therefore, phytoplankton can produce a certain level of turbidity before their reproduction is affected. During periods of high erosion in the basin, such as during rainstorms, the water becomes too turbid to permit a plankton bloom and the turbidity caused by phytoplankton is negligible.

Activities of man can create turbidity not connected with rainstorms. Logging, road building, and sand and gravel mining, for example, can produce material that is transported or spilled directly into streams. All these activities occur in the Russian River basin.

The map in figure 23, modified from Goldman (1961, 1964), shows the location of 12 sand and gravel plants in the Russian River basin. Most of these plants were downstream from Healdsburg and, because most turbidity data were obtained upstream from those plants, the influence of the sand and gravel mining on turbidity was not fully noted. The Russian River, however, was observed to be turbid near Guerneville sometimes when the river was clear upstream from Healdsburg (p. 94). The conclusion could be drawn that sand and gravel mining was, at times, responsible for turbid water in the streams in the Russian River basin.

FIGURE 22.--Typical diatoms found in the suspended material in the Russian River Lasin. This sample was collected at the East Fork Russian River near Ukiah, June 24, 1964. Length of large diatom is about 0.11 mm.

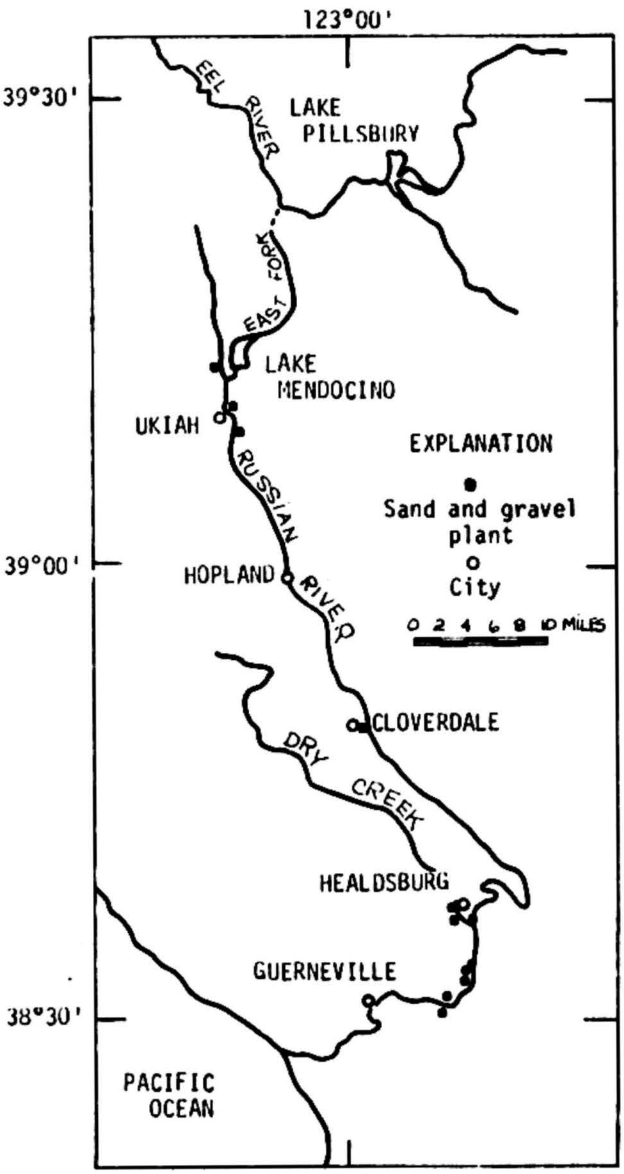


FIGURE 23.--Location of sand and gravel plants in the Russian River basin (modified from Goldman, 1961 and 1964).

Relation Between Turbidity and the Concentration of Suspended Sediment

The turbidity of a sample of a mixture of water and sediment may be related to the concentration of suspended sediment. However, differences in the mineralogy, shape, color, and size of sediment particles in samples of the same concentration will produce different values of turbidity, as turbidity is a measure of opacity rather than quantity. Nevertheless, a consistent linear relation between concentration and turbidity may exist if certain characteristics of the suspended particles remain uniform from sample to sample. In some streams in the Russian River basin, the particle-size distribution of suspended sediment varies only slightly with discharge. That is, the percentages of sand, silt, and clay are approximately the same for a wide range of discharge. If the particle-size distribution and mineralogy of the suspended sediment remains uniform with discharge, then turbidity would be an index of the concentration of the suspended sediment. The relation would likely hold only at a given section in a stream and probably would not be generally applicable for streams throughout the basin. This would be especially true in the Russian River basin where the particle-size distribution of the suspended sediment varies greatly in different streams because of the regulated flow from the Potter Valley powerhouse and Lake Mendocino. Because coarse sediment drops out of suspension as flow passes through reservoirs, the percentage of sand or larger particles is either very small or is zero in most samples from stations immediately downstream from the reservoirs. A small quantity of sand, which, because of its weight, has a great effect on concentration, may have only a minor effect on turbidity if clay is present in the sample. Because clay has a greater surface area per unit weight than sand and, thus, scatters more light than an equal weight of sand, a sample containing only clay would have a greater turbidity than a sample containing an equal concentration of sand.

Organisms, such as diatoms, have a much lower specific gravity than the clastics commonly carried in suspension. A sample containing only diatoms would have more particles and a higher turbidity than would a sample containing an equal concentration of clastics of an equal particle size. Therefore, some of the scatter of a plot of points relating turbidity to concentration may be attributed to different relations for samples containing mostly clastics and for samples containing mostly diatoms.

The scatter of points in the relation of turbidity to concentration of suspended sediment for Dry Creek near Geyserville for the 1965 water year (fig. 24) is typical of the scatter in the relation for many stations in the basin. The plot of figure 24 shows a considerable scatter of points for lower values of turbidity; however, this is expected because of the presence of organic material at low flow. Scatter throughout the plot is related to several factors, the most important of which are the characteristics and particle-size distribution of suspended-sediment particles.

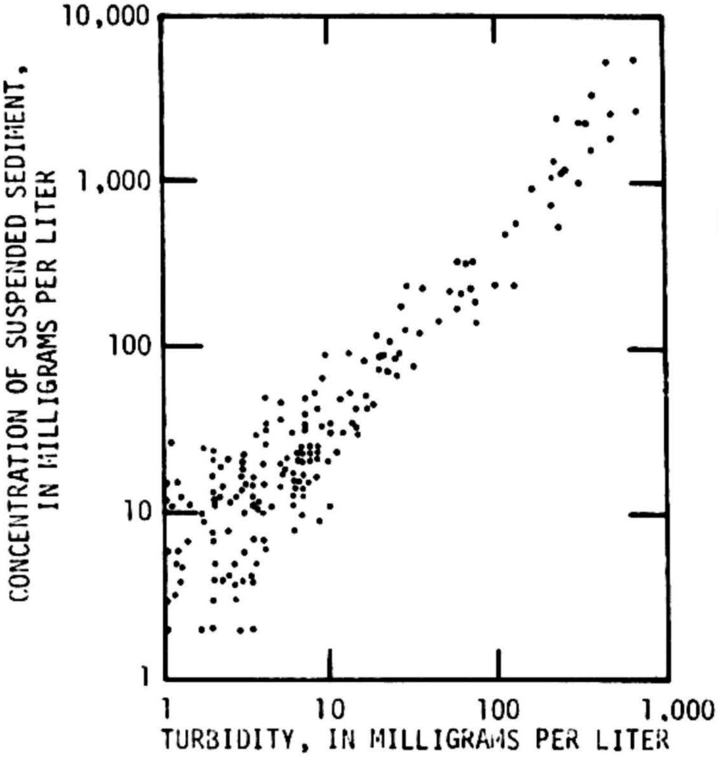


FIGURE 24.--Typical plot of turbidity versus concentration of suspended sediment in the Russian River basin. Data are for Dry Creek near Geyserville, 1965 water year.

A least-squares line was determined for the yearly relations of turbidity and concentration of suspended sediment at several stations for comparative purposes and to check for possible trends. The resulting lines and the characteristics of the data from which they were determined are shown and discussed below for each station studied. The correlation coefficient (r) was more than 0.90 except for Lake Mendocino in 1967 (r = 0.67) and 1968 (r = 0.74), and East Fork Russian River near Calpella in 1965 (r = 0.84) and 1966 (r = 0.88).

Figures 25A and 25D show the least-squares lines relating turbidity and concentration at the Potter Valley powerhouse tailrace and at East Fork Russian River near Ukiah, where the flows are released from Van Arsdale Reservoir and Lake Mendocino respectively. The samples taken at these stations and at Lake Mendocino (fig. 25C) were characterized by an absence of coarse material, and turbidity tended to be greater than concentration in a given sample.

At Russian River near Cloverdale (fig. 25F), flow was partly regulated by the storage and release of water from Lake Mendocino (fig. 25C). However, coarse material in the stream channel between the lake and the station was available for transport; thus, turbidity characteristics changed between Lake Mendocino and Cloverdale. For example, concentration was consistently higher than turbidity at Russian River near Cloverdale (fig. 25F), whereas at East Fork Russian River near Ukiah, turbidity was consistently higher than concentration (fig. 25D). The relation of turbidity to concentration was somewhat similarily affected between Potter Valley powerhouse tailrace (fig. 25A) and East Fork Russian River near Calpella (fig. 25B).

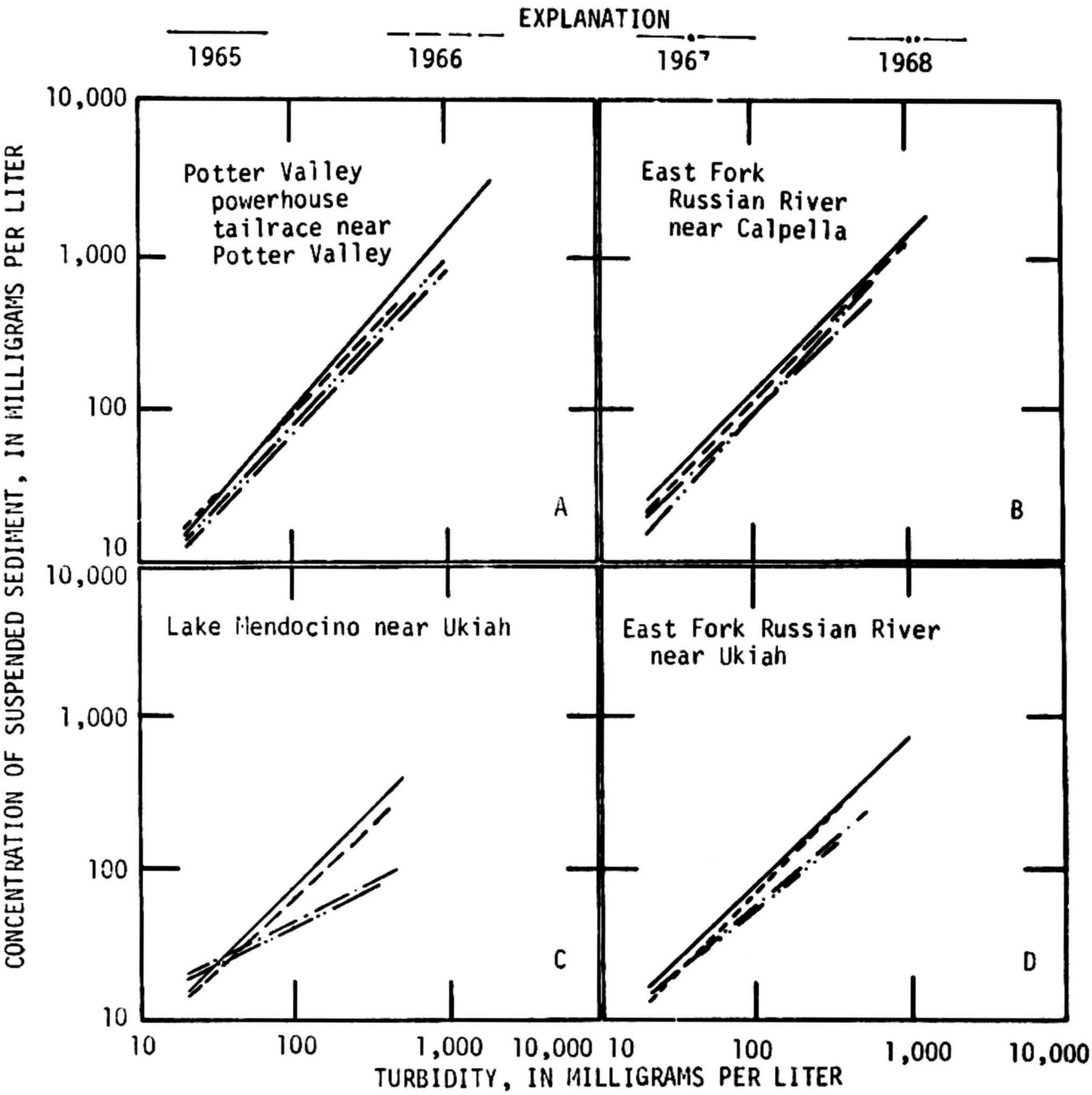


FIGURE 25.--Regression lines showing the relation between turbidity and concentration of suspended sediment for successive water years at eight stations:

A. 4710 Potter Valley powerhouse tailrace near Potter Valley.
B. 4615 East Fork Russian River near Calpella.
C. 4618 Lake Mendocino near Ukiah.
D. 4620 East Fork Russian River near Ukiah.

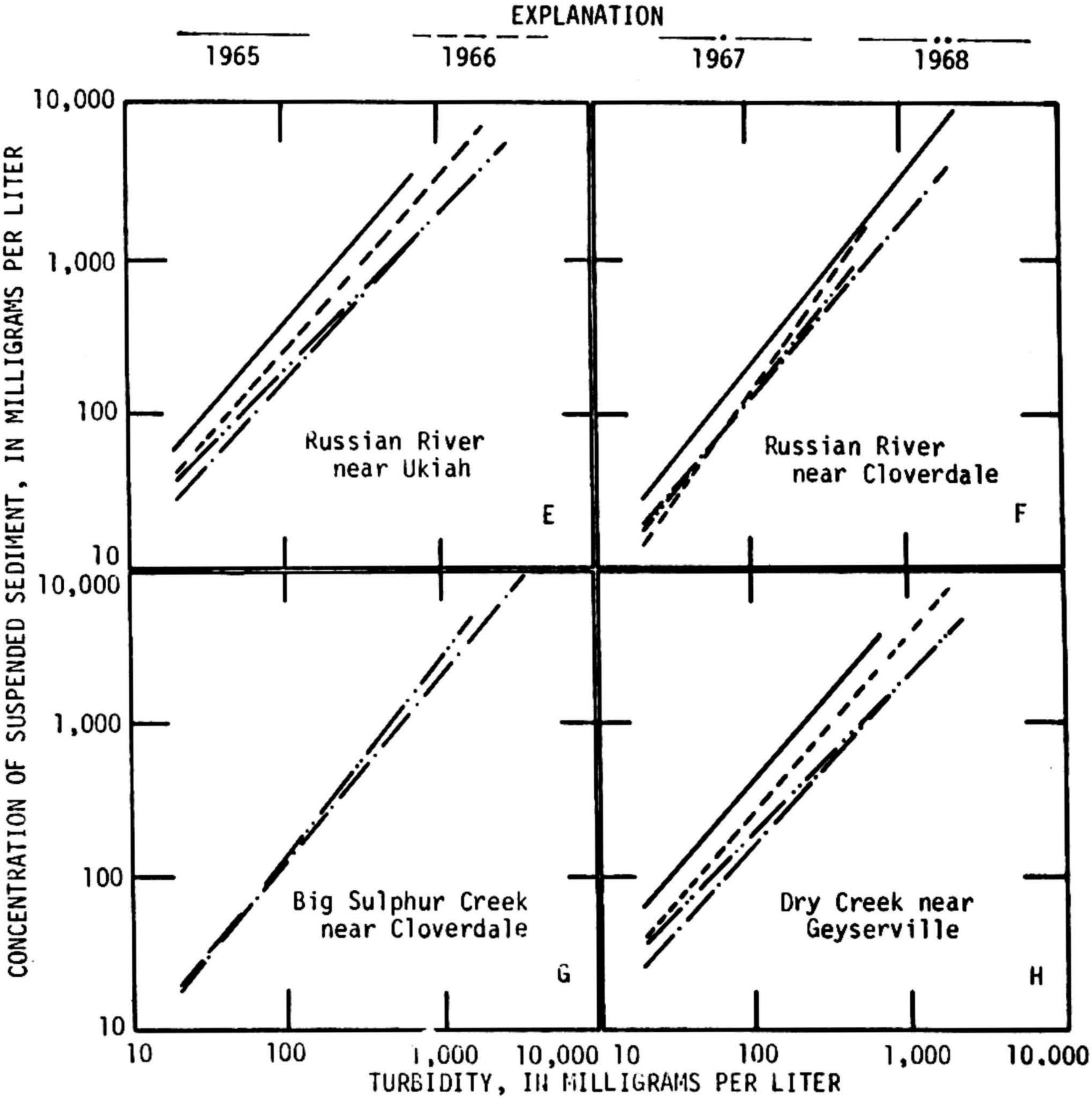


FIGURE 25.--Continued.

E. 4610 Russian River near Ukiah.
F. 4630 Russian River near Cloverdale.
G. 4632 Big Sulphur Creek near Cloverdale.
H. 4652 Dry Creek near Geyserville.

At the three stations on unregulated streams in the Russian River basin, concentration was consistently higher than turbidity, and particle-size analyses indicated 10 to 40 percent sand in most samples. Among the station records studied, the yearly change in the concentration-turbidity relation was greatest at Dry Creek near Geyserville (fig. 25H) perhaps because of the effects of severe flooding during the 1965 water year. The yearly concentration-turbidity relations at Russian River near Ukiah (fig. 25E) were similar to, but more widely scattered than, those at Russian River near Cloverdale (fig. 25F) which is partly regulated. Data were available for the 1967 and 1968 water years at Big Sulphur Creek near Cloverdale, and the plot of turbidity versus concentration at that station showed a relation similar to concentration-turbidity relations of the other stations on unregulated streams (fig. 25G).

Certain characteristics of the concentration-turbidity relation were similar at each station. Almost every line for the 1967 and 1968 water years shifted downward from the 1965 and 1966 lines. This shift is probably related to a decrease in the amount of coarse material made available for transport by the severe erosion in the 1965 water year and subsequently carried in suspension or to a change in instruments used for measuring turbidity (p. 17). Nearly all the plots of turbidity versus concentration (for example, fig. 24) had a slight curvilinear trend at the upper ends of the plots indicating that concentration increases more rapidly than turbidity. This may be related to an increase in the amounts of coarse material present in samples of higher flows, to the corresponding difficulty in measuring high turbidity because of the rapid settlement of the larger particles, and to the possibility that, as turbidity approaches its maximum, it does not increase as rapidly as it does in the lower ranges.

Persistence of Turbidity

The data from which this general discussion of the persistence of turbidity of each stream during 1964-68 are shown in the accompanying illustrations and tables. The illustrations show the days on which the water was turbid, the magnitude of the turbidity greater than 20 mg/l, the precipitation, and the percentage of algae present in the suspended material. The turbidity plotted on the illustrations is based on the turbidity of the sample collected on that day and is intended only to show a trend. It should not be regarded as an average turbidity for each day. The months of September and October were omitted from the illustrations because the water was clear during those months each year of the study. The periods and intensity of precipitation are shown for correlation with periods of turbid water.

Lake Pillsbury near Potter Valley (Sta. No. 4700)

In the fall of each study year the low level of the lake exposed the deltas formed at the mouths of tributaries to the lake. During the fall, even though the inflow was low, the inflow eroded the exposed delta, to which a considerable quantity of material was added by the flood of December 1964. The erosion of the delta created the highest turbidity (table 7) measured in the tributaries. However, because the area was not readily accessible, the inflow was not sampled during a heavy rainstorm when inflow turbidity might have been even higher. During the winter, because the erosion of the deltas continued and because the water flowing into the lake became turbid from material eroded during rainstorms in the upper basin, the lake became turbid, and the water released from the reservoir became turbid. In late spring and summer as the lake level rose, the deltas were submerged, the inflow declined, and the lake became clear.

Eel River below Scott Dam, near Potter Valley (Sta. No. 4705)

Downstream from Scott Dam, periods of high turbidity were related to periods of high turbidity in Lake Pillsbury. The turbidity downstream from Scott Dam was, with some exceptions, the same order of magnitude as the turbidity of the water passing through the tailrace of the Potter Valley powerhouse downstream (table 7).

Potter Valley Powerhouse Tailrace near Potter Valley (Sta. No. 4710)

During the study period before the flood of December 1964, the water passing through the tailrace was turbid only during storm periods and cleared up fairly rapidly after each storm (fig. 26). After the flood the water at the tailrace was turbid until July 1965. From 1966 to 1968 the water became turbid after the first major storm of the rainy season (usually in November) and remained turbid for several months each year (table 8). Algae were not a primary cause of turbid water although they may have contributed to its persistence for short periods.

TABLE 7.--*Measurements of turbidity at Lake Pillsbury and Eel River below Scott Dam and correlative measurements at Potter Valley powerhouse tailrace*

Date	Lake Pillsbury contents (thousand acre-feet)	Turbidity (milligrams per liter)						
		Lake Pillsbury				Eel River below Scott Dam	Potter Valley powerhouse tailrace
		Rice Fork inflow	Eel River inflow	Scott Dam[1] Surface	Scott Dam[1] Bottom		
Sept. 30, 1965	35.9	-	-	3	35	-	11
Nov. 10	18.1	1,210	2,270	20	50	13	5
Dec. 15	38.0	33	36	42	-	46	37
Jan. 19, 1966	67.0	4	35	126	495	580	195
Feb. 15	66.9	10	17	186	532	171	110
Mar. 22	67.1	12	50	60	150	123	70
Apr. 19	83.1	3	38	88	124	57	42
May 17	86.1	1	4	8	36	26	22
June 14	85.0	0	1	1	31	30	14
July 26	71.7	1	1	1	1	9	6
Aug. 16	62.4	1	3	2	11	8	6
Sept. 20	45.2	23	500	2	31	12	5
Oct. 18	28.3	-	-	2	8	7	7
Nov. 18	20.7	-	-	-	-	270	320
Dec. 22	66.8	616	44	420	-	322	192
Jan. 17, 1967	62.9	2	2	140	-	122	149
Apr. 26	78.0	10	20	40	45	40	38
May 15	81.6	3	38	19	23	26	20
June 13	86.8	1	6	6	20	14	10
July 14	77.3	1	1	1	1	1	14
Aug. 15	59.9	1	10	1	15	6	12
Sept. 20	39.1	32	60	0	0	0	-
Oct. 20	25.2	305	15	2	3	-	1
Nov. 21	13.2	244	84	26	28	-	13
Dec. 20	24.1	8	45	153	155	-	120
Feb. 6, 1968	67.9	44	56	-	-	-	155
Mar. 20	75.3	13	10	45	230	-	54
Apr. 19	79.9	0	1	23	42	-	22
May 24	86.3	1	1	3	13	-	3
July 9	78.4	0	0	1	1	-	1
Aug. 23	58.7	2	3	4	3	-	-
Sept. 27	44.1	6	20	4	8	-	-

[1]Samples were collected about 50 feet upstream from dam.

TABLE 8.--*Periods of persistent turbidity, East Fork Russian River, 1965-68*

Station	Approximate period of persistent turbidity			
	Water year			
	1965	1966	1967	1968
Potter Valley powerhouse tailrace	Dec. 19-July 17	Nov. 12-May 20	Nov. 15-May 19	Nov. 30-Apr. 8
East Fork Russian River near Calpella	Dec. 20-July 16	Nov. 15-May 20	Nov. 15-May 19	Nov. 30-Apr. 15
Lake Mendocino near Ukiah	Dec. 24-May 13	Nov. 22-June 6	Nov. 21-June 1	Jan. 30-Apr. 17
East Fork Russian River near Ukiah	Dec. 21-May 19	Nov. 17-July19	Nov. 18-June 7	Dec. 2-Apr. 19

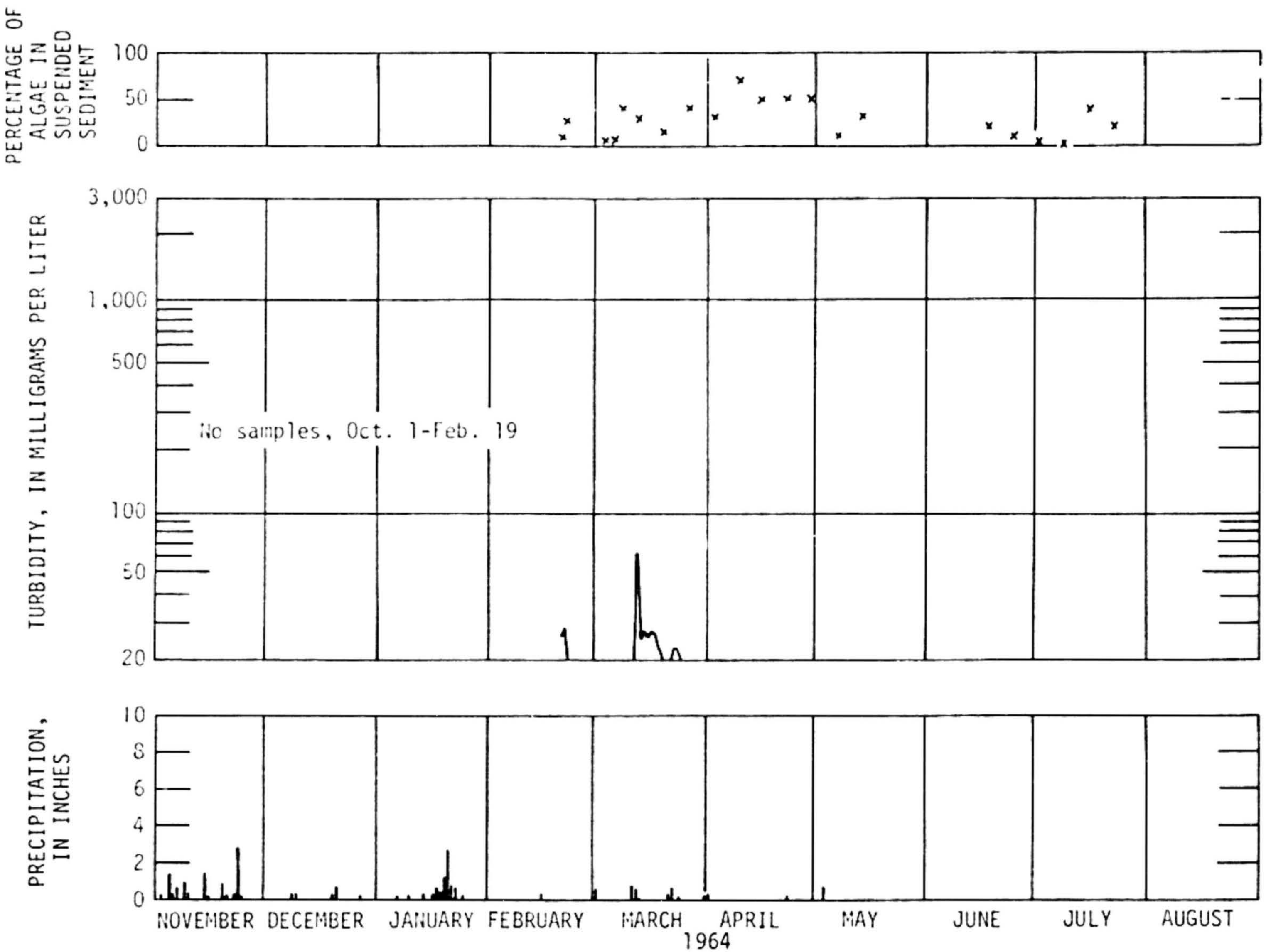
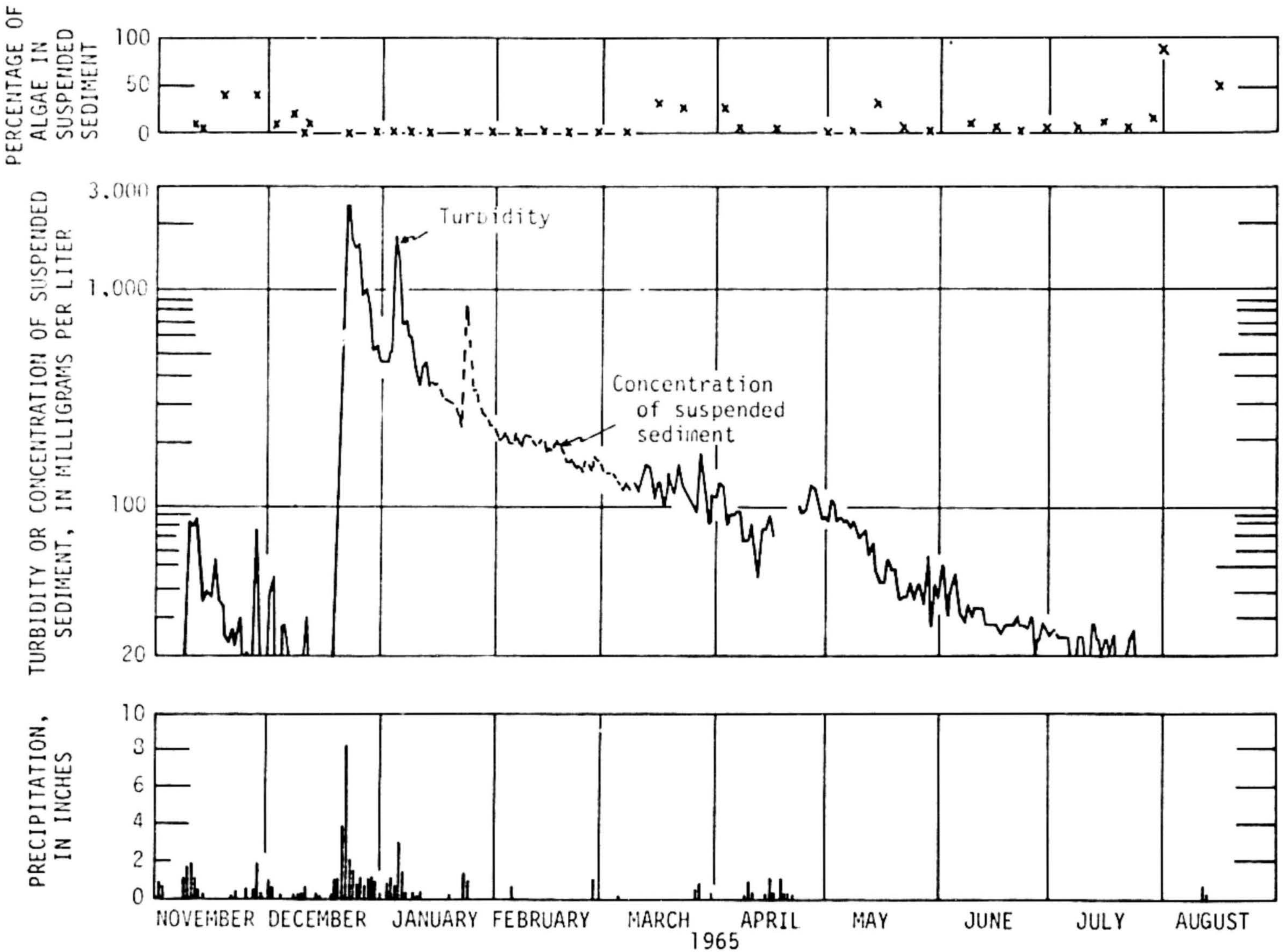


FIGURE 26.--Periods of turbid water, daily precipitation, and percentage of algae in the suspended material at Potter Valley powerhouse tailrace near Potter Valley, 1964-68. Precipitation data are from the U.S. Weather Bureau rain gage at Potter Valley.



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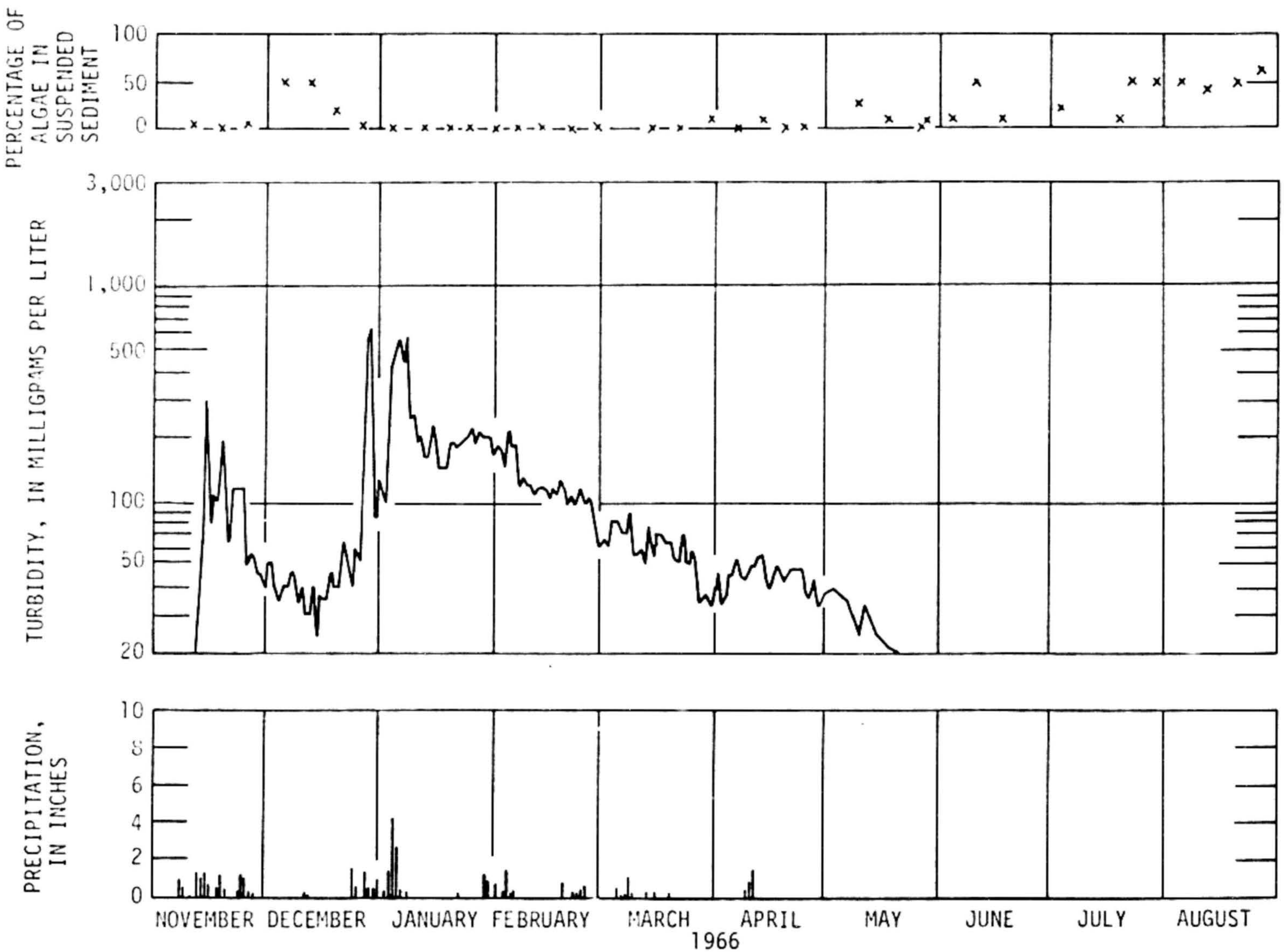

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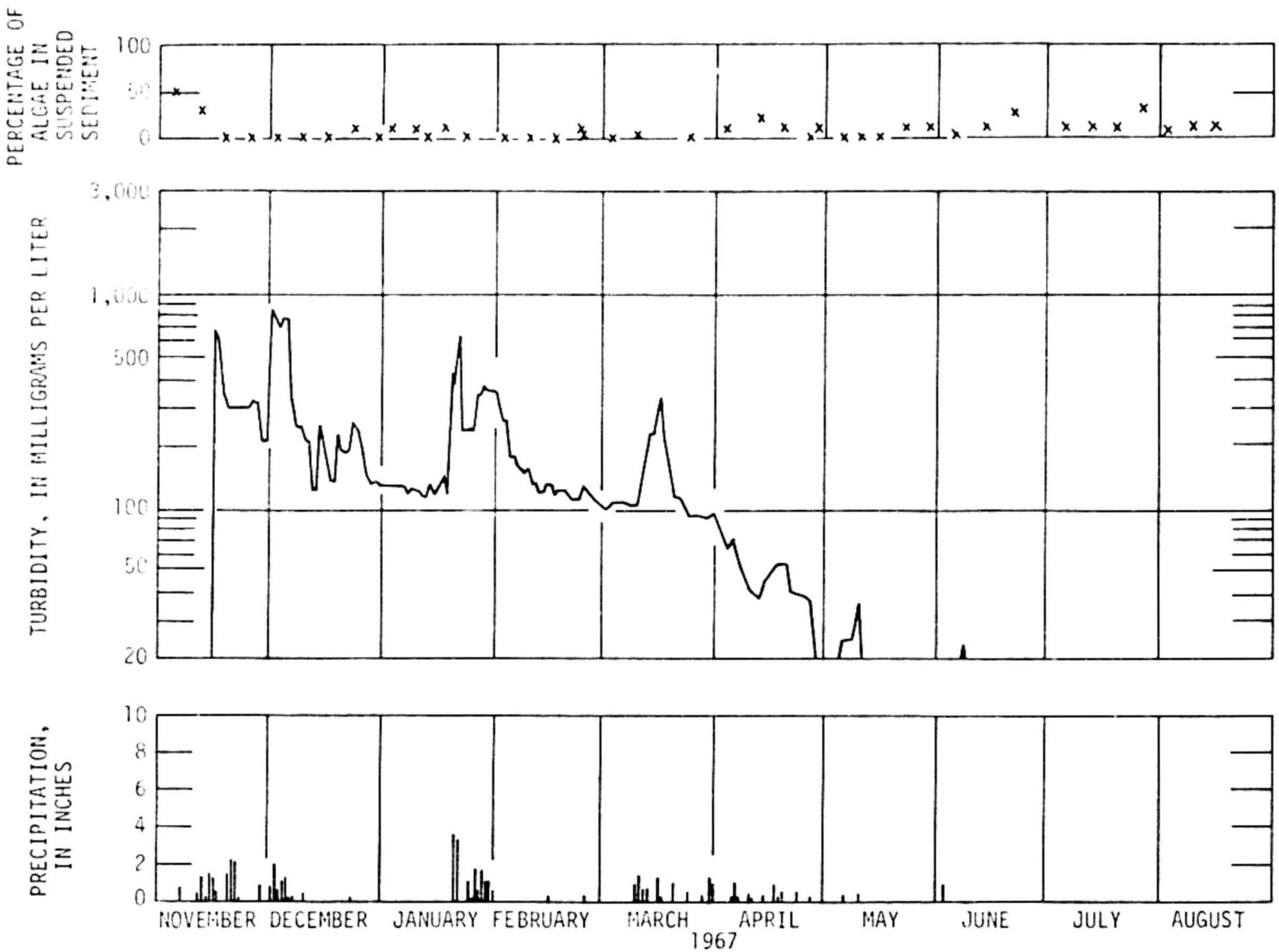

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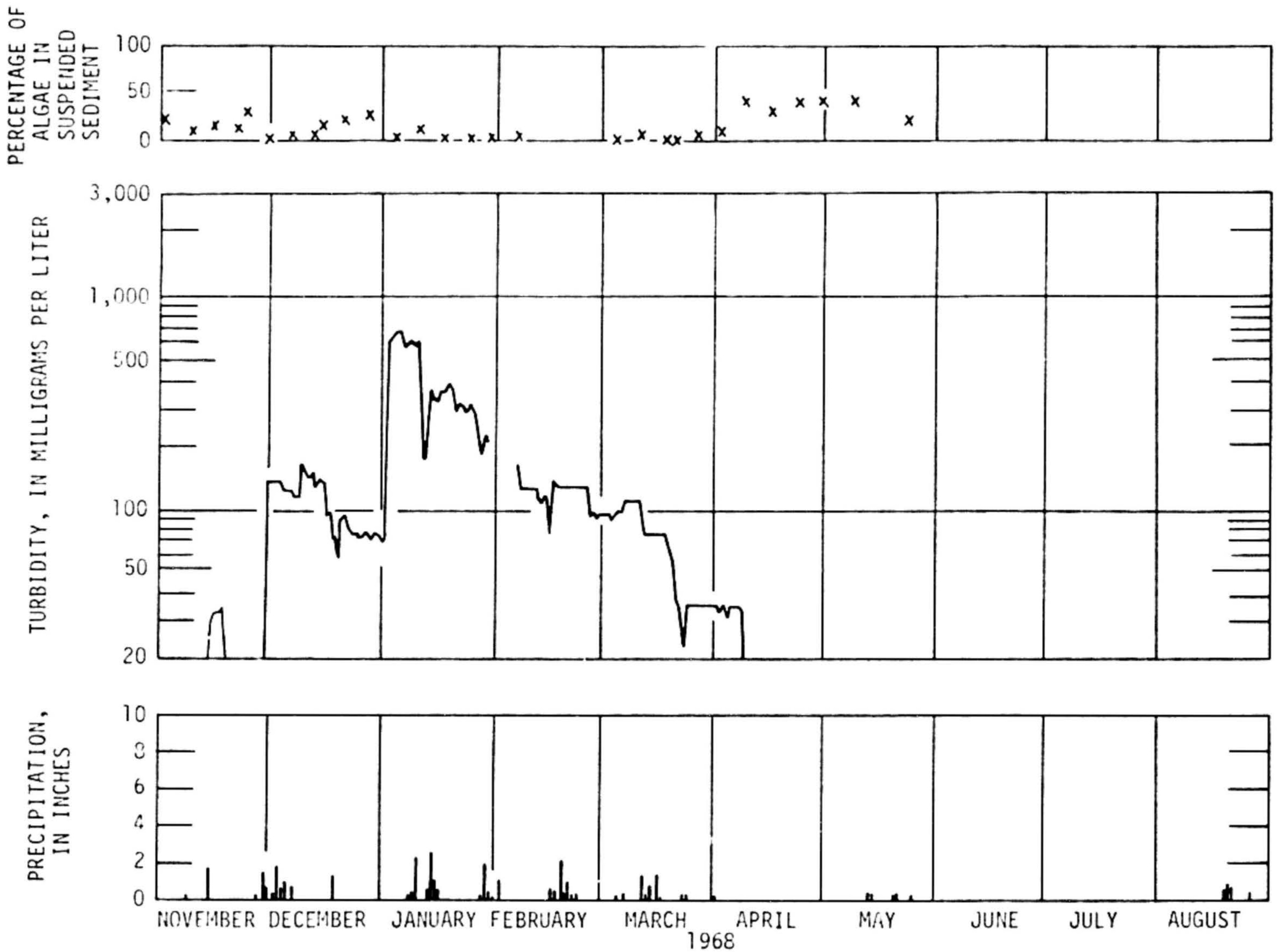


FIGURE 20.--Continued.

East Fork Russian River near Calpella (Sta. No. 4615)

During 1953-55 before Coyote Dam was constructed (p. 21), periods of turbid water in the East Fork (at the station East Fork Russian River near Ukiah) usually coincided with periods of rainfall (fig. 27A), and sometimes the water remained turbid several days after the rainfall had ceased. In 1954, however, the water remained turbid most of the time from mid-January to May 1 because of the pattern and intensity of the storms and perhaps because of turbid water diverted from the Eel River.

From February to mid-December 1964, water at East Fork Russian River near Calpella became turbid only during storms (fig. 27B). After the flood in December 1964, the river remained turbid in 1965 for about 8 months without becoming clear. In the 1966-68 water years, the river became turbid in November and remained turbid until April or May, so that for 5 to 7 months in each of those years, Lake Mendocino received an almost continuous supply of turbid water. The turbidity of the river at this station was influenced by the turbidity of the water imported from the Eel River, which was measured at Potter Valley powerhouse tailrace. The periods of persistent turbid water were generally the same at both stations (table 8). The discharge at the powerhouse tailrace represented 72 percent of the discharge at the Calpella gage and the persistence of the turbidity of the water at the powerhouse was reflected in the turbidity at the downstream gage (figs. 26 and 27B). The effect of the diverted Eel River water on the East Fork Russian River is seen in March 1965 (fig. 27B). The 1 day of that month that the turbidity dropped below 20 mg/l can be correlated with a decrease in discharge through the Potter Valley powerhouse tailrace. In the summer turbid water in the East Fork sometimes was created by the flushing of irrigation ditches and road construction in the basin.

Lake Mendocino near Ukiah (Sta. No. 4618)

The turbid conditions described in this section are based on samples taken from a depth of 10 feet or less near the outlet tower. The samples were collected almost daily from February 6, 1964, to September 30, 1965; afterwards sampling was done weekly. Usually the depth sampled near the outlet tower was about 40 feet and usually the turbidity of the samples of the entire column was similar. Only in 1968 was there enough difference between the turbidity of the surface and deepest samples to be plotted in figure 28. Because of the configuration of the dam and the structure beneath the outlet tower, the deepest sample collected was about 40 or 50 feet above the bottom and was not representative of bottom conditions in the reservoir.

The turbidity near the surface of the lake at the outlet tower was not particularly affected by storms in late 1964 before the severe storm in late December (fig. 28). A few days after the peak of that storm, the water near the surface became turbid and remained turbid for several months (table 8), and in 1966 and 1967 became turbid in November in a few days after a large storm and remained turbid for several months. In 1968 the surface was only intermittently turbid from December to April. Algal blooms helped to prolong turbid conditions almost every year.

The relation of depth to the turbidity of samples collected monthly at other sites in the lake (fig. 15) was similar to the relation of depth to the concentration of suspended sediment at point A as shown in figure 16 although turbidity was usually slightly higher than a corresponding concentration. A representation of the monthly turbidity values for 1966 at the three sites is shown in figure 29. The relation of surface to bottom turbidity in other years was similar, at all three sites, the surface turbidity was less than the turbidity near the bottom for most months, and the highest turbidities occurred in the period from December to March.

Currently, water released from the bottom of the lake is more turbid, generally, than water near the surface of the lake. If, however, a release of water could be made from near the surface, turbidity currents would not pass through the reservoir and out the bottom outlet, which would be closed, the water near the surface then might become more turbid from the accumulation and circulation of turbid water transported by the turbidity currents, and the difference in the turbidity of the surface and bottom waters might become less. A continuous release from the water near the surface, therefore, might not be much lower in turbidity than a release from the bottom. An optimum release to gain minimum turbidity might be obtained from a combination of selective releases from water near the bottom or the surface of the reservoir depending on the quantity and turbidity of the inflow, rate of release needed for storage requirements, and the quantity and clarity of water available for release from the upper part of the reservoir. Releasing from the surface where temperatures are the highest in the reservoir (especially in the summer) would also increase the temperature of water downstream, which might affect fish and other life in the river downstream.

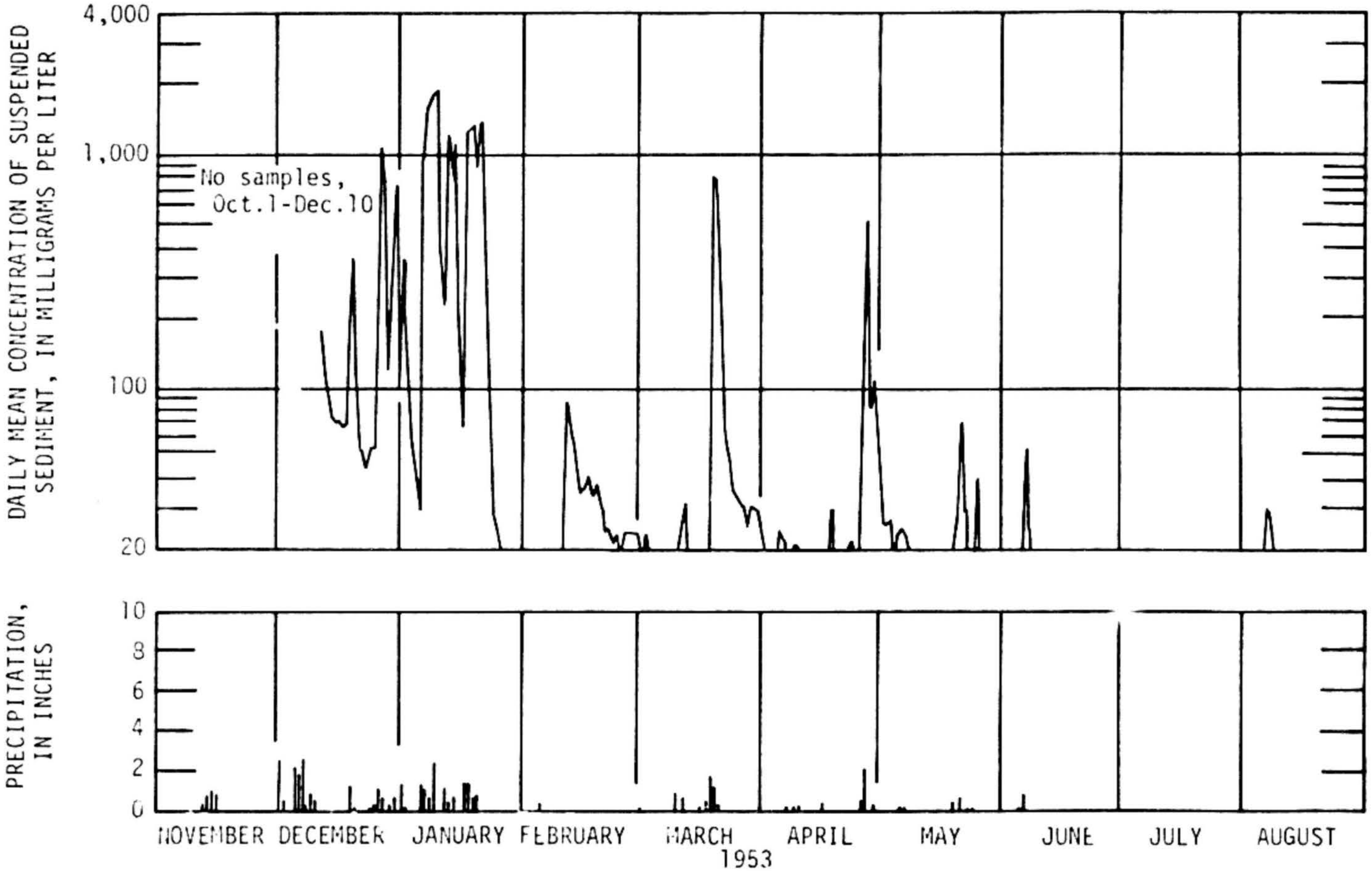
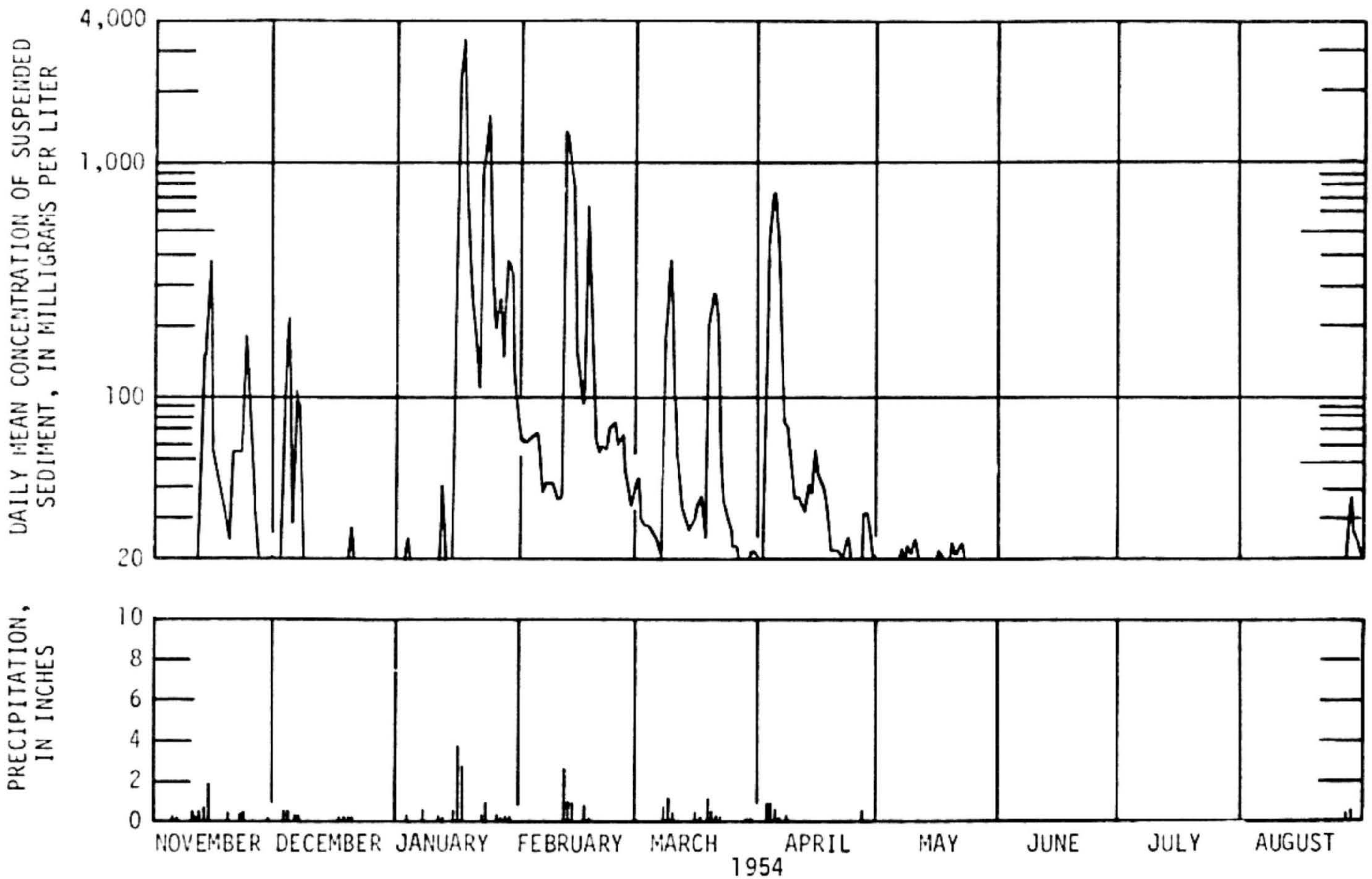


FIGURE 27A.--Periods of turbid water and daily precipitation in the suspended material at East Fork Russian River near Ukiah, 1953-55. Precipitation data are from the U.S. Weather Bureau rain gage at Potter Valley. Concentration of suspended sediment is used as an indicator of turbidity during 1953-55 because turbidity was not measured then.



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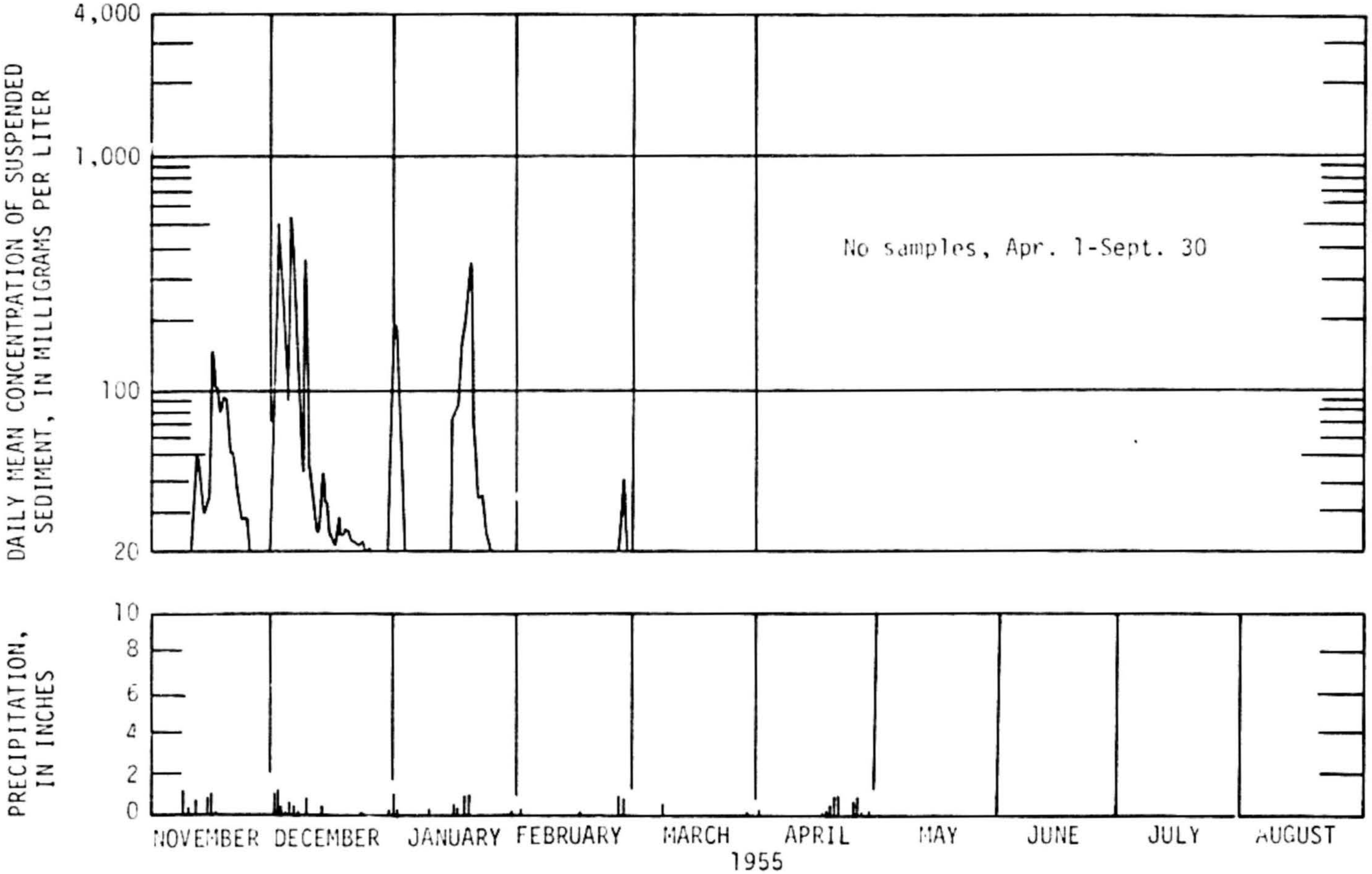

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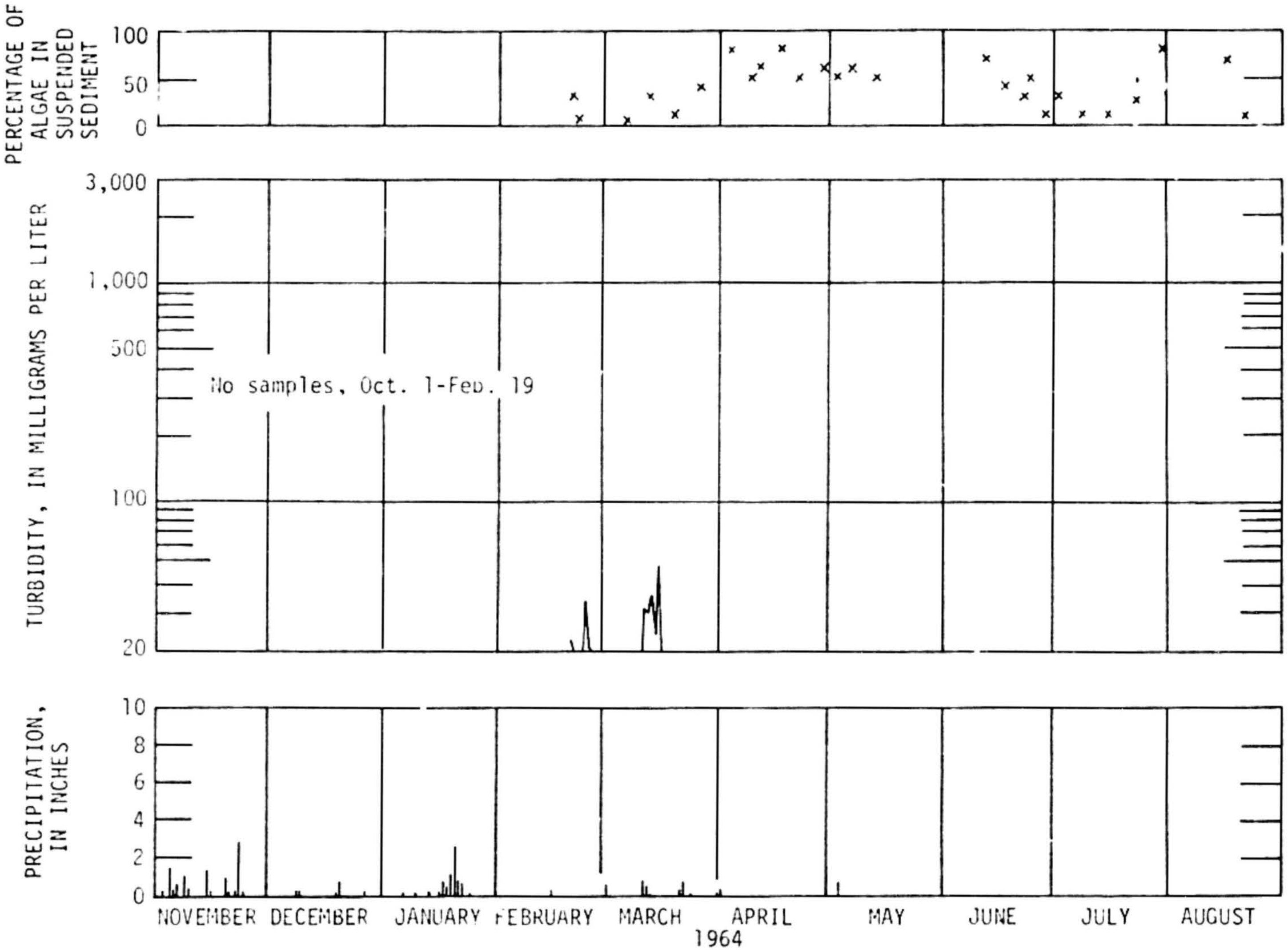
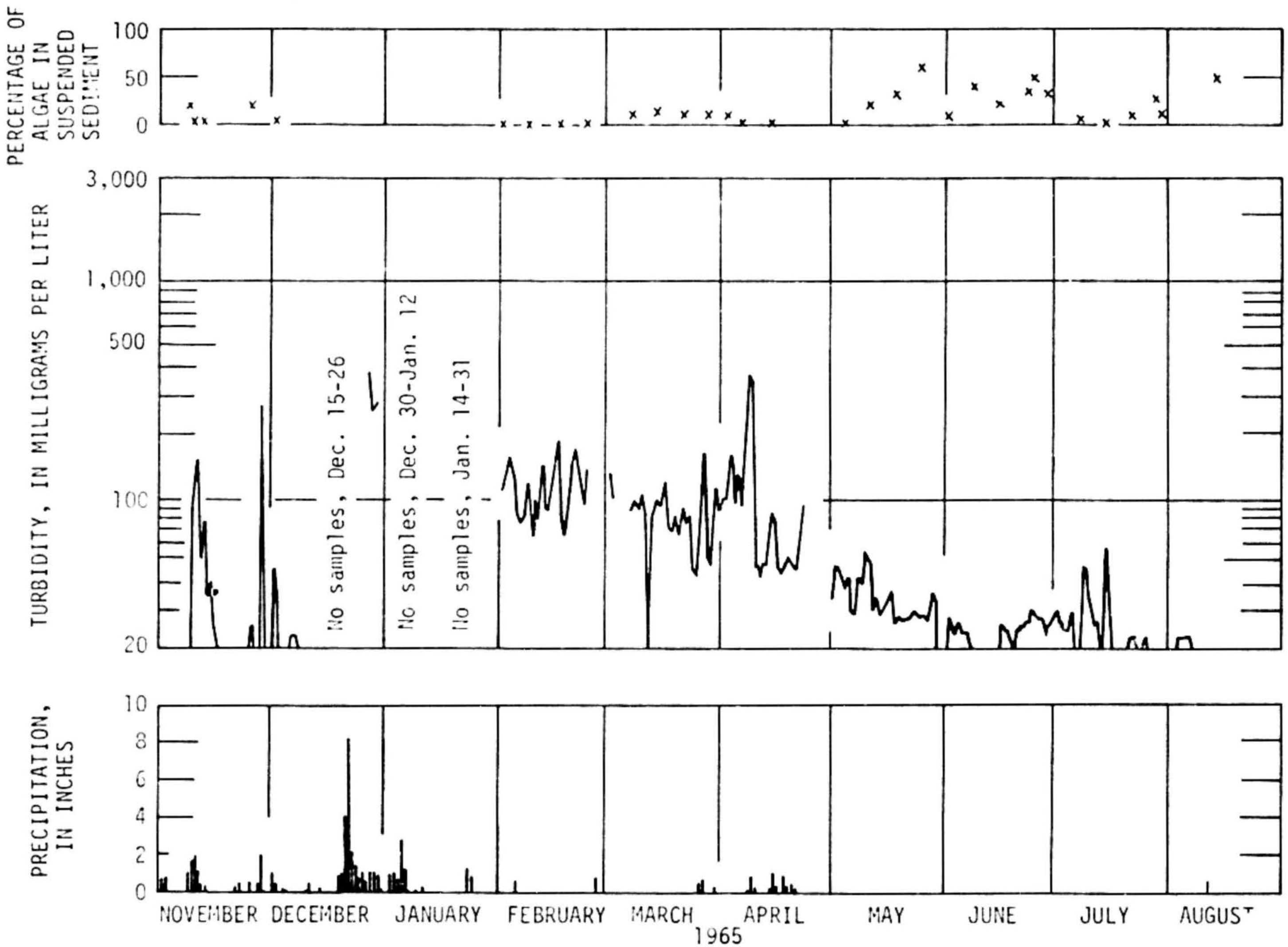


FIGURE 27B.--Periods of turbid water, daily precipitation, and percentage of algae in the suspended material at East Fork Russian River near Calpella, 1964-68. Precipitation data are from the U.S. Weather Bureau rain gage at Potter Valley.



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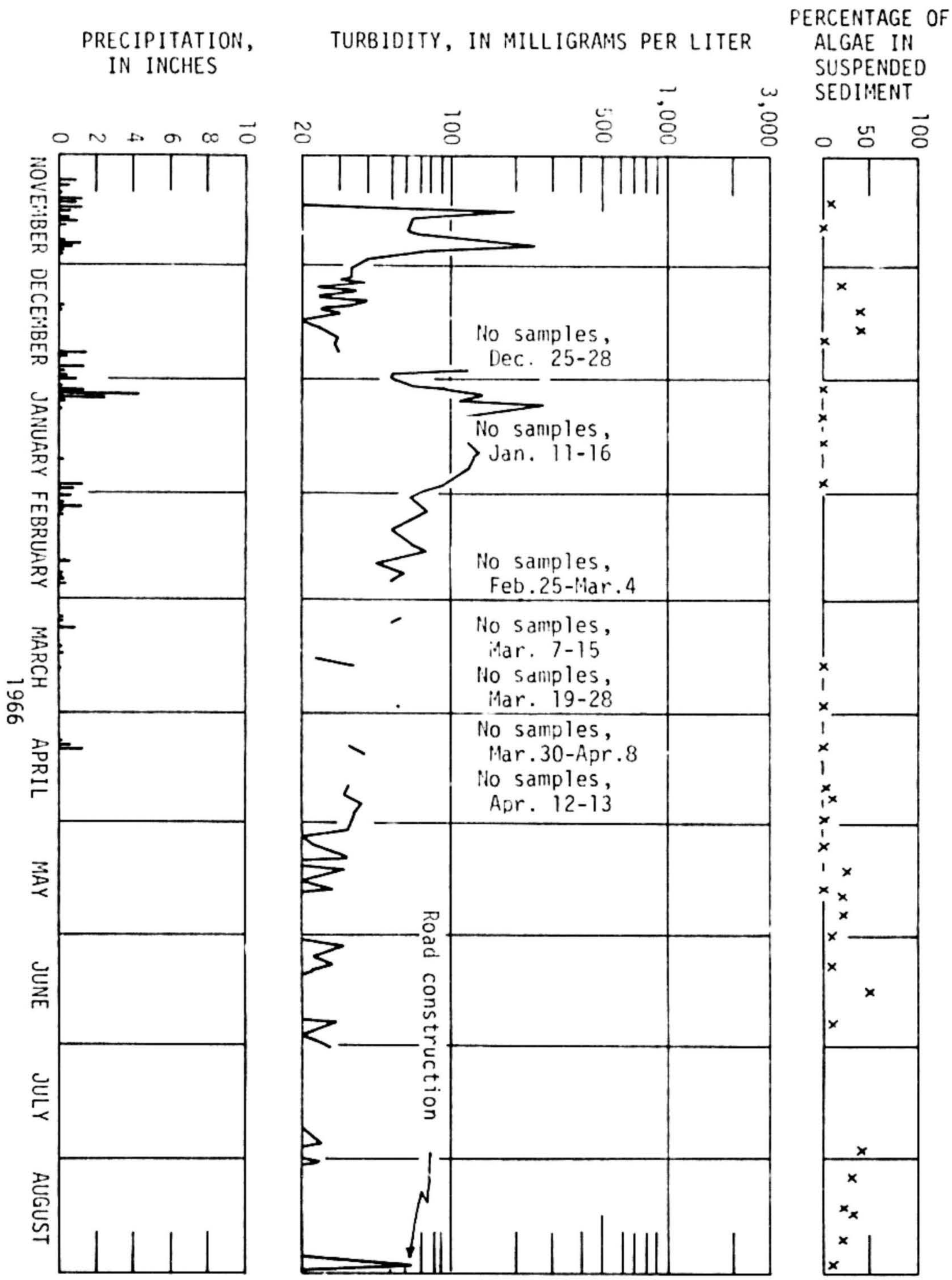

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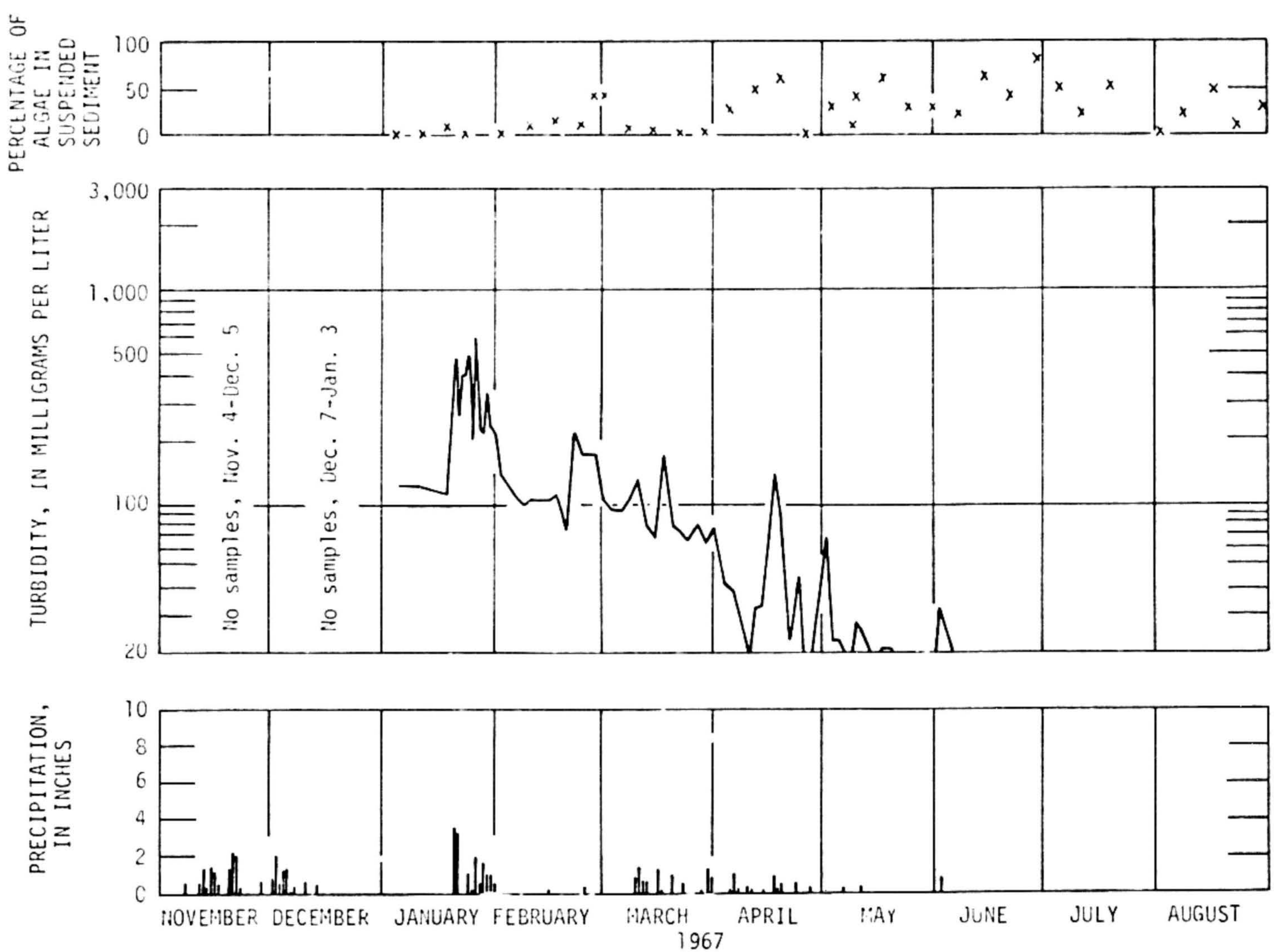
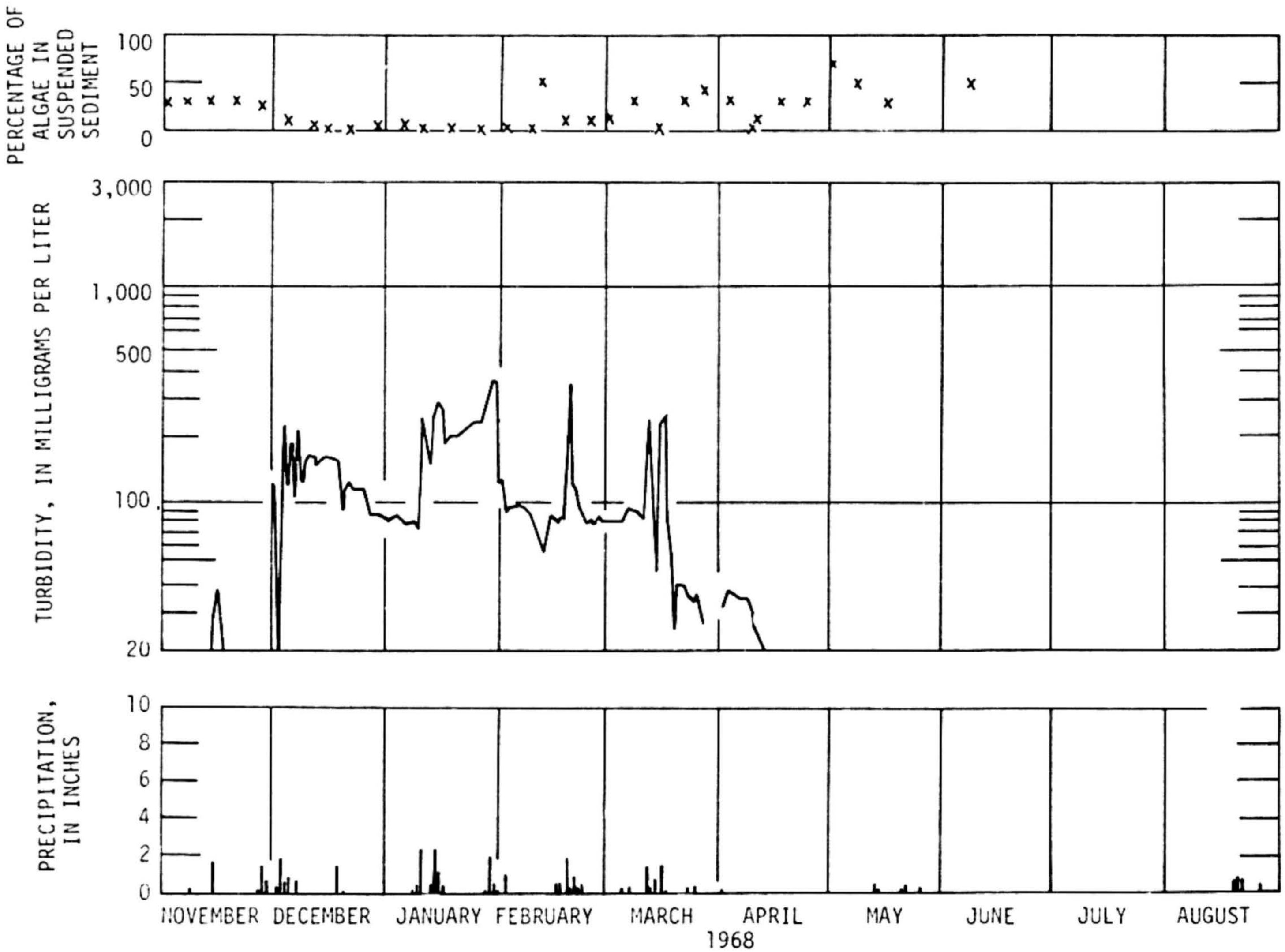


FIGURE 27B.--Continued.



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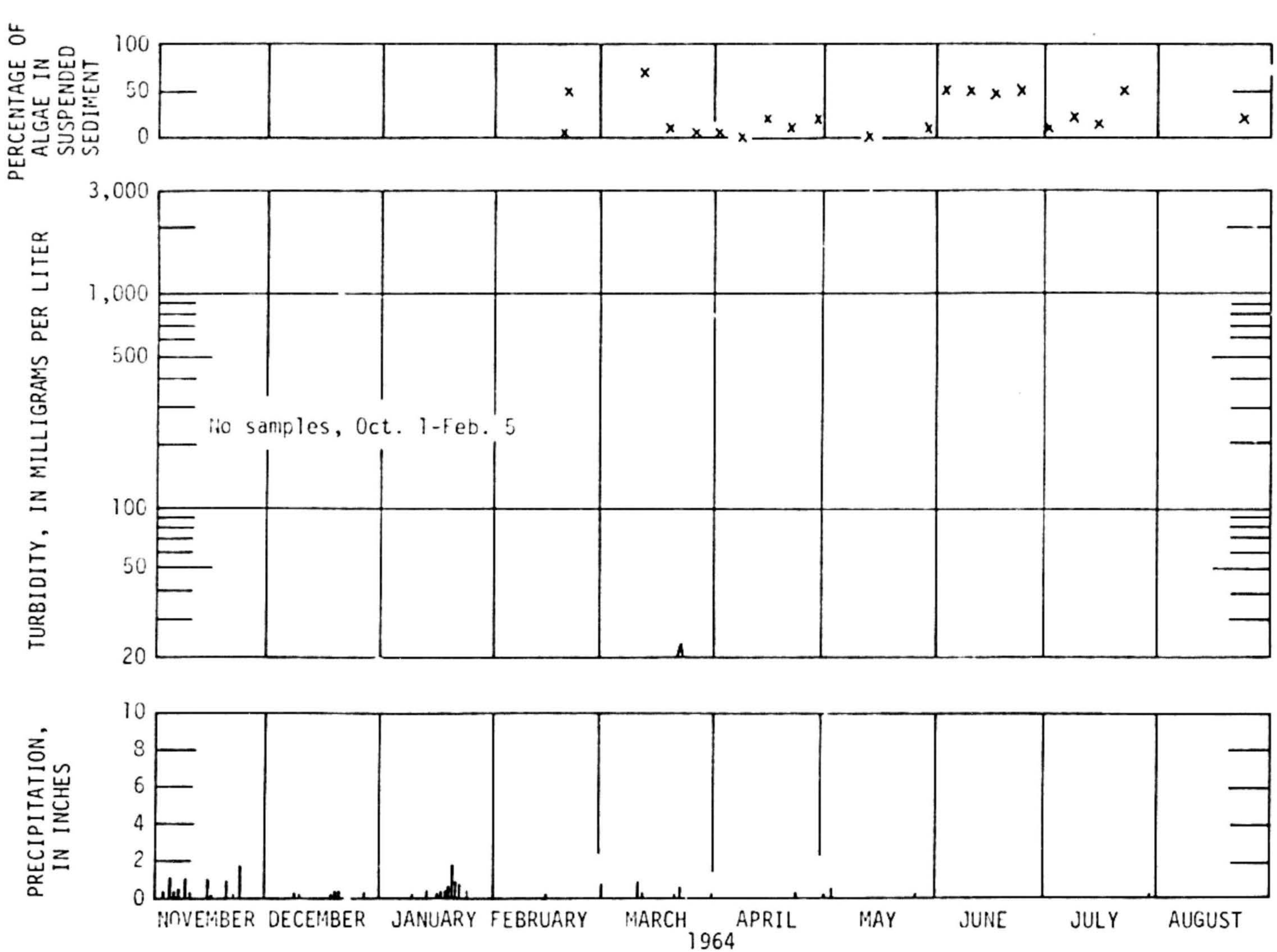
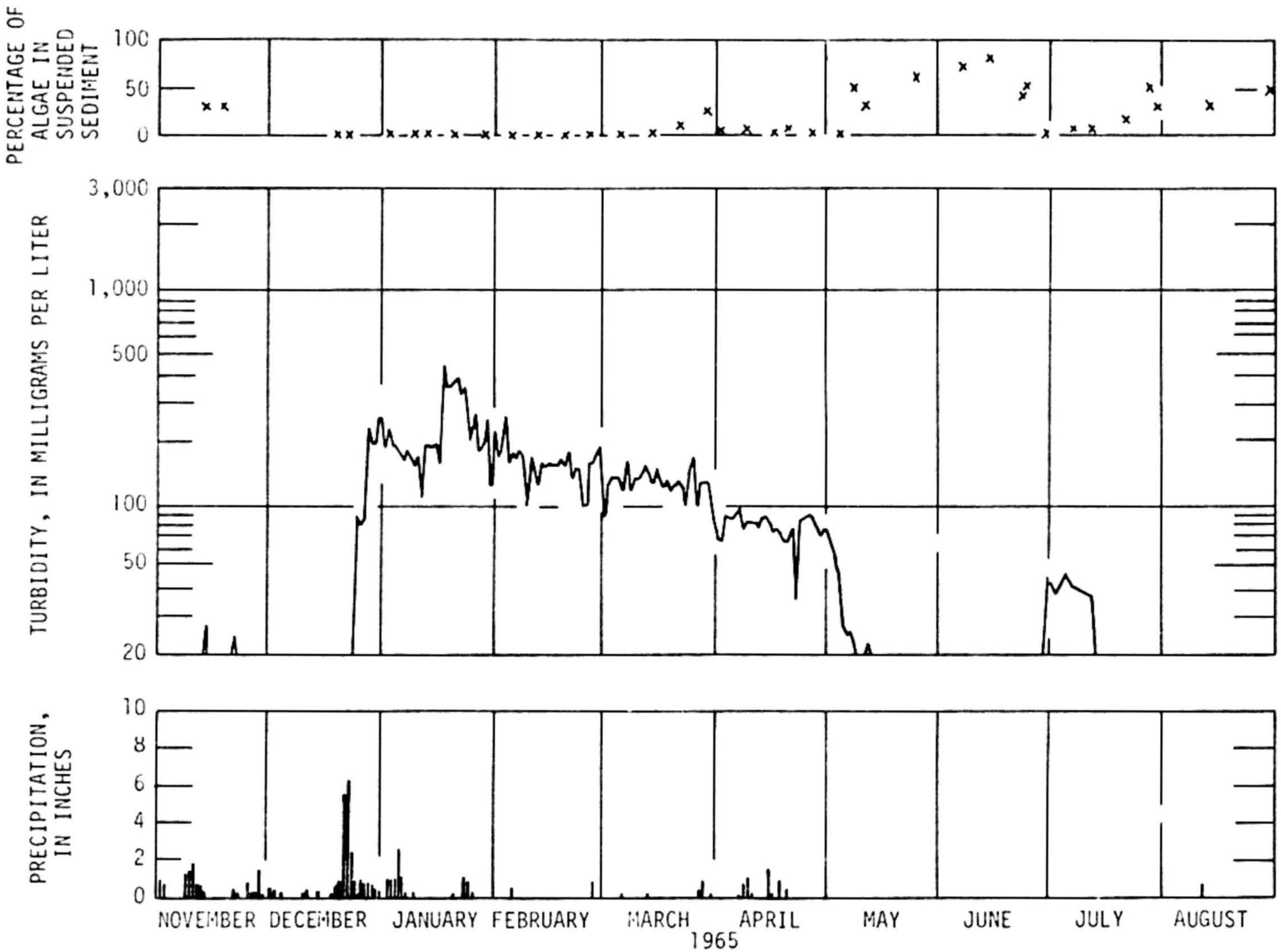


FIGURE 28.--Periods of turbid water, daily precipitation, and percentage of algae in the suspended material at Lake Mendocino near Ukiah, 1964-68. Precipitation data are from the U.S. Weather Bureau rain gage at Ukiah.



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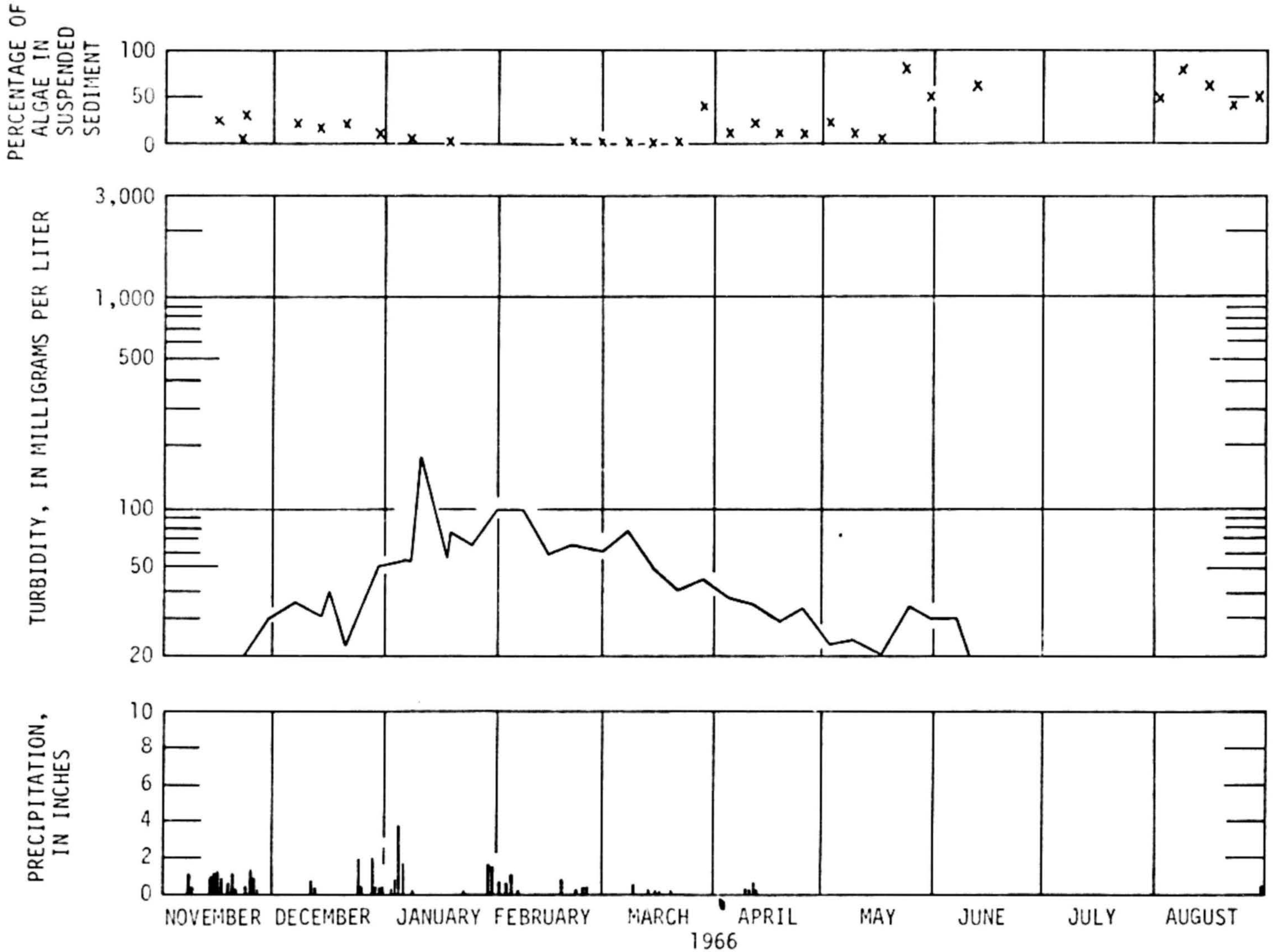

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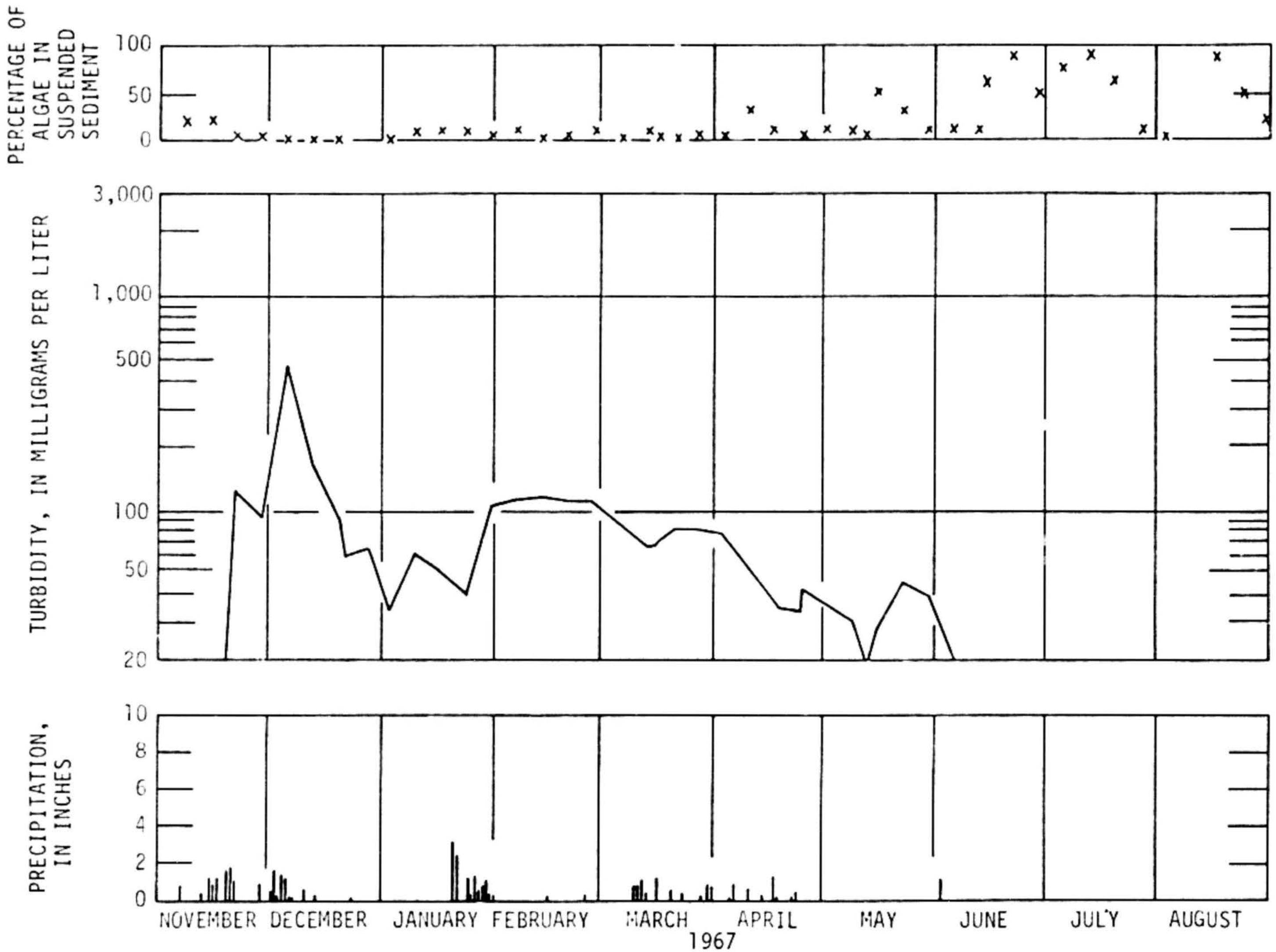

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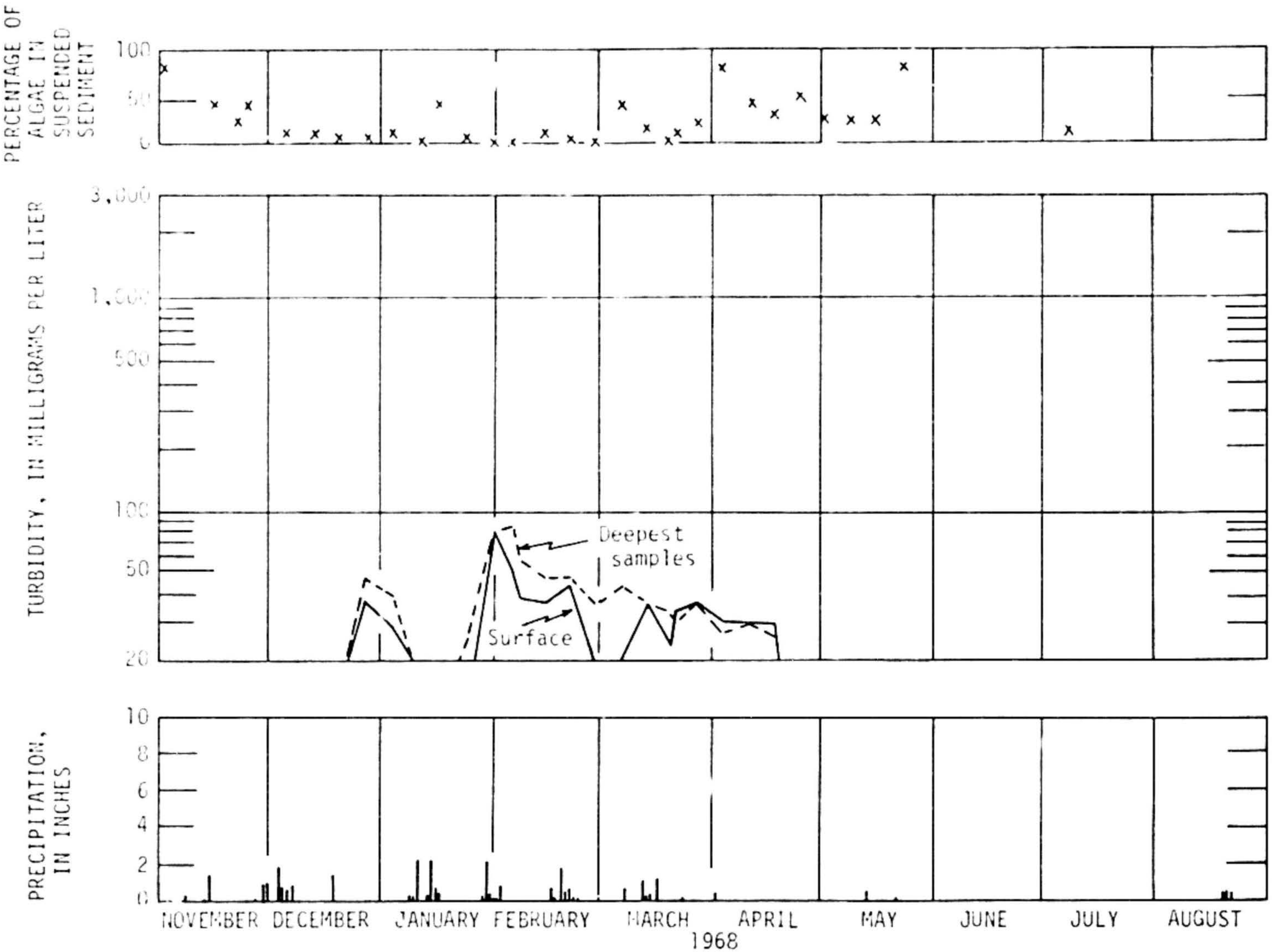

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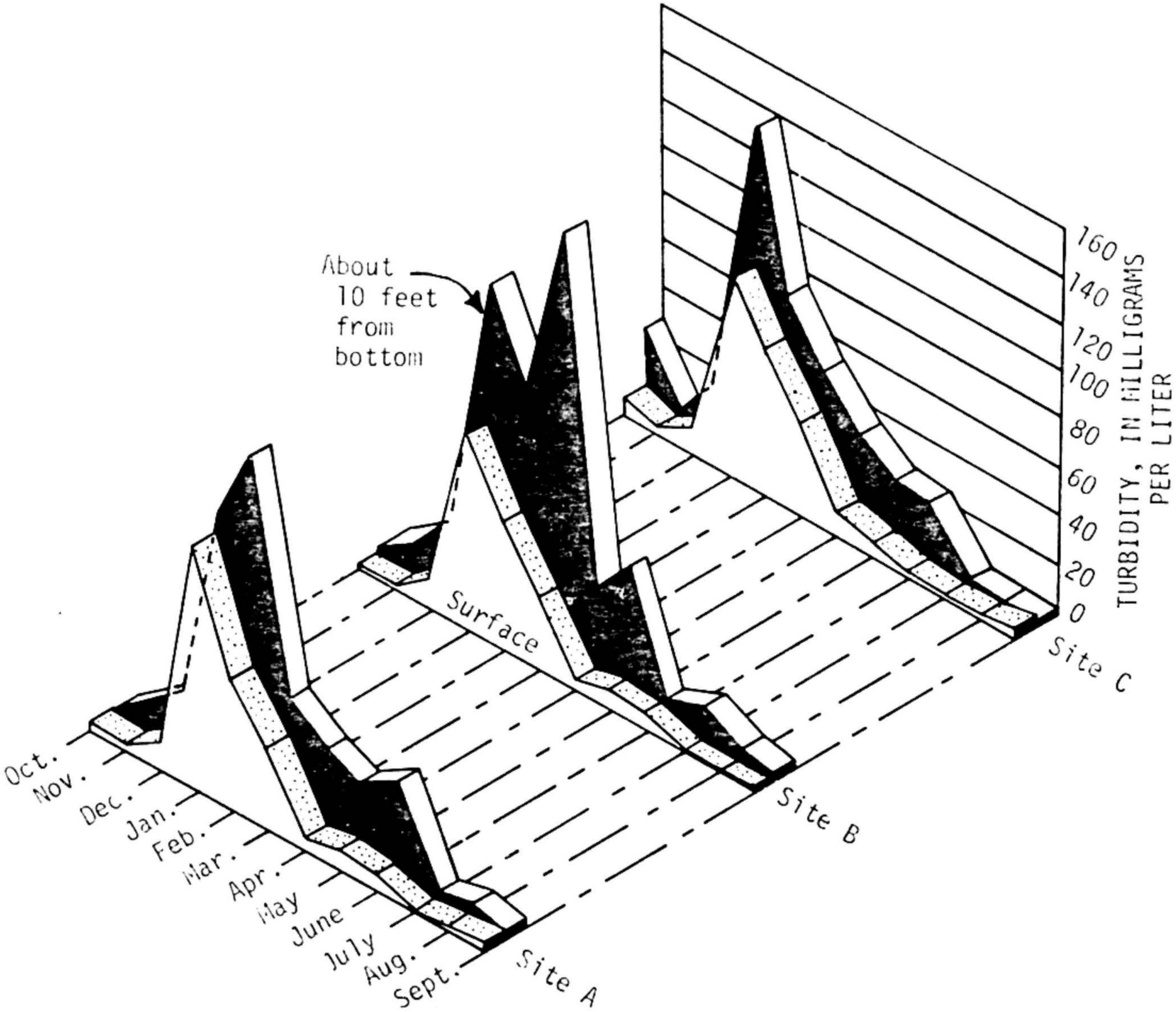


FIGURE 29.--Turbidity of surface and bottom samples collected monthly at three sites in Lake Mendocino, 1966 water year. For location at sites, see figure 15.

East Fork Russian River near Ukiah (Sta. No. 4620)

From February 1964 to the time of the flood of December 1964, the water released from Lake Mendocino usually became turbid when the water flowing into the lake became turbid during rainstorms (fig. 30) even though the water near the surface of the lake remained comparatively clear (fig. 28). Thus, turbid water probably flowed through the reservoir as a turbidity or density current. After the flood, the water flowing into the lake was turbid continuously for several months each water year, and as a result the water released from the lake was turbid also for about the same period (table 8). Algae at times may have caused turbid water.

Russian River near Ukiah (Sta. No. 4610)

Most turbid water at this station was related to storms passing through the region and lasted not much longer than the storms (fig. 31). However, gravel mining and other earth moving upstream from the gage also produced turbid water (for example, late November and early December, 1964, fig. 31). Algae, although at times a major part of the suspended material, probably did not often cause turbid water.

Russian River near Cloverdale (Sta. No. 4630)

The turbidity of the water at Russian River near Cloverdale (fig. 32) was affected by erosion caused by rainstorms and by the turbidity and quantity of water released from Lake Mendocino. During periods of little or no rainfall, the water became clear if the quantity of water released from Lake Mendocino was negligible or if the released water was clear. For example, in February 1965 the water was clear when the discharge from Lake Mendocino was low (fig. 33). The yo-yo release schedule for the reservoir, whereby periods of high releases are followed by periods of low releases, allowed the water downstream to clear during the periods of low release. This type of release, however, often causes sloughing of the banks when the water is low. During periods of high releases the turbidity of the water at Russian River near Cloverdale was about the same as that of the water released from the reservoir, but the concentration of suspended sediment at the downstream gage was much higher than the concentration of the release water. The higher concentrations indicate that material was picked up as the water of the high release flowed downstream. Turbidity of the release water and the erosion of material sloughed from the banks during low flow and other types of erosion (fig. 34) probably combined to increase the turbidity downstream. Algae rarely seemed to be a major cause of turbid water.

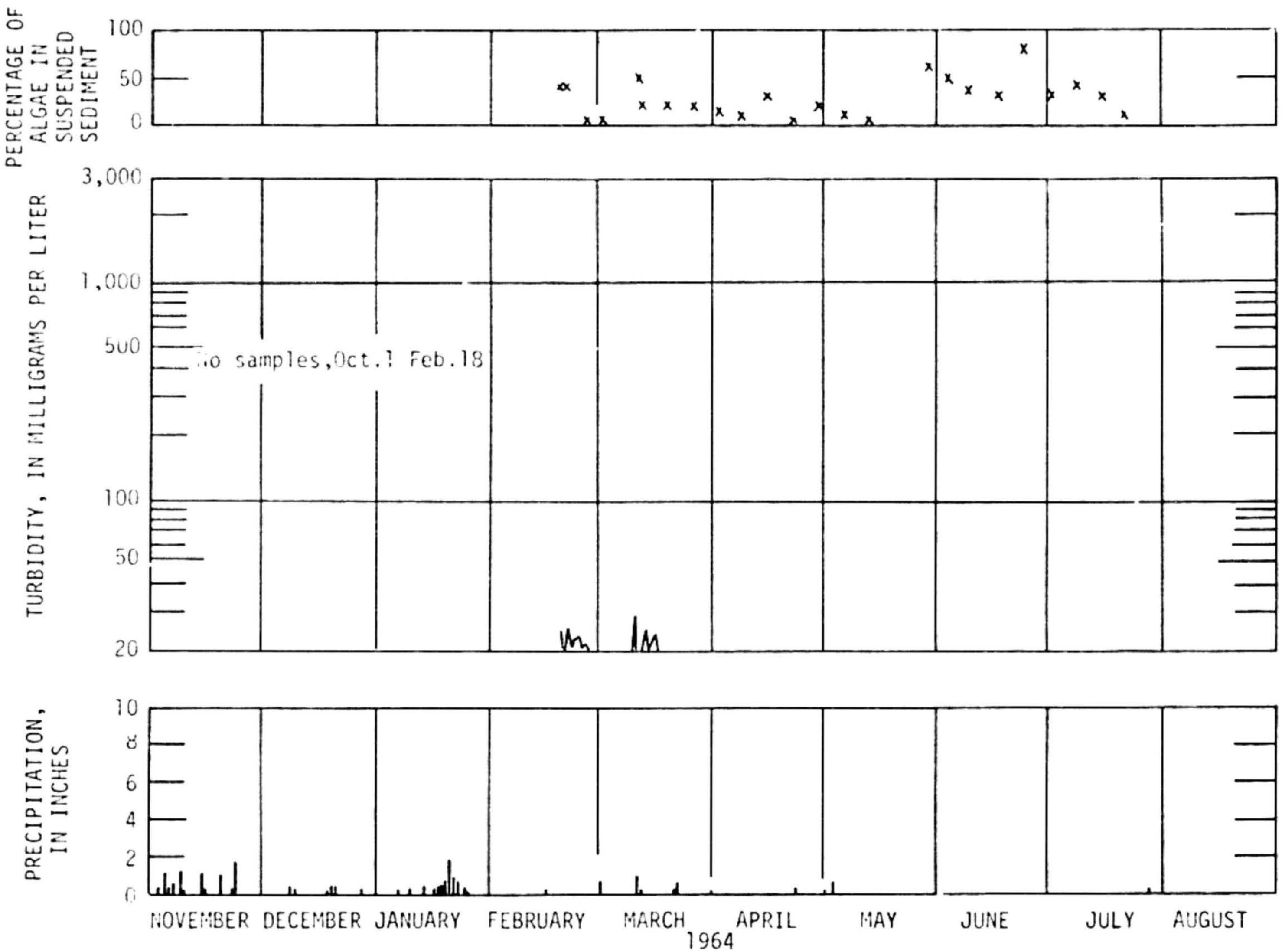


FIGURE 30.--Periods of turbid water, daily precipitation, and percentage of algae in the suspended material at East Fork Russian River near Ukiah, 1964-68. Precipitation data are from the U.S. Weather Bureau rain gage at Ukiah.

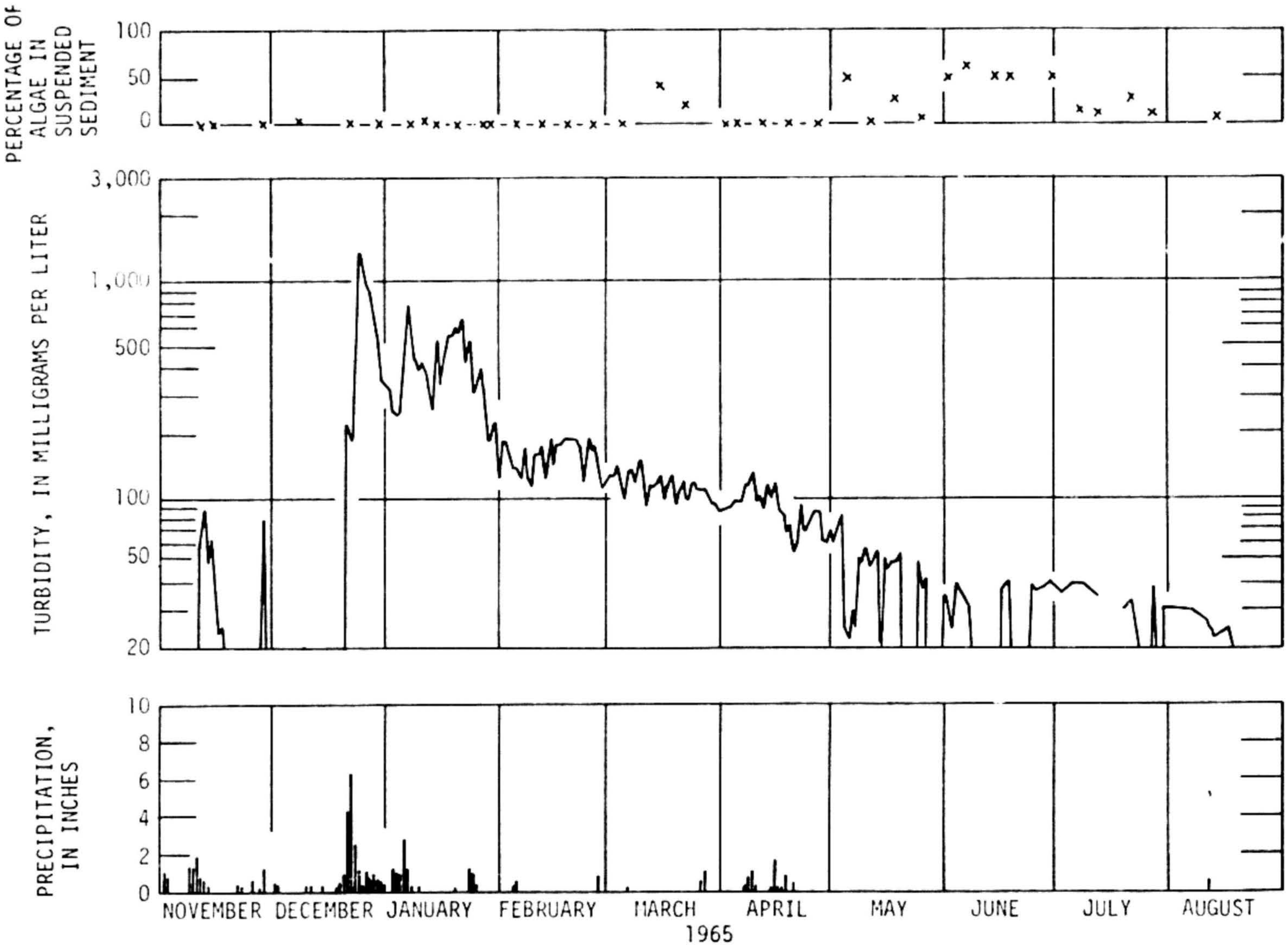
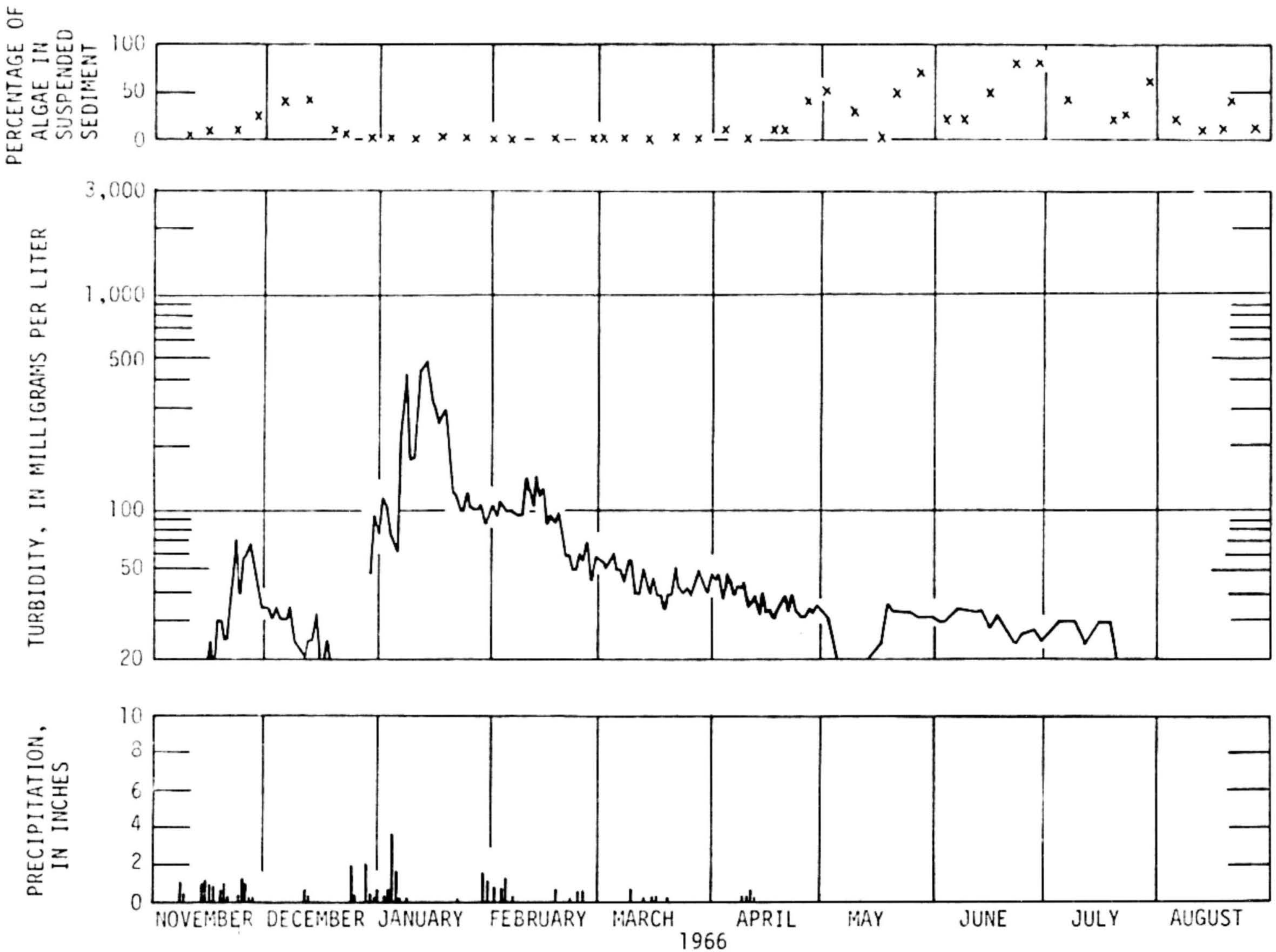


FIGURE 30.--Continued.



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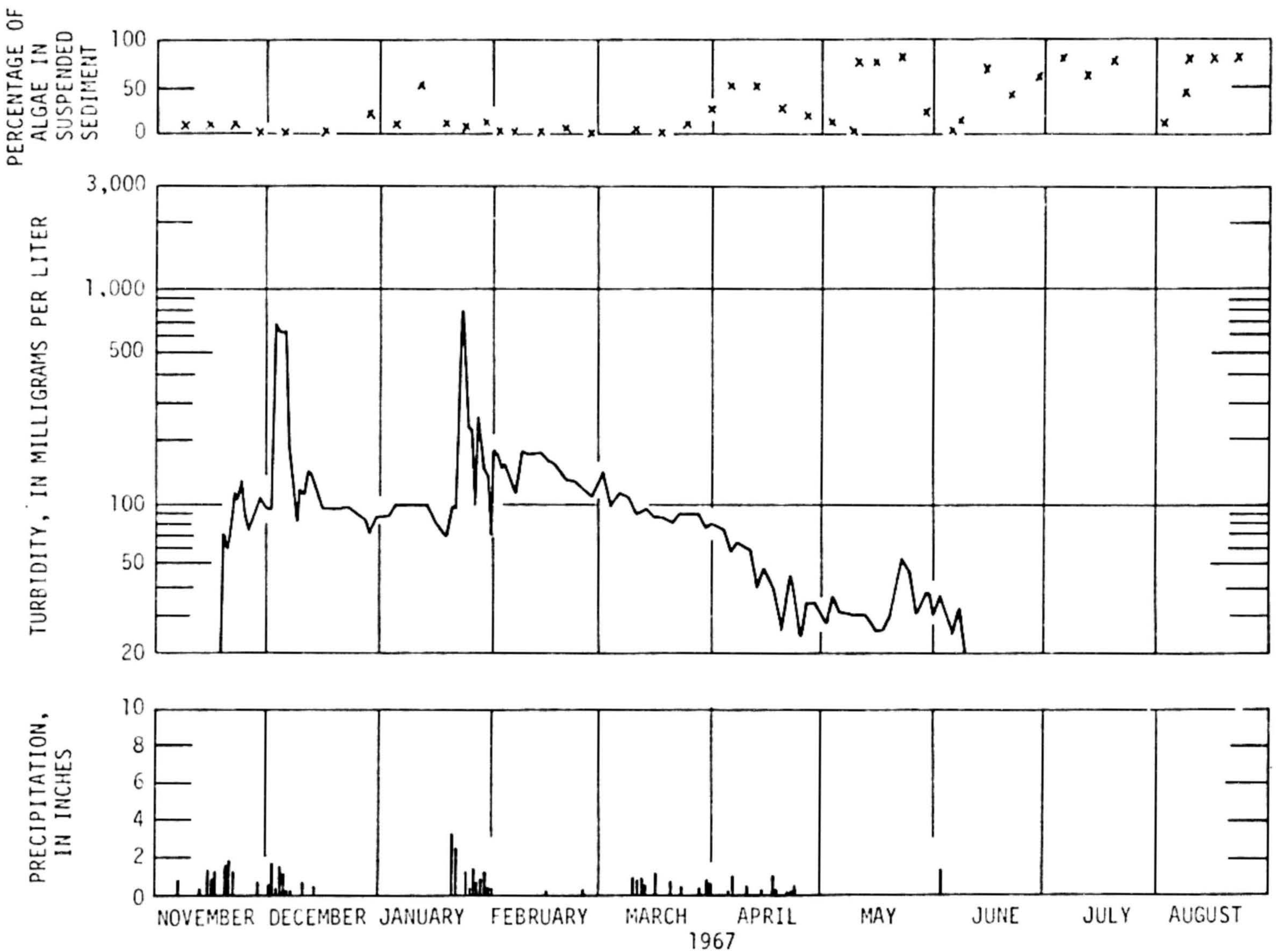

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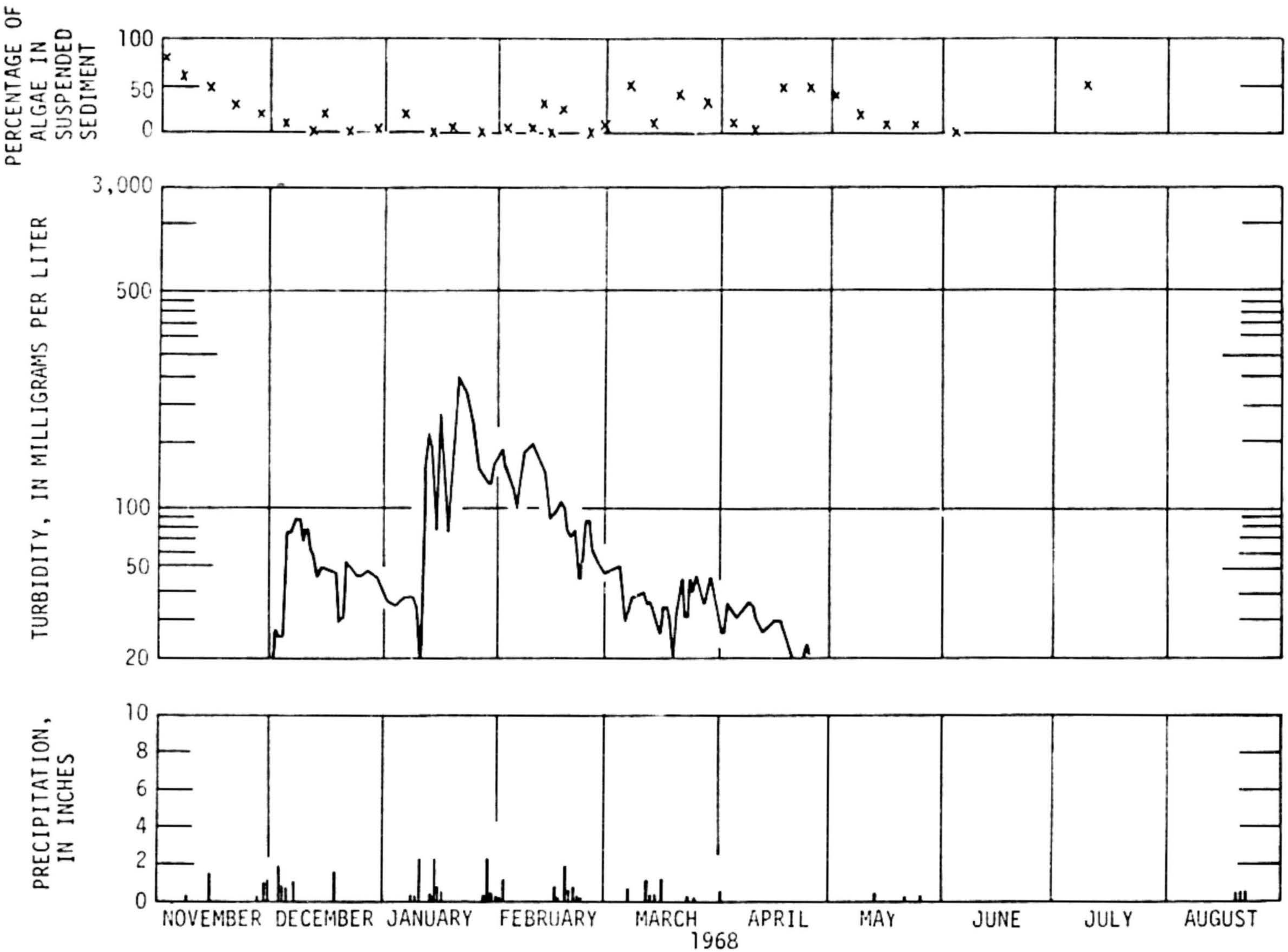

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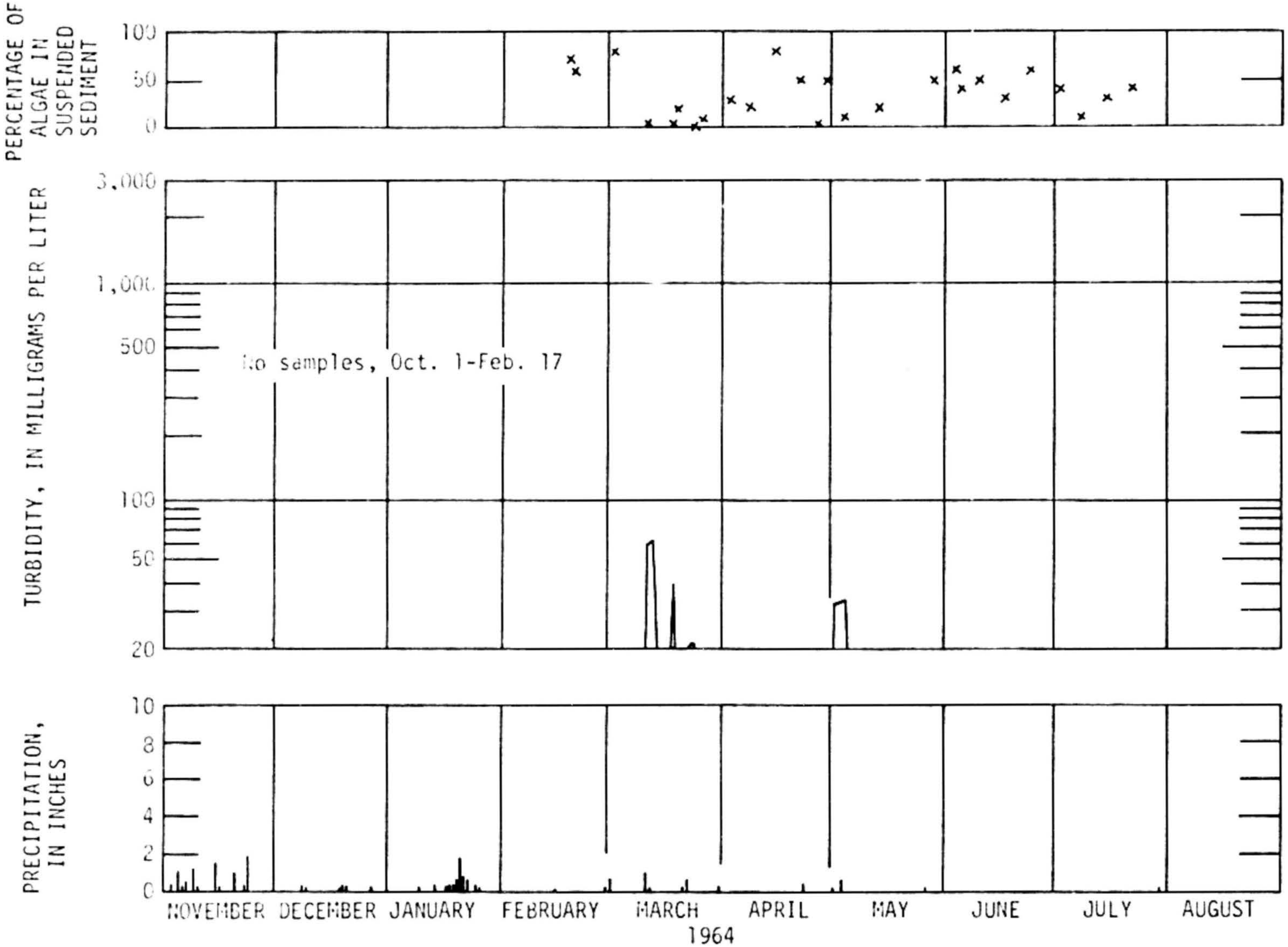
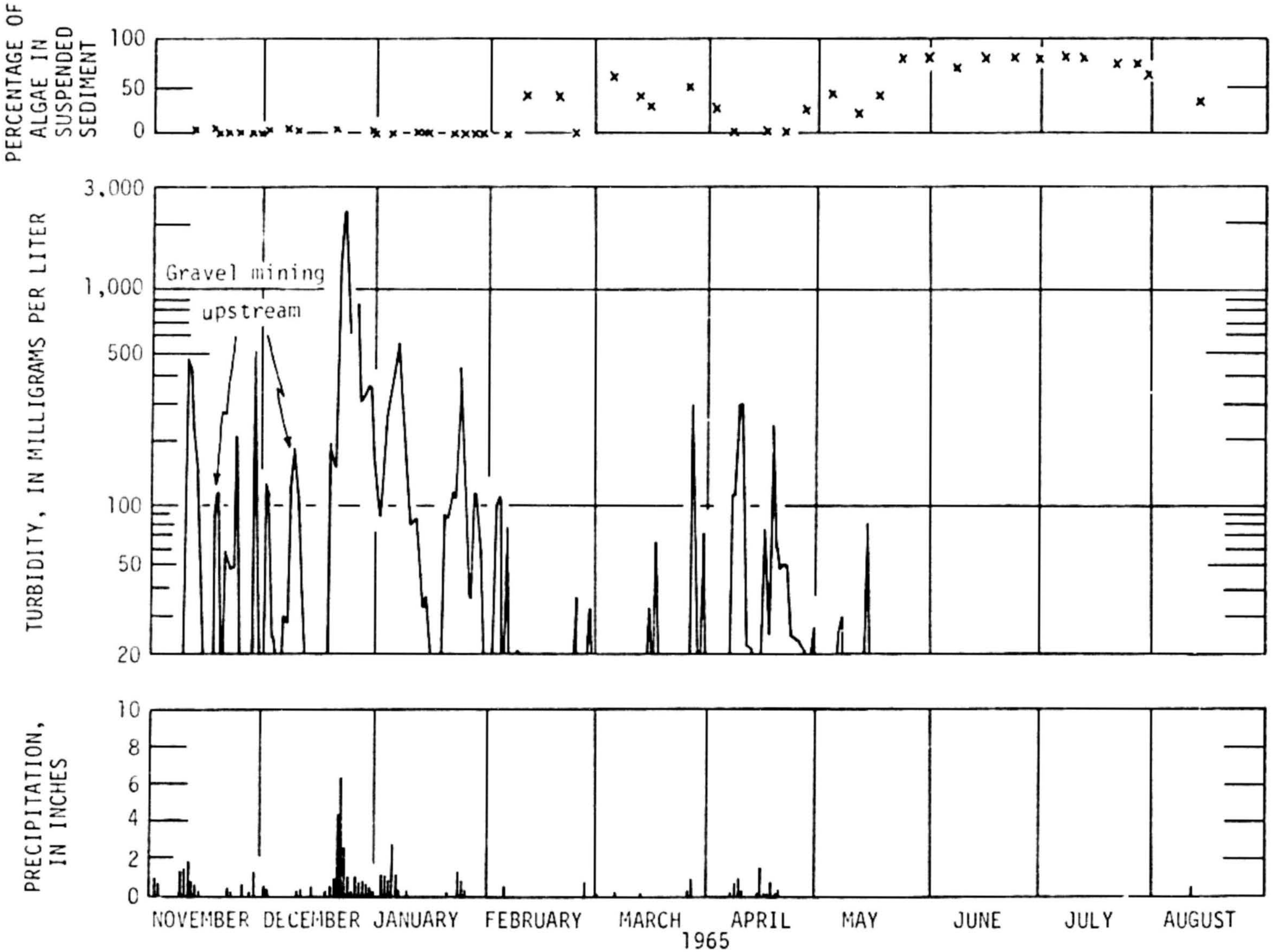


FIGURE 31.--Periods of turbid water, daily precipitation, and percentage of algae in the suspended material at Russian River near Ukiah, 1964-68. Precipitation data are from the U.S. Weather Bureau rain gage at Ukiah.



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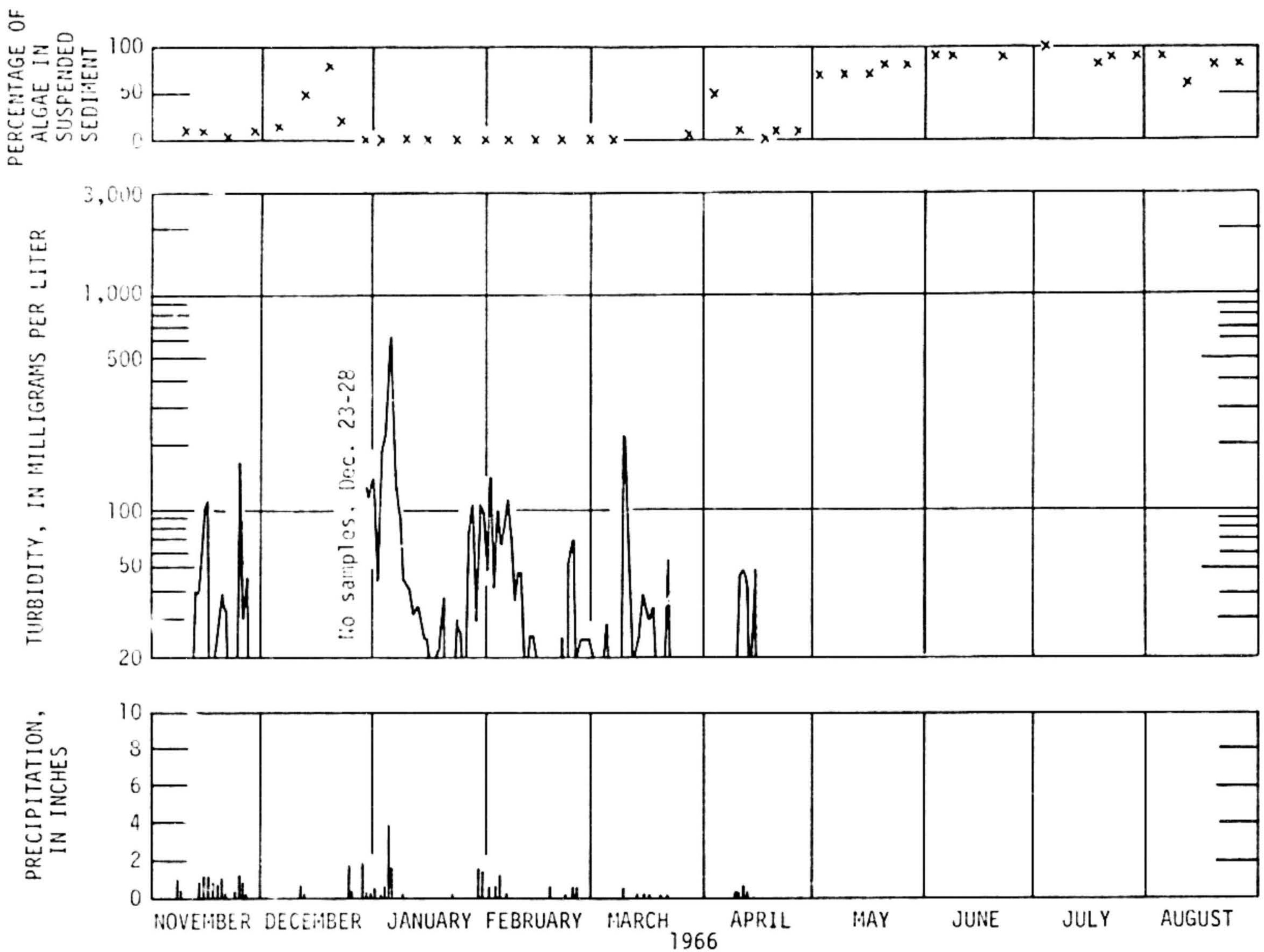

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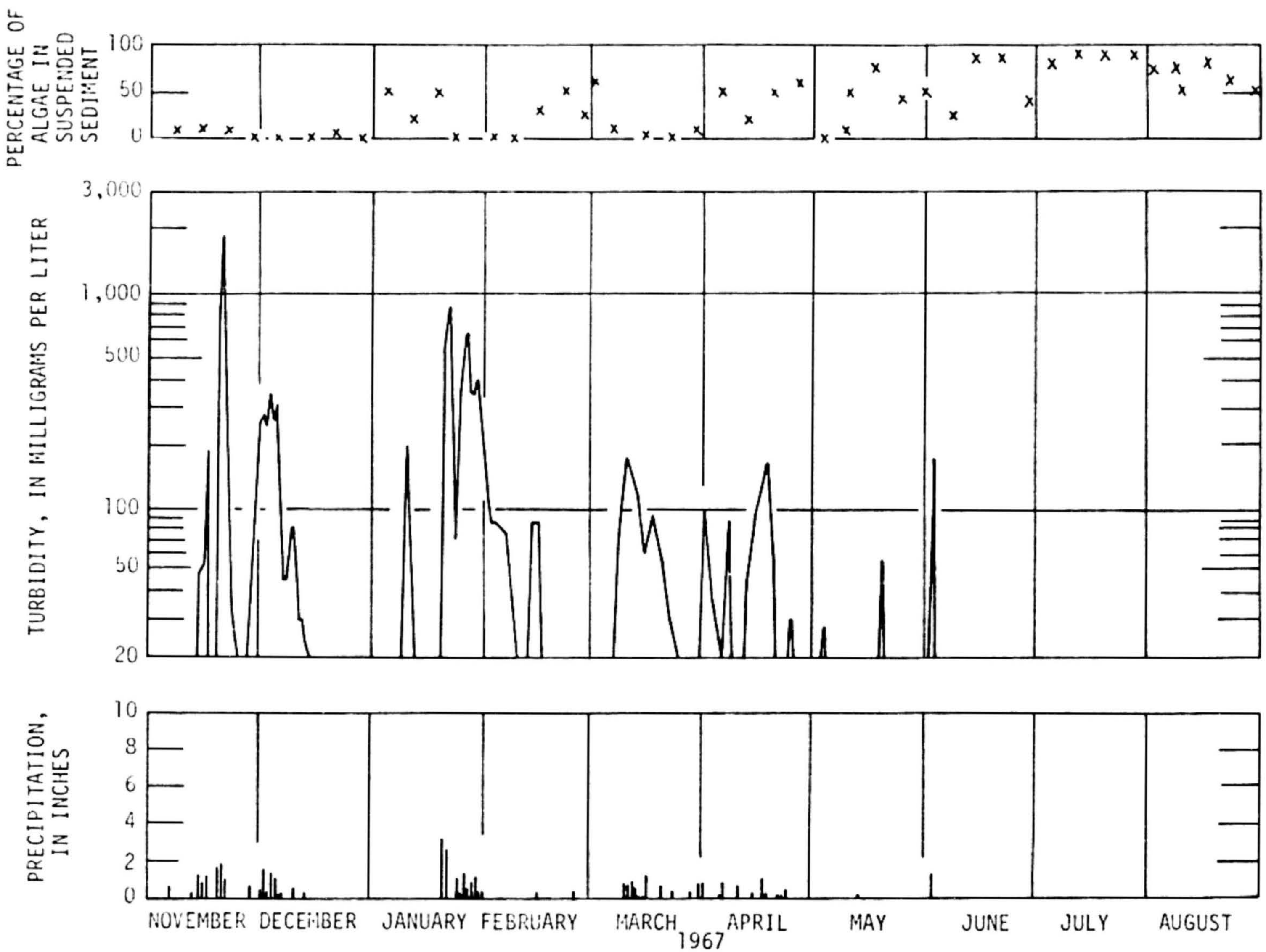


FIGURE 31.--Continued.

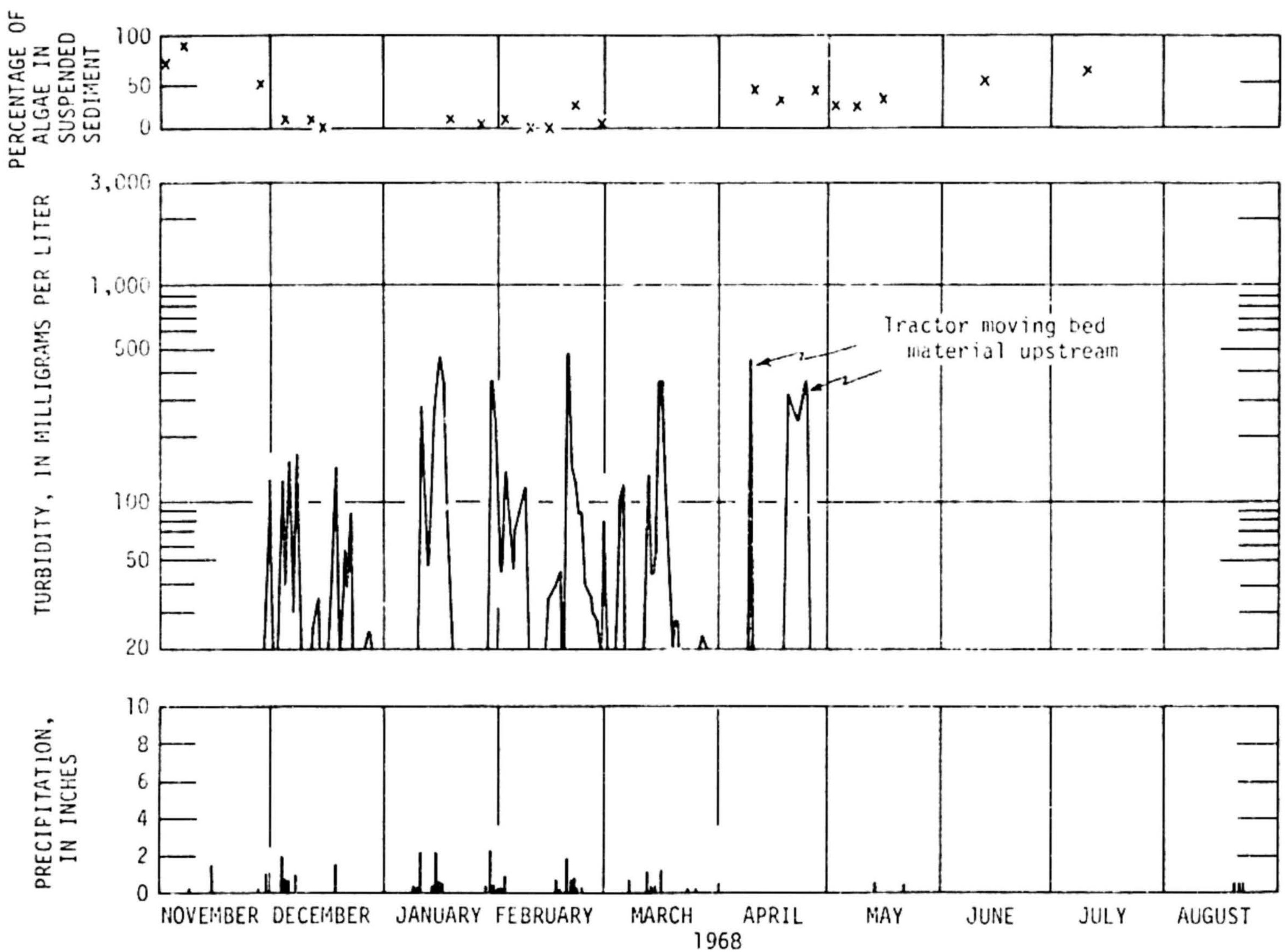


FIGURE 31.--Continued.

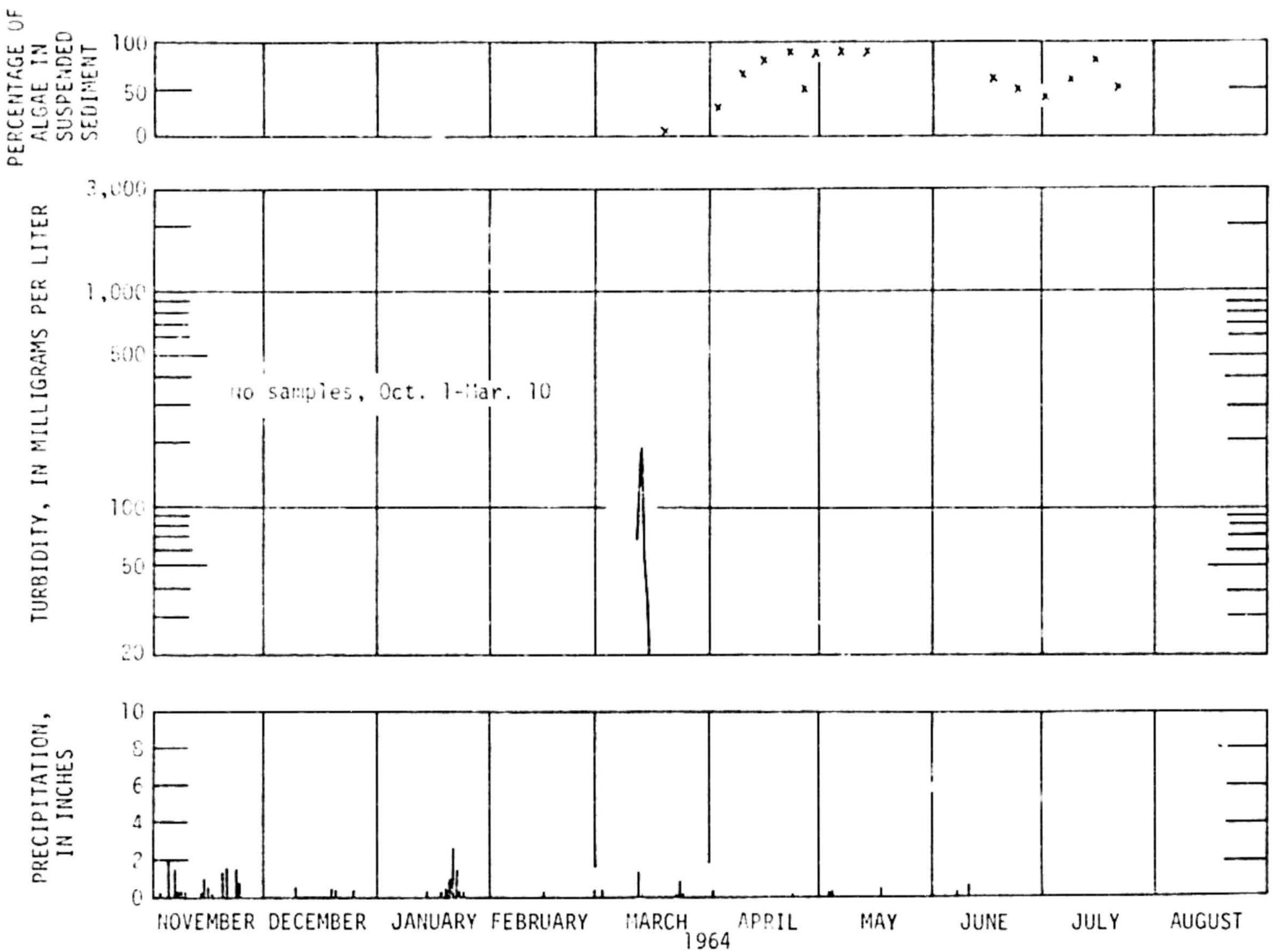


FIGURE 32.--Periods of turbid water, daily precipitation, and percentage of algae in the suspended material at Russian River near Cloverdale, 1964-68. Precipitation data are from the U.S. Weather Bureau rain gage at Cloverdale.

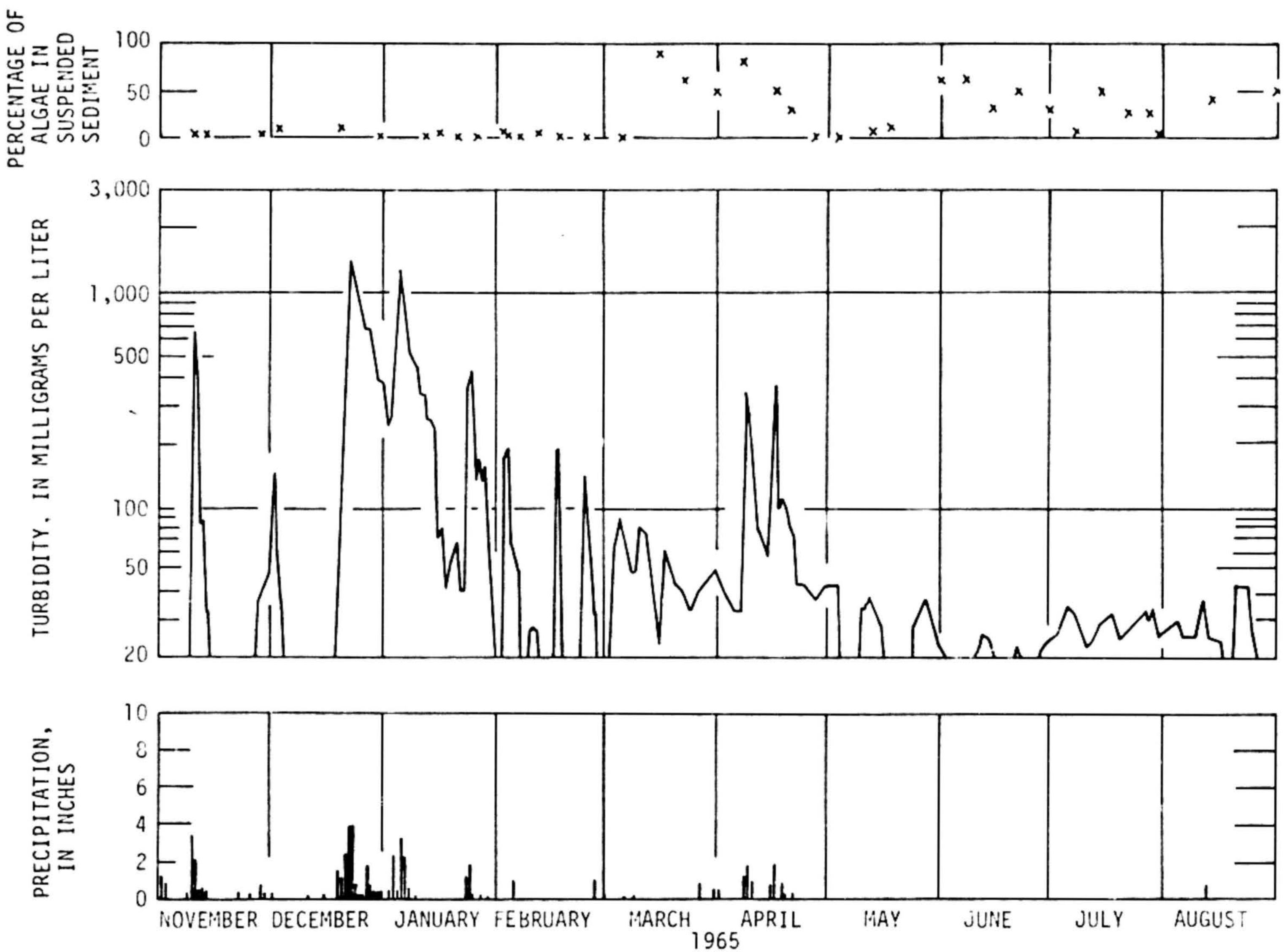


FIGURE 32.--Continued.

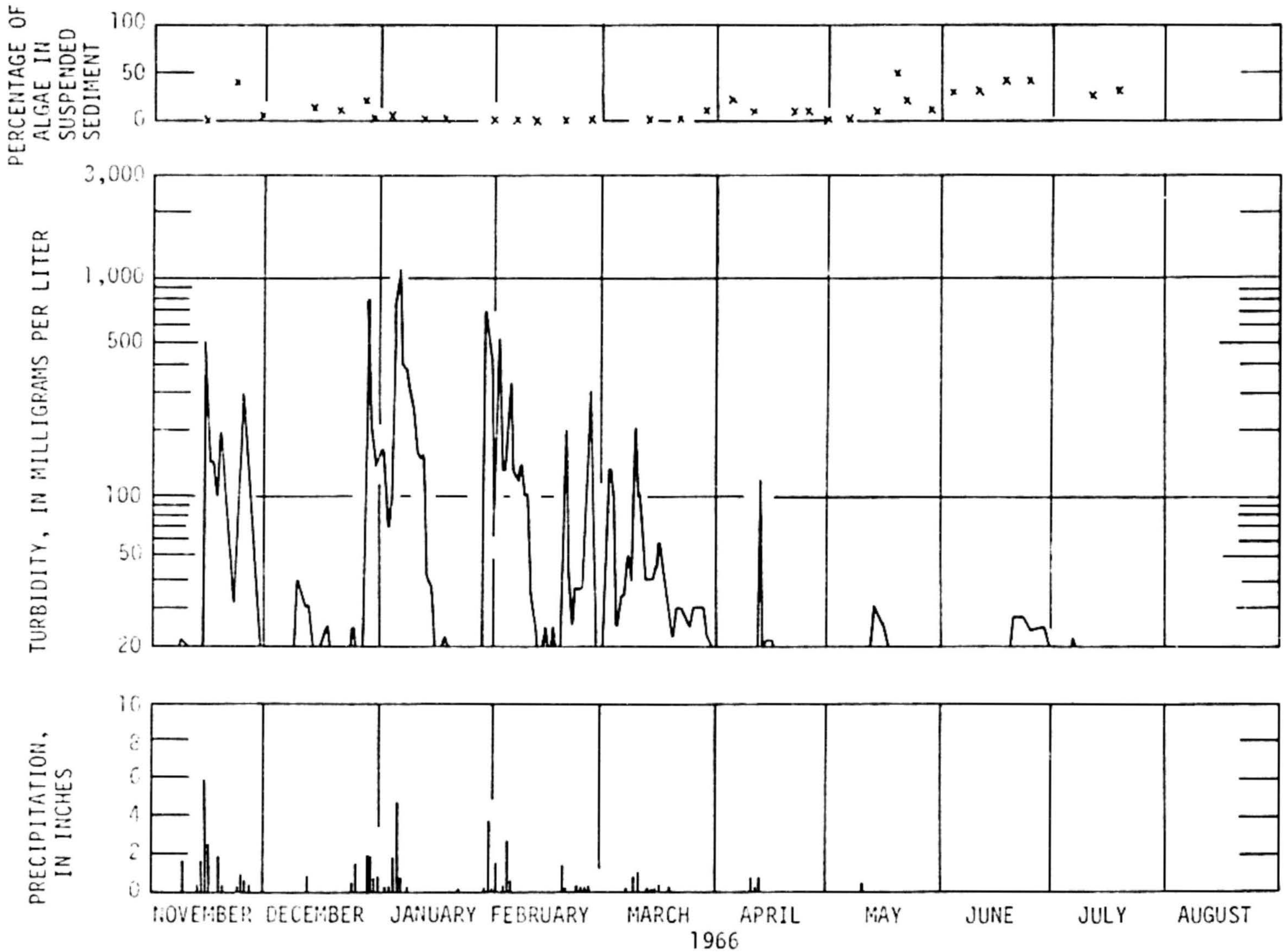
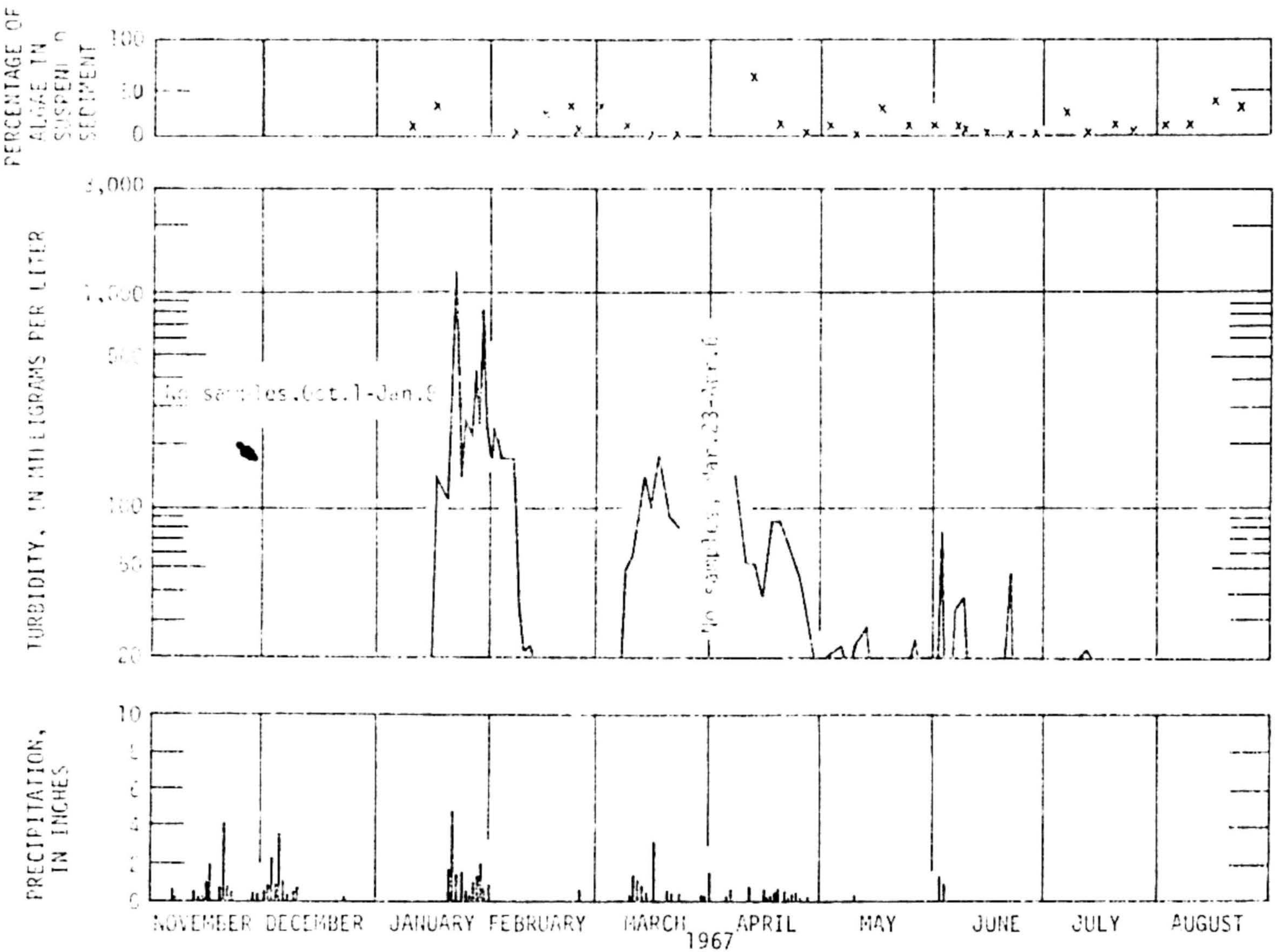


FIGURE 32.--Continued.



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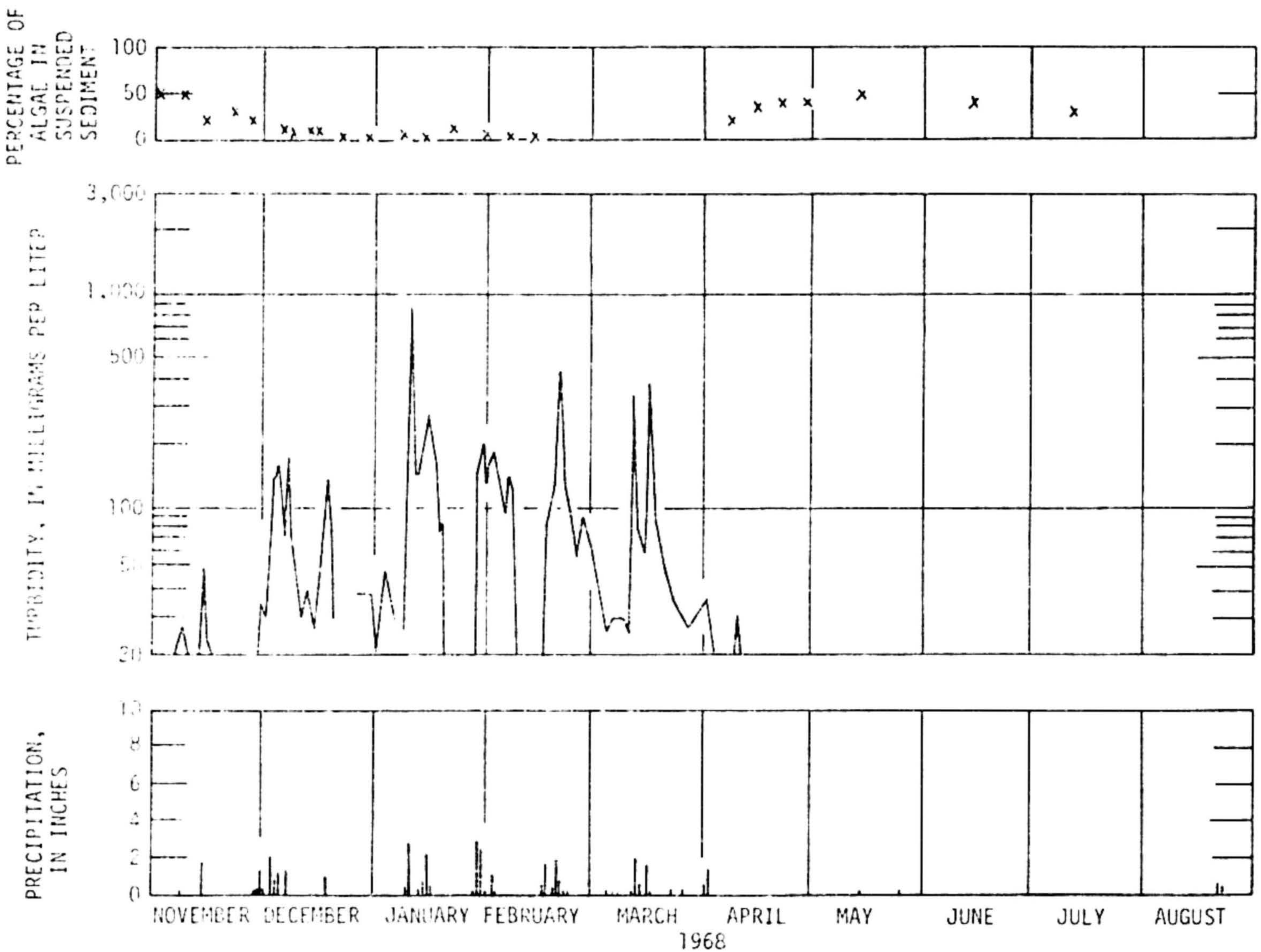

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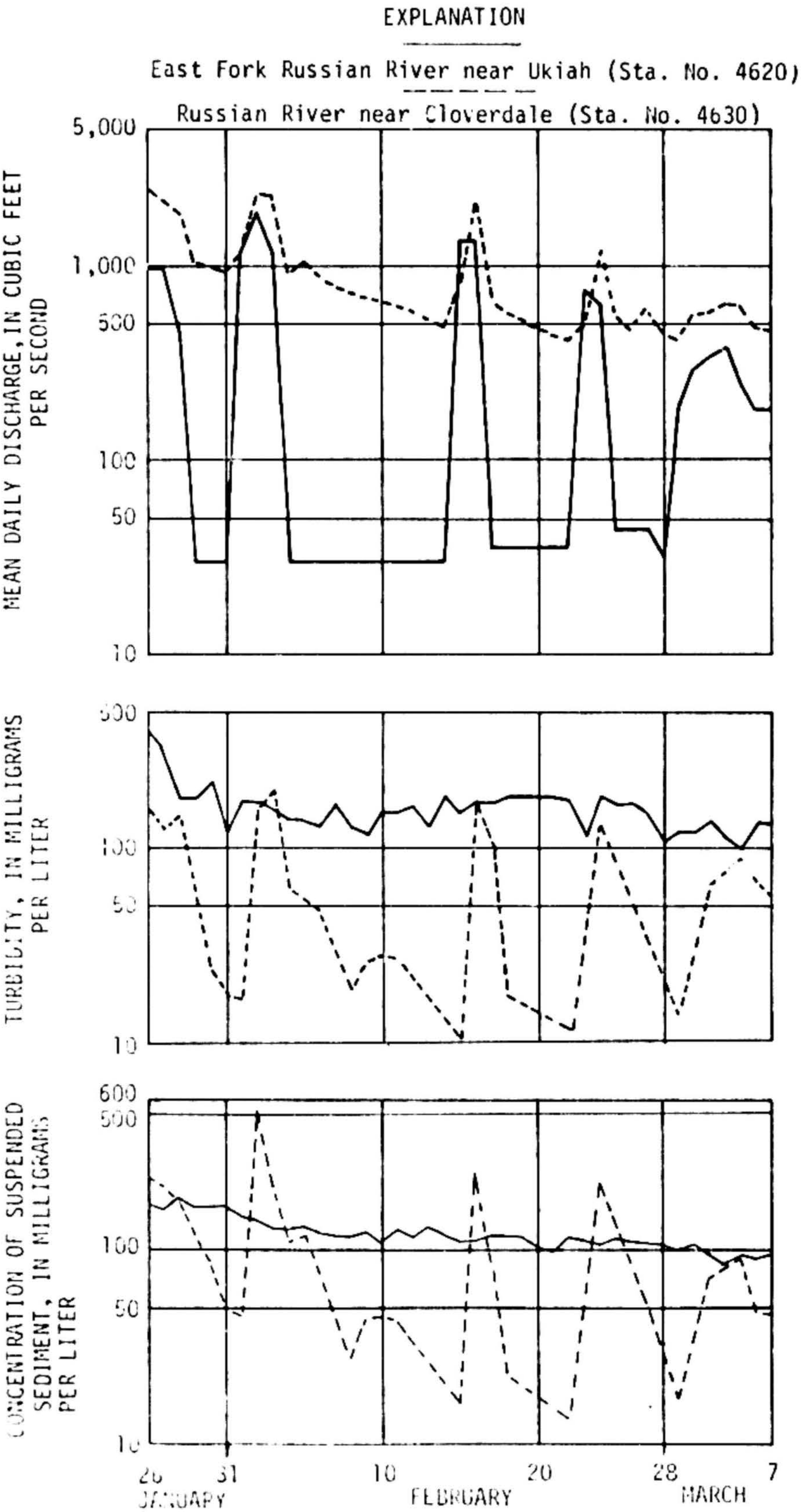


FIGURE 33.--Effect of releases from Lake Mendocino on the water discharge, turbidity, and concentration of suspended sediment at Russian River near Cloverdale, January-March 1965.

FIGURE 34.--Bank erosion near the station, Russian River near Cloverdale. Russian River is in the foreground.

Big Sulphur Creek near Cloverdale (Sta. No. 4632)

The periods of turbidity of Big Sulphur Creek were correlative with periods of rainstorms (fig. 35). During storms the creek was turbid and between storms was clear. Algae did not seem to influence the turbidity.

Dry Creek near Geyserville (Sta. No. 4652)

Like other stations unaffected by upstream dam releases, such as Big Sulphur Creek near Cloverdale and Russian River near Ukiah, the water at Dry Creek near Geyserville became turbid as a consequence of rain in the area (fig. 36). The water remained turbid longer at this station than at the other two probably because the drainage area of Dry Creek was much larger and the discharge remained high longer. Earthmoving and gravel-mining operations (fig. 37) downstream near Healdsburg may have affected the turbidity of the Russian River downstream from its confluence with Dry Creek.

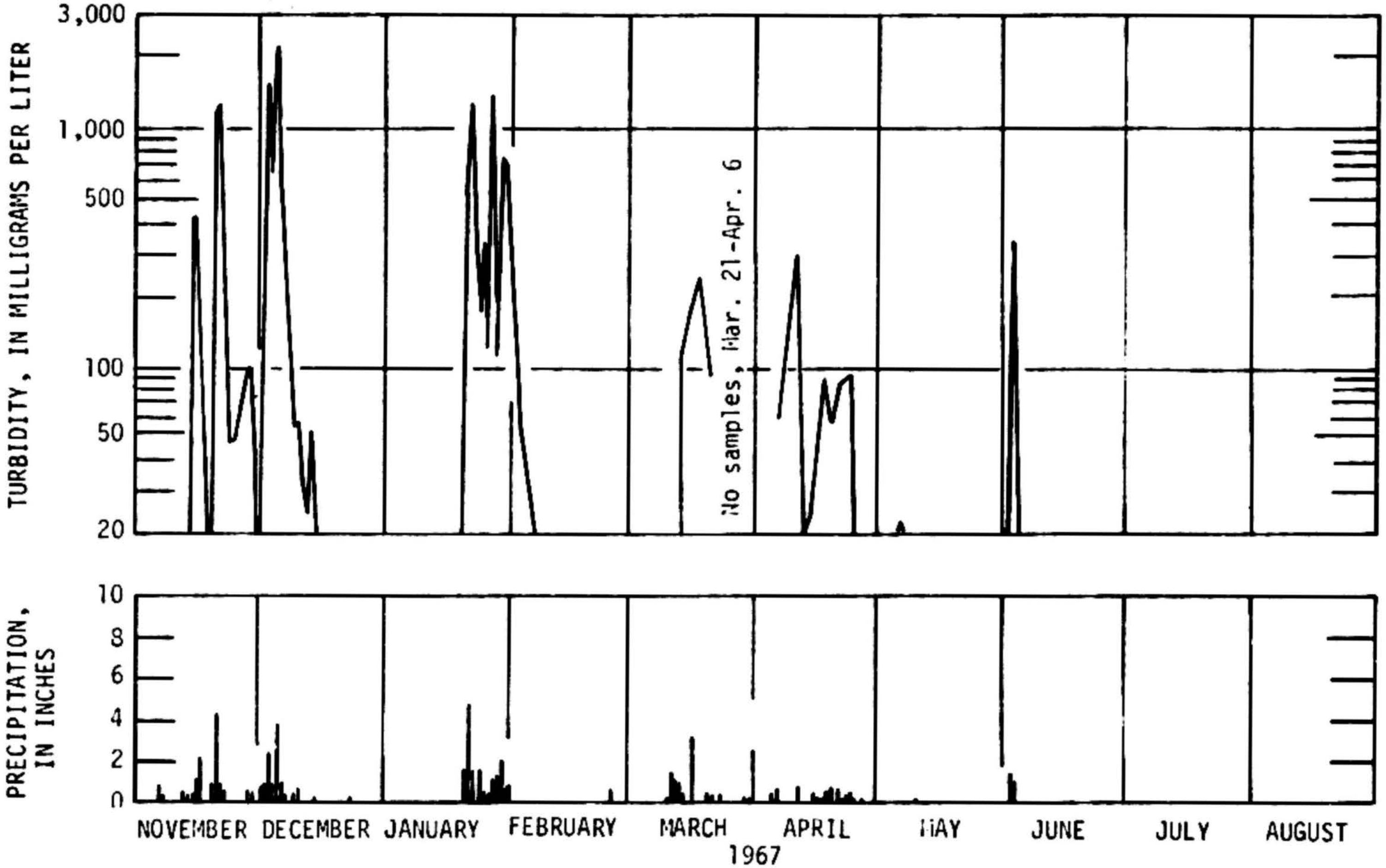
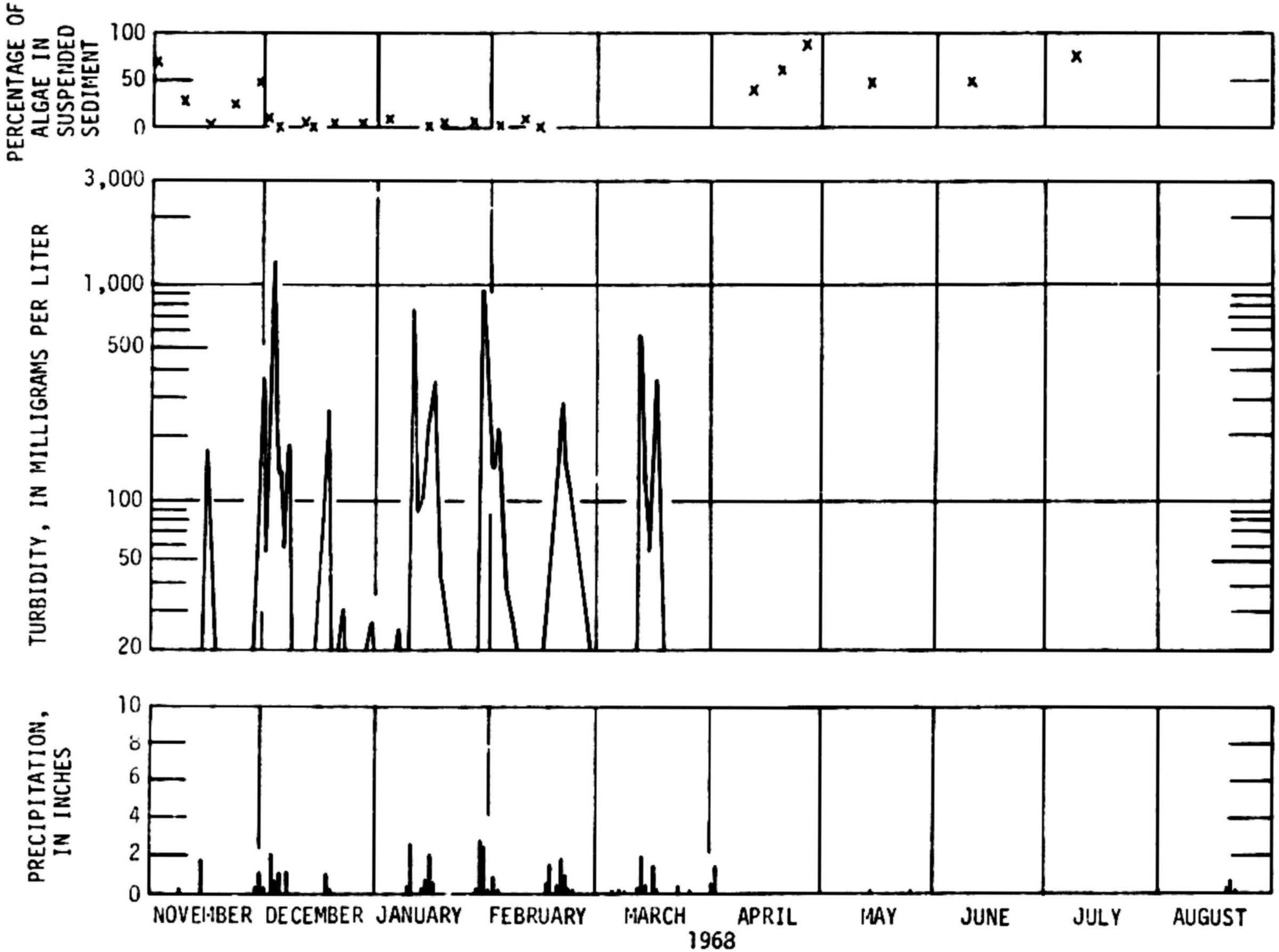


FIGURE 35.--Periods of turbid water, daily precipitation, and percentage of algae in the suspended material at Big Sulphur Creek near Cloverdale, 1967-68. Precipitation data are from the U.S. Weather Bureau rain gage at Cloverdale.



TURBIDITY

FIGURE 35.--Continued.

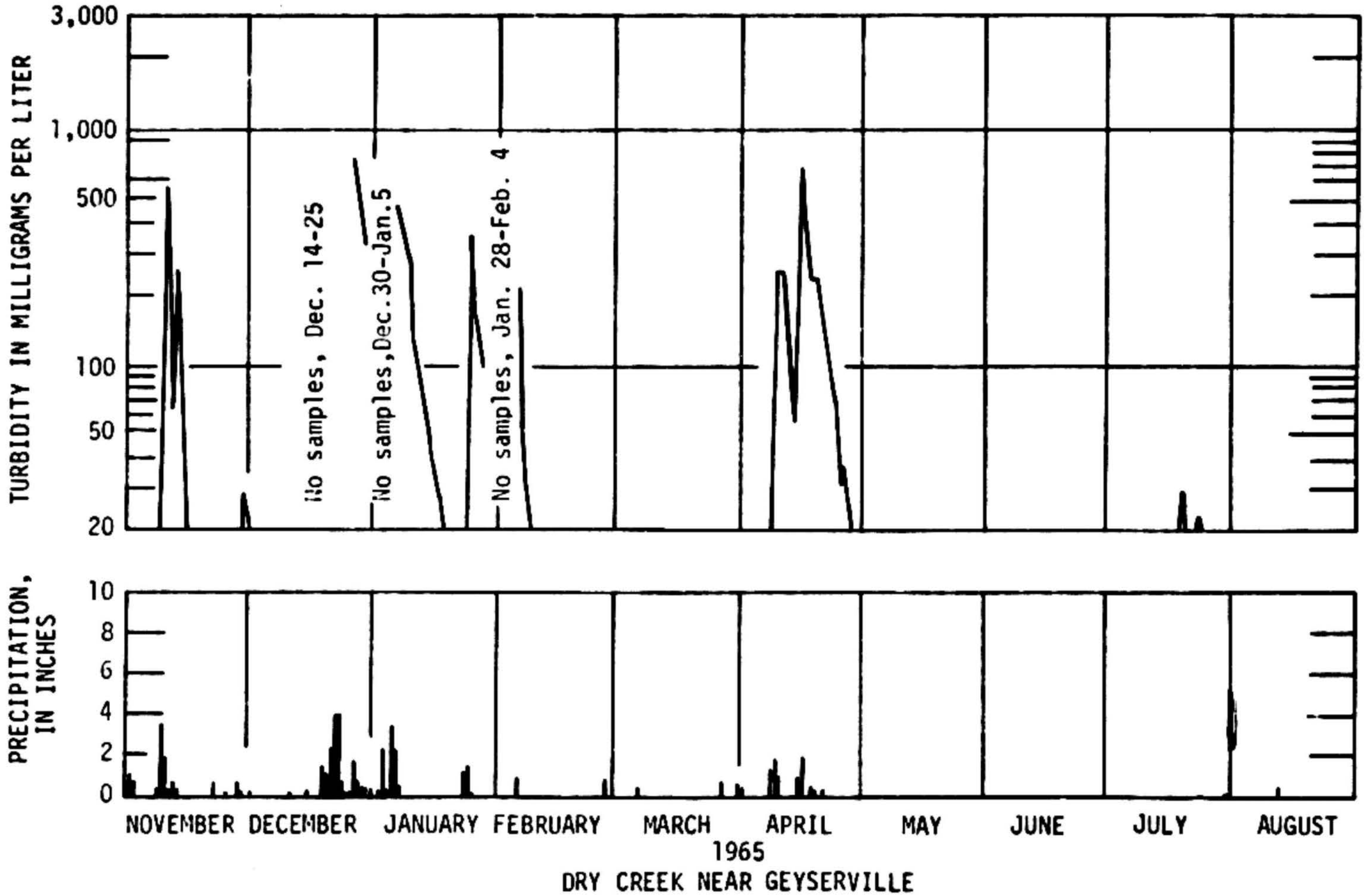


FIGURE 36.--Periods of turbid water and daily precipitation at Dry Creek near Geyserville, 1965-68. Precipitation data are from the U.S. Weather Bureau rain gage at Cloverdale.

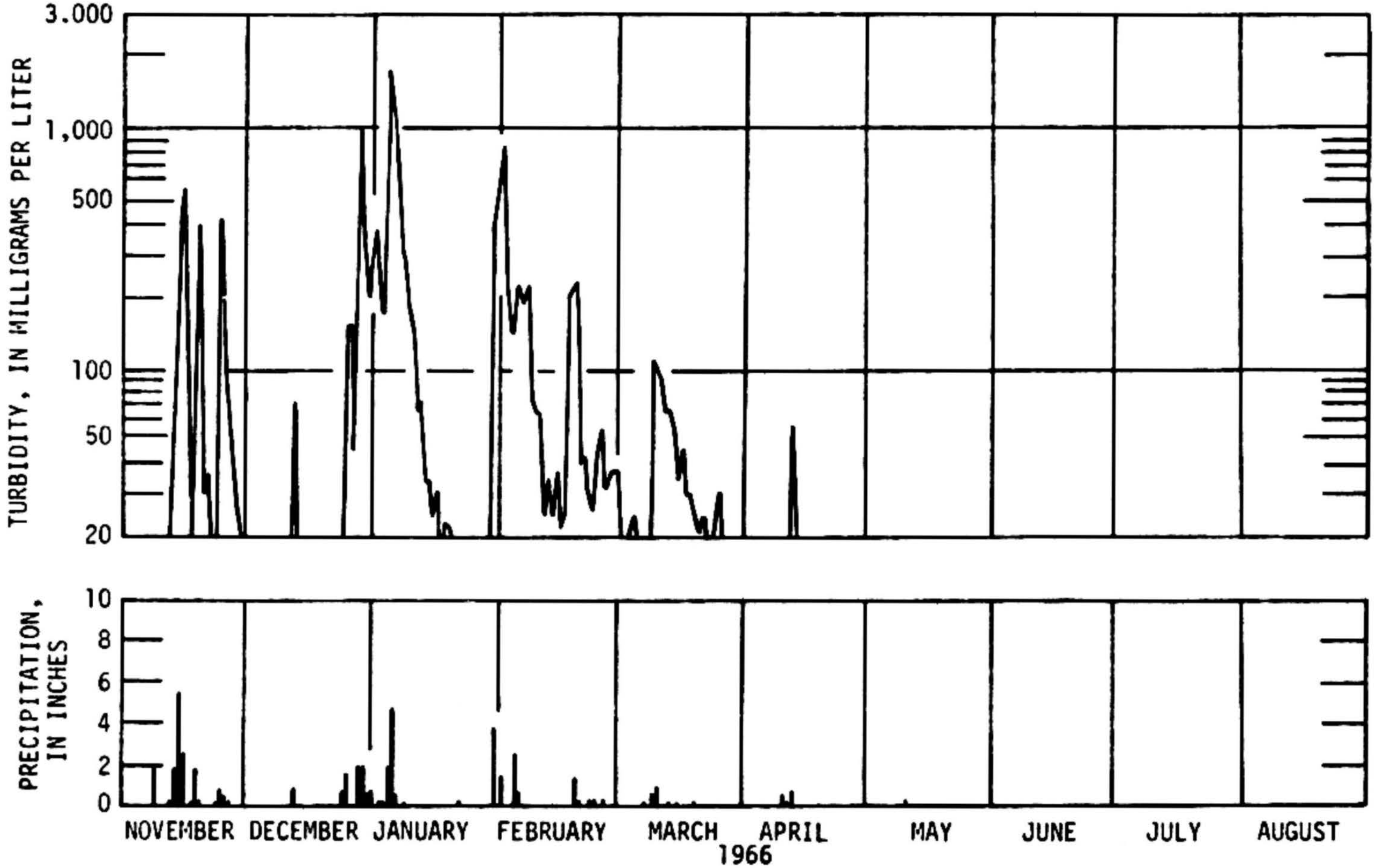


FIGURE 36.--Continued.

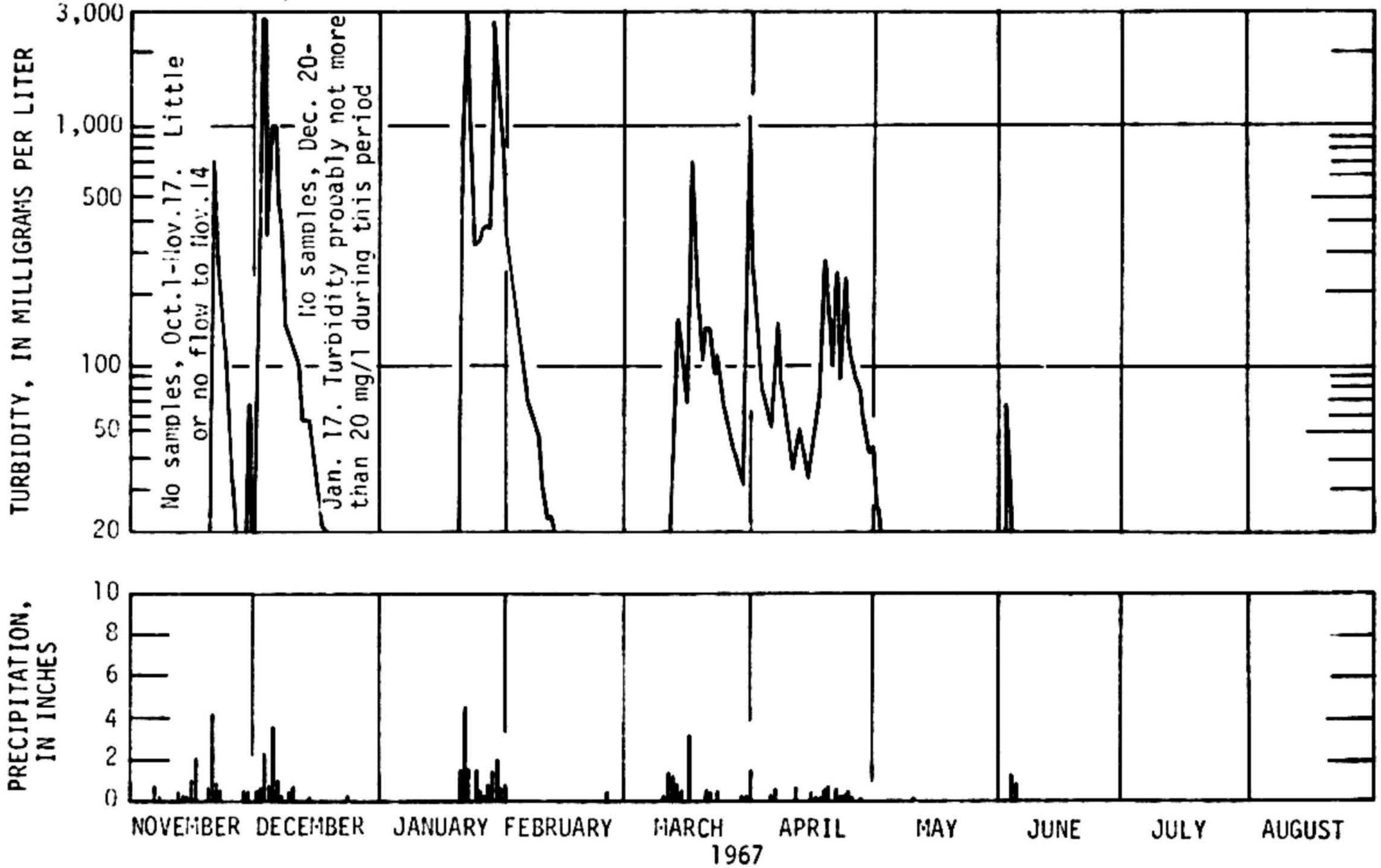


FIGURE 36.--Continued.

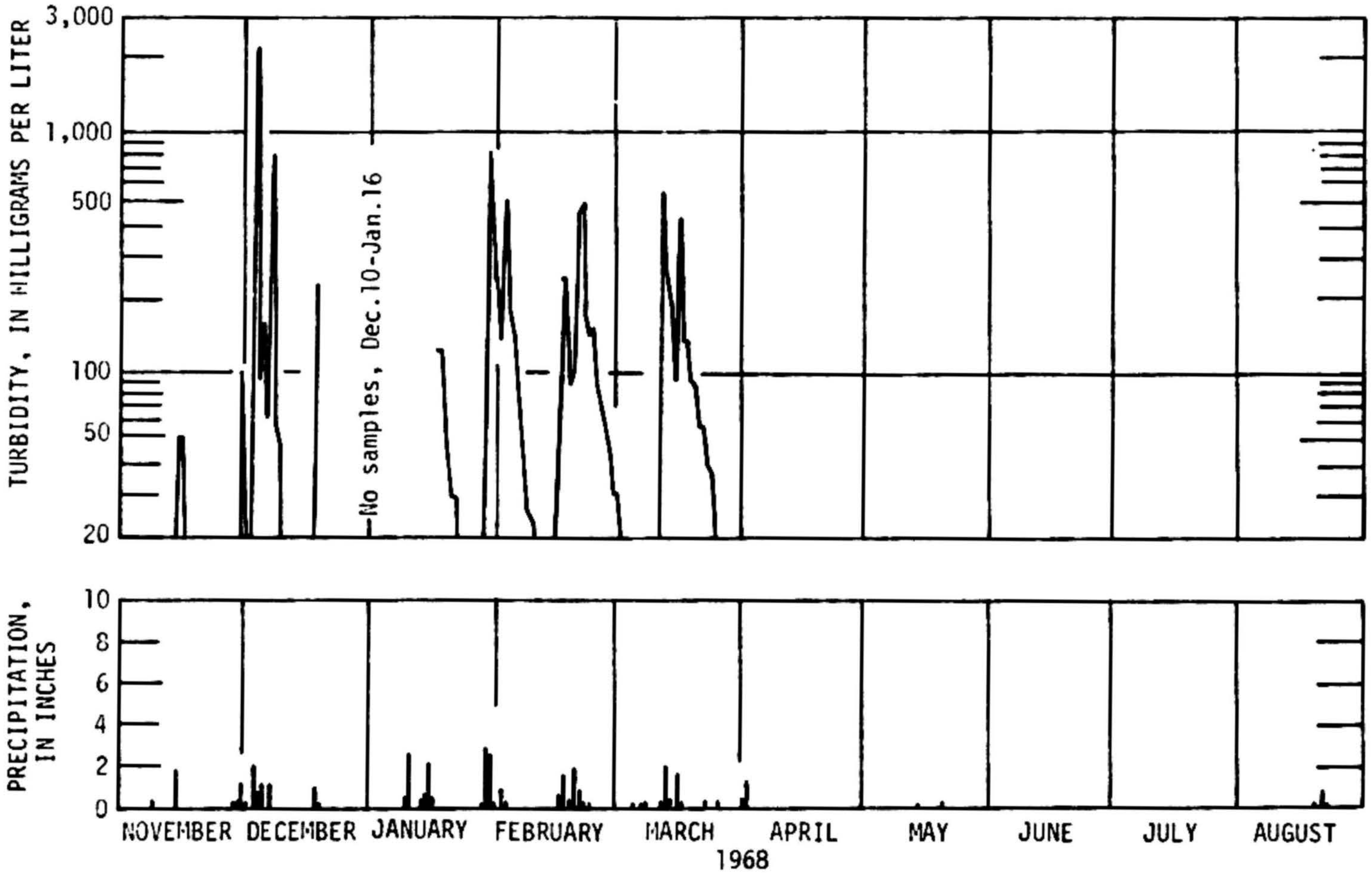


FIGURE 36.--Continued.

Russian River near Guerneville (Sta. No. 4670)

The frequency of sampling at this station was not sufficient to prepare an illustration like those for the other stations (such as figs. 35 and 36); however, samples collected for several periods during 1966-68 showed a general pattern of periods of turbid water similar to the patterns at Russian River near Cloverdale and Dry Creek near Geyserville, There were notable exceptions, however. For example, the water at Guerneville was turbid throughout most of November 1967, whereas the water at the upstream stations was generally clear (table 9). The cause of that anomalous turbid water may have been sand and gravel mining between Healdsburg and Guerneville.

TABLE 9.--*Turbidity of samples collected at Russian River near Guerneville in November 1967 compared with turbidity of samples collected at nearest upstream stations*

Station	Turbidity, in milligrams per liter							
	November							
	1	8	9	13	20	22	24	27
Russian River near Guerneville	91	87	18	90	96	94	93	88
Dry Creek near Geyserville	1	1	1	1	3	1	1	1
Big Sulphur Creek near Cloverdale	1	3	-	1	3	3	-	1
Russian River near Cloverdale	12	24	-	3	5	5	-	3

FIGURE 37.--Sand and gravel mining in the channel of Dry Creek near Healdsburg, August 1969.

EXPLANATION OF PERSISTENCE OF TURBIDITY

The rainstorms from February to December 1964 seemed to produce turbid water in the streams and lakes of the Russian River basin only for the duration of the storm or a few days thereafter. Even during 1953-55, prior to the construction of Coyote Dam, turbid water on the East Fork usually coincided with periods of rainstorms. Although in 1954 the water of the East Fork remained turbid for most of a 4-month period, the water did become clear for brief intervals. For the most part, during 1953-55, the duration of turbid water after a rainstorm seemed to depend on the intensity and length of the storm. However, after December 1964, once the water in the East Fork became highly turbid, it remained turbid for months before becoming clear without regard to the intensity or duration of the rainstorms.

The persistence of turbidity in the streams in the Russian River basin for each year from December 1964 to September 1968 can be explained. During the first large rainstorms of the winter, the discharge of the streams tributary to Lake Pillsbury and the erosion of the uplands and the exposed deltas of the lake increased so that the water flowing into Lake Pillsbury was highly turbid. The inflow of turbid water caused Lake Pillsbury and the water released from it to become turbid for several months during the winter and early spring. That water was diverted into the East Fork Russian River through the Potter Valley powerhouse. The turbid imported water moved down the East Fork, sometimes becoming more turbid because of rainstorms in the East Fork basin, and entered Lake Mendocino.

Because the water flowing into Lake Mendocino was more turbid and denser than the reservoir water, the inflowing water moved along the bottom of Lake Mendocino as a turbidity current, probably following the old stream channel. About 3 days after it had entered Lake Mendocino, the turbid water reached Coyote Dam (fig. 38). If the water flowing into the lake remained turbid, a few days later the surface of the lake became turbid but not so turbid as the bottom water. Lake Mendocino and water released from it then remained turbid until the water flowing into the lake became clear.

Downstream the Russian River became turbid during rainstorms and, commonly, became clear after the rainstorm had passed from the area. However, if a large quantity of turbid water from Lake Mendocino was released during a period of little or no rain, the Russian River downstream remained turbid. If the quantity of water released from the lake was small, the river downstream became clear if algal blooms or sand and gravel mining upstream did not increase the turbidity.

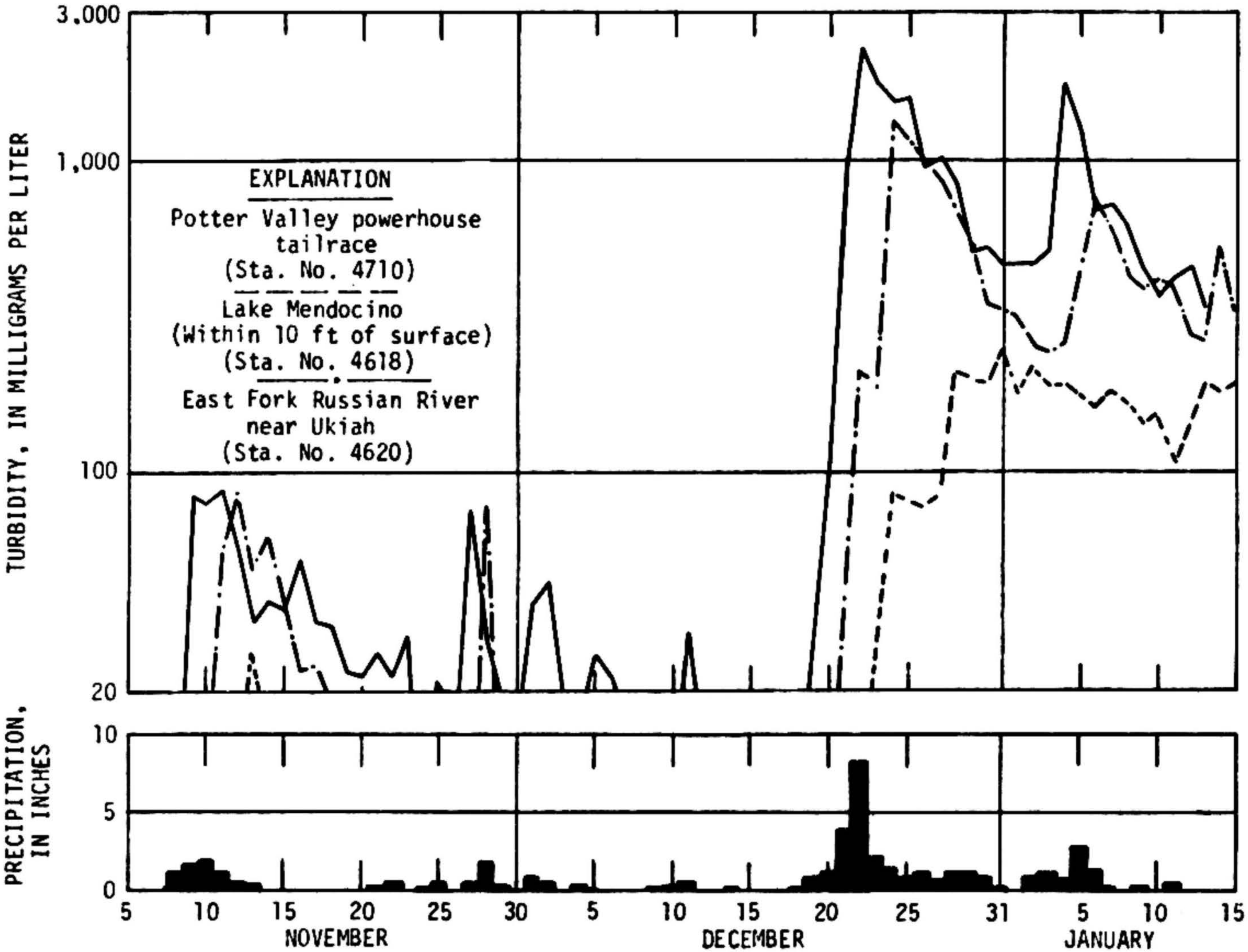


FIGURE 38.--Occurrence of turbid water upstream from Lake Mendocino (Potter Valley powerhouse tailrace), near the surface of Lake Mendocino, and downstream from Lake Mendocino (East Fork Russian River near Ukiah) and periods of precipitation, November 5, 1964, to January 15, 1965. Precipitation data are from U.S. Weather Bureau rain gage at Potter Valley.

It is important to point out that if Lake Mendocino did not exist, the turbid water that entered the lake would have flowed down the East Fork unobstructed and then down the Russian River. The turbidity of the water of the Russian River, thus, would have been increased between storm periods and the water probably would have been turbid as long as the East Fork water remained turbid even though the turbidity would have been diluted by the Russian River water. Lake Mendocino, however, interrupted the turbid flows on the East Fork and when releases from the lake were low for several days during periods between rainstorms, the water of the Russian River became clear--a condition that probably would not have occurred if the dam were not there.

For the water years 1965, 1966, and 1968, the number of days of clear water from November 8 to March 31 of each year was estimated at five sampling stations (table 10); 1967 was omitted because data for November and December at Russian River near Cloverdale were missing. November 8 was the earliest date that turbid water appeared in the basin during the 3 years and in the other years it appeared within a week of that date. The influence of turbid water from the East Fork on the turbidity downstream can be compared to the natural turbid-water conditions in the basin by comparing Russian River near Cloverdale with Dry Creek near Geyserville and Russian River near Ukiah, two stations unaffected by releases from Lake Mendocino and with East Fork Russian River near Ukiah, a station directly affected by releases from Lake Mendocino. Data for Potter Valley powerhouse tailrace show the number of days that turbid water entered Lake Mendocino.

The water at Potter Valley powerhouse tailrace was clear the fewest days each year, whereas the unregulated flow at Russian River near Ukiah and Dry Creek near Geyserville was clear the most days. The water at Russian River near Cloverdale in 1965 and 1968 was clear about the same number of days as the water at East Fork Russian River near Ukiah just below Coyote Dam, but in 1966 was clear about the same number of days as the water at Dry Creek near Geyserville, an unregulated station.

TABLE 10.--*Number of days of clear water (turbidity less than 20 mg/l) at five stations in the Russian River basin, November 8 to March 31 (145 days)*

Station	Number of days of clear water		
	1965	1966	1968
Russian River near Ukiah	71	65	75
E.F. Russian River near Ukiah	35	18	26
Russian River near Cloverdale	44	51	34
Dry Creek near Geyserville	91	49	-
Potter Valley powerhouse tailrace near Potter Valley	17	4	18

SUMMARY AND CONCLUSIONS

This investigation of the causes of turbid water in the Russian River from 1964 to 1968 found that:

1. Rainstorms and consequent erosion were the primary causes of turbid water.

2. The most persistently turbid water in the Russian River basin during 1964-68 was the water flowing through the East Fork. After the flood of December 1964, the water in that tributary remained turbid for several months, and after the first major rainstorms of each succeeding water year the water became turbid and remained continuously turbid for several months. From 1965 to 1968, however, the water became clear earlier each succeeding year. The persistence of the turbid water during the winter and spring months was attributed chiefly to the diversion of turbid water from the Eel River through the Potter Valley powerhouse tailrace, which did not permit the East Fork to become clear between rainstorms. With the exception of periods of algal blooms, the water of the East Fork generally became clear as soon as the imported Eel River water became clear.

3. The water in Lake Mendocino remained turbid about as long as the water entering the reservoir remained turbid. Turbidity currents did exist in Lake Mendocino and caused turbid releases sometimes when the surface water of the lake was clear.

4. The yo-yo release pattern of Lake Mendocino, whereby short periods of high discharges were followed by periods of low discharges, helped to clear the water in the Russian River during periods of little or no rainfall. If Coyote Dam had not been built the turbid water diverted from the Eel River would flow uninterrupted down the East Fork and then down the Russian River. The water of the Russian River would then be persistently turbid most of the winter and spring if the dilution by the clear water from other tributaries to the Russian River did not clear the water sufficiently. During the periods of low release from Lake Mendocino and no major rainstorms, the Russian River became clear because the flow of turbid water diverted from the Eel River was reduced. During periods of high release and no major rainstorms, the Russian River became turbid because of the turbid releases and possible downstream erosion.

5. The mining of sand and gravel in the channels of the streams sometimes produced turbid water when rainfall and runoff were low and possibly sometimes increased turbidity when the runoff was high.

6. The effects of road construction and logging on erosion were not thoroughly investigated, but road construction was noted as causing turbid water at least once as was the flushing of irrigation ditches.

7. Algal blooms sometimes created turbid water that prolonged the periods of turbid water first caused by erosion. Algae, however, were not the cause of highly turbid water, which would, in turn, reduce or stop production by the algae.

The area of highest sediment yield in the Russian River basin was the Dry Creek basin; much of its yield was attributed to land use. The area of lowest sediment yield was the East Fork basin. In general, sediment yield increased downstream.

The measurements of turbidity and concentration of suspended sediment correlated well at most stations although the correlation at individual stations was different and the correlation varied slightly from year to year. Turbidity usually was higher than concentration of suspended sediment at stations on the East Fork (including Potter Valley powerhouse tailrace) where little or no sand was transported. Turbidity usually was lower than concentration at the other stations where sand was a significant part of the load.

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