STATE OF LOUISIANA
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
OFFICE OF PUBLIC WORKS

Water Resources
TECHNICAL REPORT NO. 21

# HYDROLOGY AND WATER QUALITY OF THE LOWER MISSISSIPPI RIVER

Prepared by
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
In cooperation with
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
OFFICE OF PUBLIC WORKS
1980

STATE OF LOUISIANA

DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

OFFICE OF PUBLIC WORKS

In cooperation with the

UNITED STATES GEOLOGICAL SURVEY

Water Resources
TECHNICAL REPORT NO. 21

# HYDROLOGY AND WATER QUALITY OF THE LOWER MISSISSIPPI RIVER

By

Frank C. Wells
U.S. Geological Survey

Published by

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

OFFICE OF PUBLIC WORKS

Baton Rouge, La.

1980

STATE OF LOUISIANA

EDWIN W. EDWARDS, Governor

DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

GEORGE FISCHER, Secretary

OFFICE OF PUBLIC WORKS

ROY AGUILLARD, Assistant Secretary

Cooperative projects with

UNITED STATES GEOLOGICAL SURVEY

H. WILLIAM MENARD, Director

Louisiana District

A. N. CAMERON, Chief

CONTENTS

ILLUSTRATIONS

[Plates are at back]

TABLES

## FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM (SI) OF METRIC UNITS

For use of those readers who may prefer metric units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

| Multiply inch-pound units | By | To obtain metric units |
|---|---|---|
| cubic foot ($ft^3$) | 0.02832 | cubic meter ($m^3$) |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| cubic foot per second per square mile [$(ft^3/s)/mi^2$] | 0.01093 | cubic meter per second per square kilometer [$(m^3/s)/km^2$] |
| foot (ft) | 0.3048 | meter (m) |
| foot per second (ft/s) | 0.3048 | meter per second (m/s) |
| gallon (gal) | 3.7854 | liter (L) |
| inch (in.) | 2.540 | centimeter (cm) |
| mile (mi) | 1.609 | kilometer (km) |
| mile per hour (mi/h) | 1.609 | kilometer per hour (km/h) |
| million gallons per day (Mgal/d) | 1.548 | cubic foot per second ($ft^3/s$) |
| pound (lb) | 0.4536 | kilogram (kg) |
| | 453.6 | gram (g) |
| pound per day (lb/d) | 0.4536 | kilogram per day (kg/d) |
| pound per minute (lb/min) | 0.4536 | kilogram per minute (kg/min) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| ton | 0.9072 | metric ton |
| ton per day | 0.9072 | metric ton per day |
| ton per mile | 0.5642 | metric ton per kilometer |
| yard (yd) | 0.9144 | meter (m) |

To convert temperature in degree Celsius (°C) to degree Fahrenheit (°F), multiply by 9/5 and add 32.

# HYDROLOGY AND WATER QUALITY OF THE LOWER MISSISSIPPI RIVER

By Frank C. Wells

## ABSTRACT

The average flow for Mississippi River at Vicksburg, Miss., 1931-76, is about 570,000 $ft^3/s$ (cubic feet per second); and the average flow downstream from the Old River outflow channel at Red River Landing, La., and Tarbert Landing, Miss., (hereafter referred to as Red River-Tarbert Landing), 1928-76, is about 460,000 $ft^3/s$. Peak discharges of 1.3 million and 1 million $ft^3/s$ at Vicksburg and Red River-Tarbert Landing, respectively, can be expected to occur on an average of once every 2 years.

An average suspended-sediment load of 630,000 tons per day is transported past Red River-Tarbert Landing; approximately 77 percent is silt and clay. Suspended-sediment concentrations at Red River-Tarbert Landing range between 100 and 1,000 milligrams per liter 90 percent of the time.

Concentrations of dissolved solids at both St. Francisville and Luling, La., are less than 300 milligrams per liter 90 percent of the time. Calcium is the predominant cation, and bicarbonate is the predominant anion.

Concentrations of trace metals are within the recommended limits for public-water-supply sources 99 percent of the time. Nickel and zinc are the most abundant trace metals in the bed material of the river, averaging 12.3 and 29.7 micrograms per gram, respectively.

The average water temperature at St. Francisville, La., is 17.5°C, and at Luling, La., is 18.0°C.

Average concentrations of fecal coliform bacteria at Plaquemine and Violet, La., are 1,000 and 3,100 colonies per 100 milliliters, respectively.

Dissolved-oxygen concentrations in the Mississippi River exceed 75-percent saturation 90 percent of the time. The difference between the

average dissolved-oxygen concentrations at St. Francisville and Venice, La., is less than 0.5 milligram per liter.

Average concentrations of phenolic compounds range from 1.8 to 2.6 micrograms per liter and exceed 1 microgram per liter approximately 40 percent of the time. DDT, dieldrin, and endrin are the most frequently occurring organochlorine insecticides in the Mississippi River. Diazinon is the most frequently detected organophosphorous insecticide, and 2,4-D is the most prevalent herbicide. Chlordane, DDT, DDD, DDE, and dieldrin have been detected in over 50 percent of the bed materials analyzed; however, concentrations rarely exceed 10 micrograms per kilogram. Concentrations of volatile organics are generally less than 10 micrograms per liter and appear to be evenly distributed in the river between St. Francisville and Belle Chasse, La. Fourteen semivolatile compounds have been identified from the river in concentrations of generally less than 5 micrograms per liter.

The leading edge of the saltwater wedge in the Mississippi River is well defined with little mixing occurring at the freshwater interface. Chloride concentrations at the river surface exceed the recommended limit of 250 milligrams per liter for public water supplies approximately 15 to 25 miles downstream from the toe of the wedge.

The most common and most numerous benthic organisms collected from the Mississippi River are <u>Corbicula</u> and tubificid worms; differences in benthic community structure are due primarily to differences in hydrologic conditions.

An average of 6,300 million gallons per day of water was withdrawn from the river for industrial and municipal purposes in 1975, including approximately 3,700 million gallons per day for electrical powerplants.

Little difference is noted in average 5-day biochemical oxygen demand between St. Francisville and Venice, La. Average decomposition or decay-rate coefficients ($k_1$) for the Mississippi River range from 0.046 ($day^{-1}$, $base_e$) at St. Francisville to 0.058 at Luling and Violet, La. Reaeration rates ($k_2$) for the Mississippi River between Baton Rouge and Belle Chasse, La., range from 0.055 at 200,000 $ft^3/s$ to 0.080 at 1 million $ft^3/s$. Reaeration rates between Belle Chasse and Head of Passes, La., range from 0.016 at 200,000 $ft^3/s$ to 0.045 at 1 million $ft^3/s$.

Time-of-travel information presented can be used to predict the longitudinal dispersion and peak concentration of a contaminant passing a point on the Mississippi River if the discharge rate and time and place of injection are known. Depending upon the concentration and toxicity of a contaminant discharged into the Mississippi River, it is possible that a 100-mile reach of the river could be closed to use for municipal water supply.

# INTRODUCTION

The Mississippi River is of vast economic importance to the State of Louisiana and the United States. The river is navigable by ocean-going vessels as far upstream as Baton Rouge and by barge traffic for nearly the entire length of the river and major tributaries, the Arkansas, Ohio, and Missouri Rivers. The ports of New Orleans and Baton Rouge, La., the second and fourth largest ports in the Nation, respectively, serve an area that encompasses approximately 55 percent of the land area of the Nation and approximately 40 percent of the population. Over 200 million tons of waterborne commerce was handled by the two ports in 1975, grain and petroleum products comprising the two largest categories of commodities.

The Mississippi River also serves as a large source of good-quality water for industrial and municipal purposes. It is the primary source of water for public water supplies downstream from Donaldsonville, La. In 1976, 214 Mgal/d was used for municipal supplies, and 6,100 Mgal/d was used for industrial purposes.

Populations of cities and towns near the river and industrial development along the banks of the river have increased greatly in recent years. Accompanying the population and industrial growth is the increase in municipal and industrial wastes discharged into the river. Increased waste loads could cause the quality of the river to deteriorate so that it would be unfit for some present-day uses without additional treatment.

## Purpose and Scope

The purpose of this report is to define the chemical, physical, and biological characteristics of the lower Mississippi River; the suitability of the river water for municipal and industrial uses; the ability of the river to assimilate wastes; and the rate at which wastes are transported by the river. The study area extends from the Arkansas-Louisiana State line to the Gulf of Mexico with the major emphasis between St. Francisville and Head of Passes, La. (fig. 1).

## Acknowledgments

This report was prepared as a part of the cooperative program between the U.S. Geological Survey and the Louisiana Office of Public Works, Department of Transportation and Development. Streamflow and sediment data at Red River Landing, La., and Tarbert Landing, Miss., and salinity data for the river reach downstream from New Orleans, La., were provided by the U.S. Army Corps of Engineers. The Corps also provided transportation and docking facilities during the time-of-travel studies conducted on the river. Special thanks are due the U.S. Coast Guard at

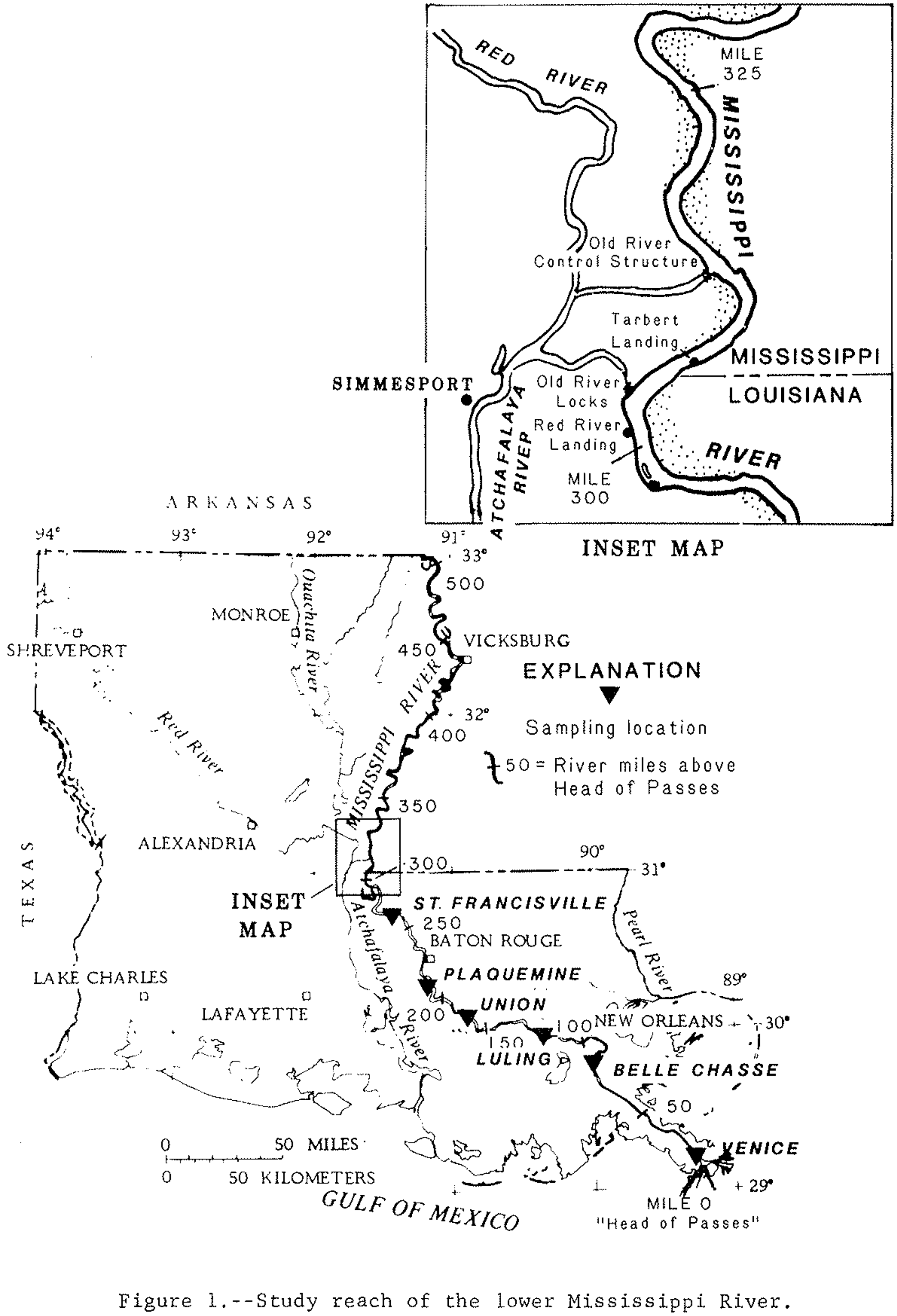



Figure 1.--Study reach of the lower Mississippi River.

New Orleans and Venice, La., for the use of their personnel, boats, and docking facilities during data-collection phases of the study.

## STREAMFLOW

The Mississippi River at its mouth has a drainage area of approximately 1.24 million $mi^2$, which is exceeded in size by only the Amazon and the Congo Rivers. Of this area, about 1 percent (13,000 $mi^2$) is in Canada, and the remainder is in the central United States. Tributaries to the river extend from New York in the east to Wyoming and Montana in the west.

Some of the largest rivers in this country make up the headwaters of the Mississippi. The drainage area, the average discharge, and the average unit discharge for the four largest tributaries are listed in the following table.

Drainage area and average discharge of major tributaries of the Mississippi River

[Based on most downstream gaging stations]

| Tributary and gaging station | Drainage area ($mi^2$) | Average discharge ($ft^3/s$) | Unit discharge [$(ft^3/s)/mi^2$] |
|---|---|---|---|
| Missouri River at Hermann, Mo | 528,200 | 80,000 | 0.15 |
| Ohio River at Metropolis, Ill | 203,000 | 265,000 | 1.31 |
| Arkansas River at Little Rock, Ark | 158,030 | 42,000 | .26 |
| Red River at Alexandria, La.1/ | 67,500 | 32,000 | .47 |

1/ Although the Red River is not a natural tributary to the Mississippi River, its discharge is included in the total outflow of the Mississippi River system.

Daily discharge records have been published for Mississippi River at Vicksburg, Miss., by the Geological Survey since July 1931. For the Mississippi River downstream from the Old River outflow channel, records have been published by the U.S. Army Corps of Engineers as follows: for Red River Landing, La., 1928-63, and for Tarbert Landing, Miss., 1964-76, (hereafter referred to as Red River-Tarbert Landing1/). Flows in the lower Mississippi River are affected by diversion into the Atchafalaya River through the Old River Control Structure (mile 314.5). Prior to completion of the Old River Control Structure in 1963 the Atchafalaya River had been receiving increasing flows from the Mississippi River.

1/ The term "Red River-Tarbert Landing" is a joint name used in this report to represent that measuring station on the Mississippi River immediately downstream from the diversion. For the period 1928-63, this was Red River Landing, La. From 1964 to 1976, the river has been measured at Tarbert Landing, Miss. This name is not an official station name of the U.S. Army Corps of Engineers or the U.S. Geological Survey.

Studies indicated that without the Old River Control Structure the Mississippi River would have changed its course to that of the Atchafalaya River by 1975. The Old River Control Structure reduced that possibility and now restricts the flow entering the Atchafalaya River to approximately 25 percent of the total flow in the Mississippi River upstream from the control structure. This diversion at the Old River Control Structure allows 30 percent of the combined flow of the Red River and the Mississippi River to be carried down the Atchafalaya River. Because of the Old River diversion, discharges at Vicksburg have averaged approximately 20 percent higher than those discharges downstream from the diversion at Red River-Tarbert Landing (fig. 2).

The average flow of Mississippi River at Vicksburg, Miss., 1931-76, is about 570,000 $ft^3/s$; the average flow downstream from the Old River diversion, 1928-76, is about 460,000 $ft^3/s$. The annual mean discharge at Vicksburg has ranged from a low of 272,000 $ft^3/s$ for the 1931 water year to a high of 995,000 $ft^3/s$ for the 1973 water year. Annual mean discharge at Red River-Tarbert Landing has ranged from 243,000 $ft^3/s$ for the 1954 water year to a high of 729,000 $ft^3/s$ for the 1973 water year.

The daily duration hydrographs and frequency curves for Mississippi River at Vicksburg, Miss., and Mississippi River at Red River-Tarbert Landing are shown on plates 1 and 2, respectively. Highest flows in the river occur from February through May. The discharge at Vicksburg exceeds 1 million $ft^3/s$ approximately 20 percent of the time during these months. Likewise, the discharges at Red River-Tarbert Landing exceed 800,000 $ft^3/s$ approximately 20 percent of the time during this same period. Lowest flows generally occur during September, October, and November. The 50-percent flow duration (median discharge) during these months is approximately 300,000 $ft^3/s$ at Vicksburg and 220,000 $ft^3/s$ at Red River-Tarbert Landing.

## High Flows

The largest flood recorded on the Mississippi River occurred in May 1927 when a discharge of approximately 2.28 million $ft^3/s$ occurred at Vicksburg, Miss. This same flood produced a discharge of approximately 1.78 million $ft^3/s$ at Red River Landing, La. Although the 1927 flood is the largest flood of record in terms of peak discharge, the 1973 flood is the largest flood of record in terms of duration. During the 1973 flood, Mississippi River at Vicksburg was above flood stage for a period of 88 consecutive days. Only once since 1927 has the discharge at Vicksburg exceeded 2 million $ft^3/s$. This occurred in February 1937 when the peak discharge reached 2.08 million $ft^3/s$. Since 1927, only two floods have equaled or exceeded 1.5 million $ft^3/s$ downstream from the Old River diversion. In April 1945 the flow at Red River Landing peaked at 1.52 million $ft^3/s$, and in May 1973 the flow reached 1.54 million $ft^3/s$ at Tarbert Landing, Miss. The lowest annual peak discharges recorded at Vicksburg and Red River-Tarbert Landing are 703,000 and 539,000 $ft^3/s$, respectively, both occurring during the 1954 water year.

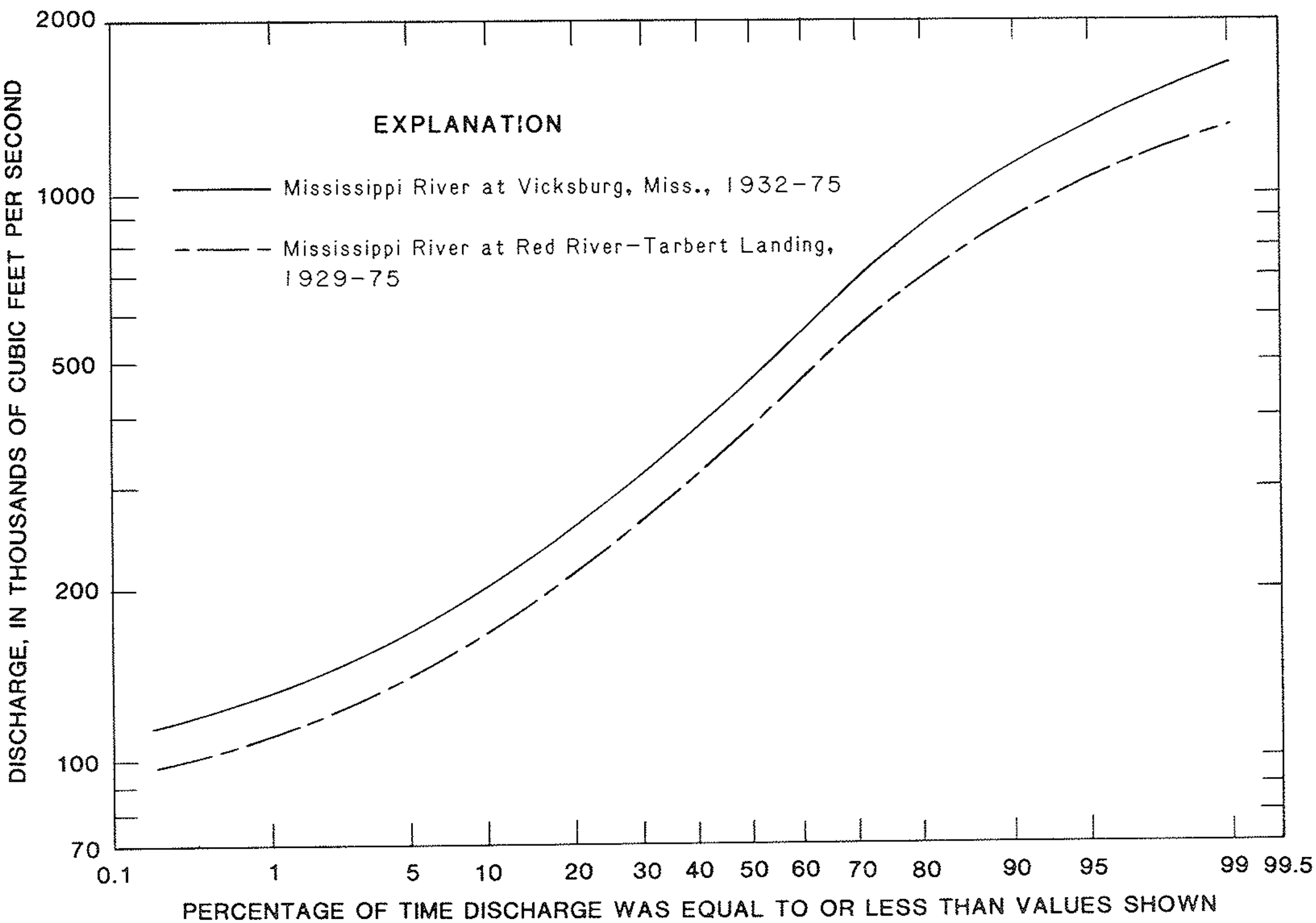



Figure 2.--Discharge-duration curves for Mississippi River at Vicksburg, Miss., and at Red River-Tarbert Landing.

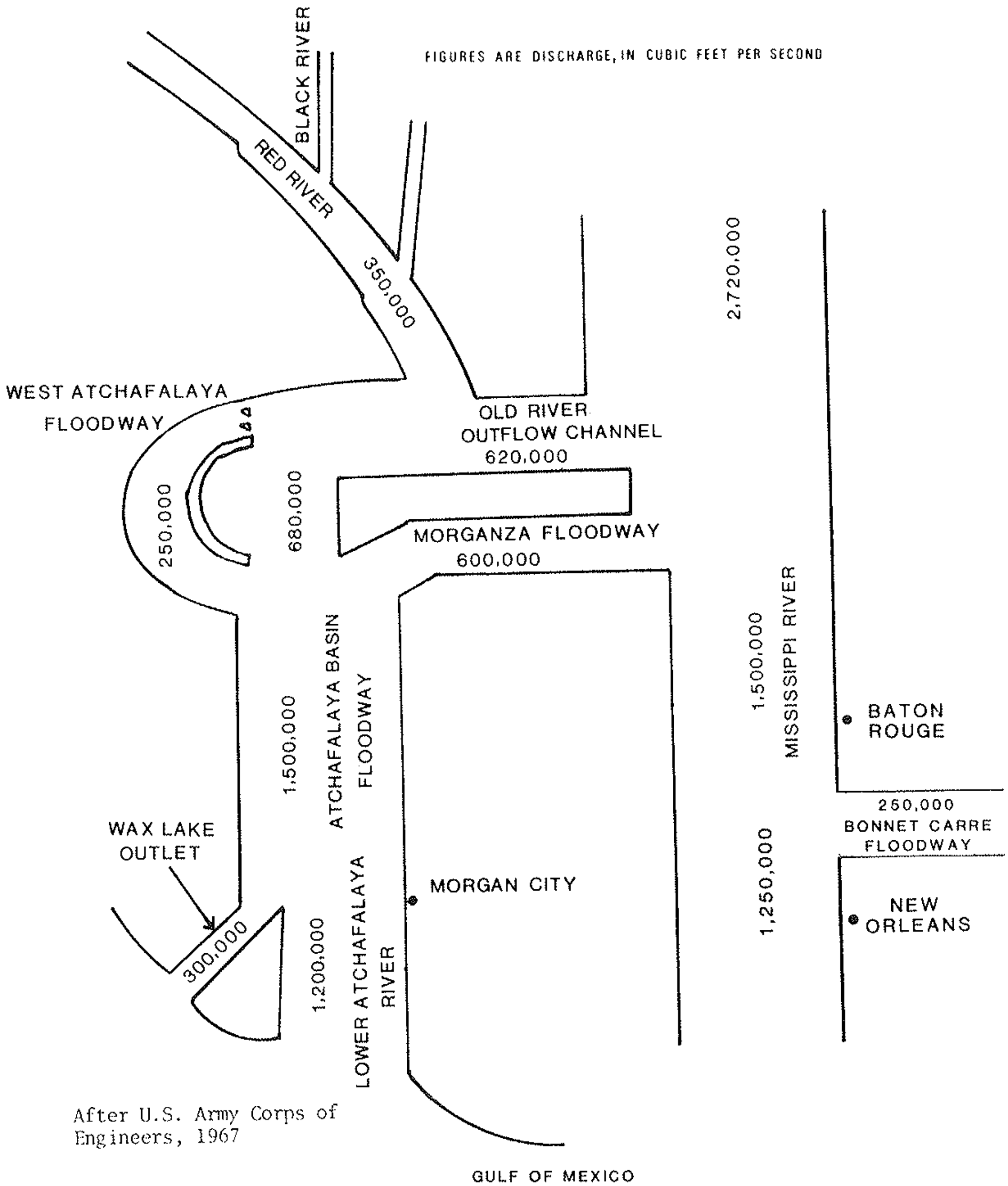
Following the 1927 flood, the U.S. Army Corps of Engineers began a vast flood control program. Flood-control reservoirs were built, canalization was done, and levees were built to control the river. The Corps of Engineers flood control program was designed to handle a flow of 3 million $ft^3/s$ (combined flow of the Red and Mississippi Rivers) at the latitude of Old River. One-half of a flood of this magnitude would be transported through the Atchafalaya River basin, and the remainder through the Mississippi River (fig. 3). Of that water diverted through the Atchafalaya basin, 680,000 $ft^3/s$ would be carried by the Atchafalaya River main channel; 250,000 $ft^3/s$ would be discharged through the West Atchafalaya Floodway; and 600,000 $ft^3/s$ would be diverted through the Morganza Control Structure into the Morganza Floodway. The remaining 1.5 million $ft^3/s$ in the Mississippi River would flow past Baton Rouge, La., to the vicinity of Norco, La., where an additional 250,000 $ft^3/s$ would be diverted through the Bonnet Carre Floodway (mile 128.0) into Lake Pontchartrain. The remaining 1.25 million $ft^3/s$ would flow down the Mississippi River past New Orleans, La., to the Gulf of Mexico.

The Bonnet Carre Floodway has been used six times since its completion: 1937, 1945, 1950, 1973, 1975, and 1979. The Morganza Floodway has been used only during the 1973 flood. During the 1973 flood, a maximum discharge of 142,000 $ft^3/s$ was diverted through the Morganza Floodway, and a maximum discharge of 195,000 $ft^3/s$ was discharged through the Bonnet Carre Floodway. The combined diversions through the Bonnet Carre Floodway, Morganza Floodway, and the Old River Control Structure during the 1973 flood amounted to about 40 percent of the flow at Vicksburg, Miss., (Chin and others, 1975).

The high-flow frequency curves for Mississippi River at Vicksburg, Miss., (pl. 1B) and Mississippi River at Red River-Tarbert Landing (pl. 2B) represent the frequency at which the highest mean discharge for the selected number of consecutive days can be expected to occur. For example, at Vicksburg a mean discharge for 30 consecutive days of 1.5 million $ft^3/s$ can be expected to occur on the average of once in a 5-year period. During 1973 the highest mean discharge for a period of 60 consecutive days (March 31-May 29) was 1.82 million $ft^3/s$. This 60-day mean discharge has a 90-year recurrence interval. The 1-day high-flow frequency curve can be used for flood-frequency analysis. It shows the relation of flood peak to the recurrence interval. For example, on the average of every 2 years, peak discharges at Vicksburg and Red River-Tarbert Landing will equal or exceed 1.3 million and 1 million $ft^3/s$, respectively. Likewise, the peak discharge of 1.962 million $ft^3/s$ at Vicksburg on May 12, 1973, has a recurrence interval of 26 years. The peak discharge of 2.28 million $ft^3/s$ for the May 1927 flood has a 100-year recurrence interval.

## Low Flows

The duration and frequency of low flows are of vital importance to users of the river. Low-flow periods of long duration increase saltwater




After U.S. Army Corps of Engineers, 1967

Figure 3.--Partial discharge-routing diagram for the lower Mississippi River project flood.

intrusion from the Gulf of Mexico, increase the effects of waste loads on the chemical quality of the river, and restrict navigation. The lowest measured discharge for Mississippi River at Vicksburg, Miss., was 99,400 $ft^3/s$, measured by the Geological Survey on November 1, 1939. The lowest daily mean flow of 100,000 $ft^3/s$ was also reported on this date. The minimum daily discharge based on stages at Red River-Tarbert Landing was 75,000 $ft^3/s$, recorded on November 4, 1939; however, this discharge may be low, as explained by Everett (1971). The lowest measured discharge for this station is 83,200 $ft^3/s$ on November 2, 1939.

The low-flow frequency curves for Mississippi River at Vicksburg, Miss., (pl. 1A) and Mississippi River at Red River-Tarbert Landing (pl. 2A) show that a 1-day mean low flow of 125,000 $ft^3/s$ has a recurrence interval of 10 and 3½ years, respectively. This same mean discharge for 30 consecutive days can be expected to occur on an average of once every 6 years at Red River-Tarbert Landing and once every 20 years at Vicksburg.

## SUSPENDED SEDIMENT

Sediment transported by the Mississippi River moves as suspended sediment or along the bottom as bedload. This report refers only to suspended sediment. An average suspended-sediment discharge of 630,000 tons per day is transported past Red River-Tarbert Landing and is ultimately deposited in the lower Mississippi River or the Gulf of Mexico. Approximately 77 percent of the suspended-sediment discharge is transported as silt and clay (particle size smaller than 0.062 millimeter). The remainder is transported as sand (particle size larger than 0.062 millimeter).

Concentrations of suspended sediment in Mississippi River at Red River-Tarbert Landing from 1950 to 1975 ranged from 14 to 2,400 mg/L (milligrams per liter), and concentrations of suspended silt-clay ranged from 13 to 2,330 mg/L. Minimum concentrations of suspended sediment generally occur in the late summer and fall, and maximum concentrations generally occur in late winter or early spring. Approximately 90 percent of the time, concentrations of suspended sediment and suspended silt and clay ranged between 100 and 1,000 mg/L.

The amount of suspended material carried by the river is dependent upon streamflow, turbulence, sediment-particle size, water temperature, and availability of sediment. Suspended-sediment concentrations in the Mississippi River generally increase as the river discharge increases. Peak sediment concentrations, however, usually occur before peak discharges. At higher flows in a flood event, the availability of sediment is generally less than the river is capable of transporting. Figure 4 illustrates this situation for three flood events. The amplitude and shape of the sediment curves are dependent upon antecedent flow conditions in the river.

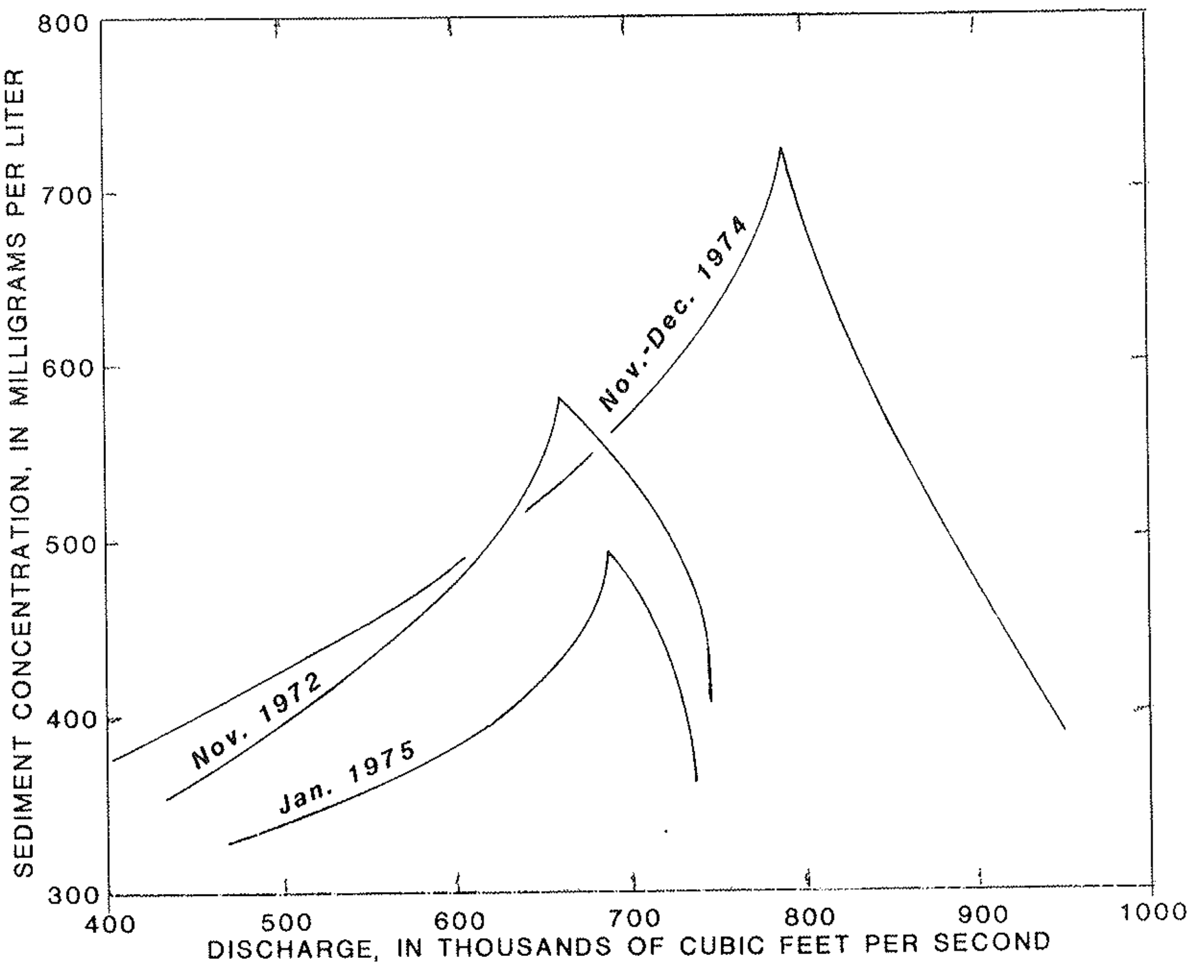



Figure 4.--Relation of suspended-sediment concentration to river discharge for Mississippi River at Red River-Tarbert Landing for three flood events.

Suspended-sediment discharge represents the total weight of suspended sediment transported by the river. The daily duration hydrograph for suspended-sediment discharge and suspended-silt-clay discharge (fig. 5) shows that the highest sediment discharges generally occur from January through June. Suspended-sediment discharges are generally greater than 500,000 tons per day during these months. The greatest difference between total suspended-sediment discharge and suspended-silt-clay discharge are also noted at these times because more sand is transported by the river during periods of high river discharge. During March, April, and May 1975, approximately one-third of the total suspended-sediment load was sand.

The lowest suspended-sediment discharges generally occur during the low-flow months of August through November. During these months, sediment discharges are generally less than 300,000 tons per day, and the total suspended-sediment and suspended-silt-clay discharges more closely

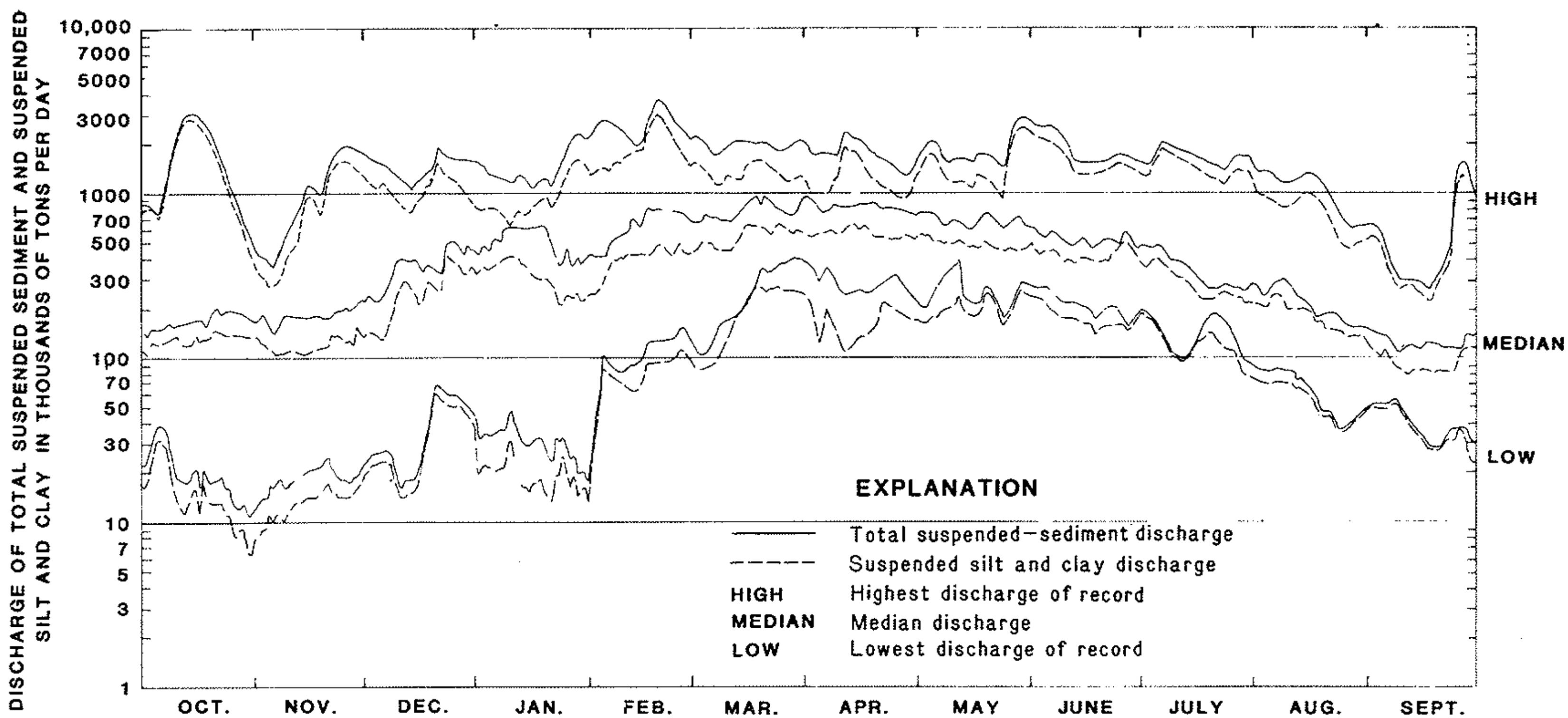



Figure 5.--Daily duration hydrograph for discharge of total suspended sediment and suspended silt and clay, Mississippi River at Red River-Tarbert Landing, 1956-75.

approximate one another. During August, September, and October 1975, approximately 90 percent of the suspended-sediment discharge was silt and clay.

The average suspended-sediment discharge for Mississippi River at Red River-Tarbert Landing is 630,000 tons per day. Daily suspended-sediment discharges ranged from a low of 4,000 tons per day to a high of 4.97 million tons per day. The average suspended-silt-clay discharge is 483,000 tons per day. Daily suspended-silt-clay discharges ranged from 3,000 to 4.1 million tons per day.

Sediment concentrations decrease as water moves downstream from St. Francisville, La., at discharges of 600,000 $ft^3/s$ or less (fig. 6). The decrease in concentrations during low-flow periods is due primarily to sand deposition. The velocity and turbulence of the river are not great enough to keep the larger particles in suspension. For example,

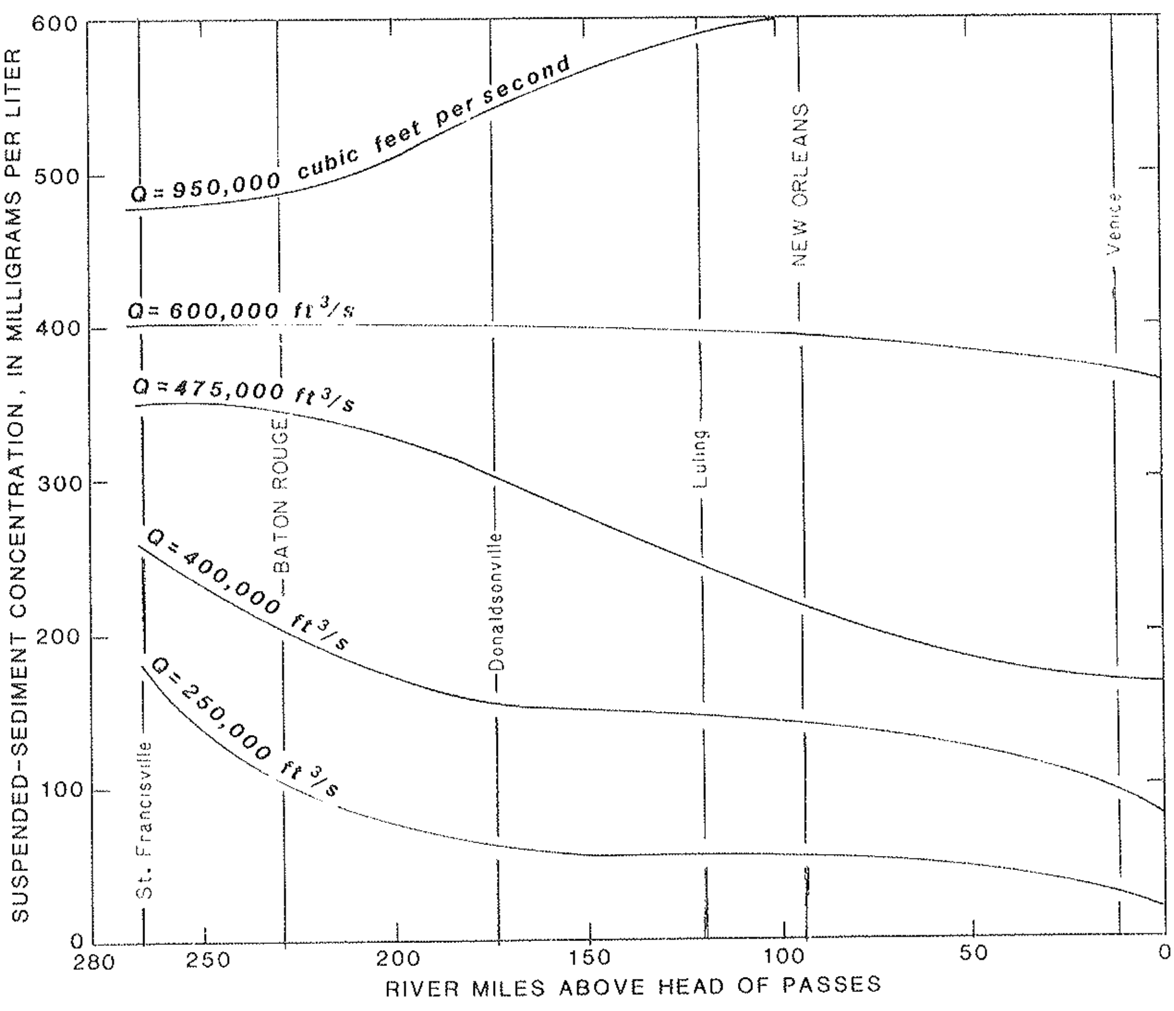



Figure 6.--Downstream changes in suspended-sediment concentrations at various discharges.

at a discharge of 475,000 $ft^3/s$, the concentration of suspended sand decreased 84 percent between St. Francisville and Venice, La. The suspended-silt-clay concentrations decreased only 28 percent. During periods of flow in excess of 600,000 $ft^3/s$, sediment concentrations increase as water moves downstream. Scouring of the riverbed occurs at higher discharges, and the velocity and turbulence of the river are great enough to keep the larger particles in suspension.

Figure 7 shows the percentage of suspended sediment remaining in suspension at New Orleans and Venice, La., at various discharges compared to the original concentration at St. Francisville, La. It is evident that more suspended sediment remains in suspension at higher

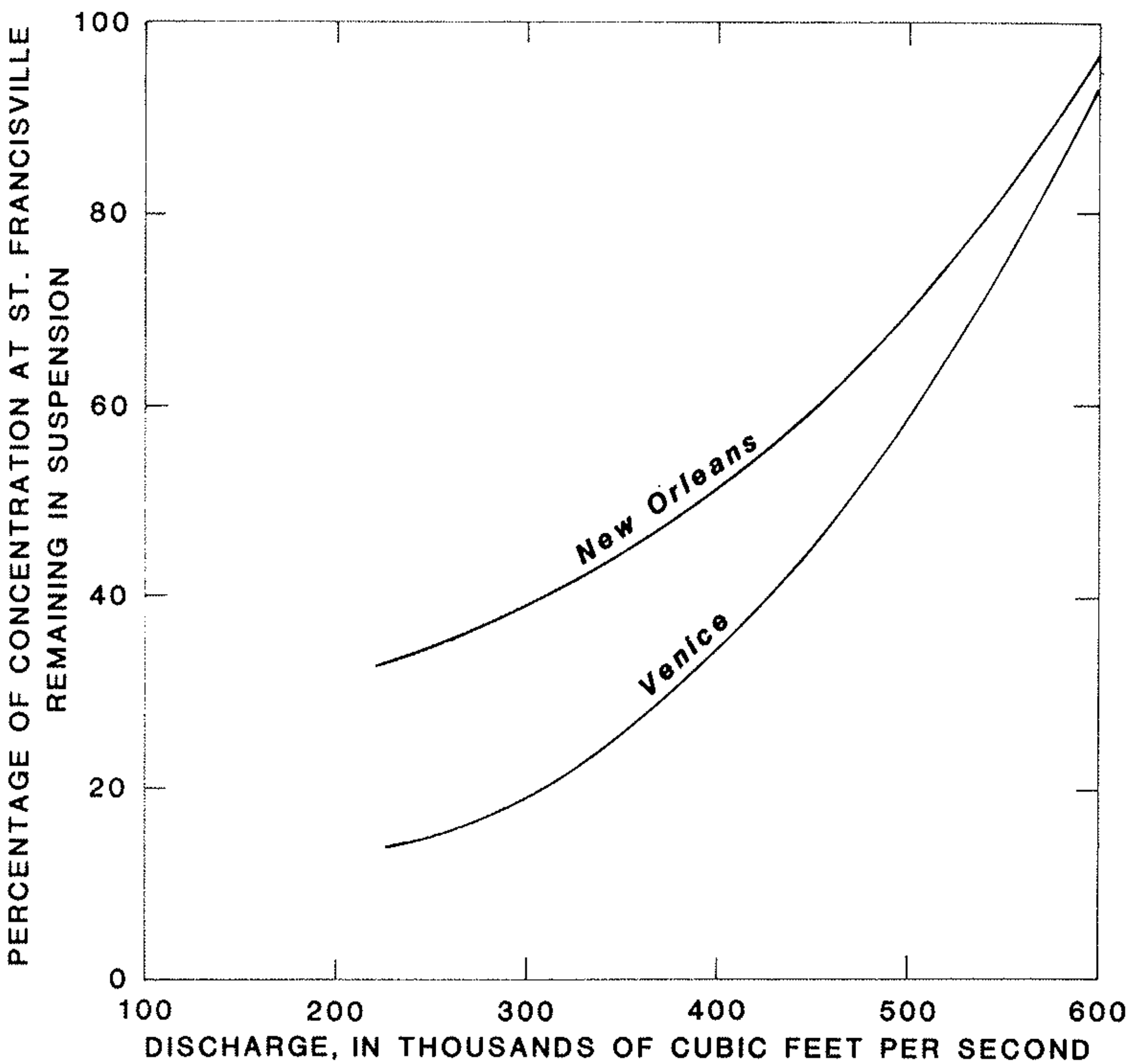



Figure 7.--Relation between suspended-sediment concentration at St. Francisville, La., and percentage remaining in suspension at New Orleans and Venice, La., at various discharges.

discharges. At a discharge of 600,000 $ft^3/s$, approximately 93 percent of the suspended sediment measured at St. Francisville remains in suspension at Venice; at discharges of 300,000 $ft^3/s$, only 20 percent remains in suspension at Venice. Figure 7 also shows that most of the sediment deposition in the river takes place upstream from New Orleans. At a discharge of 300,000 $ft^3/s$, 60 percent of the sediment had settled out by the time it reached New Orleans. Between New Orleans and Venice, an additional 20 percent had settled out, leaving only 20 percent of the original concentration recorded at St. Francisville in suspension below Venice.

The vertical distribution of suspended sediment in the Mississippi River varies with depth; higher concentrations occur near the river bottom (fig. 8). At discharges exceeding 600,000 $ft^3/s$, approximately 15 percent of the suspended sediment is in the upper 20 percent of the water column, and approximately 26 percent is located in the lower 20 percent. At discharges of less than 600,000 $ft^3/s$, 18 percent of the suspended sediment occurs near the surface, and 22 percent occurs near the bottom. Most of the vertical distribution of suspended sediment can be attributed to variations in sand concentrations. Concentrations of silt-clay vary less than 2 percent from top to bottom. Sand concentrations, however, increase with depth. At discharges in excess of 600,000 $ft^3/s$, approximately 10 percent of the suspended sand is located in the upper 20 percent of the water column, and 37 percent is located in the lower 20 percent. At discharges of less than 600,000 $ft^3/s$ the vertical distribution of sand ranges from approximately 13 percent near the surface to 32 percent near the bottom. The average composition of suspended sediment is 82 percent silt-clay and 18 percent sand near the surface and 64 percent silt-clay and 36 percent sand near the bottom.

## WATER QUALITY

### Inorganic Chemical Quality

#### Major Ions

The chemical quality of the Mississippi River varies with fluctuations in river discharge. As the river discharge increases, the dissolved-solids concentration decreases (fig. 9). However, during the initial increase in discharge the dissolved-solids concentration also increases. This increase in dissolved solids is caused by inflow of highly mineralized water washed into the river during early storm runoff. Concentrations of dissolved solids are less than 300 mg/L 90 percent of the time at both St. Francisville and Luling, La. Daily variations in dissolved solids are generally less than 10 mg/L.

Concentrations of dissolved solids in the Mississippi River change very little as the water moves downstream from the Arkansas-Louisiana State line (mile 505.0). A gradual decrease in dissolved solids (generally less than 15 mg/L) occurs between the Arkansas-Louisiana State line

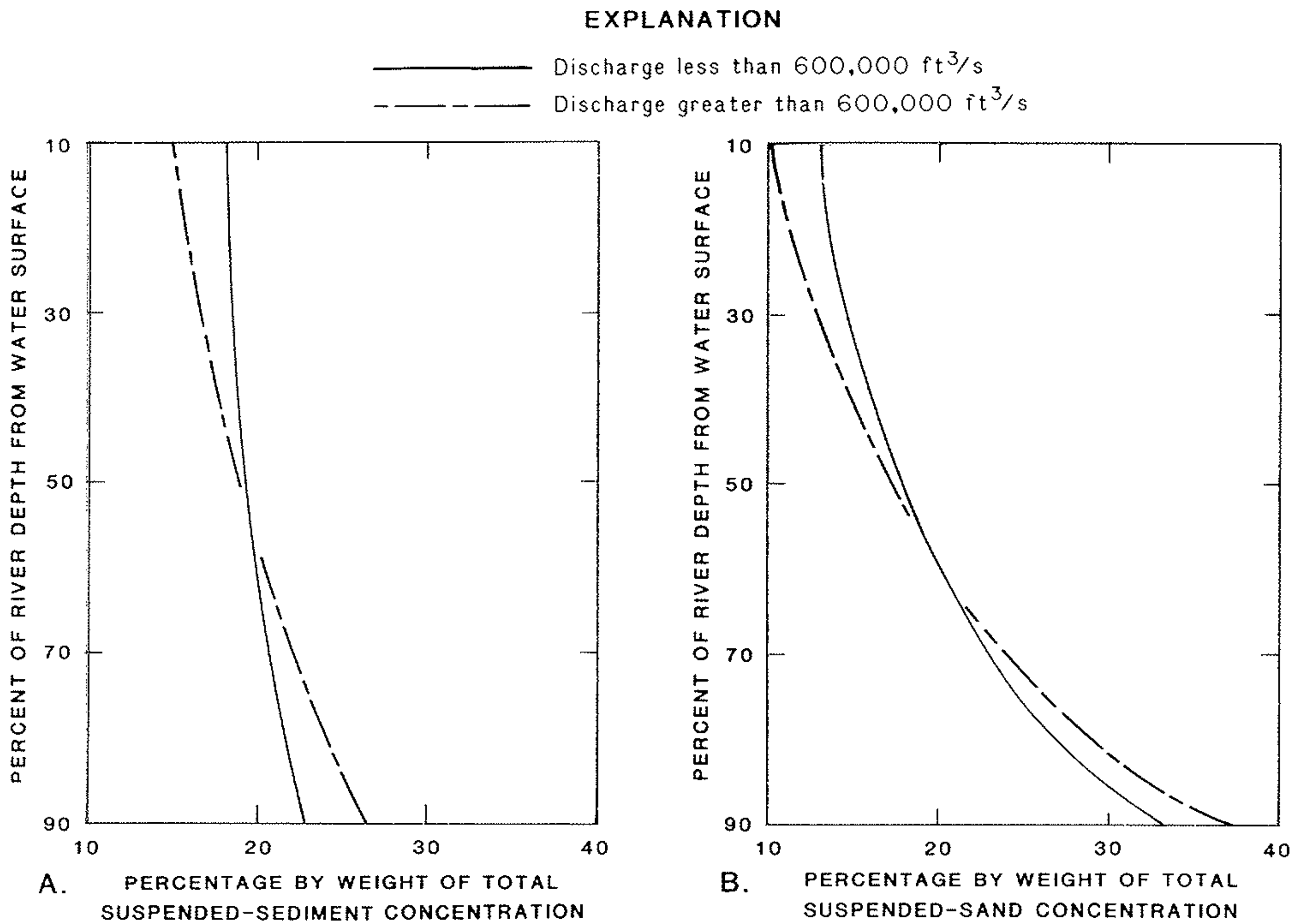



Figure 8.--Vertical distribution of suspended sediment and suspended sand, Mississippi River at Red River-Tarbert Landing.

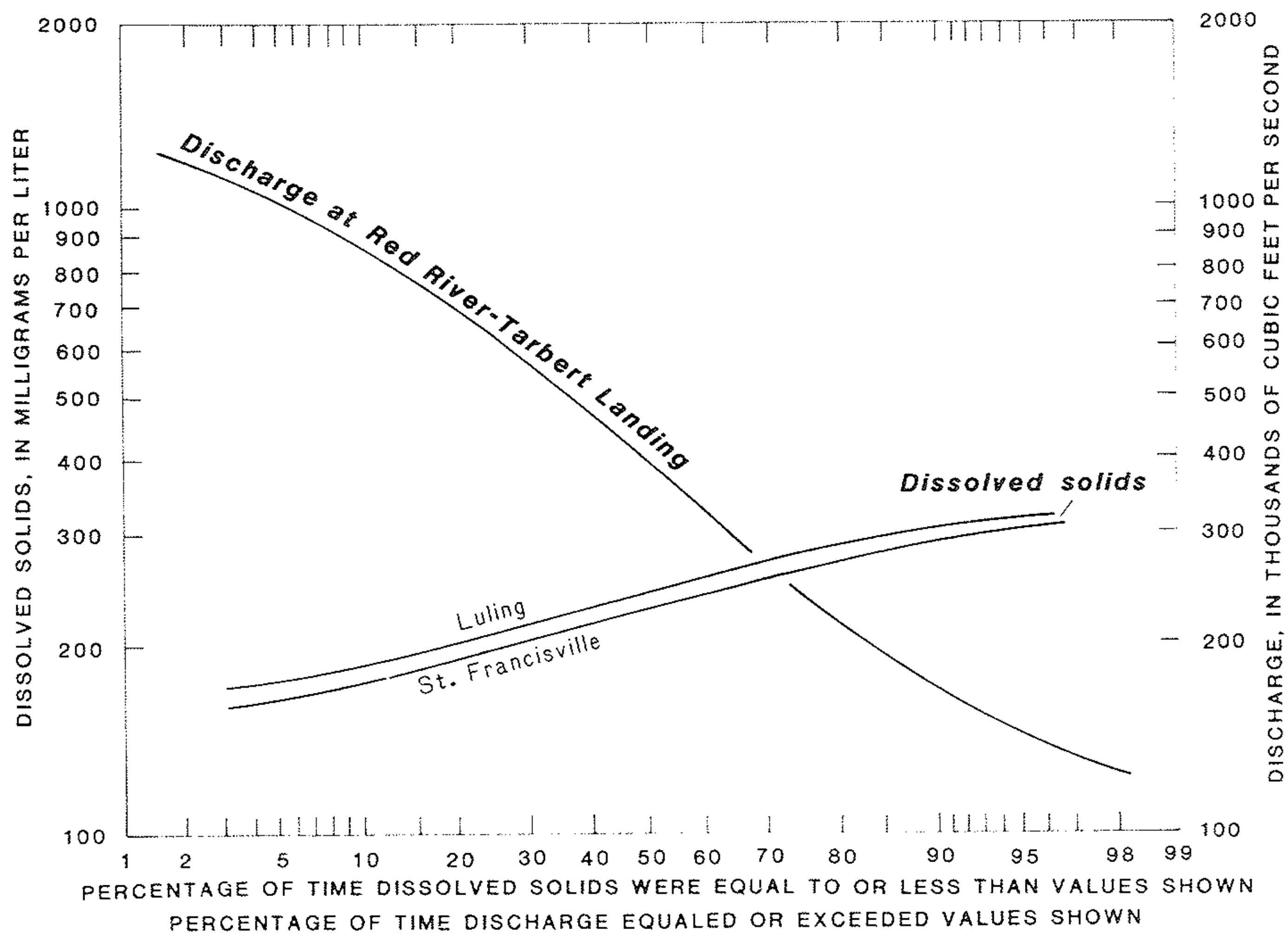



Figure 9.--Duration curves of dissolved solids for the Mississippi River at St. Francisville and Luling, La., and for discharge of Mississippi River at Red River-Tarbert Landing.

and Baton Rouge, La. The largest changes occur during periods of low flow. At a discharge of 186,000 $ft^3/s$ the dissolved-solids concentration decreased from 315 mg/L at mile 505 to 298 mg/L at Baton Rouge (mile 235). At a discharge in excess of 600,000 $ft^3/s$, no differences in dissolved solids were noted between mile 505 and Baton Rouge. The decrease in dissolved solids at lower flows between the Arkansas-Louisiana State line and Baton Rouge is attributed to the inflow of less mineralized water from the Yazoo and Big Black Rivers.

In the industrial area downstream from Baton Rouge, La., dissolved-solids concentrations in the river increase slightly. Increases in dissolved solids between Baton Rouge and Belle Chasse, La., generally range between 10 and 70 mg/L. The largest increases occur at discharges of less than 250,000 $ft^3/s$. Because there is no surface-water inflow between Baton Rouge and Belle Chasse, the increase in dissolved solids can be attributed to industrial and municipal wastes discharged into the river. Chemical constituents accounting for the largest increase in dissolved solids are chloride and bicarbonate.

No appreciable differences in mineralization occur with depth in the river except in the area affected by saltwater intrusion. The only places where significant cross-sectional differences in mineralization occur are downstream from Vicksburg, Miss., and New Orleans, La. Immediately downstream from Vicksburg, less mineralized water from the Yazoo River causes a decrease in the dissolved-solids concentrations along the left bank. Downstream from New Orleans, a small increase in dissolved solids is often noted along the left bank. This increase in dissolved solids may be caused by small volumes of saltwater entering the river from the industrial canal during locking operations. For example, in June 1977, chloride concentrations increased from 34 mg/L just upstream from the industrial canal to 48 mg/L along the left bank 4 mi downstream. The chloride concentration in the industrial canal at this time was 3,800 mg/L.

Data collected at St. Francisville and Luling, La., are used to define the inorganic chemical quality of the Mississippi River upstream from and within the heavily industrialized area between Baton Rouge and New Orleans, La. Ranges in concentration, mean values, and duration of occurrence of selected physical and inorganic chemical characteristics are given in table 1. Calcium is the predominant cation with sodium, magnesium, and potassium in lesser amounts. Bicarbonate is the predominant anion with lesser amounts of sulfate and chloride. The average concentrations and duration of the inorganic constituents are slightly higher at Luling than at St. Francisville. The average concentration of dissolved solids is 10 mg/L higher at Luling than at St. Francisville.

Specific conductance, a measure of the ability of water to conduct an electrical current, is related to the quantity and types of ionized substances in water. Because of the simplicity of the determination, specific conductance can be used to estimate dissolved-solids concentrations as well as concentrations of individual chemical constituents.

Table 1.--Variation in chemical and physical characteristics of the Mississippi River near St. Francisville, La., (1954-77) and Luling, La., (1957-77)
[Chemical constituents are in milligrams per liter]

| Characteristic | Site | Range in concentration | | | Percentage of time values were equal to or less than those shown | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Mean | 95 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | 5 |
| Discharge 1/ | Tarbert Landing | 1,780 | 75 | 461.0 | 1,050 | 890 | 700 | 560 | 470 | 385 | 320 | 260 | 215 | 165 | 140 |
| Specific conductance 2/ | St. Francisville | 683 | 173 | 369 | 490 | 460 | 430 | 410 | 390 | 370 | 350 | 325 | 300 | 280 | 255 |
| | Luling | 636 | 219 | 390 | 520 | 490 | 460 | 430 | 410 | 390 | 370 | 345 | 320 | 300 | 280 |
| Hardness | St. Francisville | 204 | 75 | 141 | 180 | 172 | 162 | 155 | 150 | 140 | 135 | 127 | 120 | 110 | 102 |
| | Luling | 210 | 86 | 146 | 188 | 180 | 170 | 162 | 155 | 148 | 140 | 132 | 125 | 115 | 107 |
| Calcium | St. Francisville | 61 | 22 | 39 | 49 | 47 | 44 | 42 | 40 | 39 | 37 | 35 | 33 | 30 | 28 |
| | Luling | 58 | 26 | 41 | 51 | 49 | 46 | 44 | 42 | 41 | 39 | 37 | 35 | 32 | 30 |
| Magnesium | St. Francisville | 24 | 3.9 | 10.7 | 14.5 | 13.7 | 12.8 | 11.9 | 11.3 | 10.6 | 10.0 | 9.2 | 8.2 | 7.2 | 6.4 |
| | Luling | 21 | 3.2 | 10.9 | 16 | 14.5 | 13.2 | 12.3 | 11.5 | 10.8 | 10.3 | 9.4 | 8.5 | 7.4 | 6.6 |
| Sodium | St. Francisville | 43 | 7.8 | 20 | 33 | 30 | 26 | 23 | 21 | 19 | 17 | 15 | 13 | 11.5 | 10.5 |
| | Luling | 53 | 7.6 | 22 | 37 | 34 | 29 | 26 | 24 | 21 | 19 | 17 | 15 | 12.5 | 11.5 |
| Potassium | St. Francisville | 6.4 | 1.2 | 2.9 | 3.9 | 3.7 | 3.3 | 3.2 | 3.1 | 2.9 | 2.8 | 2.6 | 2.5 | 2.2 | 2.0 |
| | Luling | 5.6 | 1.2 | 3.0 | 4.0 | 3.8 | 3.4 | 3.1 | 3.0 | 2.8 | 2.7 | 2.5 | 2.4 | 2.1 | 1.9 |
| Bicarbonate | St. Francisville | 174 | 64 | 122 | 160 | 152 | 143 | 135 | 128 | 120 | 114 | 108 | 100 | 90 | 84 |
| | Luling | 194 | 67 | 125 | 164 | 156 | 147 | 138 | 131 | 124 | 118 | 112 | 104 | 94 | 87 |
| Sulfate | St. Francisville | 90 | 22 | 50 | 73 | 67 | 61 | 56 | 52 | 48 | 45 | 41 | 37 | 34 | 32 |
| | Luling | 100 | 28 | 52 | 76 | 70 | 64 | 58 | 55 | 51 | 48 | 44 | 40 | 37 | 34 |
| Chloride | St. Francisville | 53 | 8.5 | 22 | 35 | 31 | 27 | 25 | 23 | 21 | 19 | 17 | 15 | 13 | 12 |
| | Luling | 65 | 12 | 25 | 41 | 36 | 32 | 29 | 26 | 24 | 21 | 19 | 17 | 15 | 14 |
| Dissolved solids | St. Francisville | 342 | 152 | 231 | 300 | 285 | 268 | 254 | 240 | 230 | 218 | 205 | 193 | 178 | 168 |
| | Luling | 344 | 151 | 241 | 317 | 300 | 280 | 268 | 254 | 240 | 225 | 212 | 200 | 285 | 177 |
| Silica | St. Francisville | 10.0 | .7 | 6.0 | 8.4 | 7.7 | 7.0 | 6.6 | 6.3 | 6.0 | 5.8 | 5.2 | 4.7 | 3.5 | 2.5 |
| | Luling | 8.8 | .8 | 6.1 | 8.5 | 7.8 | 7.2 | 6.8 | 6.5 | 6.2 | 6.0 | 5.5 | 5.0 | 3.6 | 2.5 |
| Fluoride | St. Francisville | 1.0 | .0 | .22 | ------ | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| | Luling | 1.4 | .0 | .42 | ------ | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| Water temperature 3/ | St. Francisville | 30.5 | 1.0 | 17.5 | 28.0 | 27.5 | 26.0 | 24.0 | 21.0 | 18.0 | 14.0 | 11.0 | 8.0 | 6.5 | 5.0 |
| | Luling | 32.0 | 3.0 | 18.0 | 28.5 | 28.0 | 27.0 | 25.0 | 22.0 | 19.0 | 15.0 | 12.0 | 8.5 | 6.5 | 5.5 |
| Color 4/ | St. Francisville | 100 | 0 | 20 | 45 | 30 | 25 | 20 | ----- | 15 | ----- | 10 | ----- | 5 | ----- |
| | Luling | 100 | 0 | 20 | 45 | 30 | 25 | 20 | ----- | 15 | ----- | 10 | ----- | 5 | ----- |

1/Thousands of cubic feet per second.
2/Micromhos per centimeter at 25° C.
3/Degrees Celsius.
4/Units of platinum-cobalt scale.

The dissolved-solids concentration, in milligrams per liter, of water in the lower Mississippi River is approximately 61 percent of the specific conductance (fig. 10). In figures 10 and 11 the relation of total solids, hardness, and specific chemical constituents to specific conductance at St. Francisville and Luling, La., is shown graphically. The correlation coefficients listed on the curves are a measure of the interdependence of specific conductance and the major anions and cations. A complete lack of correlation between the two variables would give a correlation coefficient of 0, and a perfect correlation would give a correlation coefficient of 1. Using these curves, concentrations of the major ions can be estimated from specific conductance. From a conductance value of 400 micromhos per centimeter at St. Francisville the following ionic concentrations can be

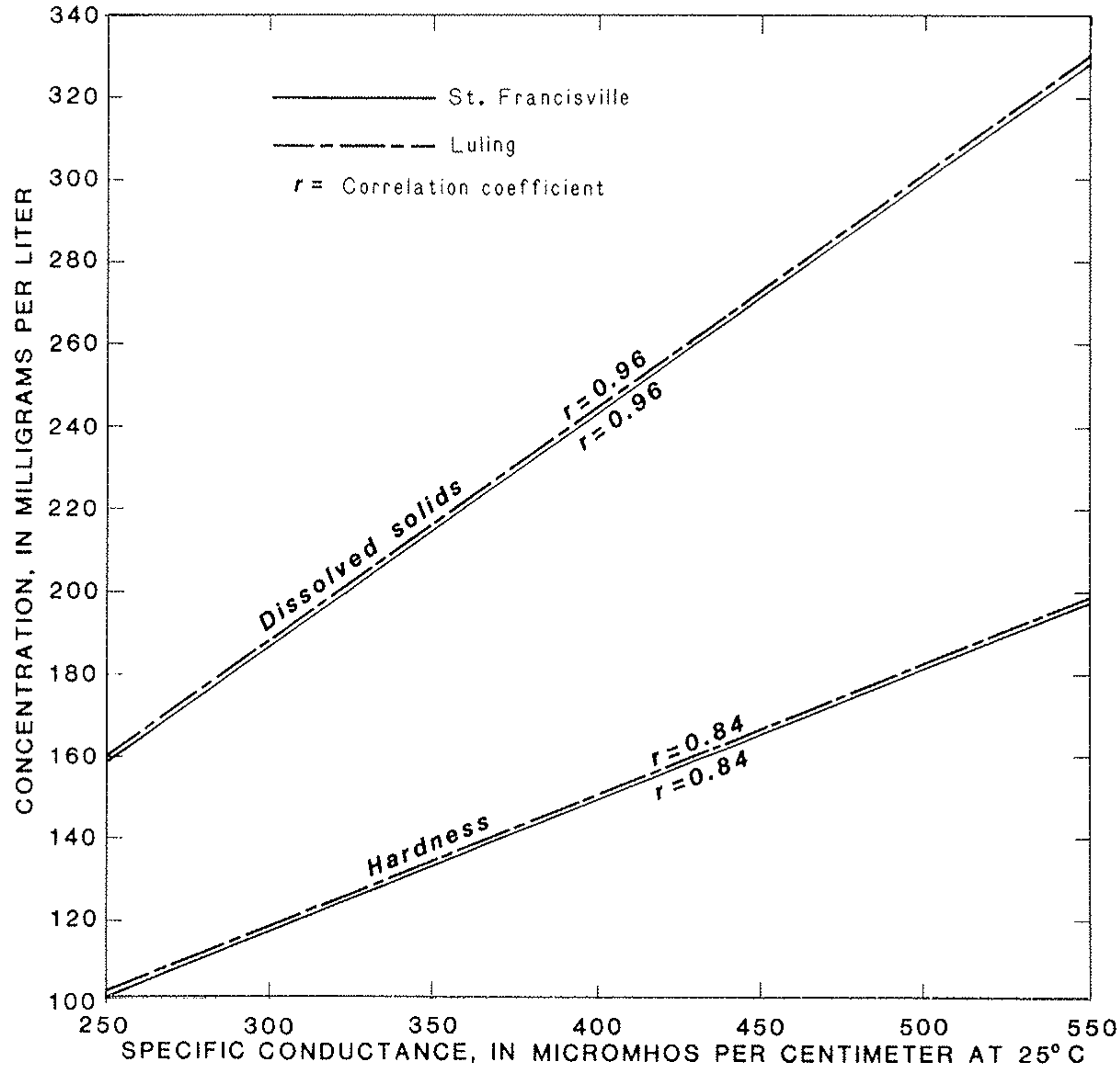



Figure 10.--Relation of specific conductance to dissolved solids and hardness for the Mississippi River at St. Francisville and Luling, La.

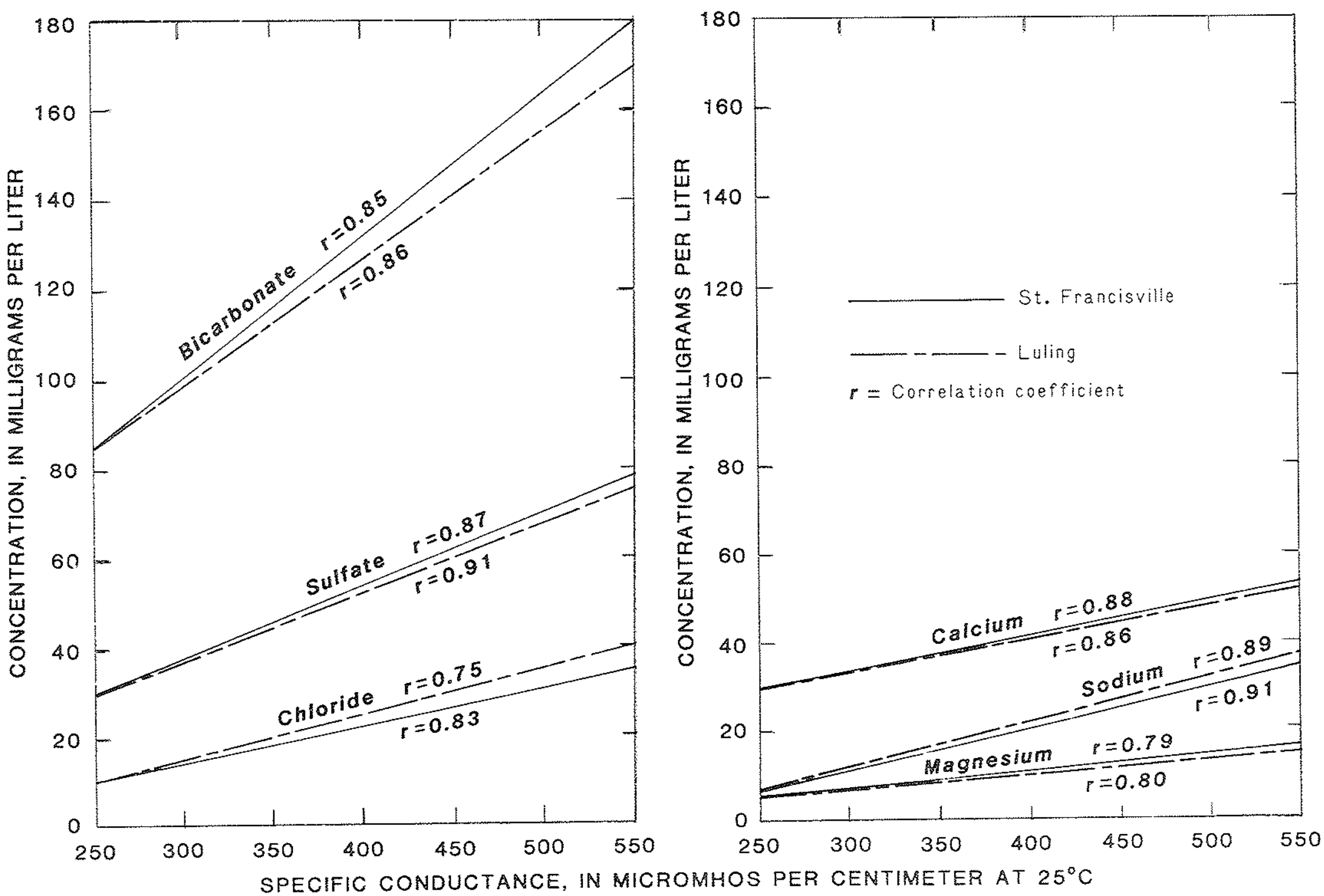



Figure 11.--Relation between specific conductance and major anions and cations for the Mississippi River at St. Francisville and Luling, La.

estimated: bicarbonate, 135 mg/L; sulfate, 55 mg/L; chloride, 24 mg/L; hardness, 150 mg/L; calcium, 41 mg/L; sodium, 21 mg/L; magnesium, 12 mg/L; and dissolved solids, 245 mg/L. It should be noted that these curves provide a reasonable estimate of ionic concentrations and not actual values.

## Trace Metals

The occurrence of trace metals in water is a matter of concern to water users and planners because of the potentially harmful physiological effects of these elements. Undesirable concentrations of trace metals in water may render it unsuitable as a public water supply. Many trace metals may also be concentrated at successive steps in the aquatic food chain, rendering fish and other aquatic life undesirable for human consumption.

In addition to geologic sources, other sources of trace metals in the lower Mississippi River are industrial and municipal waste-water discharges. Because most of the discharges of industrial and municipal wastes to the lower Mississippi River are downstream from Baton Rouge, La., concentrations of trace metals at St. Francisville, La., are considered representative of the reach upstream from Baton Rouge.

A statistical summary of trace-metals data (table 2) collected between St. Francisville and Head of Passes, La., shows that concentrations of trace metals in the Mississippi River are relatively low. Average concentrations of dissolved and total arsenic, cadmium, and mercury; dissolved and hexavalent chromium; and dissolved lead and nickel are less than 5 μg/L (micrograms per liter). Average concentrations of dissolved copper, total lead, and total nickel are less than 10 μg/L at all locations; total copper and dissolved-zinc concentrations are less than 20 μg/L. The average concentration of dissolved iron in the Mississippi River is generally less than 30 μg/L.

During the period 1973-78, only 11 samples were found to contain concentrations of trace metals in excess of the recommended limits for public water supplies. These were collected at St. Francisville, La., on three occasions: twice at Plaquemine, Union, and Violet, La., and once at New Orleans and Venice, La. No metals have been found to be in excess of the recommended limits of public water supplies at Luling, La. Cadmium has been detected in excess of the recommended limits for public-water-supply sources on five occasions: once each at St. Francisville, Plaquemine, and Union and twice at Violet. Total chromium has been detected in excess of 50 μg/L once at St. Francisville and once at a miscellaneous sampling location in the New Orleans, La., harbor area. Total mercury has been detected in excess of 2 μg/L once each at St. Francisville, Plaquemine, Union, and Venice. Arsenic, dissolved iron, lead, and zinc have not been detected in concentrations exceeding the recommended limits for public-water-supply sources.

Table 2.--Statistical summary of trace-metal concentrations in the Mississippi River between St. Francisville and Head of Passes, La., 1973-77

[Concentrations are in micrograms per liter. Numbers in parentheses are maximum recommended limits for public-water-supply sources. N, number of samples; MAX, maximum; MIN, minimum]

| Station | Arsenic (50) | | | | | | | | Cadmium (10) | | | | | | | | Copper (1,000) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dissolved | | | | Total | | | | Dissolved | | | | Total | | | | Dissolved | | | | Total | | | |
| | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN |
| St. Francisville | 101 | 12 | 0 | 1.4 | 28 | 6 | 0 | 3.0 | 106 | 13 | 0 | 0.7 | 25 | 10 | 0 | 0.7 | 29 | 12 | 0 | 4.7 | 27 | 200 | 0 | 19.4 |
| Plaquemine | 106 | 10 | 0 | 1.3 | 29 | 7 | 1 | 3.0 | 106 | 14 | 0 | .8 | 29 | 3 | 0 | .4 | --- | --- | --- | --- | --- | --- | --- | --- |
| Union | 108 | 10 | 0 | 1.1 | 29 | 8 | 1 | 3.5 | 110 | 13 | 0 | .7 | 29 | 3 | 0 | .5 | --- | --- | --- | --- | --- | --- | --- | --- |
| Luling | 106 | 15 | 0 | 1.4 | 29 | 7 | 1 | 2.9 | 110 | 9 | 0 | .7 | 28 | 10 | 0 | .6 | --- | --- | --- | --- | --- | --- | --- | --- |
| New Orleans | 15 | 5 | 0 | 1.1 | 14 | 8 | 0 | 2.6 | 19 | 0 | 0 | .0 | 14 | 20 | 0 | 1.6 | 16 | 10 | 0 | 8.0 | 16 | 26 | 0 | 7.7 |
| Violet | 157 | 12 | 0 | 1.3 | 47 | 8 | 0 | 3.1 | 158 | 12 | 0 | .5 | 47 | 3 | 0 | .3 | --- | --- | --- | --- | --- | --- | --- | --- |
| Venice | 106 | 17 | 0 | 1.3 | 29 | 9 | 0 | 2.8 | 107 | 8 | 0 | .8 | 28 | 2 | 0 | .3 | --- | --- | --- | --- | --- | --- | --- | --- |
| Miscellaneous stations | 92 | 23 | 0 | 2.2 | 37 | 4 | 1 | 2.6 | 96 | 3 | 0 | .2 | 37 | 10 | 0 | .4 | 89 | 20 | 0 | 5.4 | 37 | 10 | 4 | 6.0 |

Percentage of time values were equal to or less than those shown

| Station | Arsenic Dissolved 90 | 70 | 50 | 30 | 10 | Arsenic Total 90 | 70 | 50 | 30 | 10 | Cadmium Dissolved 90 | 70 | 50 | 30 | 10 | Cadmium Total 90 | 70 | 50 | 30 | 10 | Copper Dissolved 90 | 70 | 50 | 30 | 10 | Copper Total 90 | 70 | 50 | 30 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All stations | 3 | 1 | --- | --- | --- | 4.2 | 3.5 | 3.0 | 2.4 | 1.4 | 1 | --- | --- | --- | --- | 1 | --- | --- | --- | --- | 7 | 5 | 3.8 | 2.6 | 1 | 14 | 8 | 6 | 2 | 1 |

| Station | Chromium (50) | | | | | | | | | | | | Iron (300) | | | | Lead (50) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dissolved | | | | Total | | | | Hexavalent | | | | Dissolved | | | | Dissolved | | | | Total | | | |
| | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN |
| St. Francisville | 22 | 5 | 0 | 0.4 | 28 | 70 | <10 | ---- | 103 | <10 | 0 | ---- | 106 | 120 | 0 | 23.5 | 100 | 17 | 0 | 1.8 | 24 | 31 | 2 | 9.0 |
| Plaquemine | --- | --- | --- | --- | 28 | 30 | <10 | ---- | 106 | <10 | 0 | ---- | 103 | 150 | 0 | 23.1 | 102 | 25 | 0 | 1.4 | 29 | 32 | 0 | 8.2 |
| Union | --- | --- | --- | --- | 28 | 30 | <10 | ---- | 110 | <10 | 0 | ---- | 110 | 230 | 0 | 26.7 | 110 | 15 | 0 | 2.1 | 29 | 16 | 0 | 7.6 |
| Luling | --- | --- | --- | --- | 29 | 40 | <10 | ---- | 107 | <10 | 0 | ---- | 107 | 170 | 0 | 22.1 | 107 | 10 | 0 | 1.7 | 27 | 16 | 0 | 6.5 |
| New Orleans | 16 | 10 | 0 | 1.2 | 15 | 20 | <10 | ---- | 15 | <10 | 0 | ---- | 30 | 230 | 0 | 30.7 | 18 | 3 | 0 | .9 | 13 | 32 | 0 | 9.2 |
| Violet | --- | --- | --- | --- | 47 | 40 | <10 | ---- | 154 | <10 | 0 | ---- | 157 | 260 | 0 | 22.3 | 160 | 20 | 0 | 1.9 | 46 | 30 | 0 | 10.4 |
| Venice | --- | --- | --- | --- | 28 | 40 | <10 | ---- | 107 | <10 | 0 | ---- | 100 | 200 | 0 | 20.6 | 106 | 22 | 0 | 1.9 | 28 | 15 | 0 | 5.1 |
| Miscellaneous stations | 53 | 20 | 0 | 3.1 | 38 | 100 | <10 | ---- | 30 | <10 | 0 | ---- | 37 | 60 | 0 | 13.0 | 92 | 9 | 0 | 1.0 | 37 | 21 | 0 | 5.4 |

Percentage of time values were equal to or less than those shown

| Station | Chromium Dissolved 90 | 70 | 50 | 30 | 10 | Chromium Total 90 | 70 | 50 | 30 | 10 | Hexavalent 90 | 70 | 50 | 30 | 10 | Iron Dissolved 90 | 70 | 50 | 30 | 10 | Lead Dissolved 90 | 70 | 50 | 30 | 10 | Lead Total 90 | 70 | 50 | 30 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All stations | 6 | --- | --- | --- | --- | 20 | 10 | --- | --- | --- | <10 | --- | --- | --- | --- | 50 | 20 | 10 | --- | --- | 5 | 1 | --- | --- | --- | 14 | 9 | 6 | 4 | 1 |

| Station | Mercury (2) | | | | | | | | Nickel | | | | | | | | Zinc (5,000) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dissolved | | | | Total | | | | Dissolved | | | | Total | | | | Dissolved | | | | Total | | | |
| | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN | N | MAX | MIN | MEAN |
| St. Francisville | 29 | 0.2 | 0 | 0.06 | 103 | 5.0 | 0 | 0.12 | 15 | 4 | 0 | 1.5 | 14 | 18 | 4 | 9.2 | 106 | 190 | 0 | 16.6 | 28 | 70 | 5 | 26.6 |
| Plaquemine | 29 | .3 | 0 | .08 | 102 | 4.0 | 0 | .10 | 15 | 8 | 0 | 1.3 | 15 | 24 | 2 | 9.9 | 105 | 80 | 0 | 11.4 | 29 | 130 | 10 | 43.2 |
| Union | 29 | .3 | 0 | .08 | 110 | 5.0 | 0 | .16 | 14 | 4 | 0 | 1.1 | 14 | 19 | 3 | 7.9 | 110 | 140 | 0 | 13.1 | 29 | 170 | 0 | 45.4 |
| Luling | 29 | .2 | 0 | .04 | 108 | 1.6 | 0 | .09 | 14 | 7 | 0 | 2.1 | 14 | 14 | 3 | 7.4 | 108 | 190 | 0 | 16.5 | 29 | 70 | 10 | 29.3 |
| New Orleans | 14 | .2 | 0 | .04 | 16 | .5 | 0 | .10 | --- | --- | --- | --- | --- | --- | --- | --- | 20 | 60 | 0 | 19.5 | 15 | 70 | 10 | 35.3 |
| Violet | 47 | .2 | 0 | .04 | 161 | 1.8 | 0 | .09 | 17 | 4 | 0 | .9 | 17 | 37 | 1 | 10.4 | 161 | 120 | 0 | 18.8 | 45 | 250 | 0 | 66.3 |
| Venice | 28 | .2 | 0 | .06 | 107 | 4.5 | 0 | .11 | 14 | 4 | 0 | 1.3 | 14 | 22 | 0 | 7.6 | 107 | 100 | 0 | 12.9 | 28 | 120 | 9 | 32.2 |
| Miscellaneous stations | 90 | .6 | 0 | .05 | 38 | .6 | 0 | .07 | 92 | 9 | 0 | 1.5 | 37 | 17 | 0 | 5.9 | 89 | 30 | 0 | 8.6 | 37 | 60 | 10 | 27.6 |

Percentage of time values were equal to or less than those shown

| Station | Mercury Dissolved 90 | 70 | 50 | 30 | 10 | Mercury Total 90 | 70 | 50 | 30 | 10 | Nickel Dissolved 90 | 70 | 50 | 30 | 10 | Nickel Total 90 | 70 | 50 | 30 | 10 | Zinc Dissolved 90 | 70 | 50 | 30 | 10 | Zinc Total 90 | 70 | 50 | 30 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All stations (Violet not included for zinc) | 0.1 | --- | --- | --- | --- | 0.2 | 0.1 | --- | --- | --- | 3 | 1 | --- | --- | --- | 14 | 9 | 6 | 4 | 1 | 30 | 10 | 5 | --- | --- | 60 | 35 | 25 | 15 | 8 |
| Violet (zinc) | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 120 | 80 | 45 | 20 | 10 |

Most trace metals have a strong affinity for the suspended sediment transported by the river. During periods of deposition the riverbed acts as a depository for sediment, including the metals attached to the sediment. Analysis of bed material for trace metals, therefore, provides information on the presence and distribution of metals over a long period of time. Areas having high concentrations of trace metals in bed material are potential sources of contamination. During periods of high flow the bed material is scoured, and these metals may be resuspended in the river.

Table 2 shows that there is essentially no difference in the average concentrations of arsenic, cadmium, chromium, copper, iron, lead, nickel, and mercury between St. Francisville and Head of Passes, La. The only noticeable increase in metals occurs at Violet, La., where total zinc concentrations are higher than at other locations. The average total zinc concentration at all locations, excluding Violet, is 38 μg/L. The average concentration of total zinc at Violet is 66 μg/L. The highest concentration of total zinc (250 μg/L) was detected at Violet. As little difference is noted in concentrations of metals between St. Francisville and Head of Passes, data from all locations were combined to determine the duration of occurrence of trace metals in the lower Mississippi River. Total arsenic, total lead, total nickel, total zinc, and total and dissolved copper are the most prevalent metals, occurring in approximately 95 percent of the samples. Dissolved chromium and total and dissolved cadmium occur least often, being detected in less than 25 percent of the samples.

Analysis of bed material from 19 miscellaneous sampling sites between Baton Rouge and Head of Passes, La., shows that concentrations of trace metals in bed material of the Mississippi River are relatively low (table 3). The average concentrations of arsenic, cadmium, chromium, copper, and lead were less than 10 μg/g (micrograms per gram). Concentrations of mercury in bed material did not exceed 1 μg/g. Nickel and zinc are the most abundant metals in the bed material. The average concentration of nickel was 12.3 μg/g, and concentrations of zinc ranged from 6 to 88 μg/g with an average concentration of 29.7 μg/g.

The data in table 2 indicate that industrial and municipal wastes have not significantly increased the concentrations of trace metals in the Mississippi River downstream from St. Francisville, La. Ninety-nine percent of the time, concentrations of trace metals in the Mississippi River are within the recommended criteria proposed by the U.S. Environmental Protection Agency for public water supplies. Trace metals detected in the water or bed material of the Mississippi River should not pose any serious ecological problems.

Table 3.--Variation in trace-metal concentrations in bed material of the Mississippi River at miscellaneous sampling sites between Baton Rouge and Head of Passes, La., 1973-77

[Concentrations are in micrograms per gram]

| Metal | Number of samples | Range in concentration | | | Percentage of samples in which concentrations were equal to or less than those shown | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Mean | 90 | 70 | 50 | 30 | 10 |
| Arsenic ------ | 56 | 12 | 0 | 3.6 | 8 | 4 | 2 | 1 | -- |
| Cadmium ---- | 56 | 3 | 0 | 1.1 | 2 | 1 | -- | -- | -- |
| Chromium---- | 56 | 40 | 1 | 8.8 | 17 | 12 | 6 | 3 | 1 |
| Copper------- | 56 | 28 | 0 | 6.2 | 18 | 6 | 2 | -- | -- |
| Lead--------- | 54 | 30 | <10 | ----- | 20 | 10 | -- | -- | -- |
| Mercury------ | 56 | .8 | 0 | .04 | .1 | -- | -- | -- | -- |
| Nickel------- | 56 | 30 | 1 | 12.3 | 24 | 16 | 10 | 8 | 5 |
| Zinc--------- | 56 | 88 | 6 | 29.7 | 75 | 40 | 15 | 10 | 5 |

## Temperature

Water temperature can greatly affect industrial and ecological aspects of the Mississippi River. High temperatures reduce the cooling capacity of the water used by many industries located along the river and speed up biochemical reactions such as waste assimilation, bacteria die-off, and other life processes. High temperatures also lower oxygen-saturation levels and reduce stream-reaeration rates. Lower temperatures slow down reaction rates while increasing oxygen-saturation levels, reaeration rates, and cooling capacities.

Water temperatures of the Mississippi River at St. Francisville, La., have ranged from 1.0 to 30.5°C and are less than 28.0°C 95 percent of the time (table 1). The average water temperature at St. Francisville is 17.5°C. Water temperatures at Luling, La., are slightly warmer than those at St. Francisville, ranging from 3.0 to 32.0°C. The average temperature at Luling is 18.0°C. Highest average monthly temperatures for St. Francisville and Luling occur in July and August (table 4), and lowest average monthly temperatures occur during January. Differences between the average monthly temperatures at St. Francisville and Luling are equal to or less than 1.0°C from December through July. Discharges are highest at these times, minimizing the effects of solar radiation and the return of heated industrial effluents. From August through November the differences in average monthly temperatures between St. Francisville and Luling range from 1.0 to 2.0°C with the largest difference occurring in November. Solar radiation and the return of heated industrial effluents have a more pronounced effect on the temperature of the river at this time because the river discharges are generally less than 300,000 $ft^3/s$ during these months.

Table 4.--Monthly temperature of the Mississippi River at St. Francisville, La., (1954-77) and Luling, La., (1957-77)

| Month | Station | Range in temperature (°C) | Average temperature (°C) | Percentage of time values were equal to or less than those shown | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 90 | 70 | 50 | 30 | 10 |
| January | St. Francisville--- | 1.0-14.0 | 7.0 | 10.0 | 8.0 | 7.0 | 6.0 | 4.5 |
| | Luling---------- | 3.0-14.5 | 7.5 | 10.0 | 8.0 | 7.0 | 6.0 | 5.0 |
| February | St. Francisville--- | 3.0-14.5 | 7.5 | 10.0 | 9.0 | 8.0 | 7.0 | 5.0 |
| | Luling---------- | 4.0-14.5 | 7.5 | 10.0 | 9.0 | 8.0 | 7.0 | 5.0 |
| March | St. Francisville--- | 4.0-15.5 | 10.5 | 13.5 | 12.0 | 10.5 | 9.0 | 7.5 |
| | Luling---------- | 4.5-15.5 | 10.5 | 13.5 | 12.0 | 10.5 | 9.0 | 7.5 |
| April | St. Francisville--- | 9.0-21.0 | 15.0 | 19.0 | 17.0 | 15.5 | 14.0 | 12.0 |
| | Luling---------- | 8.5-21.5 | 15.5 | 19.5 | 17.0 | 15.5 | 14.0 | 12.5 |
| May | St. Francisville--- | 15.5-26.5 | 21.0 | 24.0 | 22.0 | 21.0 | 19.5 | 18.0 |
| | Luling---------- | 17.0-26.5 | 21.0 | 24.0 | 22.0 | 21.0 | 20.0 | 19.0 |
| June | St. Francisville--- | 17.0-28.5 | 25.0 | 27.5 | 26.5 | 26.0 | 25.0 | 23.0 |
| | Luling---------- | 21.0-29.0 | 25.5 | 28.0 | 27.0 | 26.5 | 25.5 | 23.5 |
| July | St. Francisville--- | 23.0-30.5 | 28.0 | 29.5 | 29.0 | 28.0 | 27.5 | 26.0 |
| | Luling---------- | 23.5-32.0 | 28.5 | 29.5 | 29.0 | 28.0 | 27.5 | 26.0 |
| August | St. Francisville--- | 20.5-30.5 | 28.0 | 30.0 | 29.5 | 29.0 | 28.0 | 26.5 |
| | Luling---------- | 26.5-32.0 | 29.0 | 30.0 | 29.5 | 29.0 | 28.0 | 27.0 |
| September | St. Francisville--- | 15.5-29.0 | 26.0 | 28.5 | 27.5 | 26.5 | 25.5 | 23.0 |
| | Luling---------- | 23.0-31.0 | 27.5 | 29.0 | 28.0 | 27.5 | 27.0 | 25.5 |
| October | St. Francisville--- | 9.5-27.5 | 20.5 | 24.0 | 22.0 | 21.0 | 19.5 | 17.0 |
| | Luling---------- | 15.5-28.0 | 22.0 | 27.0 | 24.0 | 22.0 | 21.0 | 19.0 |
| November | St. Francisville--- | 3.5-21.0 | 14.5 | 18.0 | 16.5 | 15.0 | 13.5 | 11.5 |
| | Luling---------- | 9.5-23.0 | 16.5 | 20.0 | 18.0 | 16.5 | 15.0 | 13.0 |
| December | St. Francisville--- | 3.5-16.0 | 9.5 | 12.0 | 11.0 | 10.0 | 8.5 | 7.0 |
| | Luling---------- | 4.0-16.5 | 10.5 | 13.5 | 12.0 | 11.0 | 9.5 | 8.0 |

## Bacteria

Coliform bacteria have long been used as indicators of the sanitary quality of water because they originate from the intestinal tracts of humans and other warmblooded animals. However, poor correlations to sanitary quality occur with respect to the total coliform group because some strains are not specific to fecal material. A more specific indicator of fecal pollution from warmblooded animals is fecal coliform bacteria. Concentrations of fecal coliform bacteria have been used to determine a correlation between fecal coliform and the presence of *Salmonella* (a pathogenic organism) in nonsaline waters (Geldrich, 1969). The percentage of occurrence that *Salmonella* can be expected at different levels of fecal coliform concentrations in freshwater is given in the following tabulation:

| Levels of fecal coliform concentrations (colonies per 100 milliliters) | Percentage of occurrence of *Salmonella* |
|---|---|
| 1- 200 | 28 |
| 201-2,000 | 85 |
| >2,000 | 98 |

The lowest concentrations of total and fecal coliform in the river occur at St. Francisville, La., and at the Carrollton Street water intakes in New Orleans, La., (table 5). The highest concentrations occur downstream from Baton Rouge and New Orleans at Plaquemine and Violet, La., respectively. Average concentrations of fecal coliform bacteria at St. Francisville and New Orleans are less than 400 colonies per 100 mL (milliliters) and less than 800 colonies per 100 mL, respectively, 90 percent of the time. At Plaquemine, approximately 25 mi downstream from Baton Rouge, the average concentration of fecal coliform bacteria is 1,000 colonies per 100 mL, and concentrations exceed 2,000 colonies per 100 mL approximately 10 percent of the time. At Violet, approximately 20 mi downstream from the New Orleans Carrollton Street water intakes, the average concentration of fecal coliform bacteria is 3,100 colonies per 100 mL, an increase of approximately 850 percent over concentrations at the Carrollton Street water intakes. Concentrations of fecal coliform bacteria at Violet are greater than 2,000 colonies per 100 mL 30 percent of the time. Such frequent occurrences of high concentrations of fecal coliform bacteria strongly suggest that *Salmonella* or other pathogenic organisms may be present in the river. *Salmonella* have been isolated and serologically confirmed from the river at both Plaquemine and Violet. Concentrations of fecal coliform bacteria at Violet exceeded the recommended limits for public-water-supply sources approximately 30 percent of the time.

The high concentrations of fecal coliform bacteria downstream from Baton Rouge and New Orleans, La., can be attributed to inadequately treated sewage discharged into the river. Baton Rouge currently (1979) has primary sewage treatment at two of its three sewage-treatment facilities. Its central plant began secondary treatment in 1979. The other two plants will provide secondary treatment by about 1985. New Orleans currently discharges raw sewage into the river; however, the city's sewage is scheduled to receive secondary treatment by early 1980. The better sewage-treatment facilities designed for Baton Rouge and New Orleans should result in considerably lower bacteria concentrations downstream from the two cities.

## Dissolved Oxygen

Dissolved-oxygen concentrations are of primary importance in any aquatic ecosystem. Fish and other aquatic life require adequate levels of dissolved oxygen for egg and larvae development as well as normal growth and activity. There is no specific dissolved-oxygen concentration that is favorable to all aquatic species and ecosystems. However,

Table 5.--Total and fecal coliform bacteria concentrations in the Mississippi River between St. Francisville and Venice, La., 1973-77

[Maximum recommended limits for public-water-supply sources are 20,000 colonies per 100 mL total coliform and 2,000 colonies per 100 mL fecal coliform]

| Station | Total coliform bacteria (colonies per 100 mL): Number of samples | Range in concentration: Maximum | Range in concentration: Minimum | Mean | Percentage of time values were equal to or less than those shown: 90 | 70 | 50 | 30 | 10 | Fecal coliform bacteria (colonies per 100 mL): Number of samples | Range in concentration: Maximum | Range in concentration: Minimum | Mean | Percentage of time values were equal to or less than those shown: 90 | 70 | 50 | 30 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| St.Francisville- | 97 | 14,000 | 90 | 2,410 | 6,000 | 3,000 | 1,700 | 1,200 | 500 | 90 | 3,000 | 5 | 390 | 800 | 350 | 230 | 130 | 50 |
| Plaquemine--- | 99 | 26,000 | 310 | 4,800 | 10,000 | 5,000 | 3,500 | 2,200 | 1,000 | 91 | 5,700 | 5 | 1,000 | 2,000 | 1,000 | 600 | 350 | 200 |
| Union-------- | 103 | 29,000 | 300 | 3,950 | 8,000 | 4,000 | 2,500 | 1,700 | 900 | 94 | 8,800 | 5 | 920 | 1,500 | 750 | 450 | 250 | 100 |
| Luling-------- | 98 | 32,000 | 60 | 3,340 | 7,000 | 3,500 | 2,200 | 1,300 | 600 | 85 | 3,500 | 5 | 570 | 1,100 | 600 | 450 | 200 | 70 |
| New Orleans -- | 33 | 16,000 | 420 | 3,770 | 7,000 | 3,500 | 2,000 | 1,000 | 450 | 36 | 1,800 | 5 | 360 | 800 | 250 | 120 | 75 | 50 |
| Violet-------- | 144 | 80,000 | 150 | 13,500 | 30,000 | 15,000 | 8,500 | 5,000 | 2,200 | 127 | 62,000 | 20 | 3,110 | 4,000 | 2,000 | 1,000 | 500 | 200 |
| Venice------- | 92 | 30,000 | 400 | 5,000 | 10,000 | 6,000 | 4,000 | 2,500 | 1,500 | 80 | 8,000 | 40 | 1,200 | 2,500 | 1,000 | 650 | 400 | 150 |

low dissolved-oxygen concentrations are unfavorable to almost all aquatic organisms. The National Academy of Sciences and National Academy of Engineering (1973) suggested 4 mg/L as the lowest acceptable oxygen concentration for freshwater aquatic life and wildlife.

The principal source of oxygen in the Mississippi River is reaeration of the water from atmospheric oxygen. The solubility of oxygen in water is inversely related to temperature. As the temperature of the water increases, the amount of atmospheric oxygen the water is capable of holding decreases. Consequently, the highest dissolved-oxygen concentrations are usually found during the winter months, and the lowest concentrations during the warm summer months.

Periodic measurements of dissolved oxygen at routine sampling sites on the Mississippi River show that dissolved-oxygen concentrations are relatively high (near saturation). The dissolved-oxygen saturation levels of Mississippi River water exceed 75-percent saturation 90 percent of the time. The maximum, minimum, and mean dissolved-oxygen concentrations and dissolved-oxygen saturation percentages for six locations on the Mississippi River are given in table 6.

Although very little difference is noted in average dissolved-oxygen concentrations between St. Francisville and Venice, La., there does appear to be a slight downstream decrease in the average concentration. The saturation values indicate that the river is well aerated, capable of assimilating oxygen-consuming wastes, and capable of supporting aquatic organisms. Dissolved-oxygen concentrations below the 4.0-mg/L limit recommended by the National Academy of Sciences and National Academy of Engineering (1973) have not been measured at the routine sampling sites on the Mississippi River. Only once since 1973 has dissolved oxygen less than the 5.0-mg/L recommended limit for the Mississippi River (Louisiana Stream Control Commission, 1977) been observed at these sites. (See table 6.)

Table 6.--Statistical summary of dissolved-oxygen concentrations in the lower Mississippi River, 1973-77

| Station | Maximum | Minimum | Mean | Maximum | Minimum | Mean |
|---|---|---|---|---|---|---|
| | Milligrams per liter | | | Percentage of saturation | | |
| St. Francisville | 12.6 | 5.7 | 8.6 | 100 | 71 | 86 |
| Plaquemine | 12.1 | 5.7 | 8.5 | 102 | 73 | 86 |
| Union | 12.8 | 5.6 | 8.5 | 103 | 67 | 86 |
| Luling | 12.1 | 5.0 | 8.3 | 99 | 64 | 84 |
| Violet | 11.6 | 5.2 | 8.4 | 104 | 66 | 85 |
| Venice | 11.9 | 4.9 | 8.2 | 102 | 64 | 83 |

At New Orleans, La., dissolved-oxygen concentrations have been monitored continuously since 1973, and a minimum dissolved-oxygen concentration of 3.8 mg/L was recorded on August 26, 1977. This low reading was of short duration, and the daily average concentration for this date was 4.1 mg/L. The longest continuous period of time that dissolved-oxygen concentrations remained below 5.0 mg/L was 14 days in August 1975. Although dissolved-oxygen concentrations have been less than 5.0 mg/L on some occasions, they are generally of short duration; and average daily concentrations are generally greater than 5.0 mg/L.

Maximum dissolved-oxygen concentrations have exceeded 11.5 mg/L at all sampling stations. Maximum dissolved-oxygen concentrations occur during the months of January and February when water temperatures are lowest.

## Organics

Organic compounds are present in almost all surface waters of the world. Naturally occurring organic compounds commonly found in surface waters result from decaying vegetation, algae, and microscopic organisms. Most of these substances found in streams are produced on land and are washed into waterways during periods of runoff. In addition to naturally occurring organic compounds, increasing amounts of organics are entering water as a result of man's activities. Leading sources of these organic compounds are industrial and municipal wastes and runoff from agricultural and urban areas. Over 1,500 organic compounds have been identified in industrial waste waters, rivers, lakes, and ground waters; and approximately 450 different organic compounds have been identified in drinking waters around the world (Keith, 1976).

The identification and quantification of these organic compounds is a difficult task, generally requiring extremely sophisticated and expensive equipment. Organic analyses commonly involve specialized techniques to identify specific compounds, such as phenolic compounds, or groups of compounds, such as pesticides. This report describes four specialized groups of compounds identified in the Mississippi River: phenolic compounds, pesticides, volatile organics, and semivolatile organics. The organic compounds in each group listed above are extracted and identified according to different analytical procedures. Some compounds identified by one method may also be extracted and identified by another method. Therefore, there may be some overlap of compounds. For example, phenols may be extracted and identified by methods used for phenolic compounds and also by methods used for semivolatile organics.

### Phenolic Compounds

Phenolic compounds include a wide variety of organic chemicals. Sources of phenolic compounds include the distillation of coal and wood, wastes from oil refineries and chemical plants, and chemical and microbial degradation of pesticides. Phenolic compounds affect water in many ways. The most noticeable effect is production of taste and odor problems in fish and in municipal water supplies.

Average concentrations of phenolic compounds at monthly sampling stations on the Mississippi River range from 1.8 µg/L at St. Francisville, Plaquemine, and Venice, La., to 2.6 µg/L at Violet, La. (See table 7.) Concentrations are equal to or less than 1 µg/L 60 percent of the time at all sampling stations and less than 7 µg/L 95 percent of the time at all sampling stations except Violet. At Violet, phenolic compounds are equal to or less than 10 µg/L 95 percent of the time. On 10 occasions, concentrations of phenolic compounds at Violet have exceeded 10 µg/L.

Table 7.--Statistical summary of concentrations of phenolic compounds in the Mississippi River between St. Francisville and Venice, La., 1973-77

[Concentrations are in micrograms per liter]

| Station | Number of samples | Range in concentration | | | Percentage of time values were equal to or less than those shown | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | Mean | 95 | 90 | 80 | 70 | 60 |
| St. Francisville-- | 110 | 11 | 0.0 | 1.8 | 7 | 5 | 3 | 2 | 1 |
| Plaquemine----- | 110 | 22 | .0 | 1.8 | 7 | 5 | 3 | 2 | 1 |
| Union---------- | 113 | 42 | .0 | 2.2 | 7 | 5 | 3 | 2 | 1 |
| Luling---------- | 102 | 12 | .0 | 1.9 | 7 | 5 | 3 | 2 | 1 |
| Violet---------- | 171 | 73 | .0 | 2.6 | 10 | 6 | 3 | 2 | 1 |
| Venice--------- | 113 | 19 | .0 | 1.8 | 7 | 5 | 3 | 2 | 1 |

Concentrations of phenolic compounds in the Mississippi River exceed the 1 µg/L recommended as a limit for domestic water supplies approximately 40 percent of the time. Excessive concentrations of phenolic compounds may adversely affect municipal water supplies because they are not efficiently removed by conventional treatment processes. Furthermore, chlorination of water supplies containing phenolic compounds may produce chlorophenols that severely increase taste and odor problems.

## Pesticides

Pesticides include a great many compounds used in improving agricultural yields and reducing the mass growth of aquatic plants. The major source of pesticide residues in water is runoff from treated lands and waters, industrial discharges, and domestic sewage. Many pesticides are extremely stable, degrading very slowly or forming persistent degradation products. Aquatic organisms may accumulate these compounds directly by sorption from water or by eating smaller organisms in the food chain that are contaminated with pesticides. Most chlorinated pesticides are relatively insoluble in water and are rapidly adsorbed on suspended sediment. In rivers, much of the chlorinated pesticide residue is transported on suspended sediment.

For the purpose of this report, pesticides are grouped into three general categories according to their chemical composition: organochlorine insecticides, organophosphorus insecticides, and chlorophenoxy acid herbicides. The range in concentration, average concentration, and standard deviation of residues detected in the Mississippi River are given in table 8.

The organochlorine and organophosphorus insecticides are used to control plant-destroying and disease-carrying insects as well as household and livestock pests. The organochlorine insecticides are an important group of insecticides in assessing water quality because of the large number of compounds, wide use, great stability, and toxicity in the environment. The organochlorine compounds are considered hazardous because of their persistence and accumulation by aquatic organisms. Some of these compounds are toxic to various aquatic organisms at concentrations of less than 1 μg/L (National Academy of Sciences and National Academy of Engineering, 1973). Governmental regulations have restricted the use of many of these compounds in recent years because of their stability and toxicity. DDT, dieldrin, and endrin are the most frequently occurring organochlorine insecticides in the Mississippi River. DDT has been detected in approximately 25 percent of the samples; however, concentrations rarely exceed 0.2 μg/L. Dieldrin has also been detected in approximately 25 percent of the samples, but concentrations have not exceeded 0.1 μg/L. Endrin has been detected in approximately 10 percent of the samples at concentrations of 0.01 μg/L.

The regulations that have been imposed to restrict the use of organochlorine insecticides have caused the number and usage of organophosphorus insecticides to increase in recent years. Diazinon is the most frequently detected organophosphorus insecticide in the Mississippi River, occurring in approximately 40 percent of the samples. Concentrations of diazinon have been detected as high as 1.2 μg/L; however, 95 percent of the time concentrations have not exceeded 0.05 μg/L.

Chlorophenoxy herbicides are often used to control aquatic plants in streams and reservoirs as well as to control weeds in agricultural areas. These compounds are commonly found in the Mississippi River. The most prevalent chlorophenoxy herbicide, 2,4-D, occurs in approximately 70 percent of the samples. However, concentrations of 2,4-D are relatively low, ranging from 0.00 to 0.15 μg/L. Concentrations are less than 0.08 μg/L 90 percent of the time. Silvex and 2,4,5-T have been found in detectable concentrations approximately 20 and 60 percent of the time, respectively. Concentrations of 2,4,5-T have been equal to or less than 0.04 μg/L 95 percent of the time, and silvex concentrations have not exceeded 0.01 μg/L.

Table 8.--Pesticide concentrations in the water and bed material of the Mississippi River between St. Francisville and Head of Passes, La., 1973-77

[Concentrations in water are in micrograms per liter; concentrations in bed material are in micrograms per gram]

| Constituent | Maximum recommended limit for water[1]/ | Mississippi River at St. Francisville (water) | | | | Mississippi River at New Orleans (water) | | | | Miscellaneous sampling stations (water) | | | | Miscellaneous sampling stations (bed material) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Number of samples | Range in concentration | | | Number of samples | Range in concentration | | | Number of samples | Range in concentration | | | Number of samples | Range in concentration | | |
| | | | Maximum | Minimum | Mean | | Maximum | Minimum | Mean | | Maximum | Minimum | Mean | | Maximum | Minimum | Mean |
| Organochlorine insecticides: | | | | | | | | | | | | | | | | | |
| Aldrin | 1.0 | 29 | 0.00 | 0.00 | 0.00 | 16 | 0.00 | 0.00 | 0.00 | 75 | 0.00 | 0.00 | 0.00 | 130 | 1.3 | 0 | 0.02 |
| Chlordane | 3.0 | 29 | .0 | .0 | .0 | 16 | .0 | .0 | .0 | 75 | .01 | .0 | .0 | 132 | 3.2 | 0 | 3.2 |
| DDD | ----- | 29 | .00 | .00 | .00 | 16 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 132 | 2.0 | .0 | 2.6 |
| DDE | ----- | 29 | .00 | .00 | .00 | 16 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 132 | 6.4 | .0 | .4 |
| DDT | 5.0 | 29 | .05 | .00 | .003 | 16 | .00 | .00 | .00 | 75 | .01 | .00 | .003 | 132 | 1.2 | .0 | 1.2 |
| Dieldrin | 1.0 | 29 | .01 | .00 | .002 | 15 | .01 | .00 | .002 | 75 | .01 | .00 | .003 | 132 | 8.0 | .0 | .6 |
| Endrin | .5 | 29 | .01 | .00 | .001 | 16 | .01 | .00 | .001 | 75 | .01 | .00 | .00 | 129 | 1.4 | .0 | .4 |
| Heptachlor | .1 | 29 | .00 | .00 | .00 | 16 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 130 | .0 | .0 | .0 |
| Heptachlorepoxide | .1 | 29 | .00 | .00 | .00 | 15 | .00 | .00 | .00 | 75 | .01 | .00 | .00 | 132 | .0 | .0 | .0 |
| Lindane | 5.0 | 29 | .00 | .00 | .00 | 16 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 130 | .0 | .0 | .0 |
| Toxaphene | 5.0 | 29 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 74 | 0 | 0 | 0 | 129 | 0 | 0 | 0 |
| Organophosphorus insecticides: | | | | | | | | | | | | | | | | | |
| Diazinon | 100 | 29 | .20 | .00 | .02 | 16 | .20 | .00 | .02 | 74 | 1.2 | .00 | .02 | 112 | .0 | .0 | .0 |
| Ethion | 100 | 29 | .00 | .00 | .00 | 12 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 112 | .0 | .0 | .0 |
| Malathion | 100 | 29 | .00 | .00 | .00 | 16 | .00 | .00 | .00 | 75 | .08 | .00 | .001 | 112 | .0 | .0 | .0 |
| Methyl parathion | 100 | 29 | .00 | .00 | .00 | 16 | .00 | .00 | .00 | 75 | .01 | .00 | .00 | 112 | .0 | .0 | .0 |
| Methyl trithion | 100 | 29 | .00 | .00 | .00 | 12 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 112 | .0 | .0 | .0 |
| Parathion | 100 | 29 | .00 | .00 | .00 | 16 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 112 | .0 | .0 | .0 |
| Trithion | 100 | 29 | .00 | .00 | .00 | 12 | .00 | .00 | .00 | 75 | .00 | .00 | .00 | 112 | .0 | .0 | .0 |
| Chlorophenoxy herbicides: | | | | | | | | | | | | | | | | | |
| 2,4-D | 20 | 28 | .13 | .00 | .04 | 16 | .08 | .00 | .02 | 74 | .15 | .00 | .04 | --- | --- | --- | ---- |
| 2,4,5-T | 2.0 | 28 | .08 | .00 | .01 | 16 | .04 | .00 | .01 | 74 | .04 | .00 | .01 | --- | --- | --- | ---- |
| Silvex | 30 | 28 | .03 | .00 | .01 | 16 | .01 | .00 | .003 | 74 | .01 | .00 | .03 | --- | --- | --- | ---- |

1/National Academy of Sciences and National Academy of Engineering (1973).

Analysis of bed material for organochlorine and organophosphorus insecticides from 68 sites along the Mississippi River between Baton Rouge and Head of Passes, La., indicate that only organochlorine insecticides are present in the bed material in detectable quantities. The organochlorine insecticides are much more stable than the organophosphorus insecticides and persist in the environment for much longer periods of time. The presence of organochlorine insecticides in the bed material provides information on possible sources of contamination during periods of high flow and scouring of bed material.

Chlordane, DDT, DDD, DDE, and dieldrin are the organochlorine insecticides detected most frequently in the bed material, occurring in over 50 percent of the sample. The frequency of occurrence of each of these compounds is given in table 9.

Table 9.--Frequency of occurrence of five organochlorine insecticides in the Lower Mississippi River

[Concentrations are in micrograms per kilogram]

| Compound | Percentage of samples in which the concentrations were equal to or less than those shown | | | | |
|---|---|---|---|---|---|
| | 90 | 70 | 50 | 30 | 10 |
| Chlordane | 8.5 | 3.5 | 0.4 | --- | --- |
| DDD | 6.4 | 3.0 | 1.3 | 0.1 | --- |
| DDE | 1.0 | --- | --- | --- | --- |
| DDT | 3.2 | 1.4 | .4 | --- | --- |
| Dieldrin | 1.5 | .7 | .3 | --- | --- |

The frequent occurrence of relatively high concentrations of organochlorine insecticides in the bed material is indicative of heavy use of these insecticides in recent years in the drainage area upstream from Baton Rouge, La. It should be noted however that the U.S. Environmental Protection Agency has suspended the production and use of these five insecticides, and a decrease in their concentrations should be noted in the future.

## Volatile Organics

Volatile organics include a large number of organic compounds having low molecular weights and boiling points less than 150°C. The most common volatile organics of interest are the trihalomethane compounds. These compounds received national recognition when the U.S. Environmental Protection Agency (1974) released its "Draft Analytical Report--New Orleans Water Supply Study." In that study, chloroform was detected in the drinking water of New Orleans, La., at a concentration of 133 µg/L. National Organics Reconnaissance Survey of 80 cities conducted in 1975 revealed that volatile halogenated organics were common in the finished water of many municipalities, but not in the raw water. The study concluded that the halogenated volatile organics were produced during the chlorination process of water treatment. Because the Mississippi River was not sampled for volatile organics in the above-mentioned studies, their prevalence in the raw-water supply of New Orleans was unknown. Volatile organic compounds were sampled as part of this study to identify the compounds and quantify the level of volatile organics in the lower Mississippi River. No attempt was made to analyze for volatile organics in the New Orleans drinking water.

Samples for determination of volatile organics were collected from the Mississippi River at St. Francisville, Plaquemine, Union, Luling, and Belle Chasse, La., in June 1977 at a discharge of 215,000 $ft^3/s$; in October 1977 at a discharge of 400,000 $ft^3/s$; and again in July 1978 at a discharge of 350,000 $ft^3/s$. Samples were collected at midchannel, 20 ft below the surface, using a sewage sampler to minimize aeration. Samples were treated with ascorbic acid to prevent chlorination and oxidation of the organics in the water sample and were stored at 4°C until time of analysis. Analyses were completed within 7 days of collection by the Physical and Engineering Sciences Division of Gulf South Research Institute, New Orleans, La., using a Hewlett Packard[2/] 5982 GC/MS (gas chromatograph/mass spectrometer) system. The analyses were performed using the Bellar sparging technique developed by the U.S. Environmental Protection Agency (Bellar and Lichtenberg, 1974).

Eight volatile organic compounds were identified in the samples from the Mississippi River, and concentrations were generally less than 10 µg/L. Benzene, toluene, and chloroform were detected at all five sampling sites (table 10). Dichloromethane was detected at St. Francisville, Plaquemine, Union, and Belle Chasse, La. Tetrachloroethylene was detected at St. Francisville and Luling, La., and dichloroethane was detected at Union and Belle Chasse. Trichlorofluoromethane was detected at St. Francisville and Belle Chasse. Tetrachloroethane was detected only at Luling. The volatile organics appear to be fairly evenly distributed in the reach of river between St. Francisville and Belle Chasse. At least five of the eight compounds were detected at each sampling location. Although no firm conclusions can be drawn from three sets of samples, it appears that industrial and municipal wastes from the Baton Rouge-New Orleans, La., area have a minimal effect on concentrations of volatile organics in the river. The relatively low concentrations of these volatile organic compounds may be attributed to the fact that they are relatively volatile and relatively insoluble in water.

---

2/ The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Table 10.--Concentrations of volatile organics in the lower Mississippi River, 1977-78

[Concentrations are in micrograms per liter; N, not detected; T, trace]

| Station | Compound | Concentration | | |
|---|---|---|---|---|
| | | June 1977 | October 1977 | July 1978 |
| St. Francisville | Benzene | 0.85 | N | 1.0 |
| | Tetrachloroethylene | 1.8 | N | N |
| | Toluene | 4.8 | N | 1.0 |
| | Chloroform | 2.8 | N | T |
| | Dichloromethane | N | N | <1.0 |
| | Trichlorofluoromethane | N | N | 3.0 |
| Plaquemine | Benzene | .92 | N | 1.0 |
| | Toluene | 1.6 | N | 1.0 |
| | Chloroform | 1.4 | N | N |
| | Dichloromethane | N | 6.0 | <1.0 |
| | 1, 2-Dichloromethane | N | N | 1.0 |
| Union | Benzene | .86 | T | 1.0 |
| | Toluene | 1.8 | T | 1.0 |
| | Chloroform | 2.3 | .2 | 3.0 |
| | Dichloromethane | N | 4.0 | <1.0 |
| | 1, 2-Dichloromethane | N | 1.0 | 1.0 |
| Luling | Benzene | 10.6 | N | --- |
| | Tetrachloroethylene | 8.9 | N | --- |
| | Toluene | 4.1 | N | --- |
| | Chloroform | 3.8 | N | --- |
| | Tetrachloroethane | 1.2 | N | --- |
| Belle Chasse | Benzene | .32 | N | <1.0 |
| | Toluene | 1.3 | N | N |
| | Chloroform | 2.1 | 1.0 | <1.0 |
| | 1, 2-Dichloroethane | N | 4.0 | 3.0 |
| | Dichloromethane | N | 6.0 | N |
| | Trichlorofluoromethane | N | N | 3.0 |
| | Tetrachloroethylene | N | N | <1.0 |

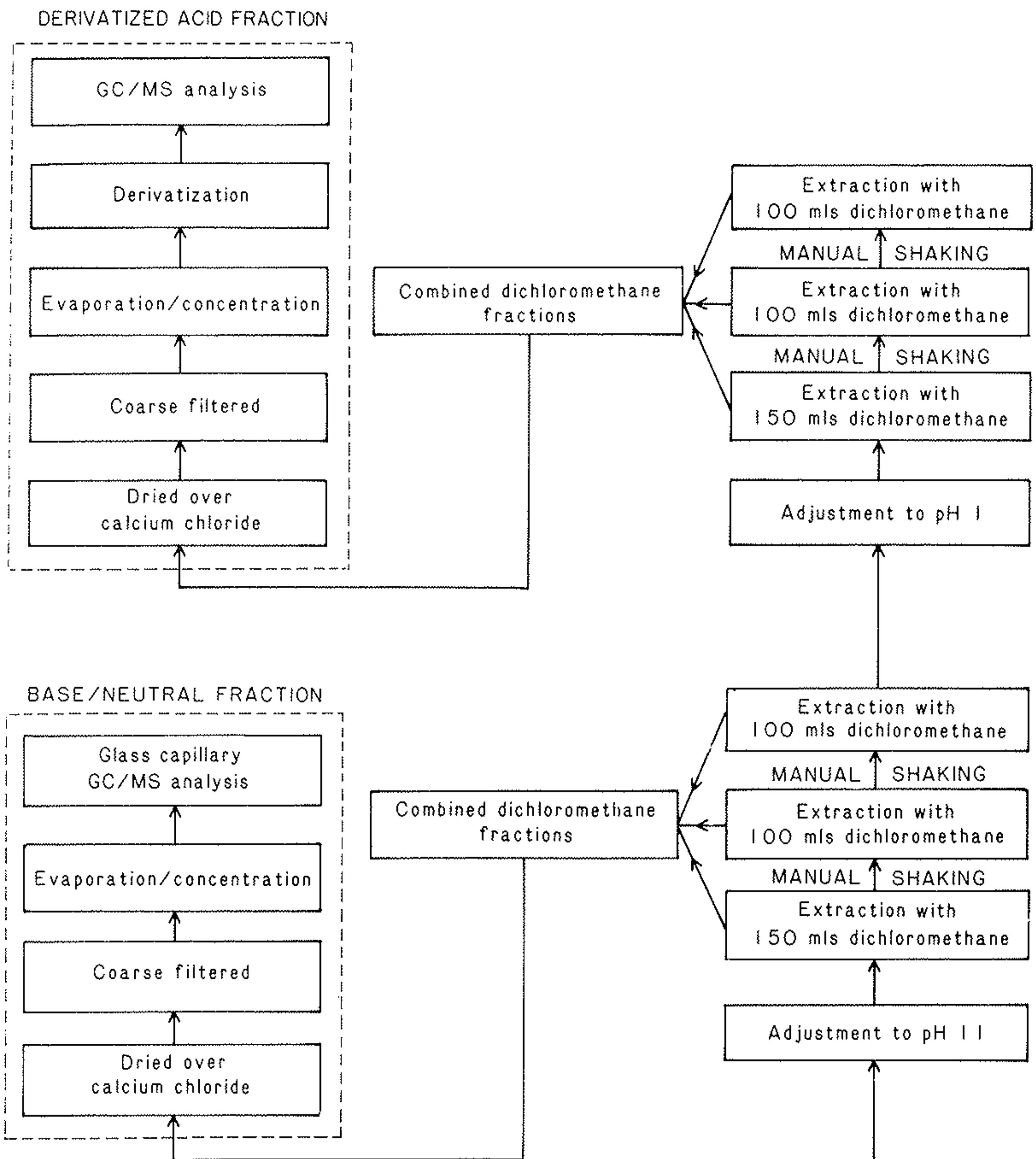
## Semivolatile Organics

Semivolatile organics include a variety of organic compounds of natural origin as well as pollutants from industrial and municipal wastes. Because of the wide range and complexity of these compounds, no widely accepted analytical methodology has yet been developed. One of the most difficult tasks involved in semivolatile analysis is separating the organics from the water and from one another (Keith, 1976). Further difficulties arise from contamination and in methods of quantifying these compounds.

Samples for determination of semivolatile organics were collected from the Mississippi River in December 1976 at a discharge of 185,000 $ft^3/s$, in June 1977 at a discharge of 215,000 $ft^3/s$, and in July 1978 at a discharge of 350,000 $ft^3/s$. Sampling sites were identical to those used for volatile organic samples. Samples were collected at three verticals in the river cross section. Point samples were taken at surface, 0.1, 0.3, 0.5, 0.7, and 0.9 of the depth at each vertical for a total of 18 samples at each sampling site. Samples were collected with a 200-pound P-63 point sediment sampler equipped with a Teflon nozzle and a Teflon gasket. Point samples were collected in quart jars and composited in a 9-liter glass container equipped with a ground-glass stopper. All glass containers were heat treated in excess of 300°C prior to sampling to prevent contamination. The samples were stored at 4°C and were transported to the laboratory within 24 hours of collection. Analyses were performed by the Physical Engineering Sciences Division of Gulf South Research Institute, New Orleans, La. All analyses were performed within 3 weeks of collection, using a Hewlett Packard 5982 GC/MS system.

The analytical methodology for separation of semivolatile organic compounds involved liquid-liquid extraction with dichloromethane. This method is similar in principle to the procedure used by the U.S. Environmental Protection Agency (1977) for analyzing industrial effluents. The December 1976 samples were extracted at a neutral pH (pH of river water). The June 1977 and July 1978 samples were extracted at two pH levels: pH 1 and pH 11 (fig. 12). Standards containing virtually all compounds in the Environmental Protection Agency list of priority pollutants were prepared and analyzed as part of the analytical procedure. Identification of each compound was based on retention time indices and mass spectral data. Quantification of the results of all gas chromatography-mass spectrometer (GC/MS) analyses were performed by comparison of integrated peak areas of compounds identified in the sample chromatogram with peak areas of known quantities of the same compounds in the standard sample. Low recovery rates from the base and the acid extracts may have resulted in the loss of some compounds and prevented the complete recovery and analysis of acids and phenols in the acid fraction. The data on semivolatile organics should be considered semiquantitative because the analytical procedures are still being researched.

Fourteen semivolatile compounds were detected in Mississippi River water (table 11). Six additional compounds have been isolated but remain unidentified. Concentrations of the semivolatile organics were generally less than 5 µg/L, and nine were detected in concentrations of less than 1 µg/L. The most frequently detected semivolatile organics were the phthalate compounds. This include dibutyl phthalate, dioctyl phthalate, butyl benzyl phthalate, bis (2-ethylhexyl) phthalate, and one unindentified phthalate compound. Atrazine, a popular herbicide used for weed control, has been detected at all five sampling locations in concentrations ranging from a trace to 4.0 µg/L.




(J. R. Troost, Gulf South Research Institute, written commun., 1978)

Figure 12.--Procedural diagram showing preparation of semivolatile organic samples for gas chromatography/mass spectrometry analysis.

Table 11.--Concentrations of semivolatile organics in the lower Mississippi River, 1976-78

[Concentrations are in micrograms per liter; N, not detected; T, trace]

| | St. Francisville | | | Plaquemine | | | Union | | | Luling | | Belle Chasse | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12-76 | 6-77 | 7-78 | 12-76 | 6-77 | 7-78 | 12-76 | 6-77 | 7-78 | 12-76 | 6-77 | 12-76 | 6-77 | 7-78 |
| Coniferal alcohol-- | 0.08 | N | N | N | N | N | N | N | N | N | N | N | N | N |
| Dibutyl phthalate-- | 2.8 | 2.2 | N | 2.3 | N | N | 3.2 | N | N | 6.4 | N | 0.9 | 0.9 | N |
| Dioctyl phthalate-- | 1.0 | N | N | 2.6 | N | N | 1.2 | N | N | .6 | N | .1 | N | N |
| Butyl benzyl phthalate ------- | .2 | N | N | .1 | N | N | N | N | N | N | N | N | N | N |
| Di-isobutyl phthalate ------- | N | N | 0.7 | N | N | 0.2 | N | N | N | N | N | N | N | N |
| Bis(2-ethylhexyl) phthalate ------- | N | 1.3 | N | N | 0.2 | N | N | 5.6 | N | N | 1.9 | N | 6.9 | N |
| Atrazine --------- | N | 4.0 | .8 | N | T | N | .6 | 1.9 | 4.0 | .5 | .9 | .3 | 2.0 | N |
| Naphthalene------ | N | N | N | .1 | N | N | .6 | N | N | N | N | N | N | N |
| Methyl naphthalene----- | N | N | N | .1 | N | N | .7 | N | N | N | N | N | N | N |
| Dimethyl naphthalene----- | N | N | N | N | N | N | .5 | N | N | N | N | N | N | N |
| Naphthalamine --- | N | N | N | .2 | N | N | N | N | N | N | N | N | N | N |
| Phenyl-B-naphthalamine -- | N | N | N | N | N | N | N | N | N | N | N | .8 | N | N |
| Methyl anthracene- | N | N | N | N | N | N | .1 | N | N | N | N | N | N | N |
| Pyrene----------- | N | N | N | N | N | N | N | N | N | .1 | N | .1 | N | N |

There are presently no analytical schemes that would permit economical routine sampling and analysis to determine whether recommended limits for all volatile and semivolatile compounds have been exceeded. Recommended criteria have been proposed under the Safe Drinking Water Act (P.L. 95-217) for trihalomethane compounds, which include chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Proposed regulations would limit the total concentration of these compounds in drinking water to 100 µg/L. Chloroform is the only trihalomethane compound that has been identified in the river, and its concentration has not exceeded 3.8 µg/L in any of the samples collected as a part of this study.

The U.S. Environmental Protection Agency (1978) has prepared a list of approximately 60 volatile and semivolatile organic compounds that serve as indicators of organic chemical contamination. Seven of the volatile organics and approximately one-half of the semivolatile organics identified from the Mississippi River are included in this list. This indicates that the organic compounds identified from the Mississippi River may have originated from industrial effluents. It should be noted, however, that the organic compounds identified from the Mississippi River are present in relatively low concentrations and occur just as frequently at St. Francisville, La., (which is upstream from most industrialization) as along the industrial complex between Baton Rouge and New Orleans, La.

## Saltwater Intrusion

The thalweg of the lower Mississippi River is below sea level as far upstream as river mile 350, approximately 15 mi downstream from Natchez, Miss. Saltwater from the Gulf of Mexico generally intrudes some distance upstream from the mouth of Southwest Pass most of the time. The extent of intrusion depends primarily on river discharge; however, flow duration, wind velocity and direction, tides, and riverbed configuration all influence the upstream movement of saltwater. The maximum absolute distance of saltwater intrusion observed anywhere in the world occurred on the Mississippi River in 1939 and 1940 when saltwater was observed near Luling, La., at river mile 120, approximately 140 mi upstream from the mouth of Southwest Pass (Lupachev, 1976).

Because saltwater is denser than freshwater, saltwater moves upstream beneath the freshwater as a wedge. The toe or leading edge of the saltwater wedge in the Mississippi River is well defined with little mixing occurring at the freshwater-saltwater interface. For example, in October 1976, at mile 57.0 the chloride concentration increased from 65 mg/L at a depth of 65 ft to approximately 6,000 mg/L at a depth of 75 ft (fig. 13). Some mixing does occur at the freshwater-saltwater interface at shallower depths, however, causing the wedge to become less stratified downstream from its leading edge. A highly stratified wedge is typical of deep rivers having a large freshwater discharge (Wright, 1971, and Everett, 1971).

Since records began in 1929, the maximum extent of saltwater intrusion into the Mississippi River occurred in October 1939 and November 1940 when the wedge was detected by the Corps of Engineers at mile 120.0 near Luling, La. During both years, the discharge at Red River Landing, La., was less than 100,000 $ft^3/s$. During 1952-54 and 1956 the saltwater wedge moved up to the Kenner Hump at mile 115.0 (depth approximately 45 ft below National Geodetic Vertical Datum of 1929) but did not pass this point because the discharge was not less than 100,000 $ft^3/s$. The movement of the 1940 saltwater wedge and the discharge hydrograph for Red River Landing is shown in figure 14.

Movement of saltwater into the river is primarily through Southwest Pass, which averages about 10 ft deeper than South Pass and 15 ft deeper than Pass a Loutre. As the river discharge decreases, the saltwater wedge moves up Southwest Pass and South Pass. The saltwater wedge in Southwest Pass will reach Head of Passes (mile 0.0) at a discharge of approximately 350,000 $ft^3/s$. The saltwater wedge in South Pass will not reach Head of Passes until the discharge drops below 300,000 $ft^3/s$. Saltwater intrusion has not been observed in Pass a Loutre at discharges greater than 200,000 $ft^3/s$.

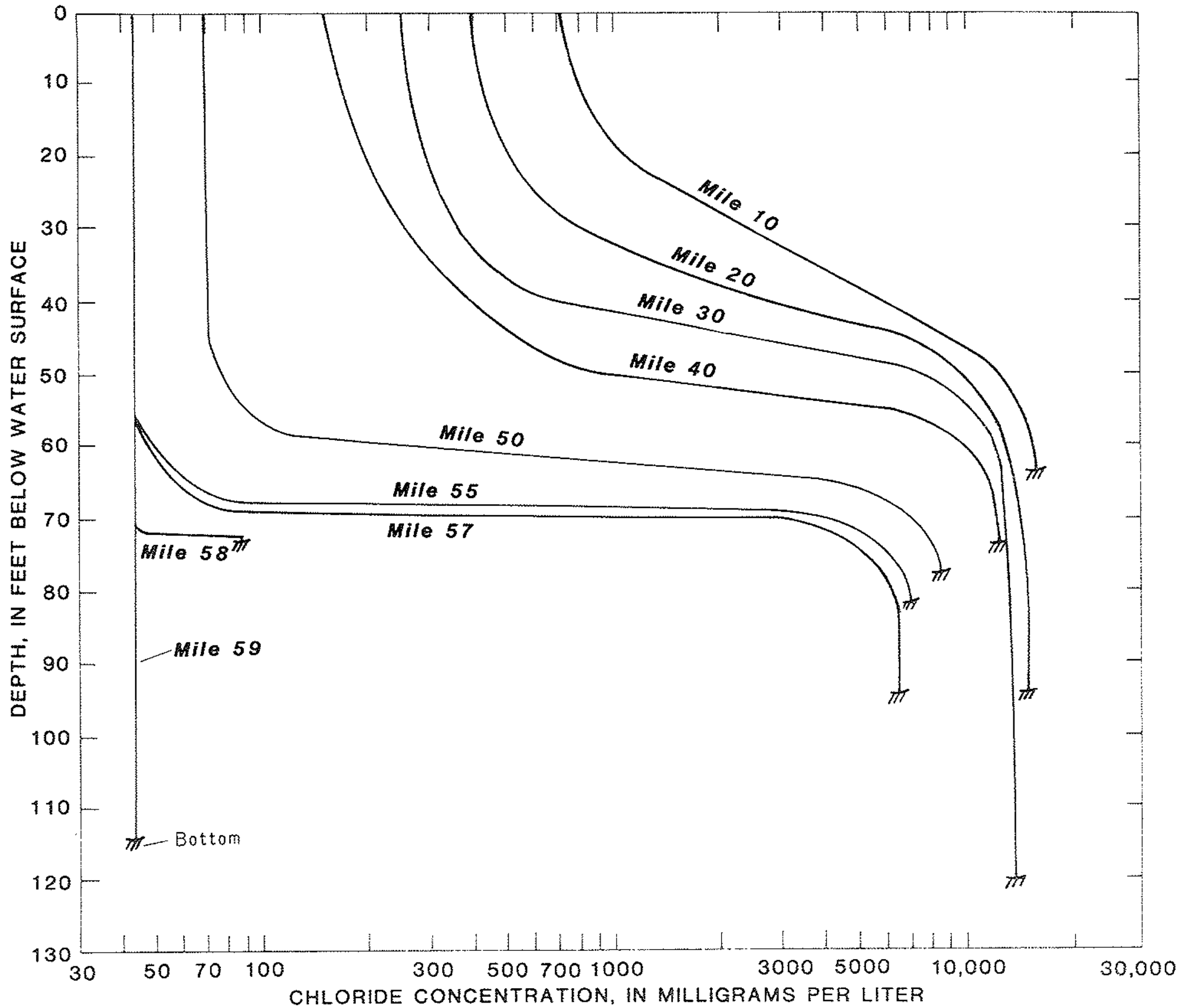



Figure 13.--Vertical distribution of chloride in the Mississippi River, October 1976.

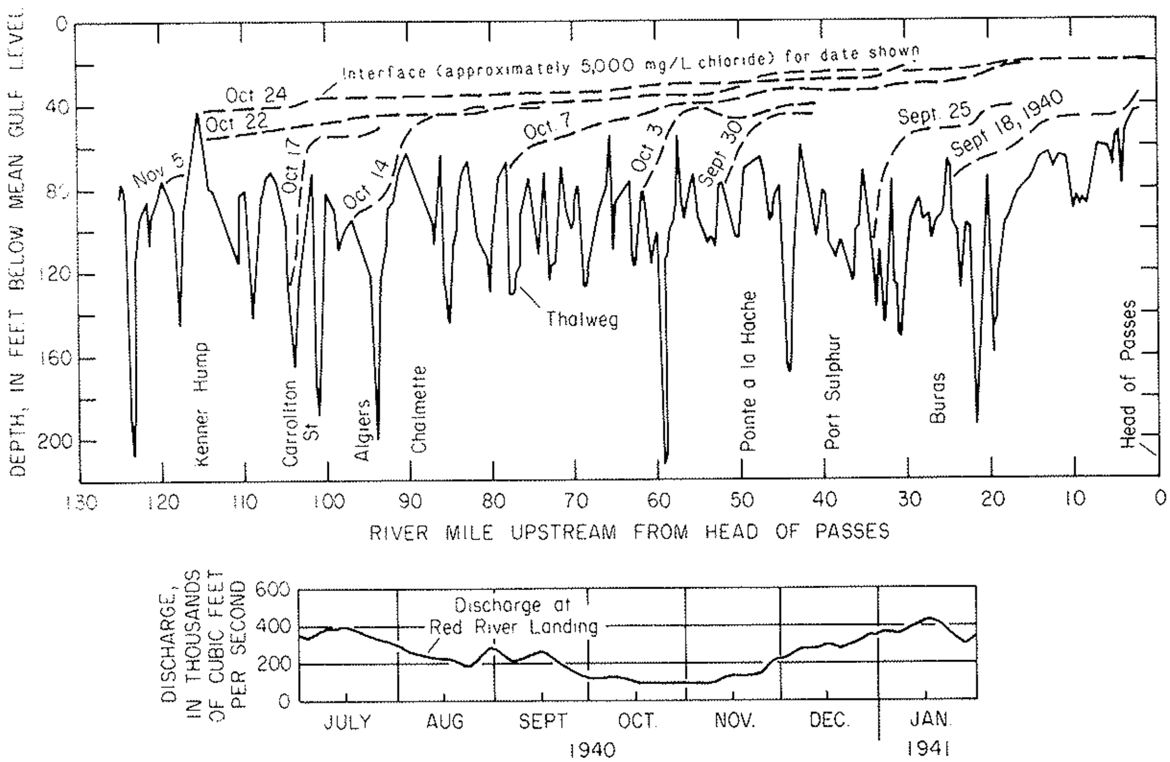



Figure 14.--Migration of saltwater wedge with change in river discharge at Red River Landing, La., September-November 1940. (Modified from U.S. Army Corps of Engineers, unpublished data.)

The maximum upstream migration of the saltwater wedge is difficult to determine because constant discharges do not prevail for a sufficient length of time. However, based on historical data collected since 1939, reasonable estimates of upstream migration can be estimated from the graph in figure 15. For example, at a discharge of 200,000 $ft^3/s$ the saltwater wedge should be located near Port Sulphur, La., at river mile 40.0. Likewise, at a discharge of 125,000 $ft^3/s$ the saltwater wedge should be located near Algiers, La., at river mile 92.0.

Using the graph in figure 15 in conjunction with the low-flow frequency curves for the Mississippi River at Red River-Tarbert Landing (pl. 2), the recurrence intervals for saltwater intrusion at various locations can be estimated. For example, from figure 15 it can be estimated that a discharge of 125,000 $ft^3/s$ should allow the saltwater to migrate to river mile 92.0 near Algiers, La. An average discharge of 125,000 $ft^3/s$ has a 7-day low-flow recurrence interval of 4 years, indicating that on the average of once every 4 years, the saltwater wedge should reach the vicinity of Algiers, La. Data show that between 1939 and 1977, a period of 38 years, the saltwater wedge has reached or passed Algiers nine times, an average of once every 4.2 years. Similarly, the saltwater wedge has only passed the Kenner Hump twice since

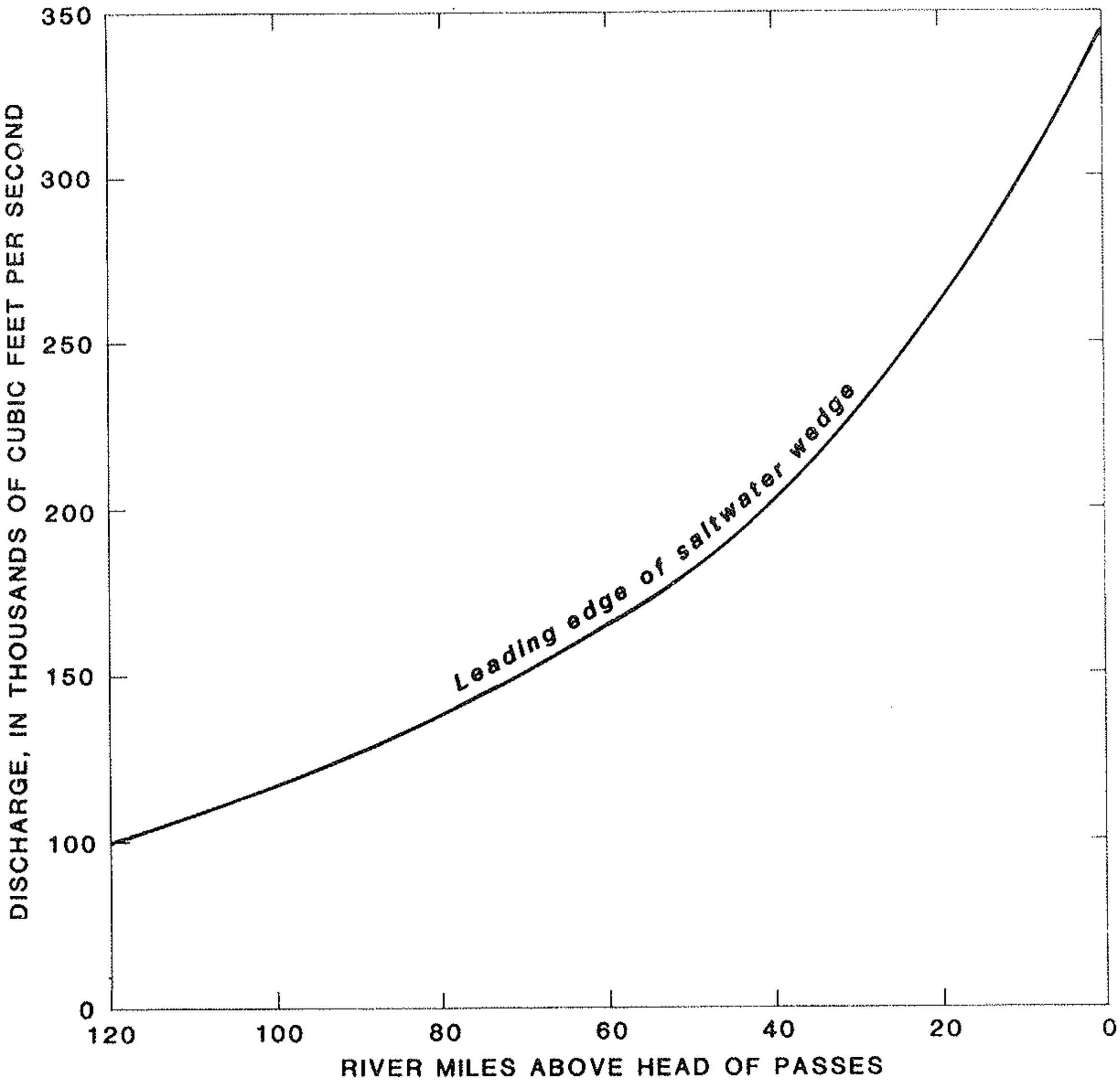



Figure 15.--Relation of discharge at Red River-Tarbert Landing to upstream migration of saltwater wedge in the Mississippi River.

1939 and only when the discharge was less than 100,000 $ft^3/s$. This averages out to once every 19 years. An average discharge of 95,000 $ft^3/s$ at Red River-Tarbert Landing has a 7-day low-flow frequency recurrence interval of 20 years.

Because some mixing does occur at the freshwater-saltwater interface, chloride concentrations in the river increase downstream from the toe of the wedge rendering the water unsuitable for municipal and most industrial purposes. Data indicate that chloride concentrations at the river surface exceed the recommended limits of 250 mg/L for public water supplies anywhere from 15 to 25 mi downstream from the toe of the wedge. The maximum observed chloride concentrations at the Carrollton Purification Plant (mile 104.0), Algiers Purification Plant (mile 95.0), and Port Sulphur (mile 40) for discharges ranging from less than 100,000 to 180,000 $ft^3/s$ are listed in the following table.

Maximum chloride concentrations at varying discharges for three locations on the lower Mississippi River

| Discharge ($ft^3/s$) | Chloride concentration (mg/L) | | | Discharge ($ft^3/s$) | Chloride concentration (mg/L) | | |
|---|---|---|---|---|---|---|---|
| | Carrollton | Algiers | Port Sulphur | | Carrollton | Algiers | Port Sulphur |
| 100,000 or less | 360 | 600 | 2,200 | 120,000 | 120 | 250 | 1,200 |
| 110,000 | 180 | 400 | 1,600 | 140,000 | --- | --- | 400 |
| | | | | 180,000 | --- | --- | 200 |

The recession of the saltwater wedge is dependent primarily upon discharge and the location of the saltwater wedge in the river. Movement of the saltwater wedge downstream from the Kenner Hump requires a fairly large increase in discharge. It appears that the Kenner Hump acts as a barrier protecting the wedge from increased discharges. While discharges must decrease to approximately 100,000 $ft^3/s$ for the saltwater wedge to reach the "hump," data indicate that the wedge will remain at that location until discharges approach 150,000 $ft^3/s$.

The recession of the saltwater wedge downstream from New Orleans, La., is generally rapid and responsive to increases in discharge. For example, during a 3-week period in November 1940 the discharge at Red River Landing, La., increased from approximately 100,000 to 145,000 $ft^3/s$, and the saltwater wedge remained at the base of the Kenner Hump (pl. 3). As the discharge continued to increase to above 150,000 $ft^3/s$, the wedge moved downstream quite rapidly, moving a distance of approximately 80 mi in 7 days.

## Benthic Invertebrates

### Sampling Locations and Procedures

Benthic invertebrates form resident communities of individuals that move very little within a particular reach of a stream or lake throughout their lifetime in the water. The composition of these communities can be indicative of the hydrologic and water-quality conditions where these organisms live (Mackenthun and Ingram, 1966). Any significant change in the hydrology or water quality can change the composition of benthic invertebrate communities. Therefore the number of taxa of benthic invertebrates at a location, as well as the number of individuals within a taxon, can yield valuable information about the hydrology and water quality of that habitat.

Benthic invertebrates were sampled from April 1976 through May 1977 at four sites in a reach of the Mississippi River extending from St. Francisville to Venice, La. The study was designed to define the benthic invertebrate communities in the lower Mississippi River and to determine differences between benthic invertebrate communities upstream and downstream from the Baton Rouge and New Orleans, La., industrial and municipal complexes. The sampling site at St. Francisville is upstream from the industrial and municipal complexes, and organisms found at this location are considered to be representative of relatively clean, unpolluted water. The sampling sites at Luling, Belle Chasse, and Venice, La., are adjacent to and downstream from the major industrial and municipal complexes. If wastes from these areas are affecting the benthic invertebrates, the numbers and types of organisms found at these locations should differ from those at St. Francisville.

The discharge of the river during the study ranged from approximately 160,000 to 700,000 $ft^3/s$. At discharges of less than 250,000 $ft^3/s$, saltwater from the Gulf of Mexico intrudes upstream from Venice, La. This saltwater was present at Venice as a saltwater wedge from August through December 1976.

Benthic invertebrate community samples were collected at five cross-sectional stations per site: left bank, left center, center, right center, and right bank. Three samples for benthic invertebrate analysis were collected at each station. In addition, at each station in the cross section a bed sample was collected for analysis of particle size and loss on ignition. These samples helped define the substrate type (either sand, silt, or clay) and the amount of organic matter present. Six sets of samples were collected seasonally, based on temperature and discharge.

U.S. Standard No. 30 sieves were used to separate the organisms from the bed material substrate. Sieved organisms were preserved with 70-percent denatured ethyl alcohol for later study and identification in the laboratory. Representative samples of specimens were sent to the Atlanta Central Laboratory of the U.S. Geological Survey for taxonomic verification. Diversity indices were calculated using the following formula as proposed by Wilhm and Dorris (1968, p. 478) and recommended by Slack, Averett, Greeson, and Lipscomb (1973, p. 24):

$$\bar{d} = -\sum_{i=1}^{s} \frac{n_i}{n} \log_2 \frac{n_i}{n}$$

where $\bar{d}$ is a measure of diversity, $n_i$ is the number of individuals per taxon, n is the total number of individuals, and s is the total number of taxa in the sample of the community.

## Benthic Populations and Habitats

Table 12 lists all organisms collected during the 13-month study period. Corbicula, an asiatic clam, and unidentified tubificid worms occurred most frequently and were the most numerous organisms collected. Several chironomid genera, Coelotanypus, Demicryptochironomus, and Crypochironomus; the tubificid Limnodrilus; and the hydroid Cordylophora were abundant at most sites. The amphipods Gammarus and Corophium, the nemertean Prostoma, and the chironomids Polypedilum and Paracladopelma were ubiquitous but in low numbers. Profiles of substrate type and water velocity at each of the four sampling sites on the Mississippi River, along with the relative abundance and diversity of benthic organisms collected at each station, are shown in figure 16.

Table 12.--Benthic organisms identified from sampling sites on the Mississippi River, St. Francisville to Venice, La., April 1976-May 1977

[List compiled from three samples collected at five stations in the cross section at each site on six different dates, a total of 360 samples. Numbers in table represent total number of organisms identified at each sampling station for all six sampling dates. X indicates presence of colonial-type organisms]

| Organism | St. Francisville | Luling | Belle Chasse | Venice |
|---|---|---|---|---|
| Hydrozoa | | | | |
| Hydroida | | | | |
| Clavidae | | | | |
| Cordylophora | X | X | X | X |
| Phylactolaemata | | | | |
| Plumatellina | | | | |
| Plumatellidae | | | | |
| Plumatella | X | ----- | ----- | ----- |
| Fredericellidae | | | | |
| Fredericella | --- | ----- | X | ----- |
| Lophopodidae | | | | |
| Lophopodella | X | ----- | ----- | ----- |
| Enopla | | | | |
| Hoplonnemertini | | | | |
| Tetrastemmatidae | | | | |
| Prostoma | --- | 16 | 3 | 14 |
| Anopla | | | | |
| Carinomidae | | | | |
| Carinoma | --- | ----- | ----- | 9 |
| Turbellaria | | | | |
| Tricladia | | | | |
| Planariidae | | | | |
| Dugesia | --- | ----- | 3 | ----- |
| Oligochaeta | | | | |
| Plesiopora | | | | |
| Tubificidae | | | | |
| Aulodrilus | --- | 7 | ----- | 16 |
| Branchiura | --- | 5 | ----- | ----- |
| Limnodrilus | 82 | 47 | 77 | 4 |
| Potamothrix | --- | ----- | 1 | ----- |
| Unidentified | 564 | 609 | 316 | 124 |
| Opisthopora | | | | |
| Haplotaxidae | | | | |
| Unidentified | --- | ----- | 1 | ----- |
| Polychaeta | | | | |
| Spionida | | | | |
| Spionidae | | | | |
| Streblospia | --- | ----- | ----- | 135 |
| Phyllodocida | | | | |
| Nereidae | | | | |
| Nereis | --- | ----- | ----- | 45 |
| Cirratulida | | | | |
| Cirratulidae | | | | |
| Cossura | --- | ----- | ----- | 2 |
| Terebellida | | | | |
| Ampharetidae | | | | |
| Asebellides | --- | ----- | ----- | 4 |

Table 12.--Benthic organisms identified from sampling sites on the Mississippi River, St. Francisville to Venice, La., April 1976-May 1977--Continued

| Organism | St. Francis-ville | Luling | Belle Chasse | Venice |
|---|---|---|---|---|
| Hirudinea | | | | |
| Pharyngobdellida | | | | |
| Erpobdellidae | | | | |
| Dina | 3 | ----- | ----- | ----- |
| Unidentified | --- | 1 | 1 | ----- |
| Crustacea | | | | |
| Mysidacea | | | | |
| Mysidae | | | | |
| Taphromysis | --- | ----- | ----- | 1 |
| Isopoda | | | | |
| Asellidae | | | | |
| Asellus | --- | ----- | ----- | 3 |
| Amphipoda | | | | |
| Gammaridae | | | | |
| Gammarus | 11 | 2 | 19 | 9 |
| Corophiidae | | | | |
| Corphium | 1 | ----- | 18 | 1,001 |
| Decapoda | | | | |
| Palaemonidae | | | | |
| Palaemonetes | --- | ----- | 2 | ----- |
| Portunidae | | | | |
| Callinectes | --- | ----- | ----- | 2 |
| Insecta | | | | |
| Collembola | | | | |
| Isotomidae | | | | |
| Isotomurus | --- | ----- | ----- | 4 |
| Odonata | | | | |
| Gomphidae | | | | |
| Gomphus | 1 | ----- | ----- | ----- |
| Ephemeroptera | | | | |
| Ephemeridae | | | | |
| Pentagenia | 93 | ----- | 1 | 1 |
| Hexagenia | 69 | ----- | 1 | ----- |
| Polymitarcidae | | | | |
| Tortopus | 119 | ----- | ----- | 14 |
| Trichoptera | | | | |
| Hydropsychidae | | | | |
| Hydropsyche | --- | 1 | ----- | ----- |
| Diptera | | | | |
| Chironomidae | | | | |
| Ablabesmyia | 4 | ----- | ----- | ----- |
| Clinotanypus | 1 | ----- | ----- | ----- |

| Organism | St. Francis-ville | Luling | Belle Chasse | Venice |
|---|---|---|---|---|
| Insecta--con. | | | | |
| Diptera--con. | | | | |
| Chironomidae--con. | | | | |
| Coelotanypus | 27 | 27 | 114 | 1 |
| Procladius | --- | 1 | ----- | ----- |
| Demicryptochironomus | 76 | 4 | 6 | ----- |
| Cryptochironomus | 77 | 29 | 84 | 7 |
| Dicrotendipes | --- | ----- | 1 | 2 |
| Einfeldia | --- | ----- | ----- | 1 |
| Kiefferulus | --- | ----- | 2 | ----- |
| Lauterborniella | 7 | ----- | ----- | ----- |
| Paracladopelma | 4 | ----- | 4 | 1 |
| Paratendipes | 1 | 2 | ----- | ----- |
| Polypedilum | --- | 1 | 1 | 16 |
| Micropsectra | --- | ----- | 1 | ----- |
| Cladotanytarsus | 1 | ----- | ----- | 258 |
| Cricotopus | --- | ----- | ----- | 1 |
| Metriocnemus | --- | ----- | 1 | ----- |
| Psectrocladius | --- | ----- | 1 | ----- |
| Unidentified | 1 | 1 | 6 | ----- |
| Ceratopogonidae | | | | |
| Palpomyia-Bezzia gp | 5 | 1 | 1 | ----- |
| Psychodidae | | | | |
| Telmatoscopus | --- | ----- | 1 | ----- |
| Tabanidae | | | | |
| Chrysops | --- | ----- | 1 | ----- |
| Gastropoda | | | | |
| Mesogastropoda | | | | |
| Hydrobiidae | | | | |
| Somatogyrus | 1 | 4 | ----- | ----- |
| Bivalvia | | | | |
| Heterodonta | | | | |
| Corbiculidae | | | | |
| Corbicula | 85 | 2,761 | 3,381 | 33 |
| Mactridae | | | | |
| Rangia | --- | ----- | ----- | 4 |
| Schizodonta | | | | |
| Unionidae | | | | |
| Lampsilis | 1 | ----- | ----- | ----- |

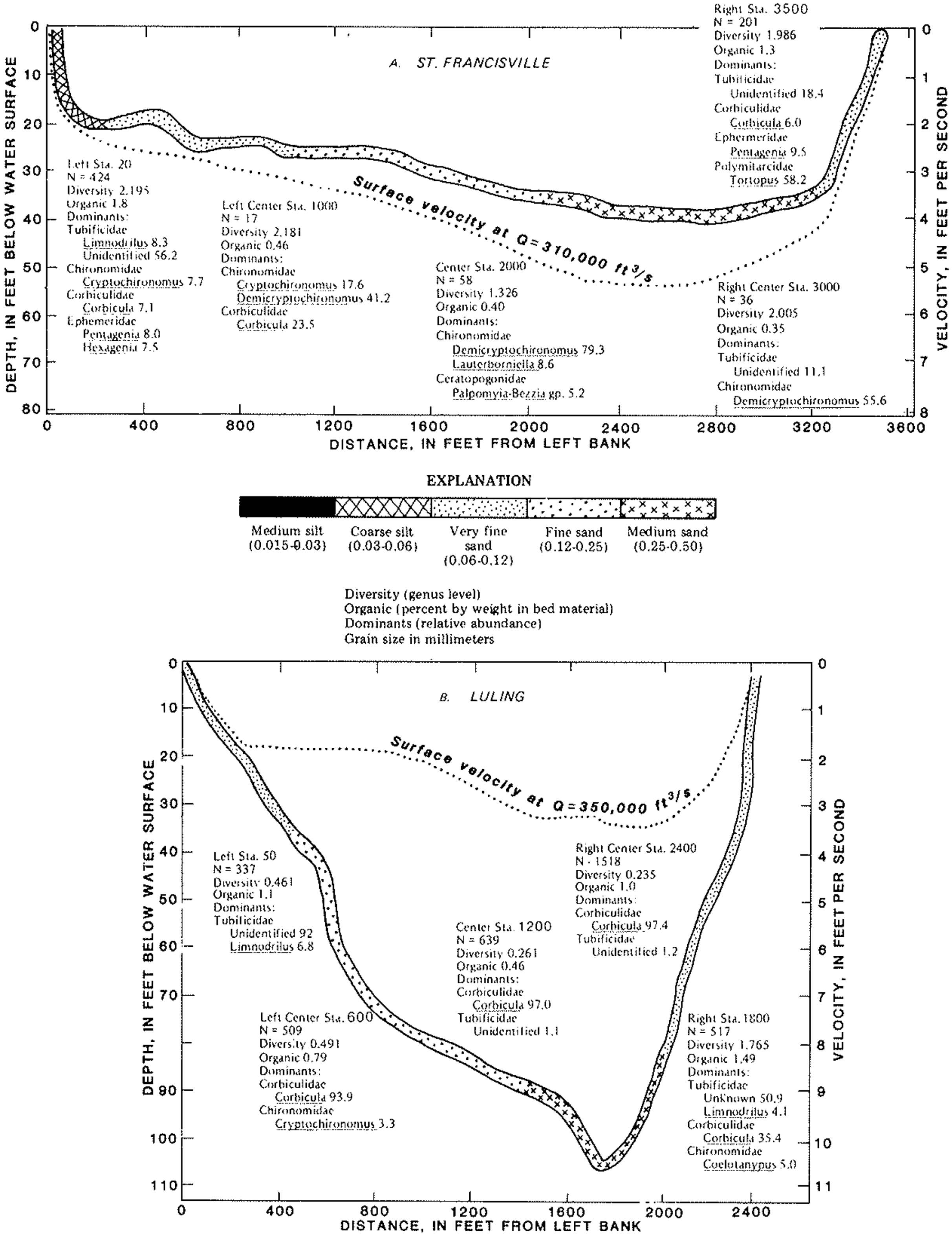
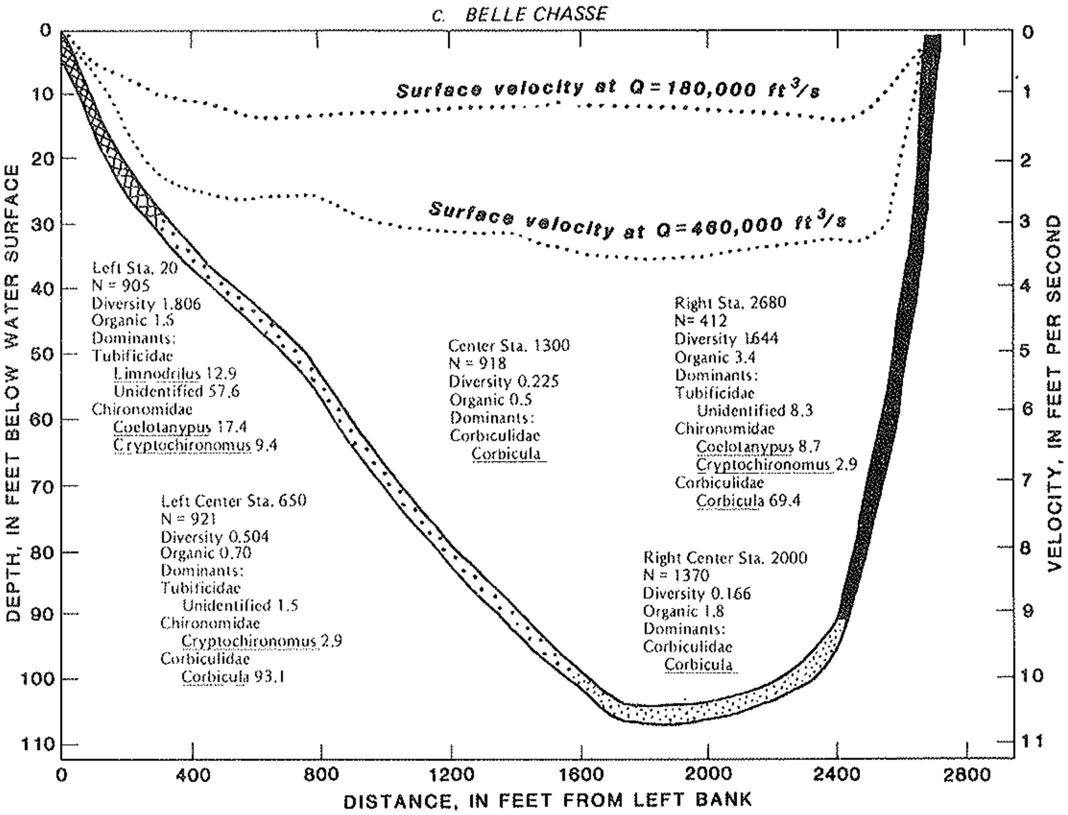
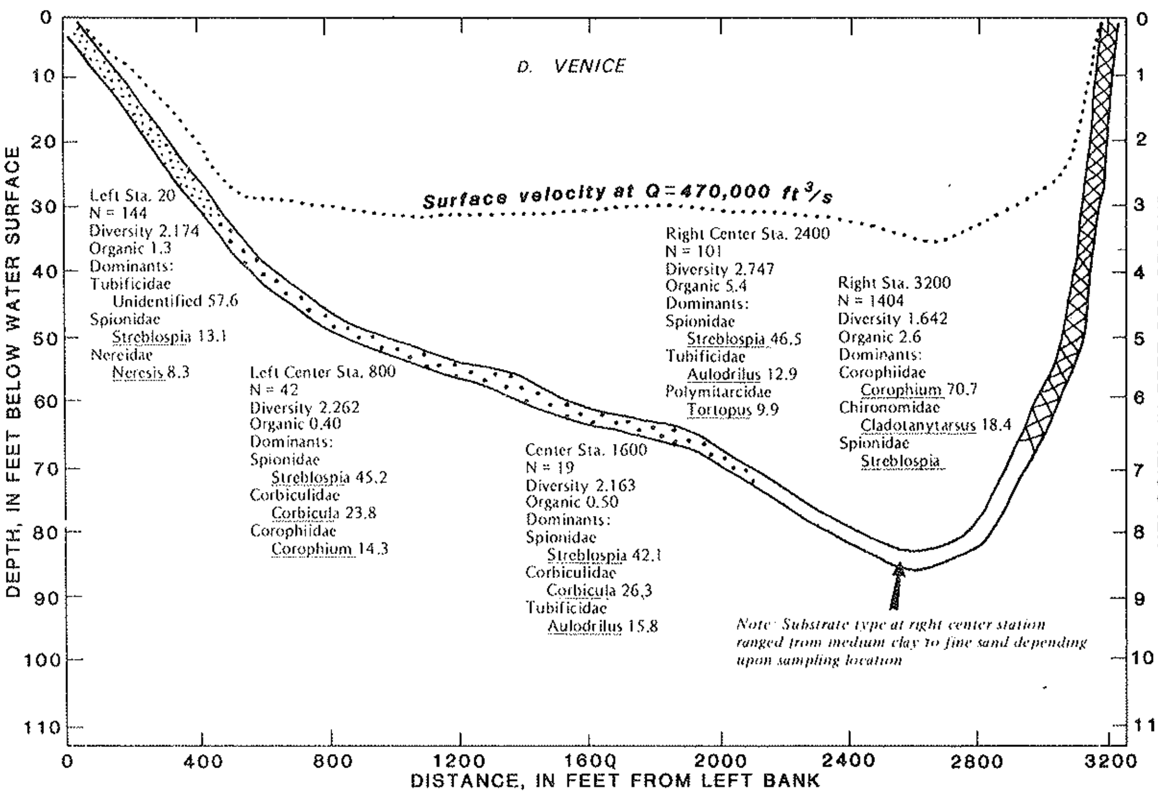



Figure 16.--Channel and surface-velocity profiles of sampling sites on organisms and particle




the Mississippi River showing relative abundance and diversity of benthic size of bed material.

At St. Francisville, La., the most numerous organisms collected were unidentified tubificidae; the mayflies Tortopus, Hexagenia, and Pentagenia, Corbicula; Limnodrilus; Cryptochironomus; and Demicryptochironomus. The composite diversity at St. Francisville at the generic level was 2.8. The majority of organisms collected at the St. Francisville site (fig. 16A) were from the left and right banks. Tubificid worms and mayflies were the most abundant organisms at these two stations.

Populations at the center, left-center, and right-center stations were very low in number and composed primarily of Demicryptochironomus. The substrates at these stations ranged from fine to medium sand and were considered to be relatively unstable.

Diversity at the generic level at St. Francisville, La., ranged from a high of 2.2 at the left bank to a low of 1.3 at the center station. The left-bank station had a more stable environment than the center station. The stable substrate, the relatively low velocities, and a constant source of allochthonous organic matter from overhanging trees probably contributed to the higher diversity and density of organisms observed at the left-bank station.

Benthic populations at Luling and Belle Chasse, La., are very similar in their distribution pattern across the transect (fig. 16, A and B). Concentrations of organisms were highest at the center, left-center, and right-center stations, where the substrate ranged from a very fine to fine sand. Corbicula was the only organism present in quantity at these stations. The Corbicula collected at these stations were in good physical condition, indicating healthy, reproducing populations. The composite diversity at the generic level for Luling and Belle Chasse was 1.0 and 1.1, respectively.

Although fewer organisms were collected at the left- and right-bank stations at Luling and Belle Chasse, La., the diversity of organisms at these stations was higher than at the center and near-center stations. Tubificid worms and chironomids were present in much greater numbers at the bank stations, usually comprising more than 50 percent of the population. The substrate type at the bank stations ranged from medium silt to very fine sand.

The types and numbers of organisms present at Venice, La., (fig. 16D) differed from those at all other sites. The amphipod Corophium, the chironomid Cladotanytarsus, the polychaete Streblospio, unidentified tubificids, and the polychaeta Nereis were the most abundant organisms collected. The composite diversity at the generic level was 2.2. The presence of submerged periphytic algae and saltwater were the two major influences on the benthic populations at Venice. Corophium and Cladotanytarsus were the most numerous organisms and were found predominantly at the right-bank station where organic vegetation and detritus were abundant. Substrates at Venice ranged from coarse silt to very fine sand.

Corbicula were found in a few samples collected at Venice, but the individuals were small. From the small size and low numbers of Corbicula collected at Venice, it appears that they were transients brought in by drift and were unable to colonize in the saline environment.

Polychaetes, crabs, tubificids, and some chironomids were also influenced by the presence or absence of the saltwater wedge. These organisms were able to survive when changes in salinity occurred and were still present after the saltwater wedge had been pushed downstream by higher discharges. It appears that the "typical" benthic communities at Venice, La., are euryhaline in nature and are just beginning to reestablish themselves following the three high-water years, 1973-75.

## Community Structure and Distribution

The benthic community structure of the lower Mississippi River is influenced by substrate type and stability, channel geometry, river velocity, presence of vegetation and organic detritus, and salinity. For example, at the bank stations, velocities are generally less than 1.0 ft/s; and the substrate types ranged from medium silt to very fine sand. Burrowing organisms such as tubificids, chironomids, and ephemerid-type mayflies adapt well to this type of environment. Sampling verified this at all bank stations with the exception of the right bank at Luling, La., where the substrate generally consisted of small amounts of silt overlying a concrete revetment. Differences were also observed in the structure of the bank-site communities. Larval mayflies, which are extremely sensitive to many pollutants, were present in large numbers only at St. Francisville, La. However, numerous mayfly adults were observed at both Luling and Belle Chasse, La., and burrows were found in the substrate at the right-bank stations at Belle Chasse. The absence of larval mayflies at Luling and Belle Chasse may be due to station location, channel morphology, or to changes in water quality brought about by the municipal and industrial complexes bordering the river. However, water-quality data collected at these stations since 1973 show little differences between the St. Francisville, Luling, and Belle Chasse stations.

The presence of aquatic vegetation and organic detritus from trees and shrubs along the banks also influences the habitats at bank stations. This was especially noticeable at the left bank at St. Francisville, La., and the right banks at Belle Chasse and Venice, La. Corophium were quite abundant in the periphytic algae along the right bank at Venice where approximately 1,000 Corophium were recovered.

At the center, left-center, and right-center channel stations, velocities are higher than at the bank stations; and substrate type is generally coarser, ranging from very fine sand to coarse sand. The largest particle sizes were found at the right-center location at St. Francisville, La., where some gravel was noted in the samples. This combination of coarse substrate and velocities in excess of 3.0 ft/s produced an unstable substrate that was unsuitable for habitation. Only 36 organisms were recovered from this station during this study. Fine and medium sand substrates were also present at Luling and Belle Chasse, La.; however, the velocities at these sites are generally less than 3.0 ft/s, and the substrates are more stable. This sand-substrate, moderate-velocity type of environment favors dense streamlined organisms such as Corbicula. At Venice, La., the substrates at the left-center and center stations were also composed of fine sand; however, these stations did not support many organisms due to the presence of saltwater.

Differences in the benthic invertebrate communities at the four sampling locations are evident. Differences in community structure between sampling sites can be attributed primarily to changes in hydrologic conditions. Berg (1943, 1948) felt that substrate type and velocity are the two most important ecological factors in classifying streams, and data collected during this study seem to verify his finding. Data also indicate that industrial and municipal wastes discharged into the river have little widespread effect on the benthic populations. The low organic content in the bed material shows no evidence of organic deposition. The majority of organisms collected during the study, with the exception of the tubificid worms, are not capable of surviving in substrates containing large amounts of decomposable organic waste (Weber, 1973). Although dredging operations affect the benthic populations locally, no effects were noted at the sampling sites. The large variation in the benthic community within a site further supports the theory that hydrologic conditions are the primary factor in determining benthic populations in the river.

## USE OF RIVER WATER

The Mississippi River is of great importance as a navigational waterway, as a source of water for industrial and municipal use, and for receiving industrial and municipal wastes. Major industrial and electrical plants located on the lower Mississippi River are shown on plate 4. Approximately 6,300 Mgal/d of water was withdrawn from the river in 1975 for industrial and municipal uses and for electrical power generation (table 13). About 95 percent of this water is returned to the river as waste water. The largest users of water along the river are electrical generating plants that withdraw approximately 3,700 Mgal/d of water. Nearly all of this water is returned to the river as heated effluent.

### Municipal Supplies

Most cities and towns from Donaldsonville to Venice, La., use Mississippi River water for municipal water supplies. The total municipal pumpage from the river in 1975 averaged 214 Mgal/d, an increase of approximately 15 percent since 1970. The largest users of water for municipal purposes are Jefferson and Orleans Parishes, which account for almost 90 percent of the total municipal pumpage.

Table 13.--Pumpage of water from the Mississippi River downstream from the Old River Control Structure for industrial, municipal, and electrical generating uses, 1975

| Parish | Pumpage from river (Mgal/d) | | |
|---|---|---|---|
| | Industrial | Municipal | Electrical |
| West Feliciana | 36 | ----- | ----- |
| Pointe Coupee | 2.5 | ----- | ----- |
| East Baton Rouge | 110 | ----- | 5 |
| West Baton Rouge | ------- | ----- | ----- |
| Iberville | 640 | ----- | 630 |
| Ascension | 120 | 1 | ----- |
| Assumption | 5.5 | 2 | ----- |
| St. James | 270 | 2 | ----- |
| St. John the Baptist | 84 | 1 | ----- |
| St. Charles | 540 | 5 | 1,500 |
| Jefferson | 34 | 58 | 1,500 |
| Orleans | ------- | 130 | 24 |
| St. Bernard | 570 | 9.0 | ----- |
| Plaquemines | 51 | 6.4 | ----- |
| Total by use | 2,463 | 214 | 3,660 |
| Total water use | | | 6,337 |

The recommended criteria for selected constituents in public water supplies established by the National Academy of Sciences and National Academy of Engineering (1973) are listed in table 14. The ranges in concentrations of these constituents in Mississippi River water at New Orleans, La., and other locations along the river are generally well within these recommended limits. The major exception is chloride concentration in areas affected by saltwater intrusion. This is especially true in Plaquemines Parish where saltwater becomes a problem when discharges fall below 250,000 $ft^3/s$. At discharges of less than 175,000 $ft^3/s$ the intakes of the Boothville, Empire, and Port Sulphur, La., waterplants are affected by saltwater. The Boothville plant stores freshwater in ponds during periods of high flow. This water is used to dilute brackish river water during low-flow periods to meet accepted chloride criteria for drinking water. The Empire and Port Sulphur plants must cease operations if the chloride concentration becomes excessive at their intakes. In the event of a shutdown, freshwater from the West Point-a-la-Hache waterplant can be pumped to the Empire and Port Sulphur areas. If the chloride concentration becomes excessive at the West Point-a-la-Hache plant, many of the people in lower Plaquemines Parish will temporarily be without a source of freshwater.

Table 14.--Recommended criteria for maximum concentrations of selected constituents in public-water-supply sources and observed concentrations for Mississippi River at New Orleans, La.

[Concentrations are in milligrams per liter except as noted]

| Constituent | Recommended maximum concentration[1] | Observed concentration | | |
|---|---|---|---|---|
| | | Maximum | Minimum | Average |
| Ammonia---------------- | 0.5 | 0.69 | 0.00 | 0.08 |
| Fecal coliform[2]--------- | 2,000 | 1,800 | 5 | 370 |
| Total coliform[2]--------- | 20,000 | 16,000 | 180 | 3,400 |
| Chloride----------------- | 250 | 64 | 11 | 26 |
| Color[3]----------------- | 75 | 60 | 0 | 13 |
| Fluoride[4] -------------- | 1.4 | 1.4 | .0 | .4 |
| Hardness---------------- | -------- | 210 | 100 | 146 |
| Iron-------------------- | .3 | .51 | .00 | .04 |
| Nitrate as nitrogen (N)--- | 10 | 2.0 | .00 | .84 |
| Nitrite as nitrogen (N)---- | 1.0 | .09 | .00 | .01 |
| Sulfate------------------ | 250 | 88 | 30 | 55 |
| Dissolved solids---------- | 500 | 327 | 130 | 240 |

1/ National Academy of Sciences and National Academy of Engineering (1973). Alternative criteria may be found in "Quality Criteria for Water" (U.S. Environmental Protection Agency, 1976).

2/ Concentrations, in colonies per 100 mL.

3/ Platinum-cobalt units.

4/ Maximum concentration based on annual averages of maximum daily air temperature of 26.5-33.0° C.

## Industrial Supplies

Demands for water from the Mississippi River for use by industries and for generating electrical power have increased approximately 200 percent since 1960. The average daily withdrawal of water from the river by industries and powerplants during 1975 was about 6,100 Mgal/d. About 2,500 Mgal/d was used by industrial plants. Most of this water is used for cooling purposes and is returned to the river. Nearly all of the 3,700 Mgal/d withdrawn by electrical generating plants is used for cooling and is returned to the river as heated effluent.

The largest increases in water use in the near future will undoubtedly be for generating electricity. Two powerplants, one coal fired and one nuclear powered, are under construction near St. Francisville, La. These two units will withdraw a combined average of 62 Mgal/d of water from the river. The nuclear powerplant under construction at Waterford, La., will use an average of 1,400 Mgal/d. This is in addition to the 618 Mgal/d currently withdrawn for the existing Waterford facility.

## Waste Disposal and Assimilation

The Mississippi River is important to industry and municipalities not only as a source of water but also as a means of waste disposal. The total waste-water discharge into the river by industry and electrical powerplants is about 5,700 Mgal/d or 8,800 $ft^3/s$. During low flow this amounts to approximately 6 percent of the total flow of the river. The three types of waste discharged into the river are inorganic, organic, and thermal.

Everett (1971) reported that dissolved solids discharged into the river between St. Francisville and Luling, La., had increased from about 4,000 tons per day in 1958 to 20,000 tons per day in 1969. This represented an increase in dissolved-solids concentrations between the two locations of approximately 5 mg/L in 1958 and 20 mg/L in 1969. Since 1969, govermental regulations have limited the amounts and types of waste discharged into the river. These regulations have curtailed the increase in dissolved solids discharged into the river. The dissolved-solids load added to the river between St. Francisville and Luling has remained fairly constant since 1970, averaging approximately 18,000 tons per day or an average of about 15 mg/L. During the two water years 1976-77, an additional 6,000 tons per day (an average of 6 mg/L of dissolved solids) was discharged into the river between Luling and Belle Chasse, La.

### Inorganic Waste Assimilation

Waste discharged into the river has a more pronounced effect on the water quality of the river during periods of low flow because there is less water to dilute the waste. For example, in November 1976 at a discharge of 270,000 $ft^3/s$ the dissolved-solids concentration increased 62 mg/L between St. Francisville and Belle Chasse, La., representing a 30-percent increase in dissolved-solids load. In March 1975 at a discharge of 825,000 $ft^3/s$ the dissolved-solids concentration increased 7 mg/L, a load increase of 6.5 percent. The river can assimilate more waste during periods of high flow because there is more water to dilute the waste. This is illustrated on plate 5 where mean daily discharge and daily concentrations of chloride during 1977 are plotted for St. Francisville, Luling, and Belle Chasse, La. During March and April the discharge generally exceeded 600,000 $ft^3/s$, and chloride concentrations were generally less than 25 mg/L. Little differences were noted among the concentrations at St. Francisville, Luling, and Belle Chasse during this period. During January, February, June, July, and August when the river discharge was generally less than 300,000 $ft^3/s$, chloride concentrations were considerably higher than during periods of high flow; and larger differences were noted among the three stations.

Although large amounts of inorganic waste are discharged into the Mississippi River daily, it appears that the river can adequately assimilate the waste at the present time. It should be noted that it takes a continuous discharge of 540 lb/d (0.375 lb/min) of a conservative waste per 100,000 $ft^3/s$ of water to increase the downstream concentration of that waste 1 µg/L. Similarly, it takes a continuous release of 270 tons per day (375 lg/min) per 100,000 $ft^3/s$ of a conservative waste to increase the downstream concentration 1 mg/L. Larger river discharges would require proportionately larger volumes of waste discharge to increase downstream concentrations. For example, at a discharge of 300,000 $ft^3/s$ it would require a continuous release of 1,620 lb/d of a conservative waste to increase the downstream concentration 1 µg/L or 810 tons per day to increase the downstream concentration 1 mg/L. From 1973 through 1977 the average discharge of the river has been approximately 550,000 $ft^3/s$; and the average concentration of dissolved arsenic, cadmium, chromium, lead, mercury, and nickel at sites from St. Francisville to Venice, La., generally differed by less than 1 µg/L each. An average increase of 1 µg/L at a discharge of 550,000 $ft^3/s$ would represent an average dissolved waste load of each of these compounds of 3,000 lb/d.

## Acidic- and Basic-Waste Assimilation

Many industries along the Mississippi River discharge acidic and basic wastes into the river. At present, these wastes have very little effect upon the pH of the water; downstream changes in pH generally vary less than 0.2 pH units. However, large increases or accidental spillage of acidic or basic waste into the river could significantly alter the pH of the river downstream, making it unsuitable for industrial or municipal use and harmful to the river ecosystem.

The buffering capacity of water is the ability of water to resist a change in pH. The buffering capacity of the Mississippi River per unit volume of water is closely related to the bicarbonate-ion concentration and is greatest during periods of low flow when the bicarbonate concentration is highest. Figure 17 shows the effect of acidic and basic wastes on the pH of Mississippi River water at various bicarbonate concentrations. Figure 17 also shows that the pH of the water is more resistant to change by acidic waste than basic waste. For example, six equivalents of acid as hydrogen ion would lower the pH of 1,000 gal of river water with a bicarbonate concentration of 130 mg/L approximately 1.7 pH units (7.6 to 5.9). Six equivalents of a base as hydroxyl ion would increase the pH of that same water approximately 2.3 pH units (7.6 to 9.9).

Using the buffering-capacity curves, river discharge, and bicarbonate-ion concentration, the ability of the river to assimilate acidic and basic wastes can also be determined. Assimilation of these wastes is closely associated with the total load of bicarbonate ion. The load may be computed from the following formula:

$$L = Q \times C \times 0.0027,$$

where L=load, in tons per day;
C=concentration, in milligrams per liter; and
Q=discharge, in cubic feet per second.

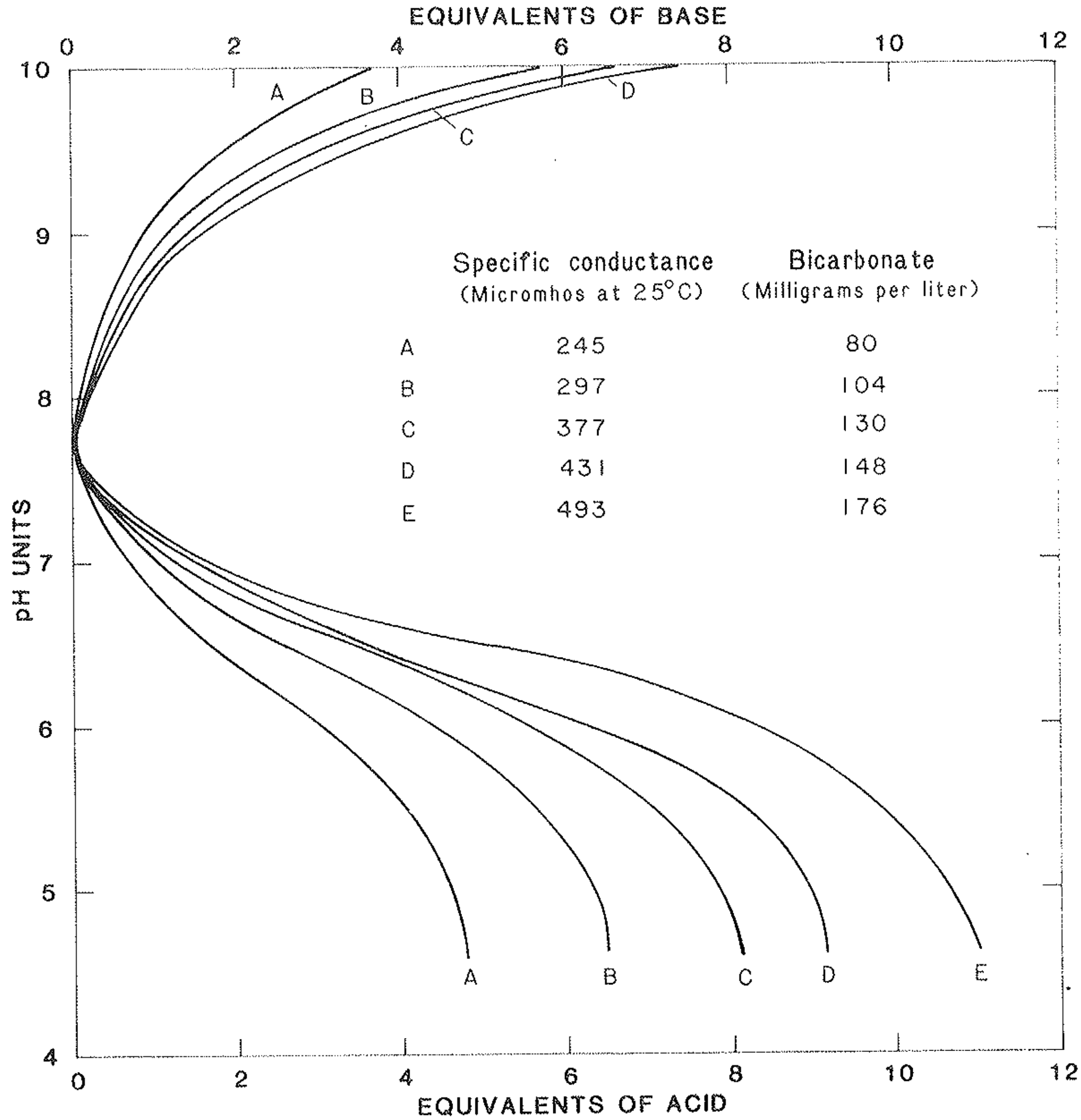



Figure 17.--Buffering-capacity curves for Mississippi River water showing equivalents of acid or base necessary to produce a given pH change in 1,000 gallons of water.

Figure 18 shows that the river can assimilate more acidic and basic wastes during high flow when bicarbonate loads are high than during periods of low flow and low bicarbonate loads. For example, an instantaneous release of 150,000 tons of (40-percent) hydrochloric acid would,

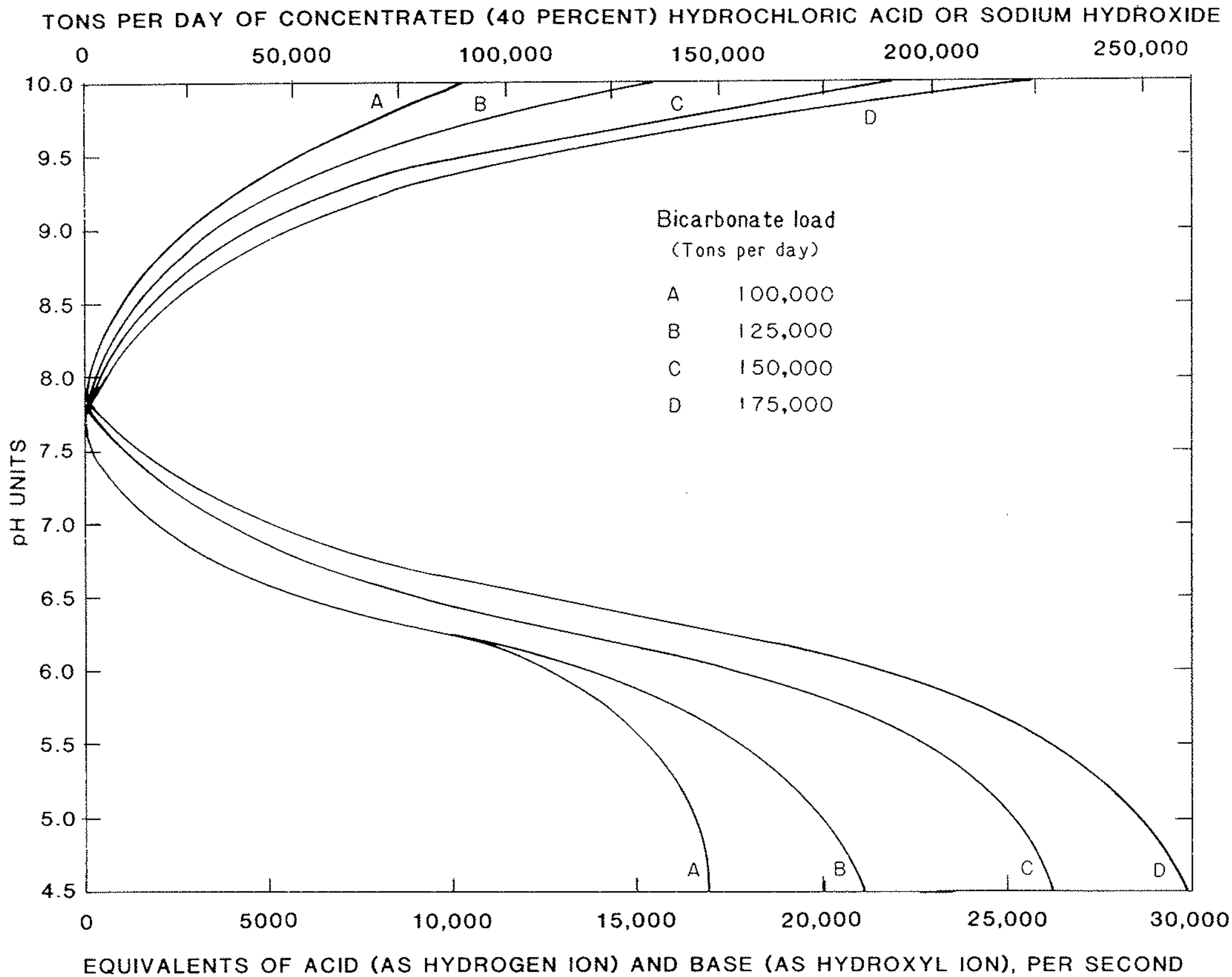



Figure 18.--Capacity of the lower Mississippi River to assimilate acidic and basic wastes.

after mixing, lower the pH of the river 1.4 pH units from 7.7 to 6.3 at a bicarbonate load of 175,000 tons per day. This same amount of acidic waste would lower the pH of the river 2.5 pH units from 7.6 to 5.1 at a bicarbonate load of 125,000 tons per day.

## Organic-Waste Assimilation

Large amounts of organic waste are discharged into the lower Mississippi River every day. Many organic wastes have an adverse effect on the water quality of the river because they impart disagreeable taste and odor to the water. Food fish affected by certain organic wastes also have a distinct oily taste. Some organic wastes, particularly chlorinated hydrocarbons, are toxic. Other organic wastes such as humic substances and simple low-molecular weight organic compounds are readily converted to low-molecular weight chlorinated hydrocarbons during chlorination of municipal water supplies (Stevens and others, 1976). Another problem commonly associated with organic waste is the consumption of dissolved oxygen during aerobic decomposition of organic compounds.

Municipalities along the river currently discharge both raw and treated sewage into the river. The average daily contribution of organic matter per person is equivalent to about 0.17 lb/d of BOD (biochemical oxygen demand) (Hardenbergh and Rodie, 1963). BOD is the amount of oxygen required to stabilize organic matter by aerobic bacterial action. Based on a population of approximately 1.5 million persons along the river between St. Francisville and Venice, La., the total BOD load added to the river by municipal waste would be approximately 130 tons per day.

Dissolved oxygen is essential for aquatic life in the river and for the natural self-purification of the river. The principal functions controlling dissolved-oxygen concentrations in the river are (1) the amount of oxygen-consuming waste in the river and (2) the amount of reaeration from atmospheric oxygen. The amount of biodegradeable oxygen-consuming wastes is measured by the BOD. The standard BOD measurement is the 5-day BOD ($BOD_5$) that measures the amount of oxygen consumed over a 5-day period at 20°C. This determination typically measures most of the carbonaceous BOD. Table 15 shows a statistical summary of $BOD_5$ data collected between St. Francisville and Venice, La., during the five water years 1973-77. Little difference is noted in the average $BOD_5$ between stations. No increase is noted in the average $BOD_5$ concentrations downstream from New Orleans, La., where raw sewage is discharged into the river. Based on a current population of approximately 600,000 served by the New Orleans sewerage plant and a 0.17 lb/d per capita of BOD, the increase in BOD load from the city would amount to about 50 tons per day or 0.1 mg/L in 200,000 $ft^3/s$ of water. To increase the BOD concentration 1 mg/L in 100,000 $ft^3/s$ would require a population of approximately 3 million to produce the required BOD waste load. This far exceeds the population along the reach of river from St. Francisville to Venice.

Table 15.--Statistical summary of 5-day biochemical oxygen demand ($BOD_5$) data for the Mississippi River

[Concentrations are in milligrams per liter]

| Station | Number of samples | Range in concentration | | |
|---|---|---|---|---|
| | | Maximum | Minimum | Mean |
| St. Francisville | 105 | 8.3 | 0.1 | 2.51 |
| Plaquemine | 93 | 8.2 | .4 | 2.52 |
| Union | 90 | 7.9 | .3 | 2.40 |
| Luling | 93 | 8.6 | .1 | 2.47 |
| Violet | 134 | 8.9 | .1 | 2.27 |
| Venice | 89 | 7.6 | .1 | 2.38 |

Studies were conducted on the river at St. Francisville, Plaquemine, Luling, and Violet, La., to (1) determine ultimate BOD ($BOD_u$), (2) detect the presence of nitrogenous BOD, and (3) determine the decomposition or decay rate coefficient ($k_1$). Data from these studies were analyzed using a computer program developed by Jennings and Bauer (1976).

The ultimate BOD represents the total amount of oxygen that would be consumed if all the biodegradable waste had been biochemically decomposed. $BOD_u$ values for the Mississippi River are generally less than 10 mg/L. Little difference in the average $BOD_u$ values was noted in samples from the St. Francisville, Plaquemine, Union, and Violet, La., sites. $BOD_u$ values from five tests conducted at each of the four stations ranged from 3.1 mg/L at Plaquemine to 15.2 mg/L at Luling. The average $BOD_u$ value for all samples was 6.2 mg/L.

Little evidence of nitrogenous BOD was noted in the river. Nitrogenous BOD represents that oxygen utilized by bacteria to oxidize organic nitrogen and ammonia to nitrite and nitrate. These biochemical reactions are carried out by highly specialized groups of bacteria that are more restricted in number and much more sensitive to environmental conditions than those bacteria responsible for carbonaceous BOD (Veltz, 1970).

The decomposition or decay-rate coefficients ($k_1$) for the Mississippi River are relatively low. Tests show that average $k_1$ ($day^{-1}$, $base_e$) values ranged from 0.046 at St. Francisville, La., to 0.058 at Luling and Violet, La. These values are about one-half the 0.1 reaction rate Veltz (1970) states as normal for mixed organic waste of urban and industrial complexes.

Reaeration of the river from atmospheric oxygen is proportional to the oxygen deficit in the river--that is, the difference between oxygen saturation and actual oxygen concentration. The larger the deficit, the greater the reaeration potential. The rate of absorption of oxygen is often expressed as

$$dc/dt=k_2(C_s-C),$$

where $C_s$=oxygen concentration at saturation;
C=actual oxygen concentration;
t=time, in days; and
$k_2$=the coefficient of reaeration.

Langbein and Durum (1967) found that $k_2$, the coefficient of reaeration, is closely related to mean depth and mean velocity of a river and can be determined from the following formula:

$$k_2=3.3v/H^{1.33},$$

where v is mean velocity, in feet per second, and H is mean depth, in feet. Using this formula, $k_2$ values for the Mississippi River between Baton Rouge and Belle Chasse, La., and Belle Chasse and Head of Passes, La., were determined at various discharges and are listed in table 16. The table shows that as discharges increase, $k_2$ values also increase. The $k_2$ values are also higher in the reach between Baton Rouge and Belle Chasse where the river is shallower and faster than downstream from Belle Chasse. Using $k_2$ values determined in the following manner, Langbein and Durum (1967) showed that the total assimilative capacity (reaeration capacity) of the river--that is, the total load of oxygen in tons per day that can be absorbed by the river for each unit of oxygen (mg/L) less than saturation--may be estimated from the following formula:

$$TAC=\frac{1}{2,700} \times \frac{QL}{v} \times k_2,$$

where Q=discharge, in cubic feet per second;
v=velocity, in feet per second;
L=length, in miles; and
$k_2$=days$^{-1}$.

Applying this formula for the two reaches of river, the maximum assimilative capacity of the river per unit of dissolved oxygen less than the saturation value is graphically shown in figure 19. The assimilative capacity is much greater in the reach from Baton Rouge to Belle Chasse than from Belle Chasse to Head of Passes because of greater turbulence in the river resulting in higher $k_2$ values. The assimilative capacity per river mile is also greater in the upper reach of the river, ranging from an average of 2.0 tons per mile at 200,000 ft$^3$/s to 5 tons per mile at 1 million ft$^3$/s per unit of dissolved oxygen deficit per day. Between Belle Chasse and Head of Passes, the assimilative capacity ranged from an average of 1.0 tons per mile at 200,000 ft$^3$/s to 4.5 tons per mile at 1 million ft$^3$/s per unit of dissolved-oxygen deficit per day.

Table 16.--Reaeration coefficients for two reaches of the lower Mississippi River

[Average velocities were determined from time-of-travel studies conducted on the river, and average depths in the reaches were estimated]

| Discharge ($ft^3/s$) | Baton Rouge to Belle Chasse | | | Belle Chasse to Head of Passes | | |
|---|---|---|---|---|---|---|
| | H (ft) | v (ft/s) | $k_2$ ($days^{-1}$) | H (ft) | v (ft/s) | $k_2$ ($days^{-1}$) |
| 200,000 | 35 | 1.9 | 0.055 | 60 | 1.1 | 0.016 |
| 400,000 | 42 | 2.6 | .059 | 62 | 2.0 | .028 |
| 600,000 | 50 | 3.6 | .065 | 64 | 2.7 | .035 |
| 800,000 | 55 | 4.7 | .075 | 66 | 3.3 | .042 |
| 1,000,000 | 60 | 5.6 | .080 | 68 | 3.8 | .045 |

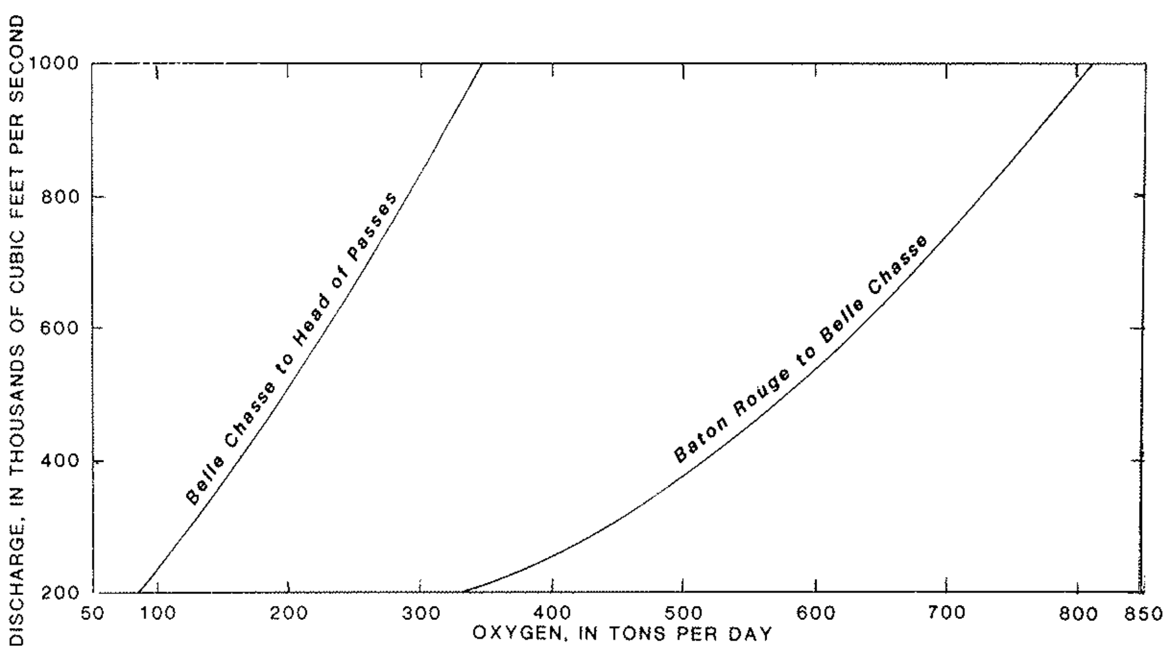



Figure 19.--Total assimilative capacity (reaeration capacity) in tons per day of oxygen per unit deficit of dissolved oxygen for two reaches of the Mississippi River.

The net result of decomposition of organic waste and reaeration from atmospheric oxygen is a gradual decline in dissolved-oxygen concentrations downstream from Baton Rouge, La., (fig. 20). Differences in dissolved-oxygen concentrations between Baton Rouge and Venice, La., are generally less than 1 mg/L. The largest differences in dissolved-oxygen concentrations occur during the summer months when the rate of organic decomposition increases because of higher water temperatures. The ability of the river to dilute the waste is also less during these months

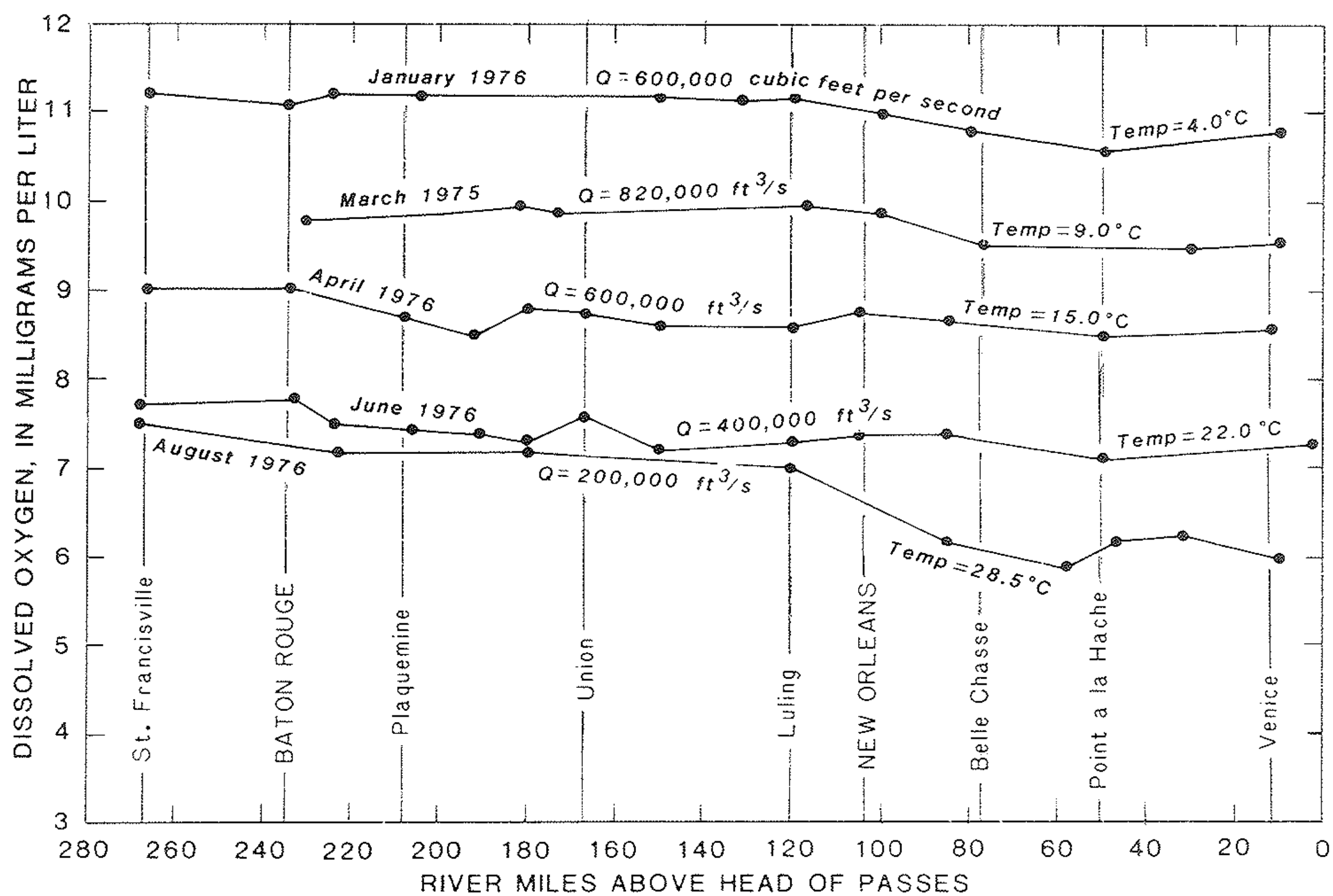



Figure 20.--Downstream changes in dissolved-oxygen concentrations.

because river discharges are generally low. For example, during a sampling trip in August 1976 the difference between dissolved-oxygen concentrations measured at St. Francisville and Venice, La., was 1.5 mg/L. (See fig. 20.) The river discharge at this time was approximately 200,000 $ft^3/s$, and the temperature was 28.5°C. The sharpest decrease occurred downstream from Luling, La., where dissolved-oxygen concentrations decreased approximately 1 mg/L between Luling and Point-a-la-Hache, La.

These data show that the river is capable of adequately assimilating the organic waste currently discharged into the river; and when New Orleans, La., sewage begins receiving secondary treatment, the river should exhibit a lesser decrease in dissolved-oxygen values during the low-flow summer months.

## Thermal Waste

Approximately 95 percent of the 6,000 Mgal/d of water withdrawn from the river for industrial and electrical generating purposes is returned to the river as heated effluent. This heated effluent has little or no widespread effect on water temperatures in the river during periods of medium or high flow, and little differences in temperatures are noted downstream from St. Francisville, La. During periods of low flow, heated effluents may amount to as much as 6 percent of the total flow of the river, and gradual increases in downstream temperatures are noted. The largest differences in average monthly temperatures between St. Francisville and Luling, La., are noted during the low-flow months of September, October, and November. The average monthly water temperatures between these two stations differ 1.5 to 2.0°C during these months.

Larger increases in water use by electrical power generating plants may cause greater increases in water temperature downstream from St. Francisville, La., in the future. This may be especially true near Waterford, La. Once the nuclear powerplant at Waterford, La., is completed it will withdraw approximately 2,000 Mgal/d of water for cooling purposes, and the Little Gypsy generating plant directly across the river will withdraw an additional 900 Mgal/d. This will represent a total of approximately 3,000 Mgal/d of water withdrawn from the river for cooling purposes. Assuming 95 percent of this water is returned to the river, this will amount to approximately 4,400 $ft^3/s$ or about 3 percent of the total flow of the river returned as heated effluent in a 1-mile reach of river during low flow.

## Effects of Dredging

One of the most important uses of the lower Mississippi River is navigation. The river serves as the gateway to an area that encompasses 55 percent of the land area in the Nation and 40 percent of the population. Approximately 6,000 ocean-going ships and 120,000 barges visit the ports of New Orleans and Baton Rouge, La., annually. Over 200 million tons of waterborne commerce were handled by the two ports in 1975, making New Orleans and Baton Rouge the second and fourth largest ports in the Nation, respectively.

The river is maintained as a deep-water ship channel (40-foot controlling depth) as far upstream as Baton Rouge, La. Upstream from Baton Rouge the river channel is maintained at a depth of 9 ft and a width of 300 ft. The river is navigable for barge traffic for nearly its entire length and into the major tributaries of the Arkansas, Ohio, and Missouri Rivers. Dredging the river to maintain these channel dimensions is a major task of the U.S. Army Corps of Engineers.

Effluents from dredging operations in the Mississippi River are generally discharged into the main channel of the river where velocities are high enough to transport the solid material downstream. Dredge effluents of this type are typically composed of 20 percent solid matter from the bed material and 80 percent water. The most obvious effects of this open-water discharge on the water quality of the river are increases in turbidity and suspended solids. These effects are generally temporary. More permanent changes may occur, however, in the physical and chemical composition of the water downstream from the effluent.

The New Orleans District of the U.S. Army Corps of Engineers conducted a study in the New Orleans Harbor area between March 1975 and February 1976 to evaluate the effects of dredging operations upon the water quality of the Mississippi River (U.S. Army Corps of Engineers, 1976). This study involved analyzing samples collected 100 yd upstream from the dredge-effluent pipe, and 100 yd downstream from the dredge discharge. These samples were collected by the Corps of Engineers and analyzed by the U.S. Geological Survey in accordance with procedures outlined in Brown, Skougstad, and Fishman (1970). The type of dredge in operation during the study was a 20-inch pipeline cutterhead dredge. Eighteen sets of samples (three samples per set) were collected during the fall of 1975 and the spring of 1976. A summary of constituents determined during analysis of the samples appears in table 17.

Comparison of data collected at the three sampling locations shows that concentrations of suspended solids, total organic carbon, total chromium, total copper, total lead, total nickel, and total zinc are significantly higher in the dredge effluent than in the water upstream from the dredge. Little difference is noted, however, in the dissolved phases of the nutrients and metals at the three sampling locations. It is evident that the dredge effluent has a minimal effect on the quality of the river water 100 yd downstream, except for turbidity. Little difference exists in the concentrations of dissolved and total constituents upstream and downstream from the dredge discharge.

This study shows that dredging in the New Orleans Harbor area does not significantly increase concentrations of chemical constituents in the Mississippi River. This conclusion is further strengthened when the

Table 17.--Summary of water-quality data collected during dredging operations in New Orleans Harbor, 1975-76

| Parameter | 100 yards upstream | Effluent | 100 yards downstream |
| --- | --- | --- | --- |
| | Average concentration, in milligrams per liter | | |
| Nitrate as nitrogen (N), dissolved | 1.1 | 0.94 | 1.1 |
| Nitrite as nitrogen (N), dissolved | .01 | .03 | .01 |
| Ammonia as nitrogen (N), dissolved | .03 | .61 | .03 |
| Kjeldahl nitrogen as nitrogen (N), dissolved | .54 | 1.9 | .50 |
| Phosphorus as P, dissolved | .10 | .07 | .09 |
| Suspended solids | 75 | 5,730 | 106 |
| Dissolved oxygen | 8.0 | 4.0 | 7.8 |
| Chemical oxygen demand | 11 | 27 | 12 |
| Biochemical oxygen demand | 2.3 | 51 | 1.8 |
| Total organic carbon | 6.5 | 320 | 7.4 |
| Cynide | .00 | .00 | .00 |
| Oil and grease | .2 | 4.6 | .6 |
| | Average concentration, in micrograms per liter | | |
| Phenols | 3.3 | 9.1 | 3.2 |
| Arsenic, dissolved | 1.1 | 2.4 | 1.2 |
| Arsenic, total | 2.5 | 180 | 3.2 |
| Cadmium, dissolved | .0 | .1 | .0 |
| Cadmium, total | .1 | 7.3 | .3 |
| Chromium, total | <10 | 180 | <10 |
| Chromium, hexavalent | .0 | .0 | .0 |
| Copper, dissolved | 4.6 | 4.7 | 5.4 |
| Copper, total | 6.8 | 240 | 7.3 |
| Iron, dissolved | 14 | 14 | 9.4 |
| Lead, dissolved | .3 | .0 | .4 |
| Lead, total | 6.3 | 400 | 7.2 |
| Manganese, dissolved | 5.0 | 790 | 6.2 |
| Mercury, dissolved | .11 | .12 | .10 |
| Mercury, total | .14 | .15 | .15 |
| Nickel, dissolved | .0 | 1.0 | .1 |
| Nickel, total | 7.3 | 770 | 9.2 |
| Zinc, dissolved | 3.9 | 4.1 | 2.9 |
| Zinc, total | 33 | 490 | 28 |
| | Micromhos per centimeter | | |
| Specific conductance | 385 | 482 | 393 |
| | Units | | |
| pH | 7.9 | 7.8 | 7.9 |

volumes of dredge material are compared to the total suspended-sediment load transported by the river. For example, in 1975 the total amount of dredge material excavated in the New Orleans Harbor area amounted to less than 2 percent of the total suspended-sediment load transported by the river.

## TIME OF TRAVEL

Accidental spillage of large amounts of industrial or municipal waste into the Mississippi River could cause the quality of the water to be unsuitable for downstream water users. Accidental spills of oil or toxic chemicals as a result of navigational accidents may also affect the utilization of river water. It has become increasingly important in recent years to know the rate of downstream movement of river water and how waste mixes in the river. By knowing the arrival time, duration (time of passage), and concentration of a contaminant in the river, withdrawal of water can be discontinued until after a contaminant has passed.

The duration and traveltime of solutes vary with discharge. During periods of low flow the velocities in the river are less and the traveltime of the river water between two points is longer than during periods of medium or high flow. Because the traveltime of the river is longer during low flows, a solute or contaminant will have more time to disperse longitudinally. To fully understand traveltime and dispersion characteristics, time-of-travel studies using rhodamine WT, a fluorescent water tracer, were conducted in the river between Baton Rouge and New Orleans, La., at discharges of 240,000 $ft^3/s$ (Stewart, 1967), 364,000 $ft^3/s$ (Everett, 1971), and 792,000 $ft^3/s$ (Martens and others, 1974). One time-of-travel study has been conducted between the Arkansas-Louisiana State line and Plaquemine, La., (Calandro, 1976) and between Belle Chasse, and Head of Passes, La., (Calandro, 1977). Data collected during the latter two studies were used to calibrate a mathematical model developed by McQuivey and Keefer (1976a, b). This model was used to predict time-of-travel information for discharges ranging from 200,000 to 1.5 million $ft^3/s$. The results of these time-of-travel studies apply only to those solutes whose density and behavior are similar to those of water. Additional considerations must be taken with materials that are not soluble in water.

Velocities of the Mississippi River are greater upstream from Baton Rouge, La., than downstream (fig. 21). Average velocities in the river between the Arkansas-Louisiana State line and Baton Rouge range from 2.0 mi/h at a discharge of 200,000 $ft^3/s$ to approximately 3.8 mi/h at 1 million $ft^3/s$. Downstream from Baton Rouge, the river channel is much larger, the slope of the river decreases, and the river discharge is affected by tides. Consequently, velocities in the river between Baton Rouge and Head of Passes, La., are much slower. Velocities downstream from New Orleans seldom exceed 3.0 mi/h and decrease to less than 1.0 mi/h at discharges of less than 200,000 $ft^3/s$.

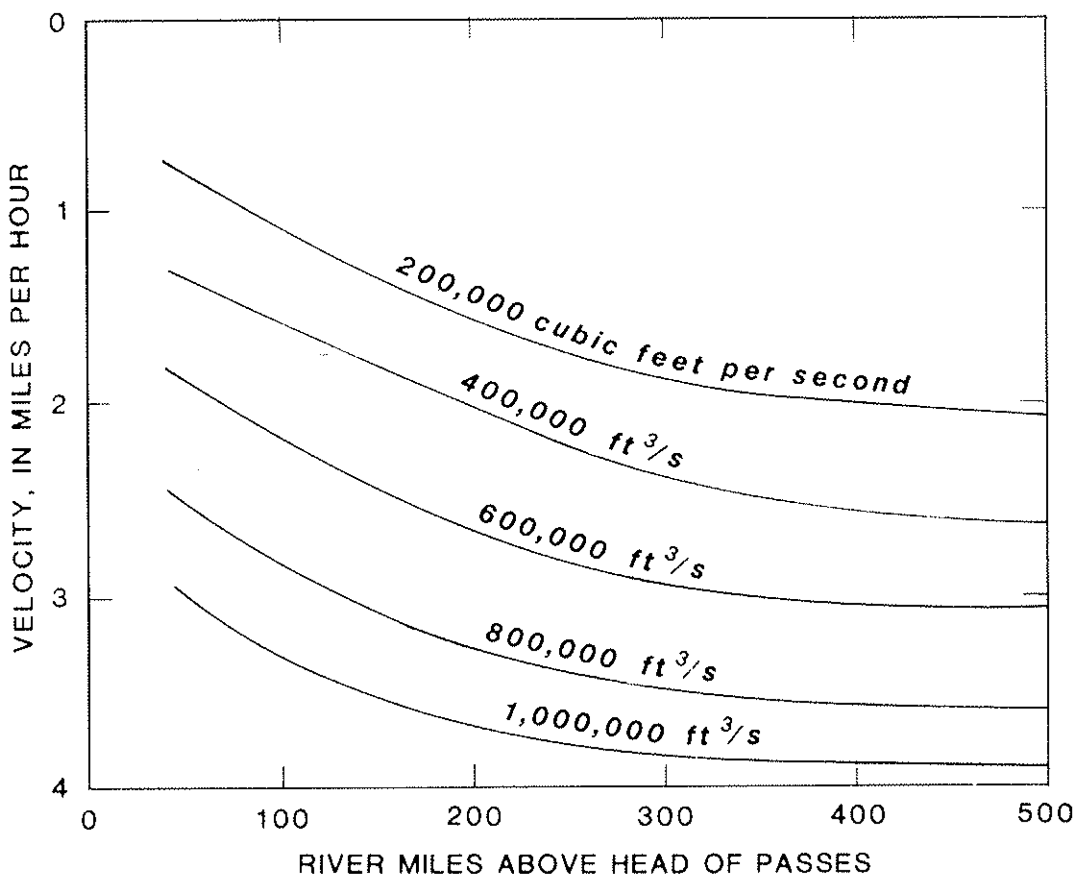



Figure 21.--Longitudinal velocity profiles of the lower Mississippi River.

## Lateral Dispersion

When a liquid is introduced into a river it disperses longitudinally, laterally, and vertically. Lateral dispersion is important to downstream users of water because a contaminant could greatly affect a user on one side of the river and have almost no influence on a user on the opposite bank. Studies by Everett (1971), Martens and others (1974), and Calandro (1976, 1977) indicate that lateral mixing in the Mississippi River is not readily achieved. These studies indicate that in the lower Mississippi River a contaminant must travel a distance of approximately 20 mi before complete lateral mixing is achieved. For example, tracers injected near the left bank, center of river, and right bank at Baton Rouge, La., (injection point mile 229.0) did not become completely mixed until the tracer reached Plaquemine, La., (mile 208.0). The tracer had passed through approximately 360° of river meanders. A similar study near Belle Chasse, La., showed that a tracer injected in the center of the river was almost completely mixed at Burbridge, 16 mi downstream. Complete mixing was accomplished at Point-a-la-Hache, La., 28 mi downstream from the injection point. The tracer in this study has passed through approximately 90° of river meanders.

## Longitudinal Dispersion

Longitudinal dispersion is useful in developing plans for minimizing the effects of a contaminant. Longitudinal dispersion can be measured in miles occupied by a contaminant or tracer cloud or by the time necessary for the cloud to pass a selected point. Knowledge of the time it takes (1) for a contaminant to arrive at a specific site and (2) for a contaminant to pass a specific site is useful in developing plans for minimizing the effects of contamination. The time-location positions of the leading edge, the peak, and the trailing edge for any elapsed time after a spill or injection of a tracer are shown in figures 22, 23, and 24. These curves can be used to calculate the approximate longitudinal dispersion of a cloud passing a point if the discharge rate and the time and place of injection are known. For example, assume that an accidental spill occurred at Baton Rouge, La., (mile 230.0) at a discharge of 400,000 $ft^3/s$ and that the longitudinal dispersion at New Orleans, La., was needed. Using the example in figure 22, it is estimated that the leading edge will arrive at New Orleans in 62 hours (158 hours at New Orleans minus 96 hours at Baton Rouge). Similarly, the trailing edge would pass New Orleans in 84 hours (232 hours minus 148 hours, fig. 24); hence, the longitudinal dispersion, or the passage time, is 22 hours.

In addition to knowing how long a contaminant would be present at a site, it is equally important to know when the peak concentration of the contaminant will arrive and to be able to predict the magnitude of the peak concentration. The time of arrival of the peak concentration can be determined from figure 23 using the same procedure as was used to determine the leading edge from figure 22.

The peak concentration can be determined from the equation

$$\text{Peak concentration} = \frac{\text{unit concentration times weight of contaminant spilled}}{\text{discharge at sampling site}}.$$

where unit concentration is the peak concentration resulting from 1 lb of tracer in 1 $ft^3$ of water assuming 100-percent recovery. Knowing the elapsed time a contaminant has been in the water, the unit concentration (determined from fig. 25), and the river discharge, the maximum peak concentration can be computed. For example, assume that 2,000 lb of a conservative contaminant were accidently spilled at Baton Rouge, La., (mile 230.0) at a discharge of 400,000 $ft^3/s$. Personnel at the New Orleans Carrollton Street water intakes (mile 103.0) could predict that the peak concentration would arrive in approximately 70 hours (183-113, fig. 23). The unit concentration would be 470 µg/L (fig. 25), and the peak concentration would be:

$$\text{Peak concentration} = \frac{470 \times 2{,}000 \text{ lb}}{400{,}000 \text{ ft}^3/\text{s}} = 2.1 \text{ µg/L}.$$

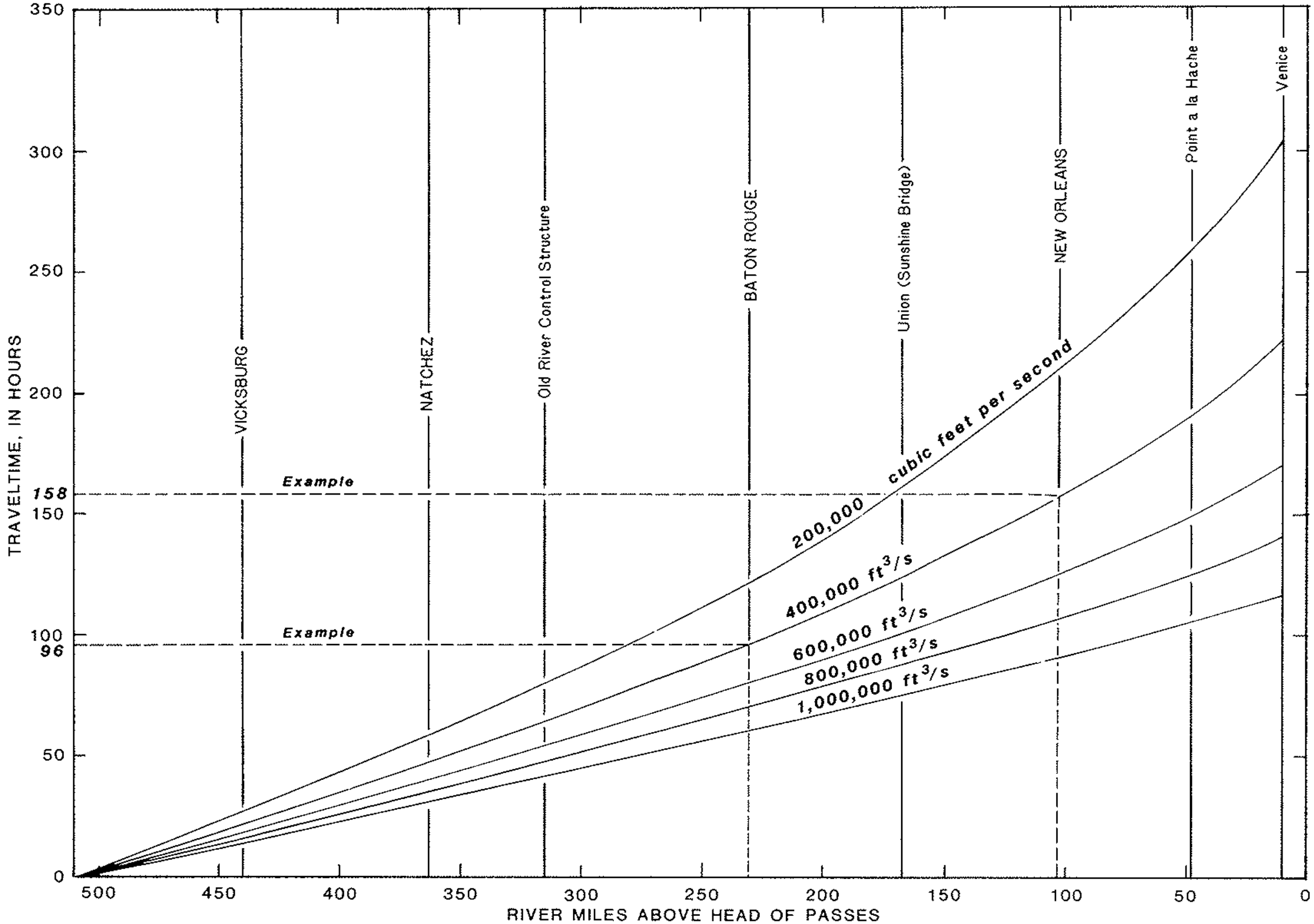



Figure 22.--Time of travel of the leading edge of a tracer cloud at downstream locations along the Mississippi River at various discharges.

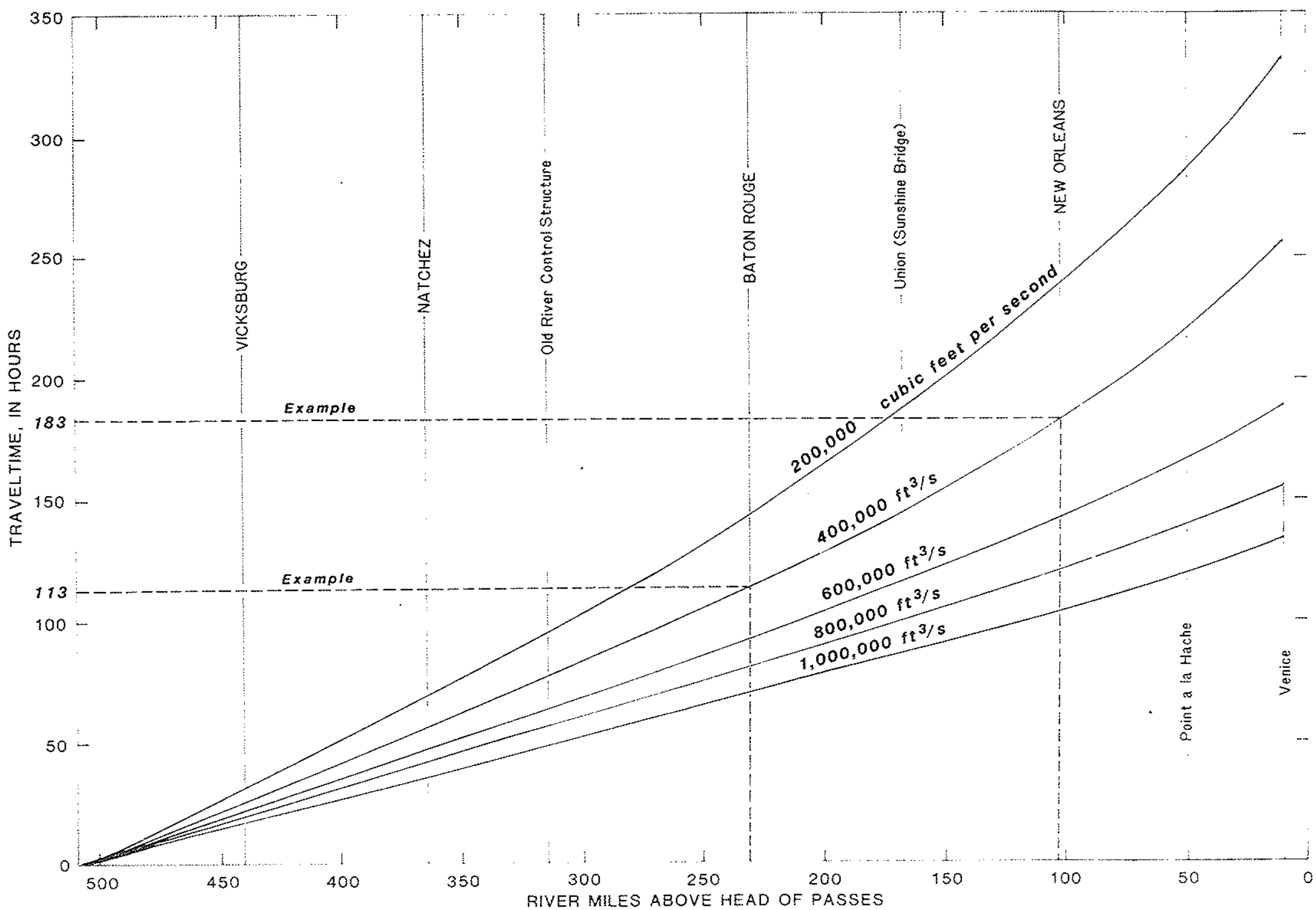



Figure 23.--Time of travel of the peak concentration of a tracer cloud at downstream locations along the Mississippi River at various discharges.

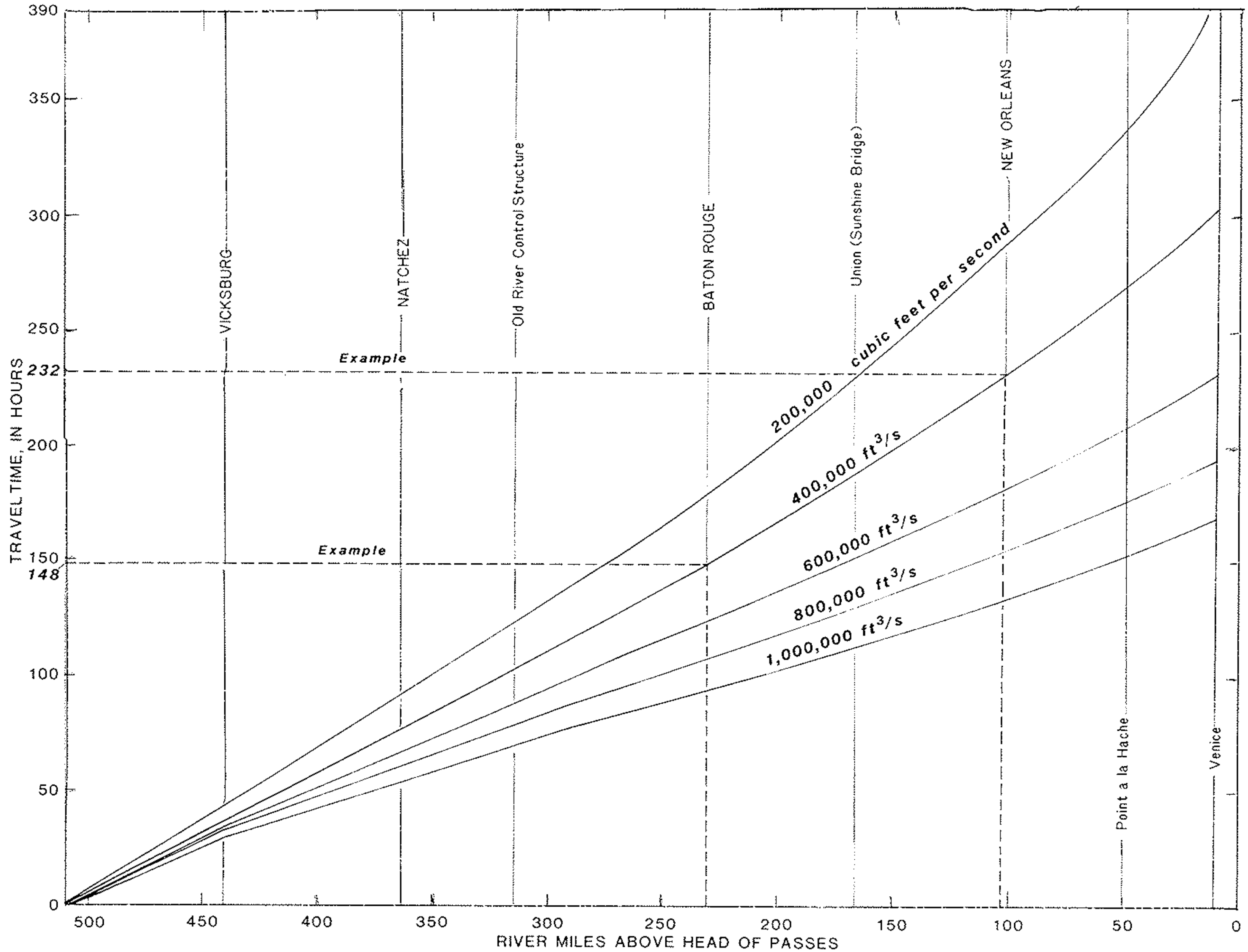



Figure 24.--Time of travel of the trailing edge of a tracer cloud at downstream locations along the Mississippi River at various discharges.

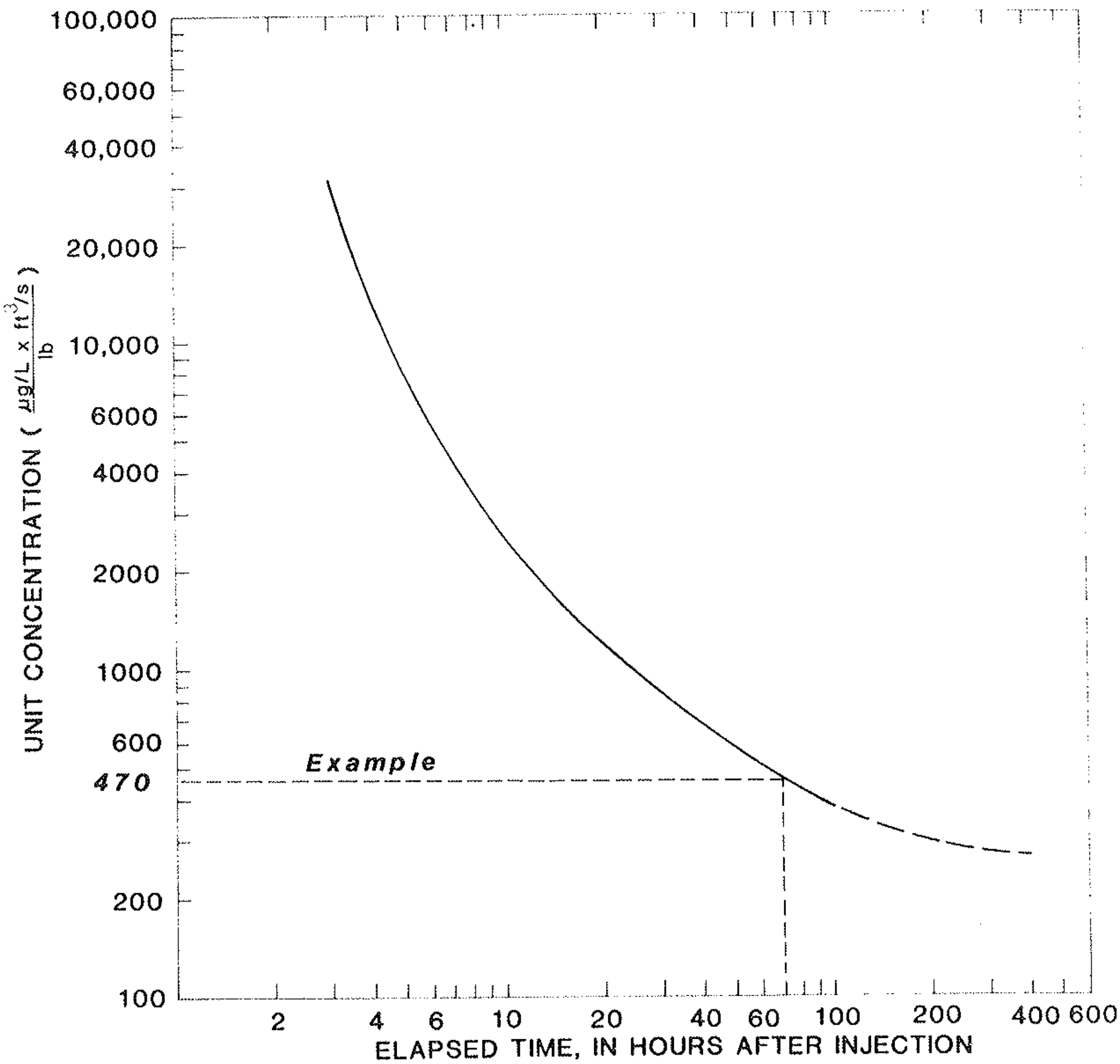



Figure 25.--Unit-concentration attenuation curve for the Mississippi River.

Using the time-of-travel curves in figures 22, 23, and 24 for leading edge, peak, and trailing edge and the formula for determining peak concentration, the movement of the contaminant down the river can be graphically illustrated. Figure 26 shows the time-concentration curves at key points downstream from the Arkansas-Louisiana State line. The figure was based on a theoretical injection of 2,000 lb of contaminant into the river at mile 507.0 at a discharge of 400,000 $ft^3/s$ upstream from the Old River Control Structure and 300,000 $ft^3/s$ downstream from the control structure. The longitudinal dispersion increases from less than 1 day at Vicksburg, Miss., to over 3 days at Venice, La. A contaminant may also affect more than one key location at a time. For example,

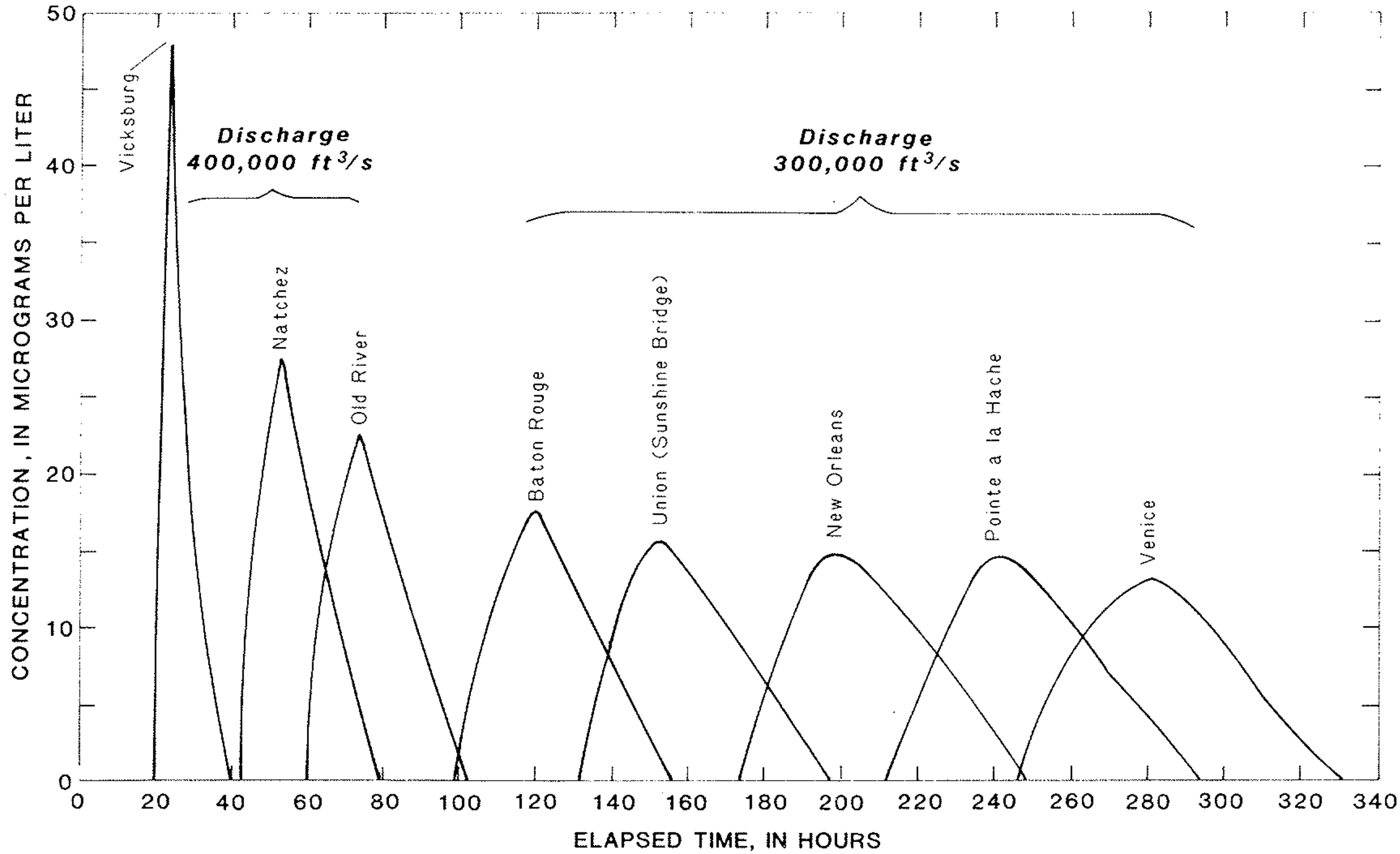



Figure 26.--Time-concentration curves for a conservative contaminant in the Mississippi River downstream from the Arkansas-Louisiana State line.

as the peak of the contaminant reaches Point-a-la-Hache, La., the trailing edge is still located near the New Orleans Carrollton Street water intakes, and the leading edge of the contaminant is just about to reach Venice. Depending upon the concentration and toxicity of a contaminant, it is conceivable that that a 100-mile reach of the river could be closed to use for municipal water supply.

## SUMMARY AND CONCLUSIONS

Flows in the lower Mississippi River are affected by diversion into the Atchafalaya River through the Old River Control Structure. Consequently, discharges at Vicksburg, Miss., have averaged 20 percent higher than those at Red-River-Tarbert Landing. Average flow of the Mississippi River at Vicksburg, Miss., 1931-76, is about 570,000 $ft^3/s$, and the average at Red River-Tarbert Landing, 1928-76, is about 460,000 $ft^3/s$. The U.S. Army Corps of Engineers flood control program for the lower Mississippi River is designed to handle a flow of 3 million $ft^3/s$ at the latitude of Old River. One-half of this flood is to be carried through the Atchafalaya River basin, and one-half through the Mississippi River. Peak discharge of 1.3 million $ft^3/s$ and 1 million $ft^3/s$ at Vicksburg and Red River-Tarbert Landing, respectively, can be expected to occur on an average of once every 2 years. A 1-day mean low flow of 125,000 $ft^3/s$ can be expected to occur on an average of once every 10 years at Vicksburg and once every 3½ years at Red River-Tarbert Landing.

An average suspended-sediment discharge of 630,000 tons per day, approximately 77 percent silt and clay, is transported past Red River-Tarbert Landing. Concentrations of suspended sediment at Red River-Tarbert Landing have ranged from 14 to 2,400 mg/L, but 90 percent of the time concentrations ranged between 100 and 1,000 mg/L. Higher suspended-sediment discharges generally occur from January through June, and the lower suspended-sediment discharges occur from August through November. Suspended-sediment concentrations decrease downstream from St. Francisville, La., at discharges of less than 600,000 $ft^3/s$ and increase downstream at discharges in excess of 600,000 $ft^3/s$. Most sediment deposition in the river between St. Francisville and Venice, La., takes place upstream from New Orleans, La. At a discharge of 300,000 $ft^3/s$, 60 percent of the sediment measured at St. Francisville is deposited by the time the water reaches New Orleans. An additional 20 percent settles out between New Orleans and Venice, leaving only 20 percent of the original concentration at St. Francisville transported past Venice.

Concentrations of dissolved solids at St. Francisville and Luling, La., are less than 300 mg/L 90 percent of the time. Increases in dissolved solids between St. Francisville and Belle Chasse, La., generally range between 10 and 70 mg/L, with the largest increases occurring during discharges of less than 250,000 $ft^3/s$. Increases in dissolved solids are attributed to industrial- and municipal-waste discharge. Calcium is the predominant cation in the Mississippi River, and bicarbonate is the predominant anion.

Average concentrations of dissolved and total arsenic, cadmium, lead, and dissolved and hexavalent chromium in the Mississippi River are less than 10.5 µg/L. Average concentrations of dissolved and total mercury are less than 0.1 and 0.2 µg/L, respectively. Average concentrations of dissolved and total copper and dissolved iron and zinc are less than 30 µg/L. No significant increase in average concentrations of metals occurs between St. Francisville and Head of Passes, La., with the exception of total zinc, which is higher at Violet, La. Concentrations of trace metals in Mississippi River water are within the recommended limits for public-water-supply sources 99 percent of the time. Average concentrations of arsenic, cadmium, chromium, copper, lead, and mercury in the bed material of the Mississippi River are less than 10 µg/g. Nickel and zinc were the most abundant trace metals detected in the bed material, averaging 12.3 and 29.7 µg/g, respectively.

The average water temperature at St. Francisville and Luling, La., is 17.5 and 18.0°C, respectively. The largest differences in average monthly temperature between St. Francisville and Luling are 1.0 to 2.0°C and occur between August and November when river discharges are generally less than 300,000 $ft^3/s$.

The lowest concentrations of total and fecal coliform bacteria in the river occur at St. Francisville, La., and at the Carrollton Street water intakes in New Orleans, La., (mile 103). The highest concentrations occur downstream from Baton Rouge and New Orleans, La. At Plaquemine, La., the average concentration of fecal coliform bacteria is 1,000 colonies per 100 mL; and at Violet, La., the average concentration of fecal coliform is 3,100 colonies per 100 mL. Salmonella, a pathogenic bacteria, has been isolated and serologically confirmed at both locations.

Dissolved-oxygen concentrations in the Mississippi River are relatively high, exceeding 75-percent saturation 90 percent of the time. Differences in the average dissolved-oxygen concentration between St. Francisville and Venice, La., is slight, a decrease of less than 0.5 mg/L. The solubility of oxygen in water is inversely related to temperature; consequently, the highest dissolved-oxygen concentrations in the river usually occur during the cold winter months, and the lowest concentrations during the warm summer months.

Average concentrations of phenolic compounds at monthly sampling stations range from 1.8 to 2.6 µg/L. Concentrations of phenolic compounds exceed the 1-µg/L recommended concentration for domestic-water-supply sources approximately 40 percent of the time.

DDT, dieldrin, and endrin are the most frequently detected organochlorine insecticides in the Mississippi River. Concentrations of DDT and dieldrin rarely exceed 0.2 and 0.1 µg/L, respectively. Endrin has not been detected at concentrations in excess of 0.01 µg/L. The most frequently detected organophosphorus insecticide is diazinon. Diazinon concentrations have not exceeded 1.2 µg/L, and 95 percent of the time concentrations are equal to or less than 0.05 µg/L. The most prevalent chlorophenoxy herbicide is 2,4-D, but concentrations are relatively low, ranging from 0.00 to 0.15 µg/L. The most frequently occurring organochlorine insecticides in the bed material of the Mississippi River are chlordane, DDT, DDD, DDE, and dieldrin. These compounds have been detected in over 50 percent of the samples analyzed; however, concentrations rarely exceed 10 micrograms per kilogram.

Benzene, toluene, chloroform, dichloromethane, tetrachloroethylene, dichloroethane, trichlorofluoromethane, and tetrachloroethane are volatile organic compounds identified in Mississippi River water in 1977 and 1978. Concentrations of these volatile organic compounds have generally been less than 10 µg/L. Volatile organics appear to be evenly distributed in the river, with benzene, toluene, and chloroform being detected at all five sampling locations between St. Francisville and Belle Chasse, La.

Fourteen semivolatile compounds have been identified from the Mississippi River. Concentrations of the semivolatile organics have generally been less than 5 µg/L, and nine of these compounds have been detected at concentrations of less than 1 µg/L. The most frequently detected semivolatile organics have been the phthalate compounds. Atrazine, a herbicide, has been detected at all five sampling locations between St. Francisville and Belle Chasse, La., at concentrations ranging from a trace to 4.0 µg/L.

The leading edge of the saltwater wedge in the Mississippi River is well defined with little mixing occurring at the freshwater-saltwater interface. Downstream from the toe of the wedge a progressive increase in mixing does occur, causing the wedge to become less distinct. Chloride concentrations at the river surface exceed the 250 mg/L recommended for public water supplies approximately 15 to 25 mi downstream from the toe of the wedge. Reasonable estimates of upstream migration of the saltwater wedge can be predicted based on historical records. Likewise, recurrence intervals for saltwater intrusion can be predicted using low-flow frequency discharge curves and upstream migration curves presented.

The most common and most numerous benthic organisms collected from the Mississippi River are Corbicula and tubificid worms. The benthic community structure of the river is influenced by substrate type and stability, channel geometry, river velocity, vegetation, organic detritus, and salinity. Burrowing organisms, such as tubificids, chiromonids, and ephemerid-type mayflies, are predominant near the riverbanks where velocities are low and the bottom substrates range from a medium silt to a very fine sand. Near the center of the river, velocities are higher, substrate materials are coarser, and only Corbicula are present in large numbers. Near the river mouth, salinity and aquatic vegetation greatly influence benthic communities. Differences in benthic community structure in the Mississippi River are due primarily to different hydrologic conditions. Industrial and municipal wastes discharged into the river appear to have little or no widespread effects on benthic populations.

An average of 6,500 Mgal/d of water was withdrawn from the river for industrial and municipal purposes during 1975. The largest single user class was electrical powerplants that withdrew 3,700 Mgal/d. Industrial withdrawals amounted to approximately 2,500 Mgal/d, and municipal withdrawals totaled 214 Mgal/d. Most of the water withdrawn for industrial use was returned to the river as heated effluent.

The dissolved-solids load added to the river between St. Francisville and Luling, La., since 1970 has remained fairly constant, averaging about 18,000 tons per day. The river presently can assimilate the large amounts of inorganic waste discharged into the river. Continuous discharges of 540 lb/d and 270 tons per day of a conservative waste discharged into 100,000 $ft^3/s$ will increase downstream concentrations 1 µg/L and 1 mg/L, respectively.

The buffering capacity of Mississippi River water is greatest during low flow when bicarbonate concentrations are high. Mississippi River water is more resistant to a change in pH from acidic waste than from basic waste. The ability of the river to assimilate acidic and basic wastes is greatest during periods of high flow when the bicarbonate load is greatest.

BOD concentrations vary only slightly between St. Francisville and Venice, La. A waste load from a population of approximately 3 million people would be required to increase the BOD concentration 1 mg/L in 100,000 $ft^3/s$. BOD values for the Mississippi River are generally less than 10 mg/L. Little evidence of nitrogenous BOD was found in the river. Average decomposition, or decay-rate, coefficients ($k_1$) for the Mississippi River are relatively low, ranging from 0.046 ($day^{-1}$, $base_e$) at St. Francisville to 0.058 at Luling and Violet, La. Reaeration rates ($k_2$) for the Mississippi River between Baton Rouge and Belle Chasse, La., increase from 0.055 at 200,000 $ft^3/s$ to 0.080 at 1 million $ft^3/s$. Reaeration rates between Belle Chasse and Head of Passes, La., increase from 0.016 at 200,000 $ft^3/s$ to 0.045 at 1 million $ft^3/s$. The net result of decomposition of organic waste and reaeration from atmospheric oxygen is a gradual decline in dissolved-oxygen concentrations downstream from Baton Rouge.

Dredging does not significantly increase concentrations of chemical constituents in the Mississippi River. Little difference is noted in concentrations of either dissolved or total constituents upstream from the dredge and 300 ft downstream from the dredge.

Time-of-travel studies conducted on the Mississippi River indicate that a contaminant must travel a distance of approximately 20 mi before complete lateral mixing is achieved. The time-of-travel information presented can be used to predict the longitudinal dispersion and peak concentration of a contaminant passing a point if the discharge rate and time and place of injection are known. Depending upon the concentration and toxicity of a contaminant discharged into the river, it is possible that a 100-mile reach of the river could be affected by the contaminant.

Average velocities in the Mississippi River between the Arkansas-Louisiana State line and Baton Rouge, La., range from 2.0 mi/h at a discharge of 200,000 $ft^3/s$ to approximately 3.8 mi/h at 1 million $ft^3/s$.

## SELECTED REFERENCES


Bellar, T. A., and Lichtenberg, J. J., 1974, Determining volatile organics at microgram-per-liter levels by gas chromotography: American Water Works Association Journal, v. 66, no. 12, p. 739-744.

Bellar, T. A., Lichtenberg, J. J., and Kroner, R. C., 1974, The occur- of organohalides in chlorinated drinking water: American Water Works Association Journal, v. 66, no. 11, p. 703-706.

Berg, K., 1943, Physiographical studies on the River Susaa: Folia Limnology Scandinavia, v. 1, 174 p.

______ 1948, Biological studies on the River Susaa: Folia Limnology Scandinavia, v. 4, 318 p.

Brown, Eugene, Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 160 p.

Calandro, A. J., 1973, An analysis of stream temperatures in Louisiana: Louisiana Department of Public Works Technical Report 6, 16 p.

______ 1976, Time of travel of solutes in Mississippi River from the Arkansas-Louisiana State line to Plaquemine, Louisiana: Louisiana Department of Public Works Water Resources Technical Report 12, 5 p.

______ 1977, Time of travel of solutes in Mississippi River from Belle Chasse to the vicinity of Head of Passes, Louisiana: Louisiana Department of Transportation and Development, Office of Public Works Water Resources Technical Report 13, 5 p.

Chin, E. H., Skelton, John, and Guy, H. P., 1975, The 1973 Mississippi River basin flood: Compilation and analyses of meteorologic, streamflow, and sediment data: U.S. Geological Survey Professional Paper 937, 137 p.

Clifton, C. E., 1957, Introduction to bacterial physiology: New York, McGraw-Hill, 414 p.

Cole, G. A., 1975, Textbook of limnology: St. Louis, C. V. Mosby Co., 282 p.

Everett, D. E., 1971, Hydrologic and quality characteristics of the lower Mississippi River: Louisiana Department of Public Works Technical Report 5, 48 p.

Gagliano, S. M., and van Beek, J. L., 1975, Environmental base and management study--Atchafalaya basin, Louisiana: Louisiana State University, Wetland Resources Coastal Resources Unit, Environmental Protection Agency report, EPA-600/5-75-006, 226 p.

Geldreich, E. E., 1969, Applying bacteriological parameters to recreational water quality: American Water Works Association Journal, v. 62, no. 2, p. 113-120.

Geldreich, E. E., and Kenner, B. A., 1969, Concepts of fecal streptococci in stream pollution: Water Pollution Control Federation Journal, v. 41, no. 8, pt. 2, p. R336-R352.

Goerlitz, D. F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 40 p.

Hardenbergh, W. A., and Rodie, E. B., 1963, Water supply and waste disposal: Scranton, Pa., International Textbook Co., 513 p.

Heller, S. R., McGuire, J. M., and Budde, W. L., 1975, Trace organics by GC/MS: Environmental Science and Technology, v. 9, no. 3, p. 210-213.

Hertz, H. S., May, W. E., Wise, S. A., and Chesler, S. N., 1978, Trace organic analysis: Analytical Chemistry, v. 50, no. 4, p. 428A-436A.

Jennings, M. E., and Bauer, D. P., 1976, Determination of biochemical-oxygen-demand parameters: Bay St. Louis, Miss., U.S. Geological Survey computer contribution, 53 p. (Available only from U.S. Department of Commerce, National Technical Information Service, PB-253 739/AS.)

Kazmann, R. G., and Argüello, Ottonigl, 1973, The Mississippi River--A water source for Texas?: Louisiana State University, Louisiana Water Resources Institute Bulletin 9, p. 4-3 through 4-12.

Keith, L. H., 1976, Identification and analysis of organic pollutants in water: Ann Arbor, Mich., Ann Arbor Science Publishers, Inc., 718 p.

Langbein, W. B., and Durum, W. H., 1967, The aeration capacity of streams: U.S. Geological Survey Circular 542, 6 p.

Louisiana Stream Control Commission, 1977, State of Louisiana water quality criteria: 49 p.

Lupachev, Y. V., 1976, Methods for calculating, forecasting and monitoring saltwater intrusion into estuaries: Moscow, U.S.S.R., State Oceanographic Institute, 27 p.

Mackenthun, K. M., and Ingram, W. M., 1966, Pollution and the life in water, in Cummins, K. W., Tryon, C. A., Jr., and Hartman, R. T., eds., Organism--substrate relationships in streams: Pennsylvania, University of Pittsburgh, Pymatuning Laboratory of Ecology Special Publication 4, p. 136-145.

Martens, L. A., and others, 1974, Time of travel of solutes in Mississippi River from Baton Rouge to Point a la Hache, Louisiana: Louisiana Department of Public Works Water Resources Technical Report 9.

McQuivey, R. S., and Keefer, T. N., 1976a, Convective model of longitudinal dispersion: American Society of Civil Engineers Proceedings Paper 12478, Hydraulics Division Journal, v. 102, no. HY 10, p. 1409-1424.

______1976b, Dispersion--Mississippi River below Baton Rouge, La.: American Society of Civil Engineers Proceedings Paper 12490, Hydraulics Division Journal, v. 102, no. HY 10, p. 1425-1437.

National Academy of Sciences and National Academy of Engineering, 1973 [1974], Water quality criteria, 1972: U.S. Environmental Protection Agency report, EPA R3-73-033, 594 p.

Neely, B. L., Jr., 1976 [1977], Floods in Louisiana, magnitude and frequency, 3d ed.: Louisiana Department of Highways, 340 p.

Rickert, D. A., Hines, W. G., and McKenzie, S. W., 1975, Methods and data requirements for river-quality assessment: Water Resources Bulletin, v. 11, no. 5, p. 1013-1039.

Rickert, D. A., Kennedy, V. C., McKenzie, S. W., and Hines, W. G., 1977, A synoptic survey of trace metals in bottom sediments of the Willamette River, Oregon: U.S. Geological Survey Circular 715-F, 27 p.

Slack, K. V., Averett, R. C., Greeson, P. E., and Lipscomb, R. G., 1973, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A4, 165 p.

Stevens, A. A., Slocum, C. J., Seeger, D. R., and Robeck, G. G., 1976, Chlorination of organics in drinking water: American Water Works Association Journal, v. 68, no. 11, p. 615.

Stewart, M. R., 1967, Time of travel of solutes in Mississippi River from Baton Rouge to New Orleans, Louisiana: U.S. Geological Survey Hydrologic Investigations Atlas HA-260.

Symons, J. M., Bellar, T. A., Carswell, J. K., DeMarco, Jack, Kropp, K. L., Robeck, G. G., Seeger, D. R., Solcum, C. J., Smith, B. L., and Stevens, A. A., 1975, National organics reconnaissance survey for halogenated organics: American Water Works Association Journal, v. 67, no. 11, p. 634-647.

U.S. Army Corps of Engineers, 1967, Flood control in the lower Mississippi River valley: U.S. Army Corps of Engineers, Engineers Division, Vicksburg, Miss.

______1976, New Orleans Harbor dredging operations--water quality--1975-1976: U.S. Army Corps of Engineers, New Orleans District, Engineering Report LMNED-HH-QWI, 19 p., 32 pls.

U.S. Environmental Protection Agency, 1972, Industrial pollution of the lower Mississippi River in Louisiana: Dallas, Tex., U.S. Environmental Protection Agency, 146 p.

______1974, Draft analytical report--New Orleans water supply study: Dallas, Tex., U.S. Environmental Protection Agency report, EPA-906/10-74-002, 30 p.

______1975, Analytical report--New Orleans water supply study: Dallas, Tex., U.S. Environmental Protection Agency report, EPA-906/9-75-003, 40 p. and appendix.

______1976, Quality criteria for water: U.S. Environmental Protection Agency report, EPA-440/9-76-023, 501 p.

______1977, Sampling and analysis procedures for screening of industrial effluents for priority pollutants: U.S. Environmental Protection Agency, 69 p.

______1978, Interim primary drinking water regulations: Federal Register, February 9, 1978, v. 43, no. 28, p. 5756-5780.

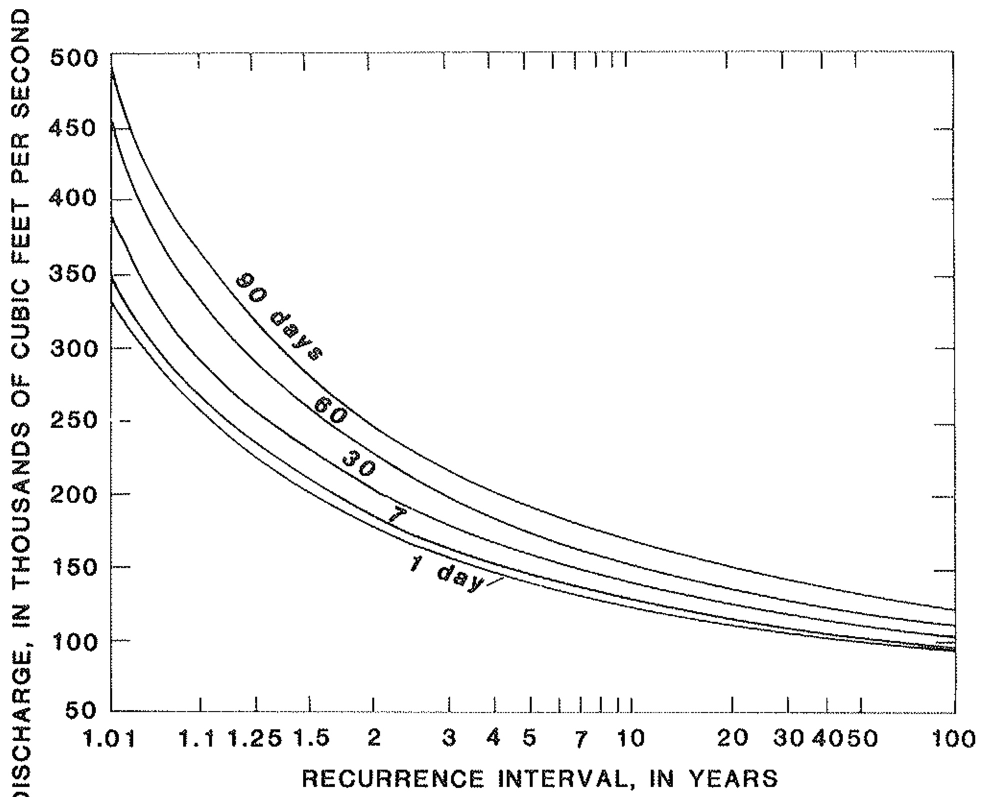
Velz, C. J., 1970, Applied stream sanitation: New York, Wiley-Interscience, 619 p.

Weber, C. I., ed., 1973, Biological field and laboratory methods for measuring the quality of surface waters and effluents: Cincinnati, Ohio, U.S. Environmental Protection Agency, Office of Research and Development report, EPA-670/4-73-001, 176 p.

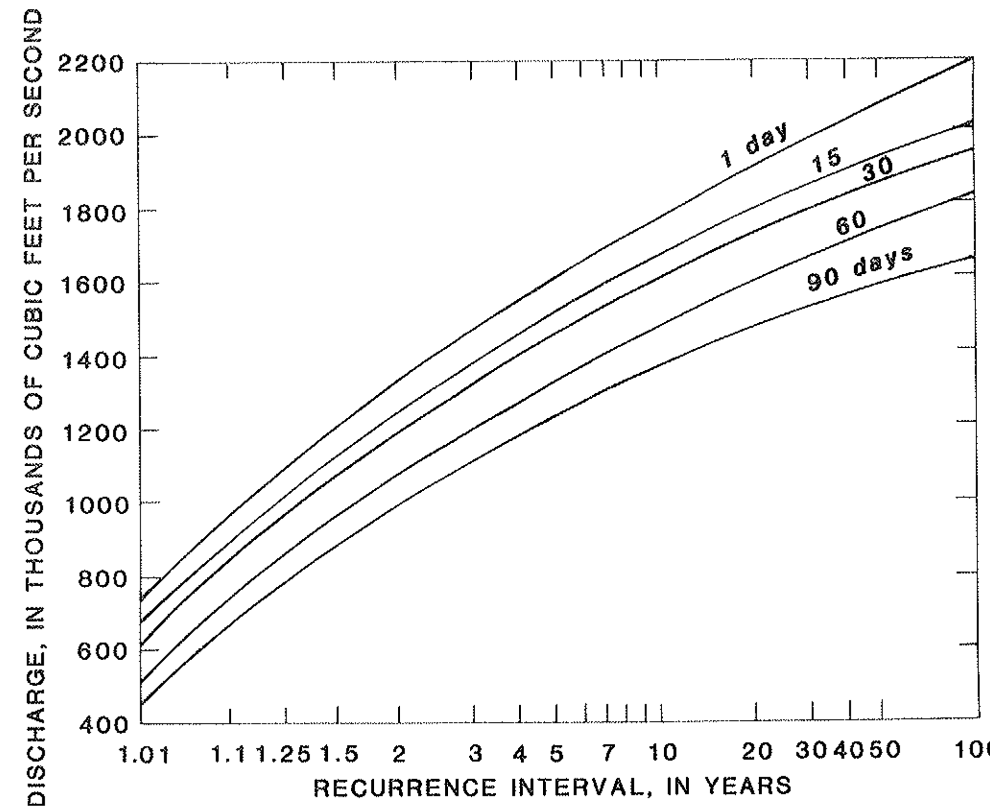
Wells, F. C., and Demas, C. R., 1979, Benthic invertebrates of the lower Mississippi River: Water Resources Bulletin (in press).

Wilhm, J. L., and Dorris, T. C., 1968, Biological parameters for water quality criteria: Bioscience, v. 18, p. 478.

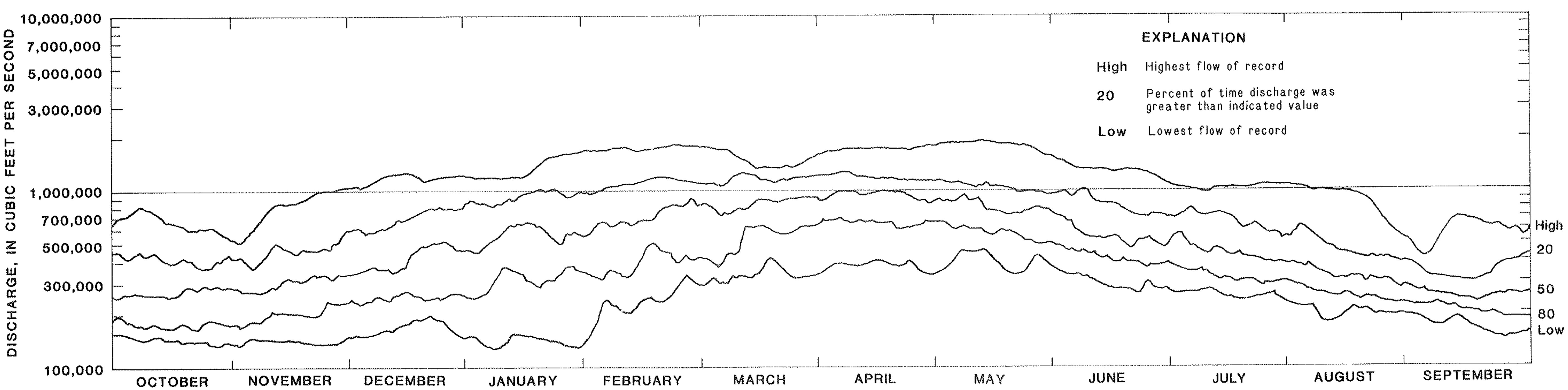
Wright, L. D., 1971, Hydrography of South Pass, Mississippi River: American Society of Civil Engineers Proceedings Paper 8290, Journal of the Waterways, Harbors, and Coastal Engineering Division, p. 491-504.




A. Low-flow frequency curves for Mississippi River at Vicksburg, Mississippi, 1933-75.

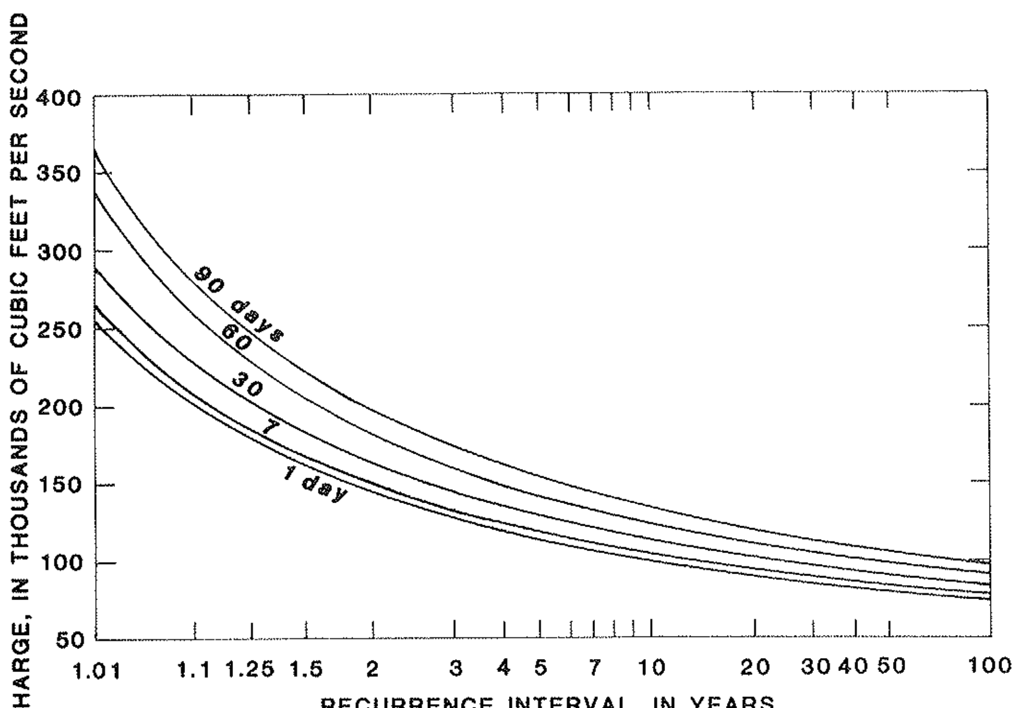



B. High- flow frequency curves for Mississippi River at Vicksburg., Mississippi, 1933-75.

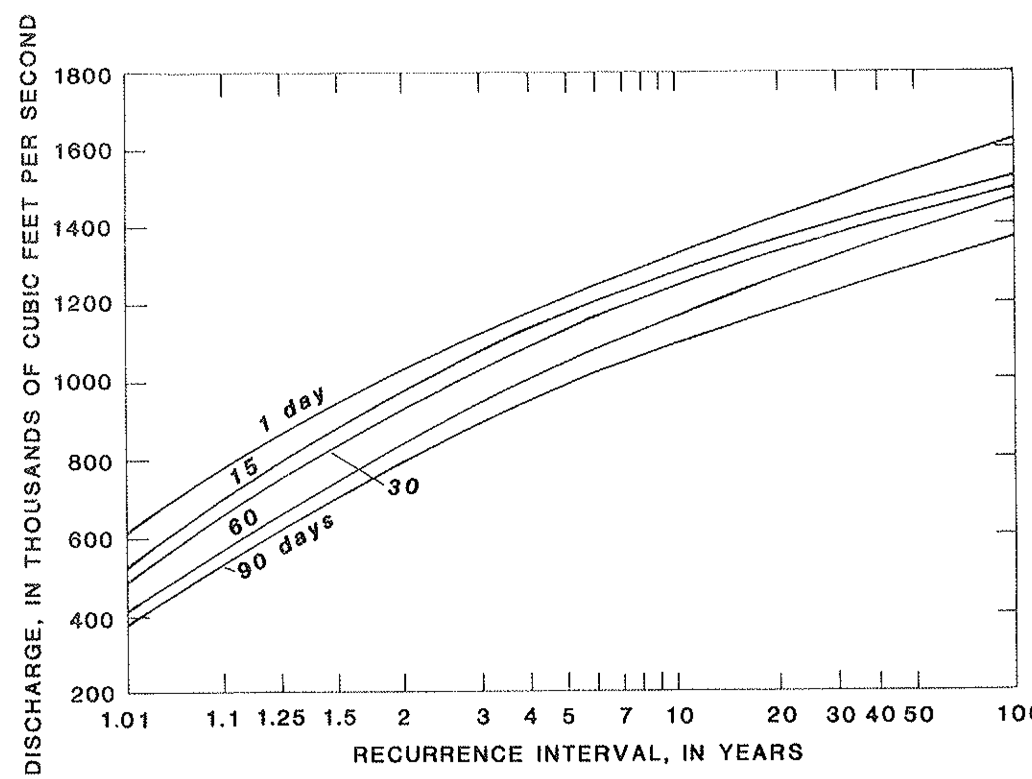



C. Daily duration hydrograph for Mississippi River at Vicksburg, Mississippi, 1945-75.

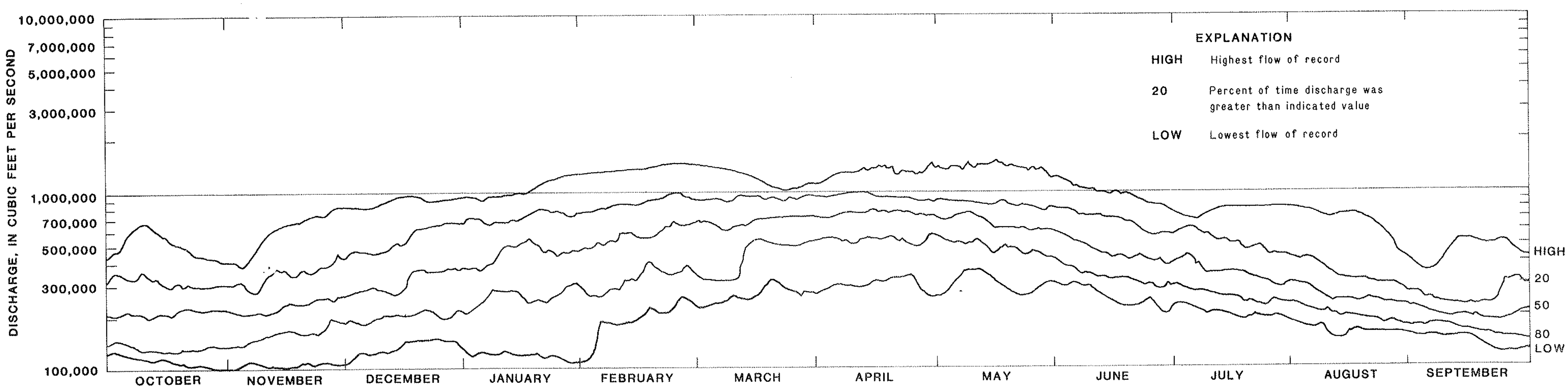
PLATE 1. DAILY DURATION HYDROGRAPH AND FREQUENCY CURVES FOR MISSISSIPPI RIVER AT VICKSBURG, MISSISSIPPI.




A. Low-flow frequency curves for Mississippi River at Red River-Tarbert Landing, 1930-75.




B. High-flow frequency curves for Mississippi River at Red River-Tarbert Landing, 1929-75.




C. Daily duration hydrograph for Mississippi River at Red River-Tarbert Landing, 1929-75.

PLATE 2. DAILY DURATION HYDROGRAPH AND FREQUENCY CURVES FOR MISSISSIPPI RIVER AT RED RIVER-TARBERT LANDING.

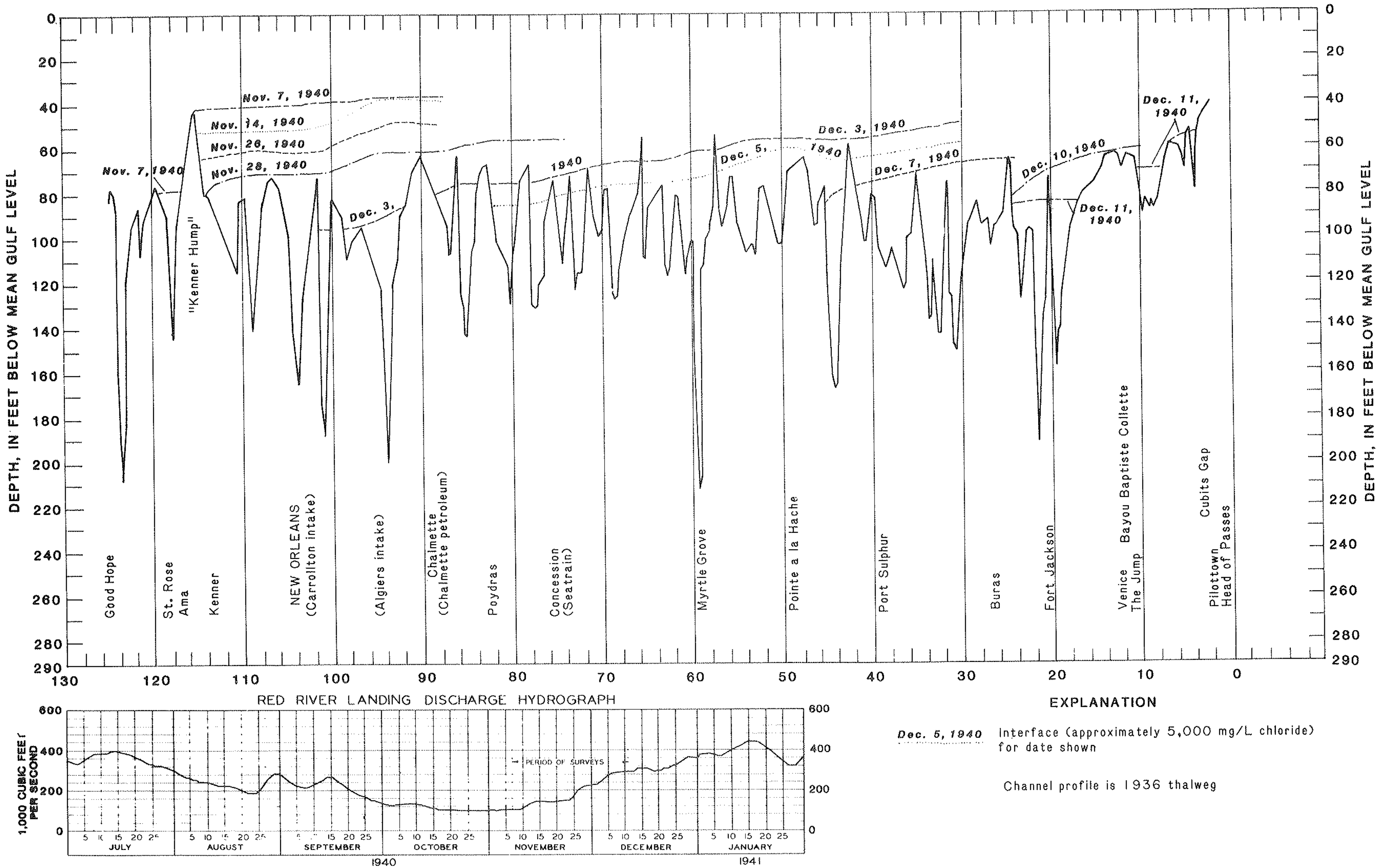



PLATE 3. RECESSION OF SALTWATER WEDGE WITH CHANGE IN DISCHARGE AT RED RIVER LANDING, LA., NOVEMBER-DECEMBER 1940. (MODIFIED FROM U. S. ARMY CORPS OF ENGINEERS, UNPUBLISHED DATA.)

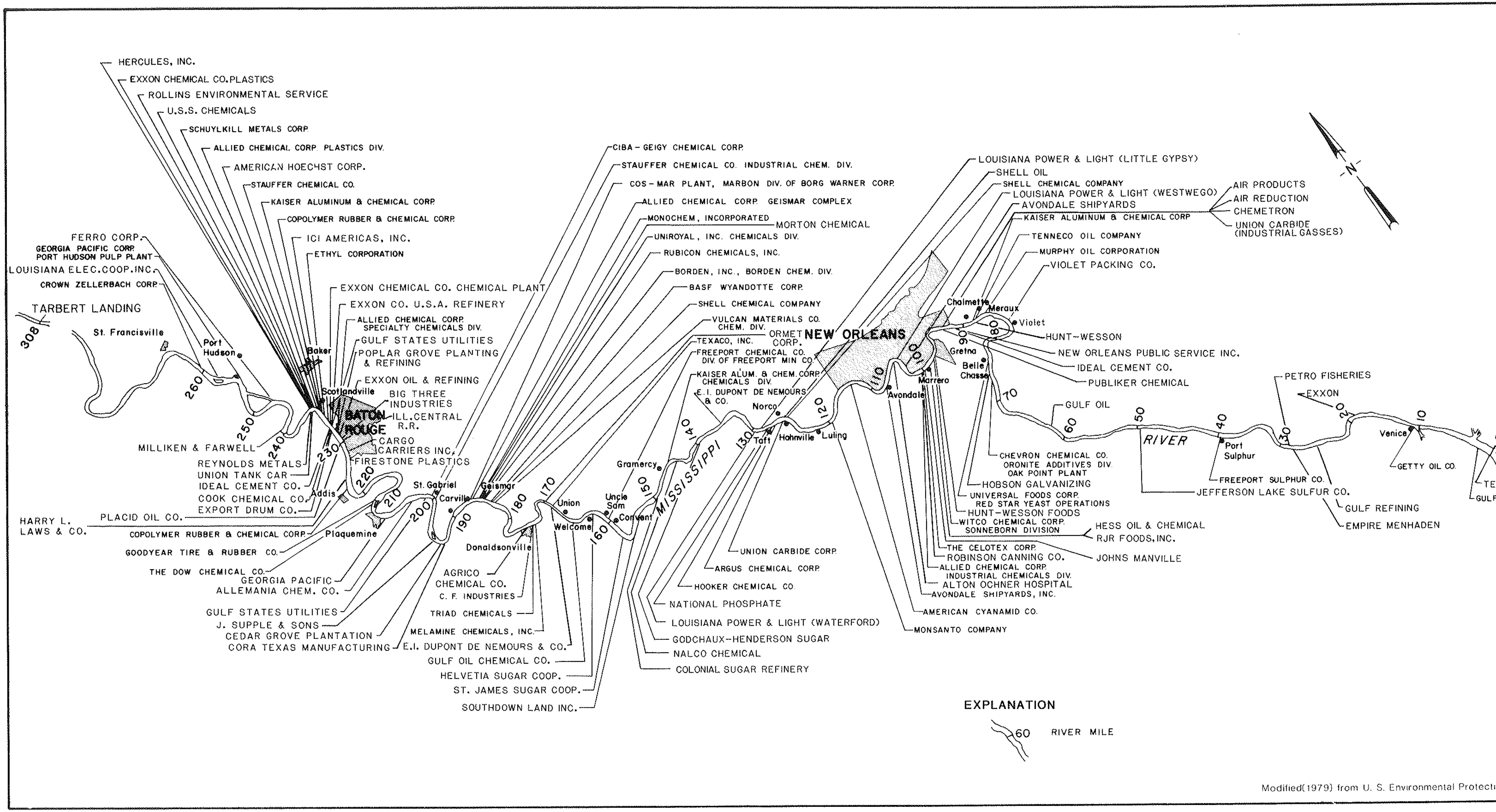



PLATE 4. MAP SHOWING LOCATION OF INDUSTRIAL AND ELECTRICAL PLANTS ALONG THE LOWER MISSISSIPPI RIVER, ST. FRANCISVILLE TO HEAD OF PASSES, LOUISIANA.

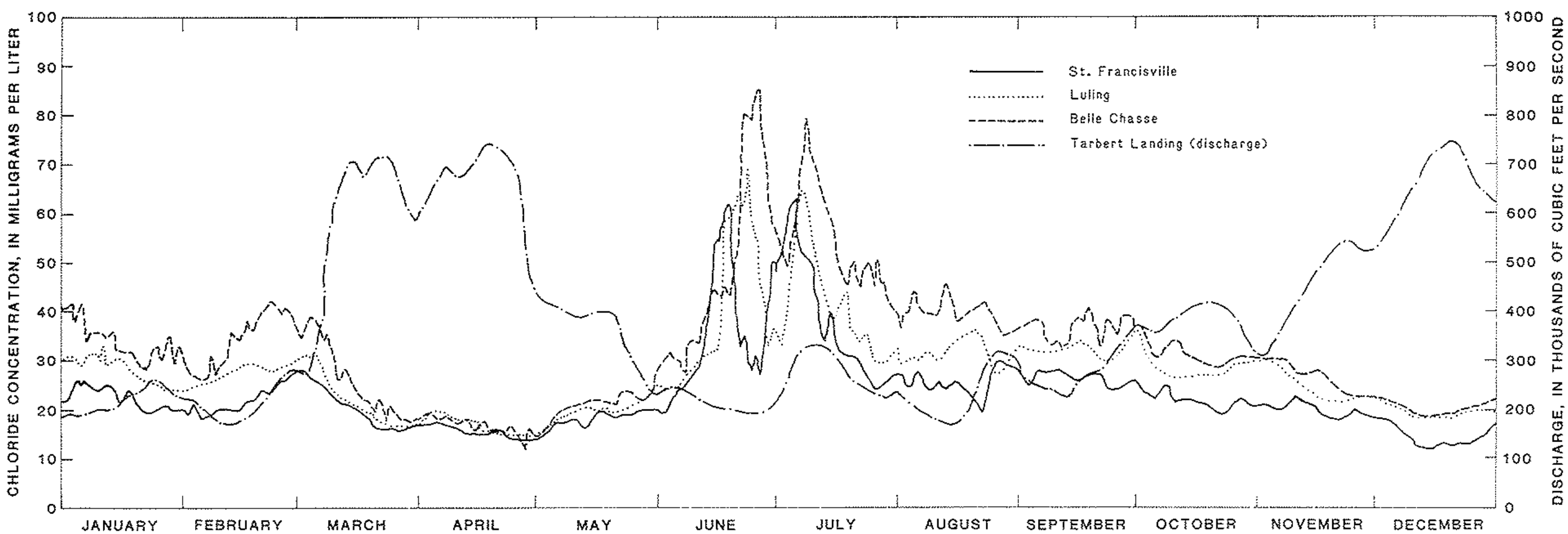



PLATE 5. GRAPHS SHOWING CHLORIDE CONCENTRATION AT ST. FRANCISVILLE, LULING, AND BELLE CHASSE, LA., AND RIVER DISCHARGE AT TARBERT LANDING, MISS., 1977.