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UNITED STATES
DEPARTMENT OF THE INTERIOR
JULIUS A. KRUG, Secretary
FISH AND WILDLIFE SERVICE
ALBERT M. DAY, Director

R. F. SHUMAN

Special Scientific Report No. 30

WATER QUALITY STUDIES OF THE MISSISSIPPI RIVER

By

Wesley S. Platner

Chicago
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Report on Analytical Findings of the 1944 Survey

By WESLEY S. PLATNER
Division of Fishery Biology

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Explanatory Note

The series, Special Scienfitic Reports, embodies results of investigations, usually of restricted scope, intended to aid or direct management or utilization practices and as guides for administrative or legislative action. It is issued in limited quantities for the official use of Federal, State or cooperating agencies and in processed form for economy and to avoid delay in publication.

INTRODUCTION

The increased demand that World War II made on the supply of protein food and the urgent need for an investigation of sources of fish protein have led State Officials of Minnesota, Wisconsin, Iowa, Illinois, and Missouri, to regard a survey of the Mississippi River as immediately desirable and necessary to the war effort and to the postwar planning program.

Dr. Ira N. Gabrielson, then Director of the Fish and Wildlife Service, considering requests of these States for our participation in a cooperative survey, approved, and assigned this task to the Water Quality Laboratories, a unit of the United States Fish and Wildlife Service under the supervision of Dr. M. M. Ellis. The purpose of the survey was to determine the physical and chemical characteristics of the Upper Mississippi River in relation to fish life. It was to cover a period of 15 months, commencing immediately after a meeting of the State and Federal authorities in Madison, Wis., in January 1944.

The Upper Mississippi River, as considered in this paper, is that portion of the stream lying north of the southeastern tip of the State of Missouri and extending to two and one-half miles above Lock and Dam No. 2 in the Hastings Pool, Minn.

Rocks of various geological ages represented in the Mississippi Drainage, and many varieties of topography are exhibited in the basin. Therefore, rock-stuff and dissolved materials of many types are to be expected in the Mississippi River water. Detailed accounts of the physiography of the river may be obtained by referring to Chambers (1910) and Galtsoff (1924).

It should be mentioned that the river from Cairo, Ill., to Minneapolis, Minn., has been improved to provide a waterway with a minimal depth of 9 feet and widths suitable for long-haul, common-carrier service. This was accomplished by a canalization plan which includes locks and dams at 26 sites.

The character of the river has undoubtedly changed as a result of this development. Some of the earlier literature concerning dam construction and the fisheries of the Upper Mississippi River has been published by Coker (1929) Galtsoff (1924), and Ellis (1931).

The rise and fall of the Mississippi River at different seasons of the year have made it necessary to plan the work so that samples would be obtained while the water was at various levels and temperatures--changes which could affect the aquatic fauna.

The tributaries (figures 1 and 2) which were sampled and are reported upon in this paper do not comprise by any means all of the rivers and creeks which enter the great river, but were chosen with regard to certain conditions which would be expected to affect the Mississippi, such as, large volume of water, pollutants, or use of the streams as potential breeding sites for fishes. Thus, those studied included some of the large rivers as well as a few small ones.

The importance of physical and chemical factors of natural waters has been stressed especially in the study of lakes, and is ably reviewed by

FIGURE 1

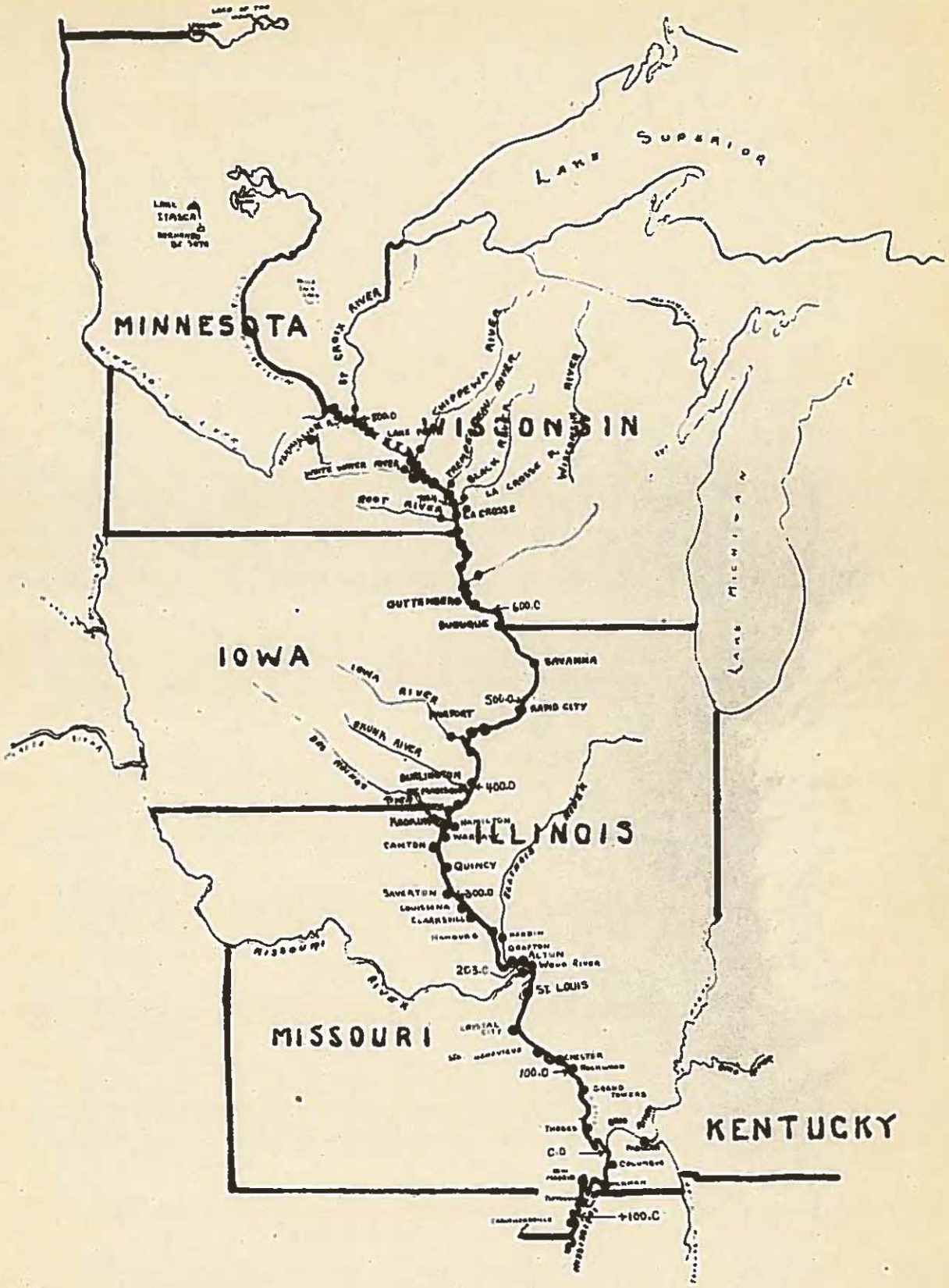
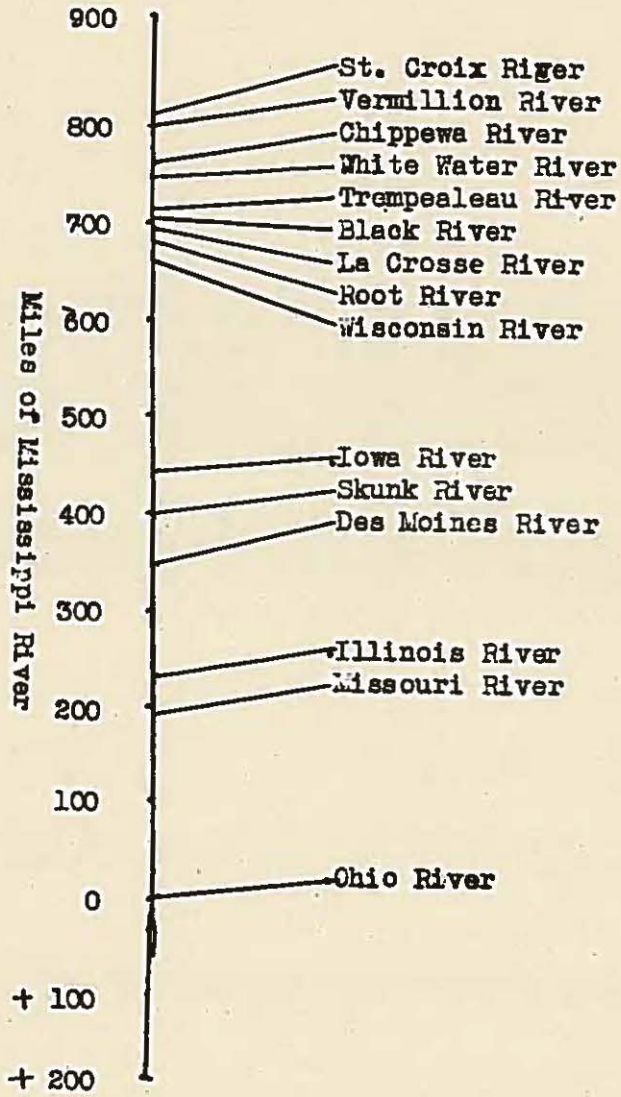

LAKE SUPERIOR
LAKE ITASCA
MINNESOTA
WISCONSIN
IOWA
ILLINOIS
MISSOURI
KENTUCKY
LAKE MICHIGAN
ST CROIX RIVER
CHIPPEWA RIVER
BLACK RIVER
LA CROSSE R
WISCONSIN RIVER
WHITE WATER RIVER
ROOT RIVER
LA CROSSE
GUTTENBERG
600.C
DUBUQUE
SAVANNA
IOWA RIVER
500.0
RAND CITY
BRUNN RIVER
BURLINGTON
400.0
HAMILTON
CANTON
QUINCY
SAVERTON
300.0
LOUISIANA
CLARKSVILLE
HANNIBAL
MARION
GRAFTON
ALTON
WOOD RIVER
203.C
ST LOUIS
MISSOURI RIVER
LONGAL CITY
CHESTER
100.0
GRAND TOWERS
THEBES
C.O
COLUMBUS
+100.C

FIGURE 2.--Confluence of tributaries with the Mississippi River



Rawson (1939). Although these factors are often regarded as basis in hydrobiological studies of inland waters, very little if any complete work has appeared in the literature concerning the relation of productivity to chemical environment in rivers. Some chemical analyses of the Mississippi River and a few of its tributaries appear in Clarke's work (1908 and 1924). These were from composite samples collected for ten-day periods in only one year at one or two points of the river.

McHargue and Peter (1921) reported on the removal of mineral plant-food by natural drainage water, some of their data relating to the Mississippi at Minneapolis, Minn., and Baton Rouge, La. These authors found that the phosphorus content decreased on its way to the Gulf of Mexico. They also found that nitrate nitrogen was absent from the Minneapolis sample but occurred in the Baton Rouge sample. Ammonia nitrogen apparently occurred only in the Baton Rouge sample and in small quantities. This led Wiebe (1931) to "determine what inorganic constituent of river water may be the factor that limits plankton production and hence fish production." He concluded that inorganic nitrogen is apparently not a limiting factor in the waters of the Mississippi River at Fairport, Iowa, and that soluble phosphorus may be at times becomes a limiting factor. Wiebe (1930b) also reported on the manganese content of the Mississippi River water at Fairport, Iowa.

Ellis (1937) includes data of an eutrophic character on the Mississippi River in a publication dealing with the detection and measurement of stream pollution. The only other work of a chemical nature published on the Mississippi River is that of Ellis (1931). This survey extended from Quincy, Ill., to Point au Sable, Minn. in Lake Pepin, and included observations on oxygen, pH and carbon dioxide, plankton, bottom conditions, temperatures, particularly stressing the problem of silting which resulted from slowing of the river by dams.

Aside from the importance of various chemical factors which have been found to influence the metabolic activity of inland waters, certain physical factors, other than temperature, turbidity, sedimentation, and bottom conditions have biological significance. For instance the amount and nature of daylight , and the selective absorption of the water itself, and the selective action of particulate and dissolved material, have been found to be important in the regulation of the activity of many animals, in the vision of fish, and especially in the photosynthesis of plants (Clarke 1939). How pronounced this effect might be on the aquatic life of the Mississippi River remains to be determined. Ellis (1936) has made a valuable contribution in showing that erosion silt has little effect on colored light transmission. The presentation of data on percentage of light of different wave lengths transmitted is offered in this report as a preliminary to further study along these lines.

It is hoped that the results of this survey will be of value when correlated with data collected by the cooperating States in relation to fish population, growth, weight, size, reproduction, and other factors. Although the Federal and State surveys were conducted indepently they cover the same period, thus the data should be relevant, at least more so than with previous surveys.

The writer desires to express his gratitude to Dr. M. M. Ellis, aquatic physiologist, in charge Water Qualities Laboratories, Fish and Wildlife Service, under whose guidance and supervision this investigation was made; to D. K. Meyer, aquatic biologist, who collaborated in almost all the field and

laboratory analyses; to H. L. Canfield, superintendent, U. S. Fish-cultural Station, at LaCross, Wis., who materially aided the field investigation by arranging for the use of a cruiser and other equipment; to Ray C. Steele, in charge of the Upper Mississippi Wildlife and Fish Refuge, Winona, Minn. for the loan of an outboard motor for part of the survey and other assistance.

The writer also wishes to make acknowledgments to Col. L. B. Feagin, Corps of Engineers, St. Louis, Mo., District Engineer, for permission to enter Locks 24, 25, and 26; and to Lt. Col. J. H. Peil, Corps of Engineers, Rock Island, Ill. District Engineer, for permission to enter the lock grounds of Dams 11 to 22, inclusive, and for the use of United States Coast Guard patrol boats Nos. 1755 and 1777 for a 24-hour study of that section of Lake Keokuk adjacent to Keokuk Dam; and to R. Iakisch for permission to work in and around the restricted area of Keokuk Dam.

METHOD OF INVESTIGATION

Extent of Survey

A total of 63 major stations varying from 40 miles to less than 1 mile apart were established in the main channel, and 68 substations were selected in sloughs, chutes, cross sections, and tributaries.

Reference to figure 3 will show the extent of this survey, the number of times a particular section of the river was visited, and the dates the samples were collected. For instance, the high-water period was sampled from March 19 to June 28, 1944, the low-water season from August 11 to September 22, 1944, and the mid-winter period from December 26 to December 30, 1944. During the latter period when true winter conditions were encountered, holes were cut through the ice to collect the water samples. Samples were not collected continuously throughout these periods but were taken at selected intervals when river conditions presented special aspects.

This study in addition to routine sampling at the major stations included the following special samplings: a cross-sectional sampling of the river and adjacent waters between Clarkesville, Mo., and Louisiana, Mo., at mile 275, mile 278, and mile 280 (see figure 4); cross-section at La Grange, Mo., mile 335.5; a cross-section of Lake Keokuk, adjacent to Keokuk Dam, mile 364.9, at which section samples were collected every six hours for a 24 hour period commencing at 10:00 a.m.; a cross-section of Lake Keokuk between Montrose, Iowa, and Nauvoo, Ill., mile 375.0; stations established at mile 653.0 in Capoli and Harpers sloughs; cross-sections of Lake Pepin at mile 781.7 and mile 774.4 (in each of these cross-sections there were three substations); and at mile 764.5 at the lower end of Lake Pepin, but above the Chippewa River, where two substations were maintained.

Fifteen different tributary rivers were sampled at various times; a list of these rivers and their approximate point of confluence with the Mississippi River is given in figure 2.

It might be mentioned in passing that well over 2,000 chemical analyses were made at the Columbia, Mo., laboratories in addition to over 1,700 determinations completed in the field.

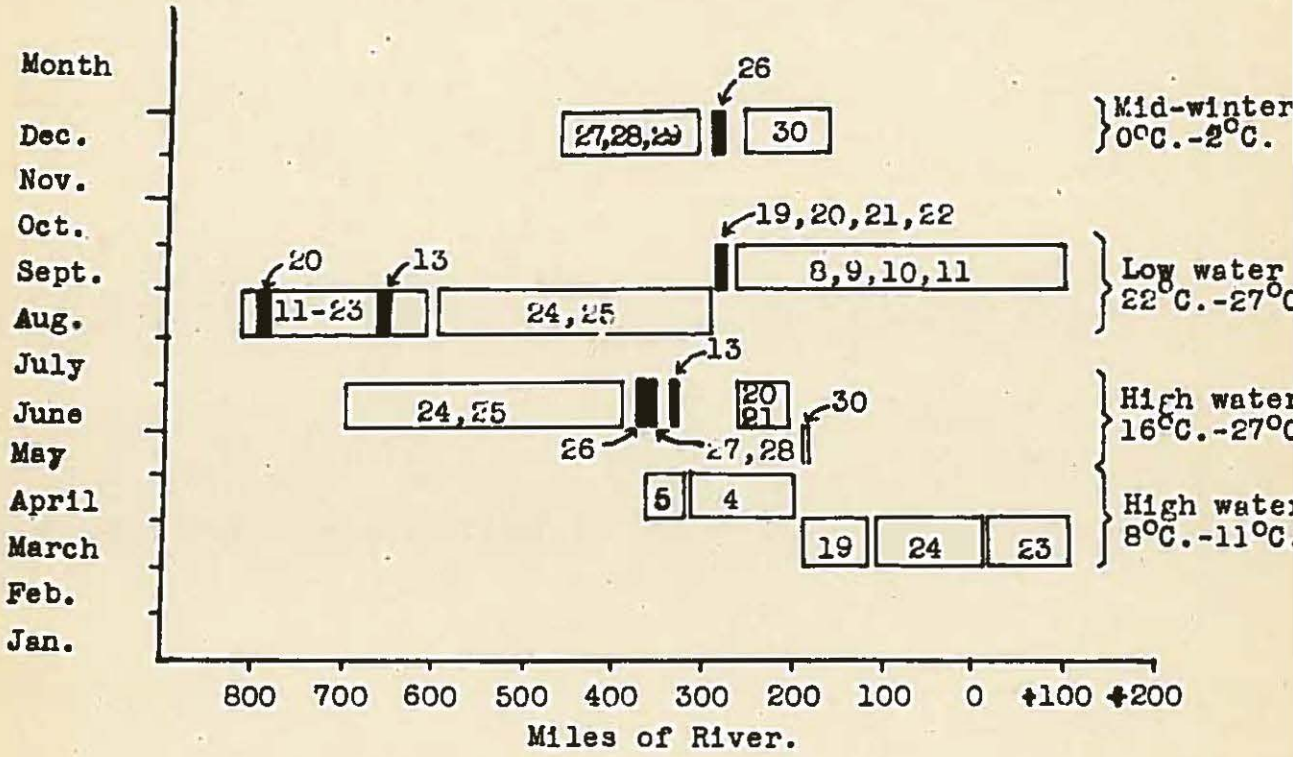


FIGURE 3.—Sections of the Mississippi River as surveyed for this report, 1944.

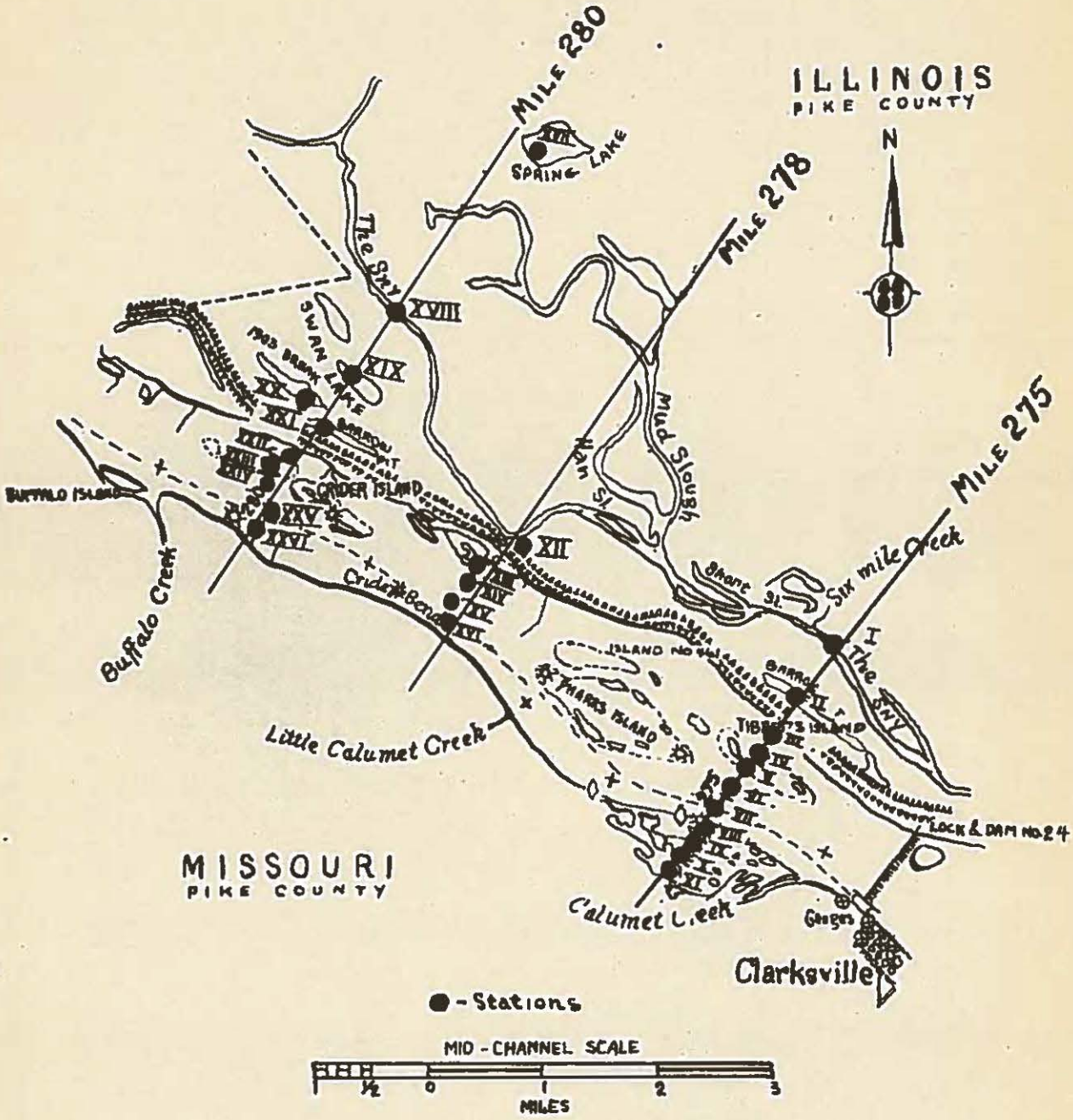


FIGURE 4.— Cross-sectional stations of the Mississippi River and adjacent waters between Clarksville, Missouri and Louisiana, Missouri. September and December, 1944.

Stations

Wherever a sample of water was collected or observations made, that place was designated as a station. In most cases samples were collected from the main channels of the Mississippi River or the tributaries. The sampling of sloughs, chutes, and the Sny River are exceptions.

The plan followed in this survey is to use the names of towns as well as mileage markers, to designate the exact location of the stations. The markers were easily found by reference to a document prepared by U. S. Engineers Office, Upper Mississippi Valley Division, St. Louis, Mo., (1940) and a publication of the U. S. Coast Guard (1944).

Cairo, Ill., at the mouth of the Ohio River, has been designated zero mileage. The number of miles increase north and south from this point. To avoid confusion in naming stations by the mileage system, miles surveyed south of Cairo, Ill., are marked with a plus sign before the mileage figure.

It must be remembered that constantly changing channels necessitate changes in mileage markers despite the fact that some are rather permanently fixed in concrete. However any other method used to designate the exact position of a station would also be subject to channel changes.

In the sampling of sloughs or sections across the river, particular attention was paid to selected stations where water conditions would be expected to be different. Therefore, such data present a physical and chemical picture of the types of water available to the Mississippi River fishes in these areas.

Method of Sampling

Water samples

The Mississippi River was always sampled from the channel and at a level of one-half the depth at that particular point, unless otherwise stated. Surface samples were taken at a depth of from 1 to 2 feet, while the term bottom water sample implies a second set of water samples taken about 6 inches above the floor of the stream. At Lake Pepin a series of such samples were collected across the lake.

Bottom samples

Samples of the bottom were obtained with a Peterson dredge. These were collected at every major station as well as at many of the substations. The character of the bottom, whether it was sand, mud or silt, plus any other peculiar inclusions was recorded. Bottom fauna were not studied in detail but a record was kept of the insect larvae, fresh-water mussels, and other large invertebrates found.

Preservation and Treatment of Samples

In this survey, interest was primarily focused on soluble or dissolved material in the water which might be of consequence in influencing the conditions of aquatic life. Therefore, silt was not included in the analysis.

The presence of silt and other detritus would certainly alter the amounts of chemical constituents present. Table 1 taken from Steiger (1914) show an analysis of silt from the Mississippi River collected at New Orleans. It is evident from this table that a true analysis of the soluble constituents of the river water could not be obtained if silt were included.

Glass fruit jars of the self-sealing type with glass lids were used throughout the investigation to transport the water samples. Three samples were collected at each station, a pint, quart, and one-half gallon. The first was preserved with a few drops of sulphuric acid for ammonia and total nitrogen determinations. The second was preserved with chloroform and was used for oxygen consumed determinations, and the third was left unpreserved for the determination of pH, specific conductance, carbonates, bicarbonates, carbon dioxide, turbidities, and light penetration. All of these determinations were completed in the field. Analyses of the unpreserved samples for trace elements and negative radicals were made at the Water Quality Laboratories of the U. S. Fish and Wildlife Service, Columbia, Mo.

The only departure from the procedure mentioned was in the case of the detailed, cross-section studies between Louisiana, Mo., and Clarksville, Mo., shown in tables 19-23. Here four one-half gallon samples of water were collected at each station and each was preserved with 1 milliliter of concentrated sulphuric acid. These samples were concentrated to small volumes and treated as discussed under total nitrogen.

Acids used to preserve samples have been found to leach out elements as manganese, iron, or zinc from silt. Therefore, our acid-preserved samples were not used for these determination.

In the determination of total nitrogen the whole sample was used which included all suspended matter. This was considered valid because all organic material might be utilized by the aquatic organisms.

All of the reagents used in the field and at the home station laboratory were of the highest quality and purity. Special precautions were taken to prevent contamination by foreign material.

Boat and Field Equipment

The field studies from Guttenburg, Iowa, mile 612.5, to Hastings Pool, Minn, mile 817.5 were completed in the 35-foot U. S. Fish and Wildlife Service cruiser no. 1230. A "John" boat equipped with an outboard motor was held in tow for use in ascending the tributaries and sloughs.

An automobile truck, equipped for field work, was used to complete the survey from Guttenburg, Iowa, mile 612.5 to Caruthersville, Mo., which is 112 miles below Cairo, Ill.

The equipment carried in the field consisted of a vacuum-tube galvanometer glass electrode, pH meter,. An apparatus for the measurement of specific conductance was made with a standard glass cell containing coated platinum electrodes in a telephone circuit with a microhummer and standard variable resistance units. All determinations of turbidity and light penetration were made with a photelometer.

Table 1.--Analysis of Mississippi Silt *

Constituent	Percent	Constituent	Percent
SiO_2	69.96	F	0.07
Al_2O_3	10.52	S	0.07
Fe_2O_3	3.47	Cr_2O_3	0.01
FeO		V_2O_3	0.02
MgO	1.41	NiO	0.017
CaO	2.17	MnO	0.06
Na_2O	1.51	BaO	0.08
K_2O	2.30	SrO	Trace
H_2O	3.78	CuO	0.0043
H_2O	1.96	ZnO	0.0010
TiO_2	0.59	As_2O_5	0.0004
ZrO_2	0.05	PbO	0.0002
CO_2	1.40	Organic matter	0.66
P_2O_5	0.18		100.6229
SO_3	0.03	Less O	0.1200
Cl	0.30		100.5029

*Analyses by G. Steiger of a composite of 235 samples collected by E. W. Shaw in the delta of the Mississippi. (Jour. Washington Acad Sci., Vol, 4, 1914, p. 59.)

Bottom samples were obtained with a Peterson dredge which was operated by hand. Water for oxygen samples was procured with a Foerst sampler. Temperature was obtained with a Centigrade mercury laboratory thermometer. Other glassware, as calibrated burettes, graduated pipettes and volumetric flasks were carried in special boxes. Imhoff-waste tubes graduated to 100 ml. were used to determine the percentage sedimentation.

PHYSICAL CHARACTERISTICS OF THE WATERS

Temperature

Temperature observations were made by drawing a sample of water at any desired depth with a Foerst sampler and immediately placing a thermometer in a jet of water escaping from the bottom valve of sampler. This procedure was found to accurate enough for purposes of this survey.

The temperature of the Mississippi River during high water in the months of March and April ranged from 6.0°C. to 11.5°C. In May and June the temperature range was from 16.0°C. to 27.3°C (table 2). Although there is quite a difference in temperature between April and June no effort was made to treat the periods separately. They are considered together as high water. It should be pointed out that the amounts of dissolved gases as oxygen and carbon dioxide would vary considerably as a result of this temperature variation. (See section on oxygen). Low water temperatures recorded during the months of August and September had a lesser range 21.8°C. to 28.5°C (see Table 3).

Temperature observations in the month of December, when most of the river was frozen over with 4 to 8 inches of ice, were from zero to 1.0°C. The readings above zero were recorded where the channel was open (table 4)

The temperature of the water in the tributaries studied showed no great difference from that of the main stream. However sloughs and bayous usually were 1 to 3 degrees warmer than the main channel. For instance the temperature of McGregor Lake was 3.4°C. higher than the channel at McGregor, Iowa, mile 633.8, both being sampled withing an hour.

Wherever the velocity of the current was diminished for any great distance, the temperature was usually altered.

The difference between top and bottom temperatures was quite uniform and usually the variation was less than one degree. However, at Lake Pepin, mile 774.4, the difference between surface No. 9 and bottom No. 10 was 1.2°C. The variation in temperature of the river between day and night according to observations in Lake Keokuk between 10:00 a.m. and 4:00 a.m. was 3.0°C.

Turbidity, Sedimentation and Bottom Conditions

The material carried down a river may be in solution, in suspension, or rolled along the bed. In the Mississippi river, erosion silt with some detritus was chiefly responsible for the three factors here discussed.

The first, turbidity, was recorded in parts per million based on readings calculated from a previously standardized Fuller's earth curve.

Table 2.--Observed temperatures of Mississippi River during High Water.
(March 19 to June 24, 1944)

Station	Miles from Cairo	Date 1944	Temp. °C Water	Temp. °C Air	Time
LaCrosse, Wis.	700.4	6/24	--	--	--
McGregor, Iowa	633.8	6/24	25.5	29.8	4:15 p.m.
Above Dam #10	627.5	6/24	25.4	28.8	5:30 p.m.
Dubuque, Iowa	580.1	6/25	25.0	24.4	8:45 a.m.
Rapid City, Ill.*	496.5	6/25	25.7	28.4	11:50 a.m.
Fairport, Iowa**	463.2	6/25	24.5	29.0	1:45 p.m.
Burlington, Iowa	402.8	6/25	27.0	31.0	4:00 p.m.
Hamburg, Ill.	258.6	6/21	24.0	23.4	10:00 a.m.
Alton, Ill.	203.0	6/20	25.7	25.5	1:15 p.m.
St. Louis, Mo.	172.5	5/30	16.0	--	--
Ft. Madison, Iowa	380.0	6/25	27.3	29.0	4:45 p.m.
Hamilton, Ill.	364.0	4/5	10.0	--	9:10 a.m.
Marsow, Ill.	349.8	4/5	6.0	4.5	8:00 a.m.
Canton, Mo.	342.6	4/5	8.2	--	2:20 p.m.
Quincy, Ill.	327.1	4/4	6.0	4.0	6:00 p.m.
Saverton, Mo.	303.5	4/4	6.5	5.0	4:45 p.m.
Louisiana, Mo.	282.5	4/4	6.5	3.0	2:00 p.m.
Clarksville, Mo.	274.8	4/4	6.5	3.0	1:30 p.m.
Hambrug, Ill.	258.6	4/4	6.5	3.0	11:30 a.m.
Grafton, Ill.	217.5	4/4	7.5	3.0	9:50 a.m.
Alton, Ill.	203.0	4/4	8.0	3.5	8:45 p.m.
Wood River, Ill.	196.7	4/4	8.0	4.0	7:30 a.m.
St. Louis, Mo.	172.5	3/19	6.0	2.0	3:00 p.m.
Crystal City, Mo.	152.0	3/19	6.0	2.0	12:20 p.m.
St. Genevieve, Mo.	124/0	3/19	6.0	2.0	10:00 a.m.
Chester, Ill.	108.6	3/19	6.0	2.0	8:00 a.m.
Rockwood, Ill.	100.0	3/24	11.1	--	4:10 p.m.
Grand Towers, Ill.	79.5	3/24	10.2	--	--
Thebes, Ill.	44.0	3/24	9.0	--	--
Columbus, Ky.	21.7	3/24	11.5	3.5	--
Hickman, Ky.	56.0	3/23	6.5	2.0	4:10 p.m.
Tiptonville, Tenn.	87.6	3/23	7.0	3.0	3:30 p.m.
Caruthersville, Mo.	112.0	3/23	7.0	3.0	2:00 p.m.

* River Stage - Pool 14.76, Tail 10.66

** Gage reading - 15.5

Table 3,--Observed temperatures of Mississippi River during low water
(August 11 to September 11, 1944)

Stations	Miles from Cairo	Date 1944	Temp. Water °C	Temp. Air °C	Time	Depth in feet
½ mi. below Mininger, Minn.	817.5	8/17	24.5	27.8	3:30 p.m.	--
½ mi. below Locks & Dam no. 2	814.5	8/18	21.8	15.8	8:50 a.m.	12
½ mil below Hastings, Minn.	813.0	8/18	23.0	22.4	10:30 a.m.	10
Diamond Bluff, Wisc.	800.0	8/18	23.0	19.0	12:50 p.m.	10
Red Wing, Minn.	791.2	8/18	23.2	22.5	3:00 p.m.	--
3.8 mi. below Red Wing, Minn.	787.2	8/18	24.2	22.5	3:30 p.m.	7
1.5 mi. below Reads Landing, Minn.	761.5	8/20	24.5	25.0	1:45 p.m.	15
5 mi. S. of Wabasha, Minn.	755.0	8/21	23.0	20.2	8:30 a.m.	8
1.9 mi. No. of Chimney Rock, Minn.	739.9	8/21	24.6	26.5	1:40 p.m.	15
.5 mi. N. of Wild's Landing, Minn.	730.0	8/22	22.8	17.5	8:50 a.m.	8
1.2 mi. S. of Lock and Dam. #5A	727.3	8/22	23.2	18.0	9:15 a.m.	9
Minneopa, Minn.	721.9	8/22	23.[illegible]	21.0	10:25 a.m.	10
Trempealeau, Wisc.	715.6	8/15	27.[illegible]	30.0	11:45 a.m.	12
River Junction, Minn.	700.4	8/15	26.[illegible]	21.2	9:00 a.m.	11
2 Mile Island Light	691.3	8/14	25.[illegible]	22.0	8:20 a.m.	12
St. Paul Day Marker	6[illegible]3.7	8/13	25.[illegible]	22.0	7:45 a.m.	--
Below Dam No. 9	646.8	8/13	25.[illegible]	22.0	7:15 a.m.	--
Prairie du Chien, Wis.	63[illegible]	8/12	28.[illegible]	27.5	3:15 p.m.	7
McGregor, Iowa	6[illegible]3.5	8/12	27.[illegible]	27.0	2:45 p.m.	9
Above Dam #10	627.5	8/12	28.[illegible]	35.0	10:35 a.m.	6
Guttenburg, Iowa	615.8	8/11	26.[illegible]	23.0	8:30 a.m.	15
Below Guttenburg	612.5	8/11	27.[illegible]	32.0	7:30 a.m.	--
Dubuque, Iowa	580.1	8/23	--	--	----	--
Savannah, Ill.	537.5	8/23	--	--	----	--
Rapid City, Ill.	496.5	8/23	--	--	----	--
Fairport, Iowa	465.2	8/24	--	--	----	--
Above Iowa River	434.5	8/24	--	--	----	--
New Boston, Ill.	432.2	8/24	--	--	----	--
Burlington, Iowa	402.8	8/24	--	--	----	--
Ft. Madison, Iowa	380.0	8/25	--	--	----	--
Keokuk, Iowa	364.8	8/25	--	--	----	--
LaGrange, Mo.	335.6	8/25	--	--	----	--
Saverton, Mo.	303.5	8/25	--	--	----	--
Louisiana, Mo.	282.5	8/25	--	--	----	--
Hamburg, Ill.	258.6	9/8	23.5	25.0	11:40 a.m.	30
Grafton, Ill.	217.5	8/8	24.0	26.0	2:00 p.m.	14
Alton, Ill.	205.0	9/9	23.5	21.0	9:05 a.m.	22
Wood River, Ill.	196.7	9/9	24.0	24.0	12:05 p.m.	11
St. Louis, Mo.	172.5	9/9	24.3	27.0	3:10 p.m.	--

Table 3,--Observed temperatures of Mississippi River during low water (August 11 to September 11, 1944)-(Continued)

Stations-Continued	Miles from Cairo	Date 1944	Temp. Water °C	Temp. Air °C	Time	Depth in feet
Crystal City, Mo.	152.5	9/10	22.0	20.3	9:45 a.m.	--
St. Genevieve, Mo.	124.0	9/10	23.5	27.5	11:10 a.m.	8
Chester, Ill.	108.6	9/10	24.8	30.8	1:10 p.m.	--
Grand Tower, Ill.	79.5	9/10	24.8	31.8	2:20 p.m.	--
Thebes, Ill.	44.0	9/11	23.0	23.5	9:20 a.m.	7
Columbus, Ky.	21.7	9/11	23.5	22.8	2:20 p.m.	--
Hickman, Ky.	36.0	9/11	23.5	22.2	3:45 p.m.	--
Tiptonville, Tenn.	87.6	9/11	23.5	22.5	4:45 p.m.	--
Caruthersville, Mo.	112.0	9/11	23.5	21.5	6:25 p.m.	--

Table 4,--Observed temperatures of Mississippi River in mid winter (December 26--December 29, 1944)

Mile from Cairo	Date	Water Temp. °C	Air Temp. °C	Time	Depth feet
463.2	Dec. 28	0.1	-7.4	12:25 p.m.	6
434.5	Dec. 29	1.0	---	4:25 p.m.	--
402.8	Dec. 27	0.0	---	8:45 a.m.	6
380.0	Dec. 27	0.0	---	3:20 p.m.	9
375.0	Dec. 27	0.0	---	2:30 p.m.	9
359.8	Dec. 29	0.0	---	9:20 a.m.	--
342.6	Dec. 27	0.0	---	12:40 p.m.	--
335.6	Dec. 27	0.0	1.0	12:00 noon	5
327.1	Dec. 29	0.0	---	10:45 a.m.	9
303.5	Dec. 27	0.0	1.0	10:25 a.m.	9
275.0	Dec. 26	0.0	-8.0	4:40 p.m.	7
258.6	Dec. 29	0.5	---	2:00 p.m.	6
196.7	Dec. 29	1.0	---	5:00 p.m.	--
172.5	Dec. 29	0.5	---	6:45 p.m.	--

The upper part of the Mississippi River had turbidity values ranging from 34 to 85 p.p.m. with an aver ge of 50 p.p.m. for the low-water period. In the lower section of the river from mile 258.6 to mile 196.0 the turbidity rose to an average of 300 p.p.m., but below the Missouri River the turbidity rose to an average reading of 1880 p.p.m. This value diminished only slightly at Caruthersville, Mo., mile 112.0.

The high-water was on an average 40 percent more turbid than the low. The suden rise in turbidity which occurred below the Missouri River remained at an elevated level for 50 miles, then began to decline very gradually. This was in extreme contrast to the sdimentation data for this same section of the river because the sedimentation dropped to a level almost equal to the value found above the confluence of the Missouri River, and remained at this level with only little change.

The percentage of sedimentation was recorded in a 100 ml. capacity mine-waste tube, one hour after collection of the sample.

The Upper Mississippi River from mile 250 to mile 812 during the low water period carried very little sediment which would settle-out in one hour. The average value was 0.02 percent. Ho wever, below the Missouri River at mile 150 the amount of such sediment increased to 0.6 percent. Beyond this point the quantity dropped sharply to 0.06 percent and remained at approximately this level to mile 112 which was the limit of this survey.

The high-water of March and June carried much more material which settled out in one hour than did the low water. From mile 380 to Wood River, Ill., mile 196.7 (just above the mouth of the Missouri River) 0.05 percent of sediment was recorded, but below the Missouri River the amount of sediment increased to 0.9 percent at mile 150 then dropped sharply to 0.1 percent at mile 108. The slight increase below mile 100 is thought to have been caused by the Kaskaskia River but since this river was not studied a positive statement cannot be made. The amount of sediment during the period of high water in the Mississippi River south of mile 44 was on an average 0.03 percent higher than that for the low-water period.

Thus, it may be said that the amount of sediment in the Mississippi River during high water from 33 to 60 percent higher than during low water. The percentage of sedimentation observed in adjacent sloughs and lakes depended chiefly on the velocity of the current and the type bottom. Strong currents over silty bottom constantly kept some of the silt in suspension. Usually a slower current allowed clearer water. As the velocity of currents was not measured these statements should be regarded as strictly subjective.

The only tributaries found which exceeded the percentage of silt in the Mississippi River were the Illinois River with 0.35 percent if compared with that part of the Mississippi above the mouth of the Missouri and the Missouri River which had 1.50 percentage sedimentation.

The bottom conditions of the Mississippi River have been reported on in detail from a survey made by Ellis (1931). The river bottom has not materially changed since that time. As only general bottom characteristics would be of importance in a survey primarily concerned with chemical analysis of the water, only general characteristics will be mentioned here. (Table 5)

Table 5.--Bottom conditions of Mississippi River

Miles from Cairo	Bottom
817.5	Sand and mud
814.5	Sand and mud
813.0	Gravel
800.0	Sandy
791.2	Sandy
787.2	Sand, with small empty clam shells
761.5	Sandy
755.0	Gavel and sand
739.9	Sandy
730.0	Sandy
727.3	Sandy
721.9	Sandy
715.6	Sandy
700.4	Sandy
691.3	Sand and fine gravel
648.7	Sand with live shells
646.8	Sand
634.0	Sand, with small empty clam shells
67[illegible].9	Sand, and empy clam shells
[illegible]03.0	Mud
196.7	Sand, silt
172.5	Sand, silt
152.5	Sand
124.0	Sand
108.6	Sand and mud
79.5	Sand and mud
44.0	Sand
+ 21.7	Sand and mud
+ 36.0	Sand
+ 87.6	Sand
+112.0	Sand

The Mississippi River was found to have chiefly a sandy, silt-covered bottom. The upper part of the river at mile 817 had mud mixed with sand. Just above Lake Pepin a sandy condition persisted for approximately 22 miles. Lake Pepin itself had a bottom of mud in which numerous bloodworms were found. Below Lake Pepin the bottom again became sandy with some silt, and remained so to the head of Lake Keokuk. Here the silt and mud became dominant factors. South of Lake Keokuk very little clean sand was found. Most of it was mixed with silt and mud. Below the Illinois and especially below the Missouri River a great deal of silt was present. At mile + 87 and mile + 112 the bottom gradually became more sandy.

The sloughs and bayous studied had without exception, bottoms of either sticky mud or silt. The bottom conditions of the tributaries are noted in tables 6-11, revealing mud with only a few exceptions, as for instance the Iowa River.

Percentage of Light Transmitted

The percentage of light penetration was measured with a photelometer through 5 cm. of water which was contained in a fused glass cell. Corning glass filters for the colors red, yellow, green, blue, and violet were used. The wavelengths as well as the percentage of light transmitted for Mississippi River water are given in figure 5.

The graphs represent a composite of data from 36 samples of the Mississippi River for each light-filter for the upper river from mile 817.5 to 580.1 and 19 samples for each light-filter for the lower part of the river, namely, mile 258.6 to mile 112. These data were collected during the low-water months of August and September, 1944.

The tributaries as well as the sloughs, and cross-sections showed essentially the same order of spectral transmission as that of the River. The readings were made in the field immediately upon collection of water samples.

Water samples from the Mississippi River below the mouth of the Missouri River had to be diluted with distilled water because the amount of suspended material prevented a normal reading.

Each filter was standardized to the same light intensity before the reading was made. The graphs in figure 5 show the percentage of light penetration for the various wave lengths based on white light as being one hundred. Further inspection of the graphs show that red light penetrates the deepest of all, undoubtedly due to selective absorption.

Except for the violet component of the spectrum, Midge Lake studied by Birge and Juday (1930) shows the same relative rates of absorption as the Mississippi River, both of which are far from clear water.

Although it is not the purpose of this report to review all of the literature pertaining to this subject a few points of interest may be mentioned.

According to ZoBell and McEwen (1935) ultraviolet light in large amounts is injurious to plankton and other organisms. Manning (1938) points out that red light is most effective for photosynthesis, while the intensity and duration of light has been shown to affect the activity of fishes and plankton, (Hoover and Hubbard, 1937; Clarke, 1934; Johnson, 1938).

Table 6.--Physical characteristics of some tributaries of the Mississippi River (March to June 1944, high-water period)

WESTERN TRIBUTARIES

Tributaries	Date 1944	Turbidity p.p.m.	Per cent sedimentation (60 min.)	Water temp. °C	Air temp. °C	Time	Sample depth feet	Bottom
Root River	6/24	---	------	27.0	30.0	----	3.0	sand
Des Moines River	4/5	416	------	8.0	----	10:00 a.m.	4.0	mud

EASTERN TRIBUTARIES

Illinois River	6/21	290	0.35	24.4	22.8	9:00 a.m.	3.0	mud
Ohio River	3/24	92	Trace	3.8	----	9:00 a.m.	6.0	mud

Table 7.--Chemical analysis of water samples from tributaries of the Mississippi (March to June 1944; high water period)

WESTERN TRIBUTARIES

Sample collected at mouth of River	Sp. Cond. Mho x 10-6 @ 25°C	pH	Parts per Million										
			Dis-solved O_2 R. S.	O_2 con-sumed	HCO_3	CO_3	CO_2	Total (N)	NH_3	PO_4	Cl	SO_4	Ca
Root River	291.0	----	------	124.0	30.0	---	----	1.18	0.21	0.18	0.70	5.4	46.0
Des Moines River	583.0	8.05	10.22	18.0	141.0	---	1.40	2.44	0.05	0.31	0.48	77.3	73.0

EASTERN TRIBUTARIES

Illinois River	530.0	7.55	1.50	19.0	104.0	0.00	Trace	0.20	0.17	0.22	10.6	59.1	62.0
Ohio River	273.0	7.75	8.21	0.9	61.0	0.00	0.00	3.49	0.20	0.04	2.6	32.0	31.0

Table 8--Physical characteristics of tributaries of the Mississippi River (August and September 1944; low-water period)

WESTERN TRIBUTARIES

Tributaries	Date 1944	Turbidity p.p.m.	Per cent sedimentation (60 min.)	Water temp. °C	Air temp. °C	Time	Sample depth feet	Bottom
Vermillion River	8/18	76	0.02	19.0	20.0	10:00 a.m.	3.0	mud
White Water River	8/21	42	Trace	20.0	30.8	11:15 a.m.	1.5	mud, sand
Root River	8/14	92	0.02	24.0	24.0	9:30 a.m.	3.0	sand
Iowa River	8/24	--	----	----	----	----------	---	sand
Skunk River	8/24	--	----	-----	----	----------	---	----
Des Moines River	8/25	--	----	-----	----	----------	5.0	mud
Missouri River	9/9	255	1.50	22.7	----	11:25 a.m.	12.0	mud, silt

EASTERN TRIBUTARIES

St. Croix River	8/18	27	0.00	24.0	22.4	11:30 a.m.	22.0	mud
Chippewa River	8/20	38	0.01	25.0	26.0	1:15 p.m.	5.2	sand
Trempealeau	8/15	110	Trace	19.0	20.0	12:30 p.m.	1.5	mud
Black River	8/15	72	Trace	26.5	24.0	8:10 a.m.	8.0	sand, mud
La Crosse River	8/15	134	0.05	25.2	24.0	8:25 a.m.	2.0	mud, sticks
Wisconsin River	8/12	76	Trace	28.5	35.0	10:35 a.m.	6.0	mud, sticks
Illinois River	9/8	138	-----	25.0	26.0	1:00 p.m.	5.0	mud
Ohio River	9/11	135	Trace	24.0	21.9	11:45 a.m.	6.0	mud

Table 9--A chemical analysis of water samples from tributaries of the Mississippi River (August and September 1944; low-water period)

WESTERN TRIBUTARIES

Sample collected at mouth of river	Sp. cond. mho x 10-6 @ 25°C	pH	Parts per million										
			Dis-solved O_2 A. S.	O_2 con-sumed	HCO_3	CO_3	CO_2*	Total (N)	NH_3	PO_4	Cl	SO_4**	Ca
Vermillion	465.0	8.20	5.80	12.0	136.0	5.40	0.00	1.36	1.08	0.33	5.00	0.00	62.[illegible]
White Water River	409.0	8.30	8.67	53.5	135.8	17.30	0.00	1.06	0.88	0.21	0.99	0.00	56.5
Root River	387.0	8.55	5.14	9.0	131.0	9.6	0.00	0.70	0.13	0.28	2.92	Trace	51.[illegible]
Iowa River	521.0	----	----	7.0	96.4	----	----	1.65	0.06	0.40	7.45	20.80	47.4
Skunk River	436.0	----	----	35.0	103.2	----	----	1.40	0.08	0.36	3.97	27.10	59.8
Des Moines River	455.0	----	----	19.5	90.8	----	----	3.21	0.09	0.42	9.67	60.40	44.[illegible]
Missouri River	434.0	7.50	6.46	42.5	69.0	4.10	0.00	3.03	0.10	0.23	3.86	64.40	50.6

EASTERN TRIBUTARIES

St. Croix River	161.0	8.14	5.74	26.0	49.1	0.00	Trace	1.28	1.07	0.18	0.00	0.00	23.4
Chippewa River	127.5	8.31	7.10	27.0	37.4	2.04	0.00	2.18	1.09	0.21	5.00	0.00	17.0
Trempealeau River	215.0	8.40	4.80	10.0	60.1	5.40	0.00	1.87	1.12	0.55	0.29	0.00	24.4
Black River	251.0	8.50	5.41	19.0	64.0	3.00	0.00	2.51	0.18	0.28	0.00	0.00	28.7
Lacrosse River	239.0	8.50	3.28	10.5	71.9	6.00	0.00	0.91	0.29	0.41	2.18	Trace	27.9
Wisconsin River	245.0	8.13	6.25	51.0	70.4	4.20	0.00	3.42	0.66	0.14	1.98	Trace	26.4
Illinois River	525.0	7.70	2.08	25.0	89.4	0.00	Trace	1.81	0.51	0.47	23.34	52.5	45.7
Ohio River	241.0	7.95	6.02	20.0	50.9	0.00	Trace	1.28	0.10	0.16	5.40	24.2	25.5

* Trace CO_2 indicates 1.0 p.p.m. or less

**Trace SO_4 indicates 0.5 p.p.m. or less

Table 10--Physical characteristics of some tributaries of the Mississippi River (December 1944; midwinter period)

WESTERN TRIBUTARIES

Tributaries	Date 1944	Turbidity p.p.m.	Per cent sedimentation (30 min)	Water temp. °C	Air temp. °C	Time	Sample depth in feet	Bottom
Iowa River	12/28	---	----	0.0	---	10:10 a.m.	2.0	sand
Skunk River	12/27	---	----	0.0	---	4:00 p.m.	3.0	---
Des Moines River	12/27	---	----	0.0	---	1:40 p.m.	4.0	mud
Missouri River	12/27	---	----	---	---	---------	3.0	mud, silt

EASTERN TRIBUTARIES

Illinois River	12/27	---	----	---	---	2:45 p.m.	4.0	mud

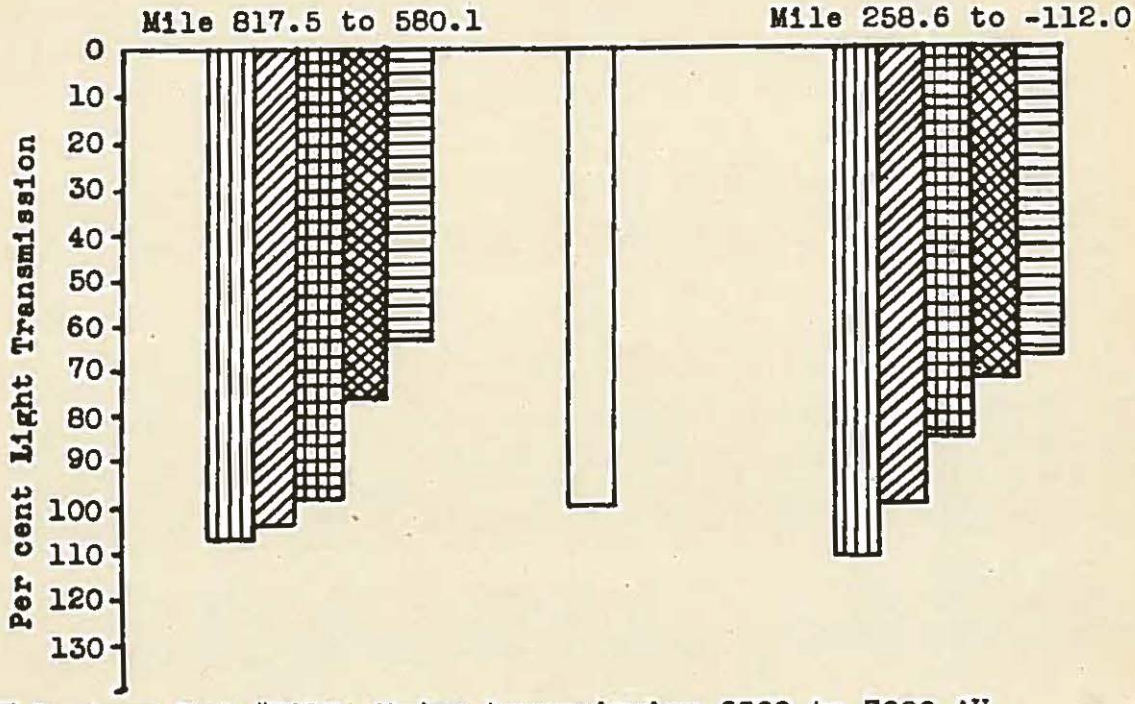
Table 11--Chemical analysis of water samples from tributaries of the Mississippi River (December 1944; midwinter period)

WESTERN TRIBUTARIES

Sample collected at mouth of river	Sp cond mho x 10^{-6} @ $25^{o}C$	pH	Parts per million										
			Dis-solved O_2 R. S.	O_2 con-sumed	HCO_3	CO_3	CO_2	Total	NH_3	PO_4	Cl	SO_4	Ca
Iowa River	1,510.0	7.90	11.12	20.0	164.0	0.00	2.64	0.08	0.50	0.06	9.62	32.5	----
Skunk River	627.0	7.85	11.50	30.5	162.5	0.00	2.64	0.08	0.76	0.17	4.92	65.6	---
Des Moines River	817.0	7.83	13.00	17.0	178.5	0.00	4.05	1.40	1.30	0.10	7.36	144.1	---
Missouri River	---	---	-----	32.0	-----	-----	----	7.83	3.43	0.28	20.00	79.5	---

EASTERN TRIBUTARIES

Illinois River	712.0	8.00	9.45	11.0	106.2	0.00	2.64	5.60	2.98	0.27	26.3	71.2	---



Lantern Red #2412. Major transmission 6300 to 7000 AU.
Noviol Shade C #3385. Major transmission 4900 to 5400 AU.
Sextant Green #4010. Major transmission 5100 to 5400 AU.
Dark theatre blue #5030. Major transmission 4000 to 4400 AU.
Violet #5113. Major transmission 3800 to 4300 AU.
White. 100 per cent transmission.

FIGURE 5.—Per cent light transmission in the Mississippi River.

CHEMICAL ANALYSES OF WATER

The data from the chemical analyses are so voluminous that they have been summarized here in the form of graphs. Although this method does not show the actual figures obtained it does show a general trend of the soluble constituents.

The variation of salts from sample to sample wassometime considerable. The rolling over of the river as described by many writers (Straub, 1942) would be expected to insure complete mixing, but this is far from the case. Density currents from tributaries, sloughs, and bayous are quite evident. Despite the fact that stations were chosen to avoid such density currents, except where their particular effect was to be studied, much variation still was found. Samples collected a few hours apart as in the cross-section studies of Lake Keokuk (tables 12-15) and Lake Pepin (tables 16 and 17) show this. (Figures 6,7, and 8).

All of the analytical data presented in the following section of this paper are expressed in parts per million, except conductivity which is given as mho x 10^{-6} at 25°C.; and hydrogen-ion concentration which is expressed as pH.

Dissolved Oxygen

Dissolved oxygen was determined by two different methods, those of: Rideal and Stewart (1901) and Winkler (1888). About 80 percent of the determinations were made by the Rideal-Stewart method. The two methods were often used in parallel and it was found that the Rideal-Stewart method usually gave a few tenths of a part per million lower, dissolved-oxygen than the Winkler methos.

The Mississippi River has a distinct seasonal oxygen pulse (figure9). In midwinter, when the river was frozen over with 4-8 inches of ice, oxygen ranged from 12.40 p.p.m. to 14.95 p.p.m. The low-water period of August and September had a range of from 3.00 to 7.10 p.p.m. of dissolved oxygen while the high-water period ranged from 4.30 to 11.50 p.p.m.

The tributaries, in general, has the same oxygen content as the Mississipp River for the three periods except the Illinois River which contained only 1.50 p.p.m. of dissolved oxygen on June 21 and 2,08 p.p.m. on September 8, 1944. This river was also comparatively low in oxygen content in midwinter, being 14. 5 percent lower than the average value for the same period in the Mississippi River (tables 6,7,8,9,10, and 11.

The dissolved oxygen in the Mississippi River tends to increase slightly downstream at least during the low-water period. The upper part of the river from mile 817.5 to mile 620.0 has an average value of 4.70 p.p.m., while the average value in the lower section, from mile 330 to mile 112, is 5.40 p.p.m. The opposite seems to be true during the high water period, that is, the oxygen content appears to decrease downstream.

This decrease in dissolved oxygen during high water may be due to the increased amount of debris, organic matter, and silt present in the river, at least this correlates with our total nitrogen values obtained for this same period (figure 11).

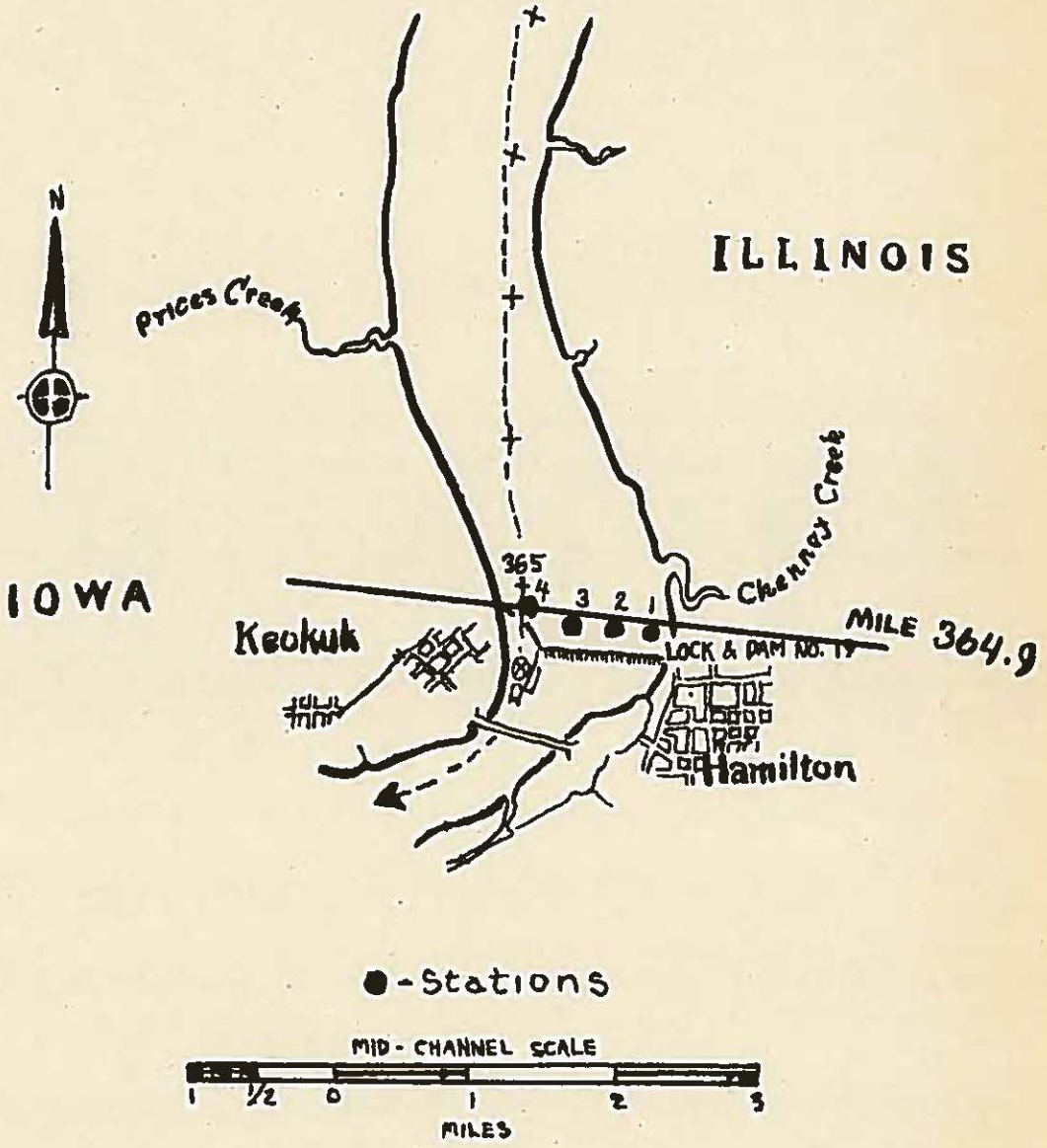


FIGURE 6.— Stations across the Mississippi River adjacent to Keokuk Dam which were sampled every six hours for 24 hours.

Table 12.--Cross-section sampling of Keokuk Lake adjacent to Keokuk dam (Samples collected every six hours for a 24-hour period, June 27 and 28, 1944)

PHYSICAL CHARACTERISTICS

10:00 a.m. Cross Section

Stations See fig. 6	tur-bidity p.p.m.	Per cent sedimen-tation (60 min)	Water temp. °C	Air temp. °C	Depth feet	Sample depth
1.	870	0.04	27.0	31.0	21.0	10.0
2.	870	0.07	26.5	31.0	18.0	9.0
3.	1110	0.10	25.6	31.0	14.0	7.0
4.	930	0.05	26.5	31.0	33.0	15.0

4:00 p.m. Cross Section

1.	930	0.04	26.9	31.0	21.0	10.0
2.	945	0.10	26.2	31.0	18.0	9.0
3.	1190	0.10	26.0	31.0	14.0	7.0
4.	1010	0.07	26.3	31.0	36.0	18.0

10:00 p.m. Cross Section

1.	1020	0.05	27.8	28.5	21.0	10.0
2.	2100	0.20	26.0	28.5	18.0	9.0
3.	1540	0.12	26.0	28.5	14.0	7.0
4.	1210	0.10	26.0	28.5	36.0	18.0

4:00 a.m. Cross Section

1.	1080	0.04	26.0	23.5	21.0	10.0
2.	1800	0.14	25.2	23.5	18.0	9.0
3.	1800	0.13	25.0	23.5	14.0	7.0
4.	1320	0.08	25.0	23.5	36.0	18.0

Note:-The bottom was mostly silt mixed with some sand at all four stations.

Table 13.--Chemical analysis of water samples collected in Lake Keokuk adjacent to Keokuk Dam (Samples collected every six hours for a 24-hour period)

10:00 a.m. Section

Station see fig 6	Sp. cond. mho x 10^{-6} at 25°C	pH	Parts per million							
			Dissolved oxygen	O.C.	HCO_3	Total	NH_3	PO_4	Cl	Ca
1.	286.5	7.45	3.94	21.5	95.3	0.62	0.20	0.24	1.2	--
2.	290.0	7.75	3.94	26.0	91.5	0.20	0.20	0.23	1.2	--
3.	285.0	7.75	4.44	24.8	87.5	0.62	0.18	0.26	0.9	--
4.	273.0	7.75	4.36	24.0	91.0	0.34	0.13	0.28	1.4	36.2

4:00 p.m. Section

1.	282.0	7.64	4.50	27.0	92.2	0.90	0.19	0.25	1.[illegible]	--
2.	277.0	7.64	4.23	23.2	89.5	0.20	0.19	0.24	1.2	--
3.	276.0	7.66	4.30	41.2	89.5	1.08	0.23	0.26	1.2	--
4.	267.0	7.64	4.36	26.0	87.6	1.18	0.19	0.24	1.0	34.1

10:00 p.m. Section

1.	277.1	7.70	4.01	33.5	89.0	3.00	0.22	0.24	1.0	--
2.	275.0	7.75	4.15	41.8	88.4	1.88	0.19	0.24	1.2	--
3.	269.0	7.75	3.45	30.3	8.4	2.30	0.15	0.23	0.7	--
4.	269.0	7.75	3.94	33.5	88.4	2.02	0.17	0.23	0.9	33.3

4:00 a.m. Section

1.	282.0	7.74	4.44	26.0	89.0	1.32	0.16	0.23	0.7	--
2.	265.0	7.75	4.28	41.7	85.8	1.60	0.15	0.20	1.2	--
3.	262.0	7.75	4.23	52.5	83.3	1.88	0.16	0.21	1.0	--
4.	267.0	7.75	4.62	30.8	84.0	1.46	0.17	0.22	1.0	33.1

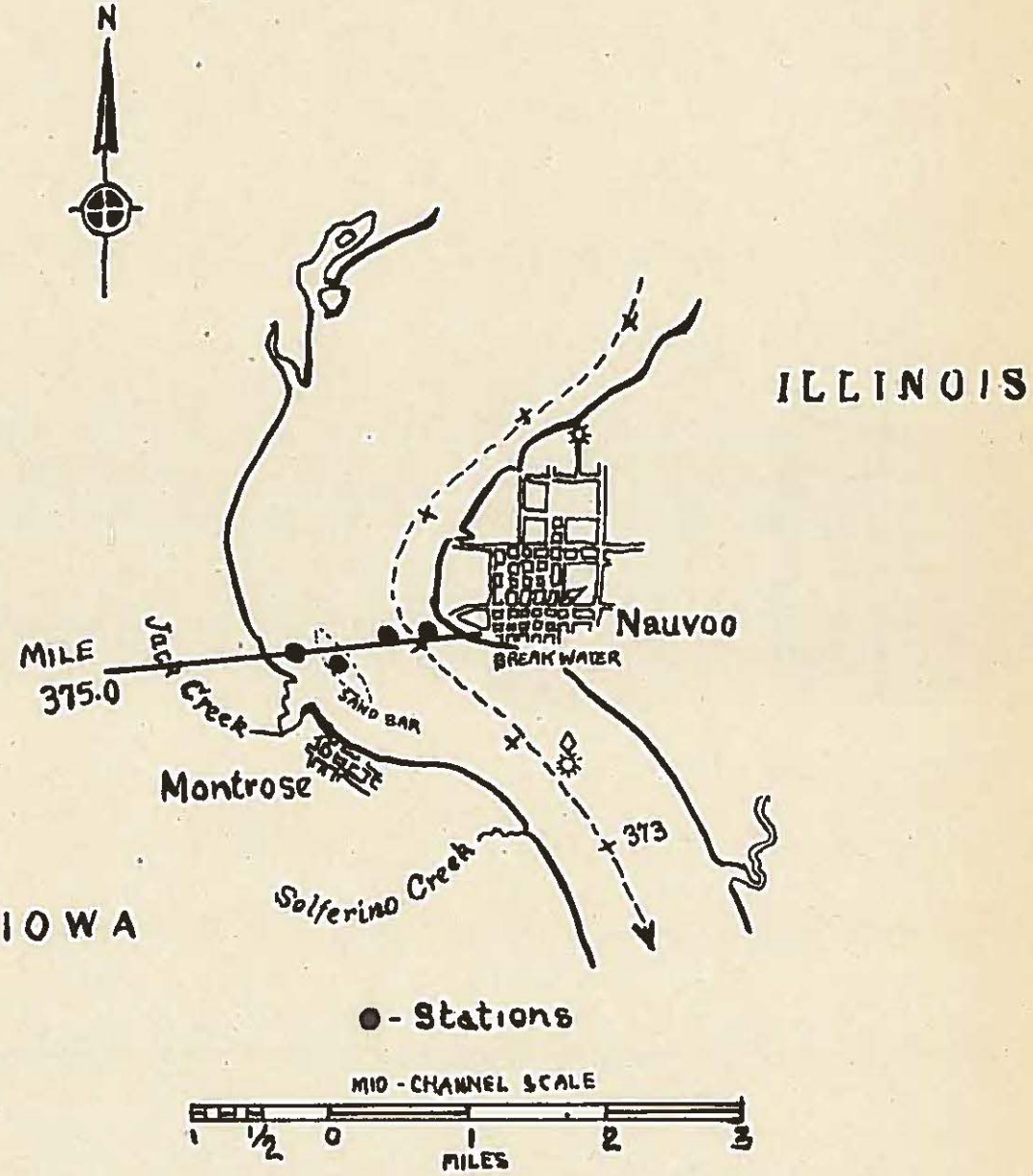


FIGURE 7. - Cross-section sampling of the Mississippi River between Montrose, Iowa, and Nauvoo, Illinois.

Table 14.--Physical characteristics of Mississippi River (Stations established across the river between Montrose, Iowa, and Nauvoo, Ill., June 26, 1944)

MILE 375.0

Stations see fig. 7	Turbidity p.p.m.	Percentage sedimentation (60 min.)	Water temp. °C	Air temp. °C	Time	Water depth feet	Sample depth feet	Bottom
East bank	935	0.11	25.3	26.0	a.m.	6.0	3.0	silt, mud
Mid channel	745	0.07	24.3	26.0	do	24.0	12.0	---------
Over sand bar	970	0.10	24.8	26.0	do	12.0	6.0	sand
West bank	1010	0.08	25.0	26.0	do	18.0	9.0	mud

Table 15.--Chemical analysis of samples of water collected across the Mississippi River between Montrose, Iowa, and Nauvoo, Ill. (June 26, 1944)

MILE 375.0

Stations see fig. 7	Sp. cond. mho x 10^{-6} @ 25°C	pH	O_2 R. S.	O. C.	HCO_3	Parts per million CO_3	CO_2	Total (N)	NH_3	PO_4	Cl	SO_4	Ca
East bank	301	7.80	3.17	26.0	96.0	0.00	Trace	2.16	0.19	0.28	1.70	0.00	34.6
Mid channel	291	7.89	3.38	25.0	89.0	0.00	do	3.14	0.28	0.27	1.70	0.00	34.6
Sand bar	299	7.83	2.82	27.5	91.5	0.00	do	0.62	0.17	0.28	1.40	0.00	34.6
West bank	350	7.89	3.17	34.8	100.0	0.00	do	4.12	0.18	0.28	2.00	5.80	34.6

Note:-Sandbar noted for good fishing for carp and catfish.
Iron, zinc, fluoride, manganese and copper were not detected by methods used.
A trace of CO indicated 1.0 p.p.m. or less.

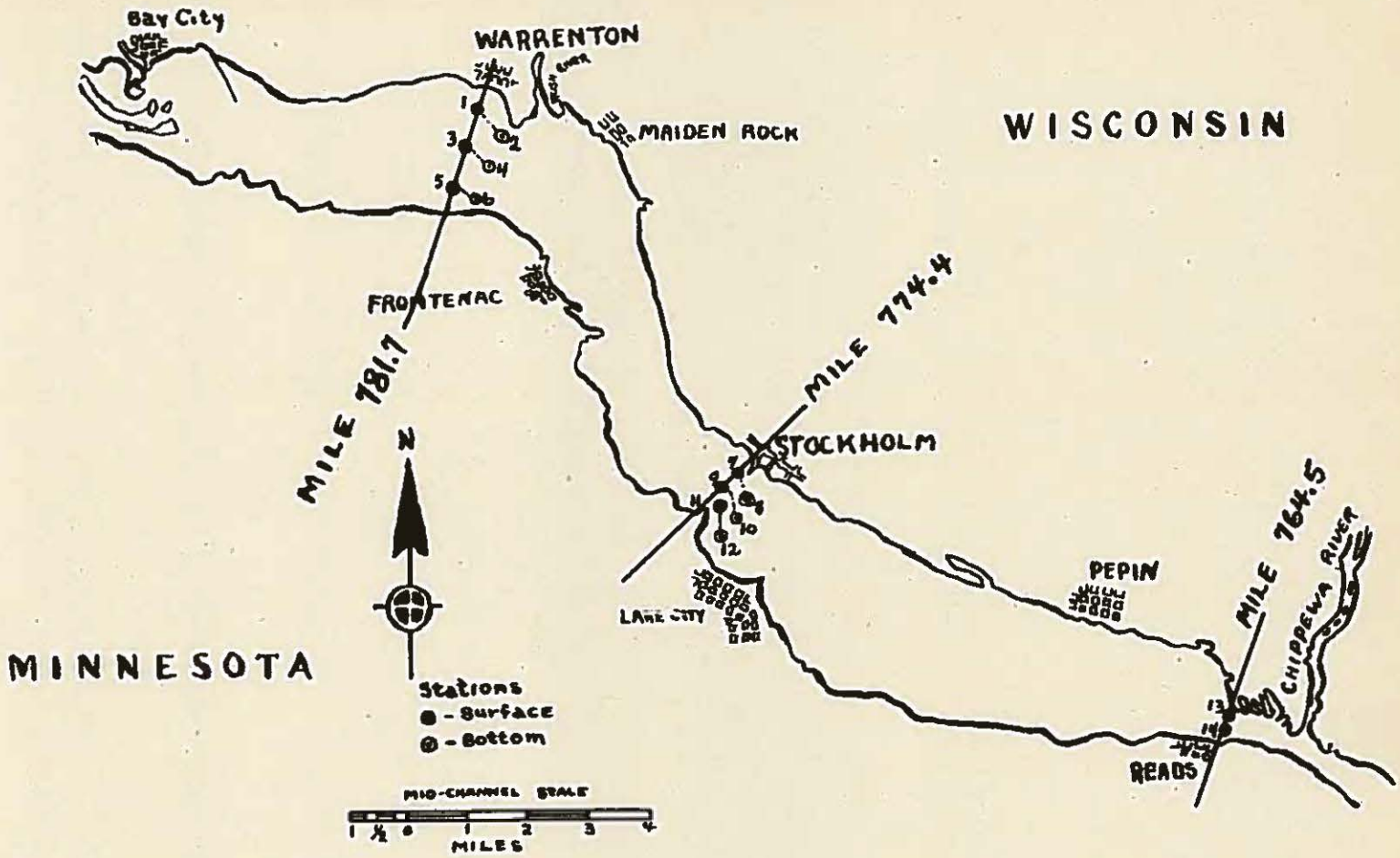


FIGURE 8.— Cross-section sampling of Lake Pepin.
(Surface and bottom samples were collected a few minutes apart)

Table 16.--Physical Characteristics of Lake Pepin (August 20, 1944)

Mile 781.7

Station See fig. 8	Turbidity p.p.m.	Percentage sedimentation (60 min.)	Water temp. °C	Air temp. °C	Time	Depth in feet	Sample Depth in feet	Bottom
1.Surface	132	Trace	23.0	20.5	8:45 a.m.	18	3.0	
2.bottom	213	0.03	23.0	20.5	8:55 a.m.	18	18.0	mud containing bloodworms
3.surface	113	Trace	23.2	20.5	9:10 a.m.	21	3.0	
4.bottom	113	Trace	23.2	20.5	9:15 a.m.	21	21.0	mud
5.surface	81	0.00	23.2	20.5	9:30 a.m.	24	3.0	
6.bottom	103	0.00	23.2	20.5	9:35 a.m.	24	24.0	mud containing bloodworms

Mile 774.4

7.surface	74	0.00	24.0	22.7	10:30 a.m.	27	3.0	
8.bottom	100	0.01	24.0	22.7	10:35 a.m.	27	27.0	mud containing bloodworms
9.surface	70	0.00	24.2	22.7	10:40 a.m.	30	3.0	
10.bottom	100	0.03	23.0	22.7	10:45 a.m.	30	30.0	" " "
11.surface	70	0.00	23.7	22.7	10:50 a.m.	39	3.0	
12.bottom	70	Trace	23.5	22.7	10:50 a.m.	39	39.0	" " "

Mile 764.5

13.	36	Trace	24.7	24.5	12:10 p.m.	9	4.5	coarse gravel
14.	43	Trace	25.6	24.5	12:40 p.m.	15	7.5	small shells, leaches

Table 17.--Chemical analysis of water samples collected in Lake Pepin (August 20, 1944)

Stations (see Figure 8)	Sp.cond. mho x 10^{-6} at $25^{\circ}C$.	pH	Parts per million								
			Dis-solved oxygen	O.C.	HCO_3	CO_3	NH_3	PO_4	Cl	SO_4	Ca
Mile 781.7											
1 Surface	277.0	8.00	5.03	--	74.2	2.76	--	--	--	--	--
2 Bottom	280.0	8.02	4.18	--	73.7	2.76	--	--	--	--	--
3 Surface	276.0	8.10	3.14	25.5	77.8	2.77	0.28	0.36	1.00	0.00	38.0
4 Bottom	268.0	8.06	3.64	--	70.5	2.76	--	--	--	--	--
5 Surface	264.0	8.20	5.20	--	70.9	3.60	--	--	--	--	--
6 Bottom	276.0	8.14	4.77	--	72.5	2.04	--	--	--	--	--
Mile 774.4											
7 surface	302.0	8.20	3.47	--	80.6	4.20	--	--	--	--	--
8 Bottom	312.0	8.15	3.25	--	81.3	3.60	--	--	--	--	--
9 Surface	270.0	8.18	5.20	25.5	77.8	2.77	0.31	0.33	1.25	0.00	39.5
10 Bottom	277.0	8.18	4.12	--	73.8	2.76	--	--	--	--	--
11 Surface	270.0	8.18	5.20	--	75.0	2.76	--	--	--	--	--
12 Bottom	271.0	8.18	4.61	--	73.3	2.76	--	--	--	--	--
Mile 764.4											
13 Surface	319.0	8.22	5.26	27.0	89.2	3.60	0.31	0.32	2.50	0.00	48.2
14 Surface	323.0	8.12	3.47	--	84.9	2.76	--	--	--	--	--

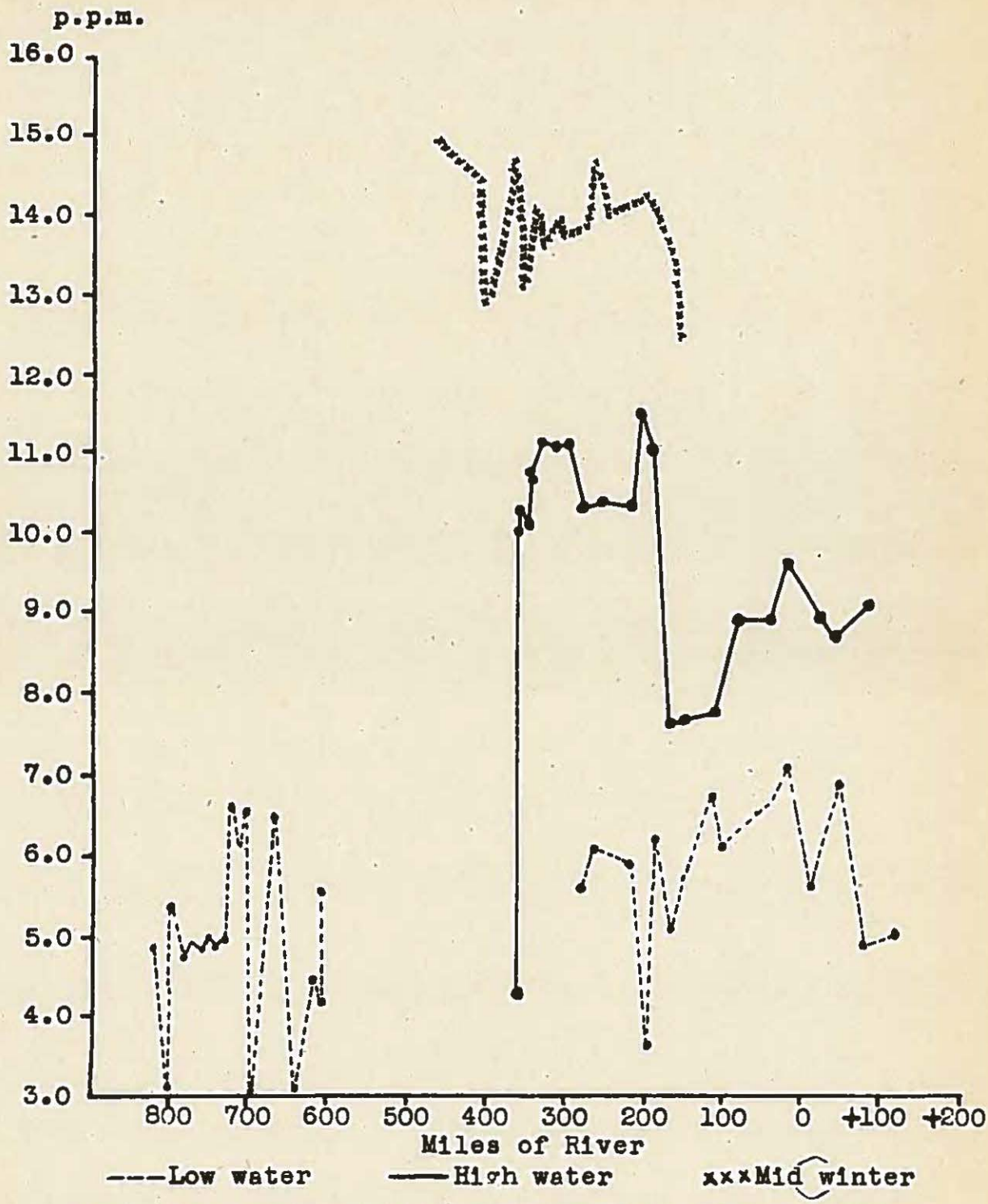


FIGURE 9.— Dissolved oxygen in the Mississippi River.

The oxygen content of the water in sloughs and wooded areas in midwinter when covered with 4 to 6 inches of ice was parallel with that found in the main channel of the Mississippi River.

Oxygen Consumed

The oxygen consumed was determined by the permanganate method (American Public Health, 1936). The 10x method was used entirely.

During the period of high water, oxygen-consumed values in the main channel of the Mississippi River ranged from 7.80 p.p.m. to 43.0 p.p.m. with an average around25 p.p.m. The upper section from mile 280 to mile 600 had less variation and averaged about 22.0 p.p.m. That section immediately below the Missouri River had higher values than any other part of the river having an average of 34 p.p.m. (figure 10).

Results obtained in the low-water period indicated that a greater amount of oxidizable material was present at mile 800 and progressively decreased to mile 170, the average oxygen-consumed value being 22.p.p.m. From mile 170 which is in the vicinity of St. Louis, Mo., to mile + 112 Caruthersville, Mo., the average value increased to 36.0 p.p.m.

The midwinter studies, although not as extensive as the low- and high-water studies indicate a range of from 23.0 p.p.m. to 50 p.p.m. with an average of about 34 p.p.m. oxygen consumed.

The tributaries are particularly interesting. Reference to table 7 will show that Root River during the period of high water had a value of 124.0 p.p.m. oxygen consumed while that for the Ohio River was exceptionally low, being only 0.3 p.p.m. It should be noted that these values are the extremes and that both occurred during the same period. Furthermore, Root River was exceptionally low in oxidizable material during the low-water period. To explain these differences would require much more sampling and more detailed study of the tributaries.

The data on oxygen consumption are very difficult to interpret because of the extremely wide variation from sample to sample. However a few general statements seem warranted.

The section of the Mississippi River below the mouth of the Missouri River definitely has an increase in matter oxidizable by permanganate. The winter studies indicate much higher oxygen-consumed values than either the low-or high-water studies covering the same section of the river between mile 450 and mile 200. There also seems to be more oxidizable material in the upper part of the river around mile 800 than there is at mile 300.

Total Nitrogen

The determination of total nitrogen in the Clarksville cross-section samples was done by Kjeldahl method as described by Peters and Van Slyke (1932). When small volumes of water were employed the micro-method of Koch and McMeekin (1924) was employed. Samples which were preserved in the field with concentrated sulphuric acid, were used without exception (figure 4 and tables 18-23) for total nitrogen determinations.

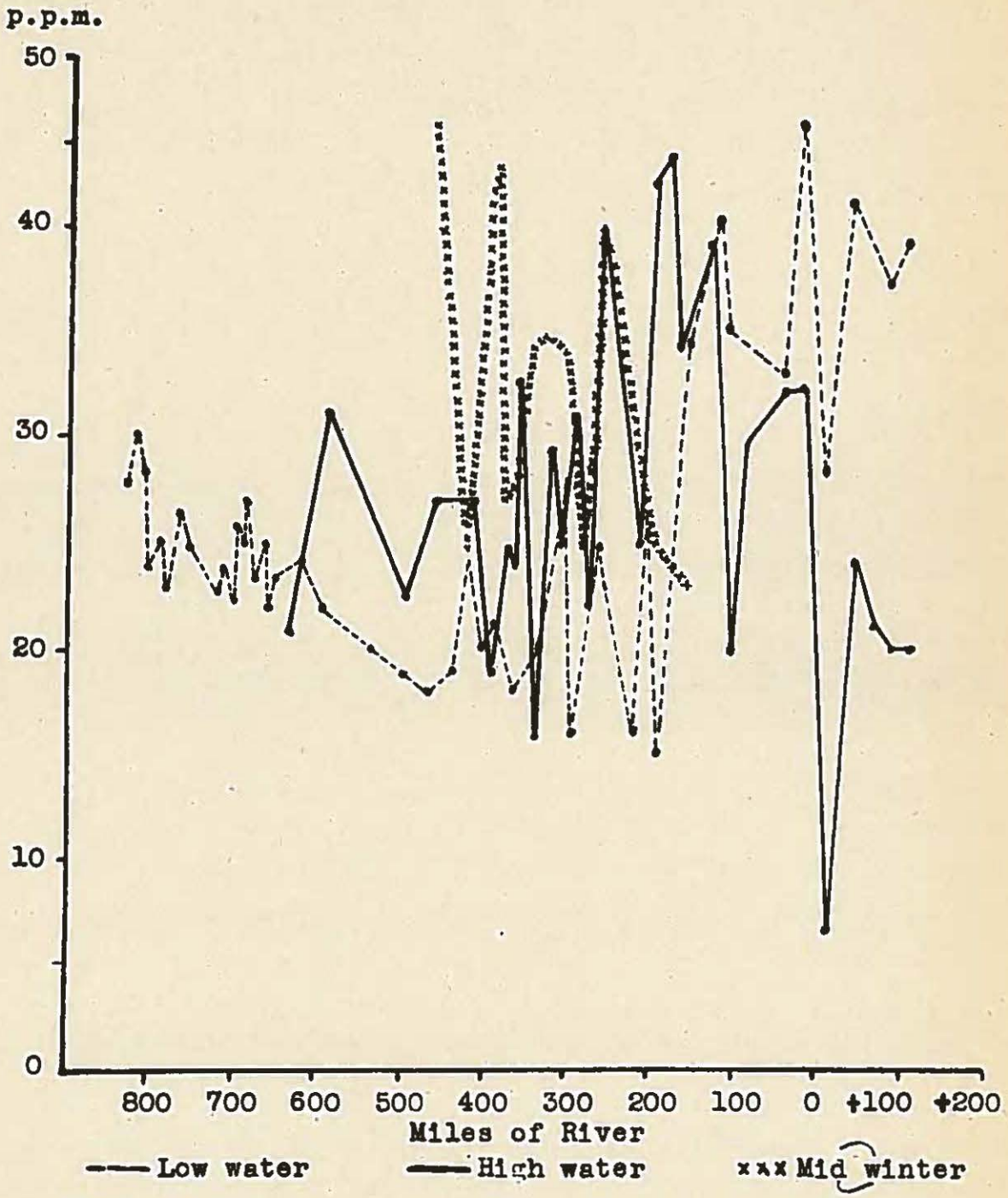


FIGURE 10.— Oxygen consumed in the Mississippi River.

Throughout the period of high water total nitrogen increases steadily as one proceeds downstream (figure 11). The individual samples for this period ranged from 0.34 p.p.m. to 9.76 p.p.m. the average being about 4.50 p.p.m.

In direct contrast to the high-water values, the low-water figures indicate a decline in total nitrogen as one proceeds down the river, the range being from 0.70 p.p.m. to 3.10 p.p.m. with an average of 1.70 p.p.m.

The midwinter values tend to increase somewhat in the lower portion of the river. The actual determinations range from 0.30 p.p.m. to 1.25 p.p.m. with an average of 0.8 p.p.m., this being about half of the value found for the low water period.

The tributaries show no correlation with the Mississippi as to total nitrogen. The Missouri River had a high value of 7.83 p.p.m. for the midwinter period as contrasted with the lower value of 2.03 p.p.m. during low water. The Iowa and Skunk Rivers in the winter were quite low, but with value of 0.08 p.p.m. while the low-water period had values of 1.65 p.p.m. and 1.40 p.p.m., respectively.

The determinations of total nitrogen for the cross-section studies of the Mississippi River between Clarksville, Mo., and Louisiana, Mo., were run on four liters of water concentrated to small volumes. These results indicate that impounded waters such as Swan Lake, Spring Lake, and barrow pit, which are usually flooded by the Mississippi River each spring, have slightly higher total nitrogen values than the main channel. (Tables 18, 19, 20, 21,22, and 23). It was interesting to note that water collected behind a series of islands and amoung dead trees had values slightly higher than those of the main channel.

Ammonia

Ammonia was determined by direct nesslerization as described by the American Public Health Association (1936), except that Nessler's reagent was made up according to Koch and McMeekin (1924). Another variation was the use of a photelometer instead of Nessler's tubes, to determine the amount of color developed. Absolute values were then read from a previously standardized curve.

The ammonia values for Mississippi River samples (figure 12) during the period of high water ranged from 0.05 p.p.m. to 0.52 p.p.m., the average being about 0.20 p.p.m. The largest amount of ammonia was found below cities where raw sewage was emptied into the river.

Values of ammonia for the low-water period appeared to be divided into three distinct sections. The sections from mile 817.5 to mile 580.0 had high values ranging from 0.18 p.p.m. to 1.5 p.p.m. with an average of 0.60 p.p.m. That from mile 580 to mile 170 (St. Louis, Mo., area) ranged from zero to 0.1 p.p.m. with an average of 0.06 p.p.m. Below St. Louis, Mo., the amount of ammonia in the river increased slightly to an average of 0.12 p.p.m.

The amount of ammonia in the Mississippi River in Midwinter averaged much higher than during either the high- or low-water periods for that section of the river where these determinations overlap. The values ranged from 0.05 p.p.m. to 1.14 p.p.m., with most of the readings around 0.4 p.p.m.

Table 18.--Physical characteristics of the Mississippi River and adjacent waters

MILE 275

Stations		Date	Turbidity p.p.m.	Percentage sedimentation*	Water temp. °C	Air Temp. °C	Time	Depth in feet	Bottom
I	Bay	Sept. 19	295	0.05	23.0	27.5	3:30 p.m.	3.5	mud, silt, sand
II	Barrow Pit	Sept. 20	98	0.02	19.8	24.0	9:40 a.m.	2.0	mud, sticks, leaves
III	Chute	do	455	Trace	22.2	24.0	9:55 a.m.	21.0	sand with silt
IV	Island	do	490	Trace	22.2	21.8	10:20 a.m.	2.0	stiff mud
V	Island	do	515	Trace	22.3	22.5	10:40 a.m.	4.0	stiff mud
VI	Channel	do	370	Trace	25.0	22.5	11:00 a.m.	20.0	sand covered silt
VII	Channel	do	370	Trace	24.0	25.0	11:15 a.m.	13.0	mud, mayfly larvae
VIII	Woods	do	185	Trace	26.1	30.5	1:05 p.m.	3.0	mud, sticks
IX	Island	do	275	Trace	25.2	31.0	1:40 p.m.	5.0	mud,
X	Island	do	270	Trace	25.5	31.0	2:00 p.m.	5.0	mud
XI	Island	do	278	0.01	25.3	31.0	2:20 p.m.	4.0	mud
VII	Channel	Dec. 26	---	----	0.0	-8.0	4:40 p.m.	15.5	mud
VIII	Woods	do	---	----	0.0	-8.0	5:00 p.m.	6.0	mud
IX	Islands	do	---	----	0.0	-8.0	5:15 p.m.	4.0	mud

*Sedimentation recorded after one hour.

Table 19.--Chemical analysis of water samples from the Mississippi River, including sloughs and and lakes flooded in periods of high water (September 1944)

MILE 275

Stations		Sp. Cond. mho x 10^{-6} @ 25°C	pH	O_2 in p.p.m. R.S.	Parts per million												
					HCO_3	CO_3	CO_2	Total (N)	NH_3	Mn	Zn	F	Cu	Fe	PO_4	Cl	Ca
I	SNY	662	7.82	5.62	115.0	0.00	3.50	1.54	1.30	1.30	0.00	0.00	0.00	1.80	0.72	103.20	55.9
II	BARROW PIT	337	7.35	0.32	96.0	0.00	15.00	3.25	2.08	1.70	0.00	0.00	0.00	3.80	3.90	0.00	39.4
III	CHUTE	354	7.90	5.52	80.5	0.00	1.70	1.09	0.75	0.00	0.00	0.00	0.00	1.20	0.53	1.54	37.4
IV	ISLAND	290	8.00	5.05	83.0	0.00	1.70	1.25	0.77	0.00	0.00	0.00	0.00	1.15	0.53	1.44	37.7
V	ISLAND	289	8.11	5.54	84.5	0.00	1.70	1.23	0.82	0.00	0,00	0,00	0,00	1.16	0.53	0.38	36.8
VI	CHANNEL	341	8.25	5.63	83.0	0.00	1.70	1.13	0.95	0.05	0.00	0.00	0.00	0.95	0.51	2.60	39.4
VII	CHANNEL	326	8.25	5.61	84.0	0.00	1.70	1.08	0.25	0.03	0.00	0.00	0.00	1.21	0.48	2.12	38.0
VIII	WOODS	362	8.50	7.23	90.0	2.40	0.00	1.42	0.37	0.15	0.00	0.00	0.00	0.70	0.34	2.22	43.6
IX	ISLAND	363	8.24	5.68	93.0	0.60	0.00	1.22	0.42	0.25	0.00	0.00	0.00	0.61	0.34	0.66	40.4
X	ISLAND	363	8.36	7.12	92.0	2.00	0.00	1.37	0.37	0.26	0.00	0.00	0.00	0.75	0.41	3.46	44.3
XI	ISLAND	364	8.51	6.43	92.0	0.60	0.00	1.18	0.35	0.15	0.00	0.00	0.00	0.75	0.34	1.16	44.6

R;S.- oxygen method of Rideal and Stewart.
Iron, manganese, zinc, fluoride and copper were determined on acidified samples.

Table 20.--Physical characteristics of the Mississippi River and adjacent waters

MILE 278

Stations	Date	Turbidity p.p.m.	Percentage sedimentation*	Water temp. °C	Air temp. °C	Time	Depth in feet	Bottom
XII Chute	Sept. 21	490	Trace	25.2	31.0	2:10 p.m.	16.0	sand
XIII Island	do	530	Trace	25.5	31.0	2:20 p.m.	3.5	mud, containing mayfly larvae
XIV Island	do	497	Trace	25.7	31.0	2:35 p.m.	3.0	do
XV Channel	do	398	Trace	24.0	31.0	3:00 p.m.	20.0	sand
XVI Channel	do	410	Trace	25.5	31.0	3:15 p.m.	20.0	do

Note:-Sample collected ½ the depth unless depth was less than 3 feet.
*Sedimentation recorded one hour after collection of sample.

Table 21.--Chemical analysis of samples of water from the Mississippi River and adjacent waters (September, 1944)

MILE 278

Stations	Sp.condl mho x 10^{-6} @ 25°C.	pH	O_2 in p.p.m. R.S.	HCO_3	CO_3	CO_2	Total (N)	NH_3	Mn	Zn	F ///	Cu	Fe	PO_4	Cl	Ca
XII CHUTE	336	8.40	6.00	86.5	0.00	1.70	1.27	0.63	0.07	0.00	0.00	0.00	1.63	0.53	0.28	39.2
XIII ISLAND	335	8.34	6.25	86.0	0.00	1.70	1.27	0.67	0.15	0.00	0.00	0.00	1.68	0.57	0.38	41.8
XIV ISLAND	336	8.20	4.15	84.0	0.00	2.60	1.20	0.69	0.15	0.00	0.00	0.00	1.58	0.54	0.66	40.5
XV CHANNEL	340	8.10	5.10	84.5	0.00	1.70	1.15	0.55	0.15	*	0.00	*	1.31	0.52	2.12	39.5
XVI CHANNEL	344	8.21	6.25	83.0	0.00	2.60	1.11	0.65	0.20	0.00	0.00	0.00	1.42	0.50	0.76	38.5

Iron and manganese determined on acidified samples. Total nitrogen, *zinc=0.0125 p.p.m., and * Copper-0.027 p.p.m., determined by acidified samples concentrated from four liters of water.
R.S.-Method of Rideal and Stewart.

Table 22.--Physical characteristics of the Mississippi River and adjacent waters

MILE 280

Stations	Date	Turbidity p.p.m.	Percentage sedimentation*	Water temp. °C	Air temp. °C	Time	Depth in feet	Bottom
XVII BARROW PIT	Sept. 21	605	Trace	22.0	22.5	11:30 a.m.	0.7	mud, sticks, leaves
XVIII CHUTE	do	195	0.04	23.8	25.5	11:45 a.m.	15.0	sand
XIX ISLAND	do	275	Trace	23.9	25.6	12:00 noon	3.0	mud, containing mayfly larvae
XX CHANNEL	DO	80	Trace	23.3	25.6	12:20 p.m.	17.0	sand
XXI CHANNEL	do	64	Trace	25.6	23.8	12:35 p.m.	21.0	sand
XXII TREES	do	435	Trace	26.5	25.6	12:55 p.m.	1.0	mud, sticks, leaves
XXIII SPRING L.	Sept. 19	585	Trace	26.3	31.0	2:00 p.m.	3.5	mud, sand
XXIV SWAN L.	Sept. 22	585	Trace	23.0	21.0	3:15 p.m.	3.0	mud, sticks, leaves
XXV SNY	do	335	Trace	22.2	21.0	1:00 p.m.	18.0	hard-packed mud
XXVI 1903 BREAK	do	510	Trace	23.0	21.0	2:30 p.m.	2.0	mud, leaves
XXIII SPRING L.	Dec. 29	---	-----	2.0	----	12:45 p.m.	3.0	mud
XXV SNY	Dec. 29	---	-----	2.0	----	12:30 p.m.	2.0	hard mud

Note:-Sample collected $\frac{1}{2}$ the depth unless depth was less than 3 feet.
*Sedimentation recorded one hour after collection of sample.

Table 23.--Chemical analysis of samples of water from the Mississippi River and adjacent waters (September 1944)

MILE 280

Stations	Sp. Cond. mho x 10^{-6} @ 25°C	pH	Parts per million													
			O_2 R.S.	HCO_3	CO_3	CO_2	Total	NH_3	Mn	Zn	F	Cu	Fe	PO_4	Cl	Ca
XVII SPRING LAKE	212	8.21	4.72	55.5	0.00	1.70	1.66	0.63	0.75	0.00	0.00	0.00	2.10	0.59	0.00	24.4
XVIII THE SNY	582	8.10	6.64	95.5	0.00	5.30	1.14	0.96	0.70	0.00	0.00	0.00	1.55	0.56	65.60	47.2
XIX SWAN LAKE	297	7.77	6.26	63.5	0.00	1.70	1.84	0.84	0.80	*	0.00	0.00	1.50	0.63	3.86	30.4
XX 1903 BREAK	408	7.65	6.80	114.0	0.00	8.80	1.04	0.96	1.95	0.00	0.00	0.00	1.95	0.33	0.70	46.8
XXI BARROW PIT	345	7.50	2.45	93.0	0.00	10.50	0.67	0.50	1.20	0.00	0.00	0.00	1.20	1.25	0.96	41.9
XXII CHUTE	336	7.60	3.65	83.0	0.00	1.70	1.17	0.46	1.52	0.00	0.00	0.00	1.52	0.52	0.08	36.8
XXIII ISLAND	339	8.05	5.40	86.0	0.00	1.70	1.35	0.52	2.00	0.00	0.00	0.00	2.00	0.62	2.12	38.0
XXIV ISLAND	336	8.20	6/05	83.0	0.00	1.70	1.08	0.50	1.40	0.00	0.00	0.00	1.40	0.53	1.14	38.5
XXV CHANNEL	348	8.14	5.35	83.0	0.00	1.70	1.16	0.60	1.35	0.00	0.00	*	1.35	0.46	1.92	38.1
XXVI TREES	351	8.20	7.55	83.0	0.00	1.70	1.36	0.73	1.70	0.00	0.00	0.00	1.70	0.53	2.50	38.9

Iron and manganese determined from acidified samples.
Total nitrogen, *zinc-p.465 p.p.m., *copper-0.027 p.p.m., determined from acidified samples concentrated from four liters of water.
R.S.--Method of Rideal and Stewart.

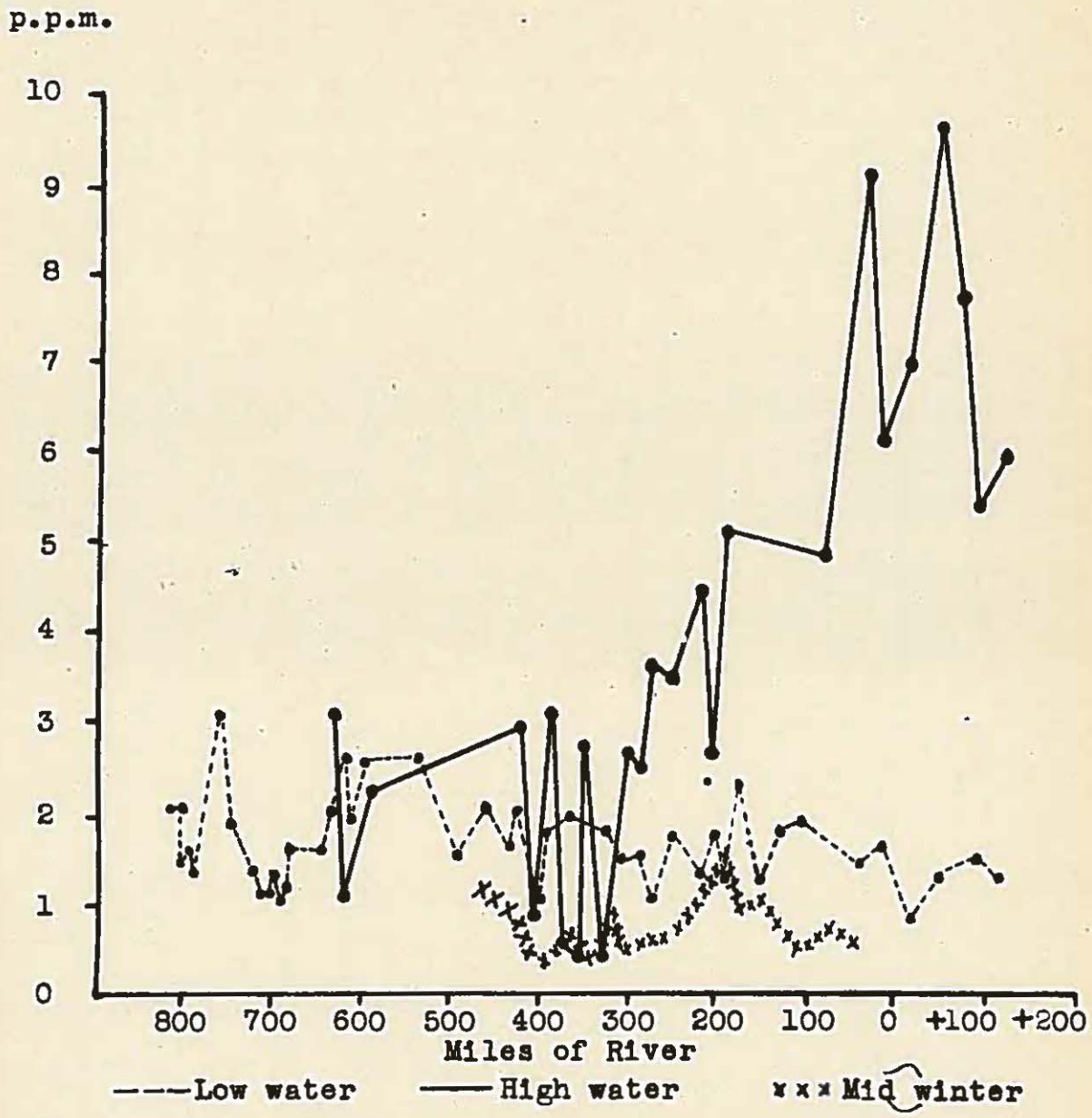


FIGURE 11.— Total Nitrogen (N) in the Mississippi River.

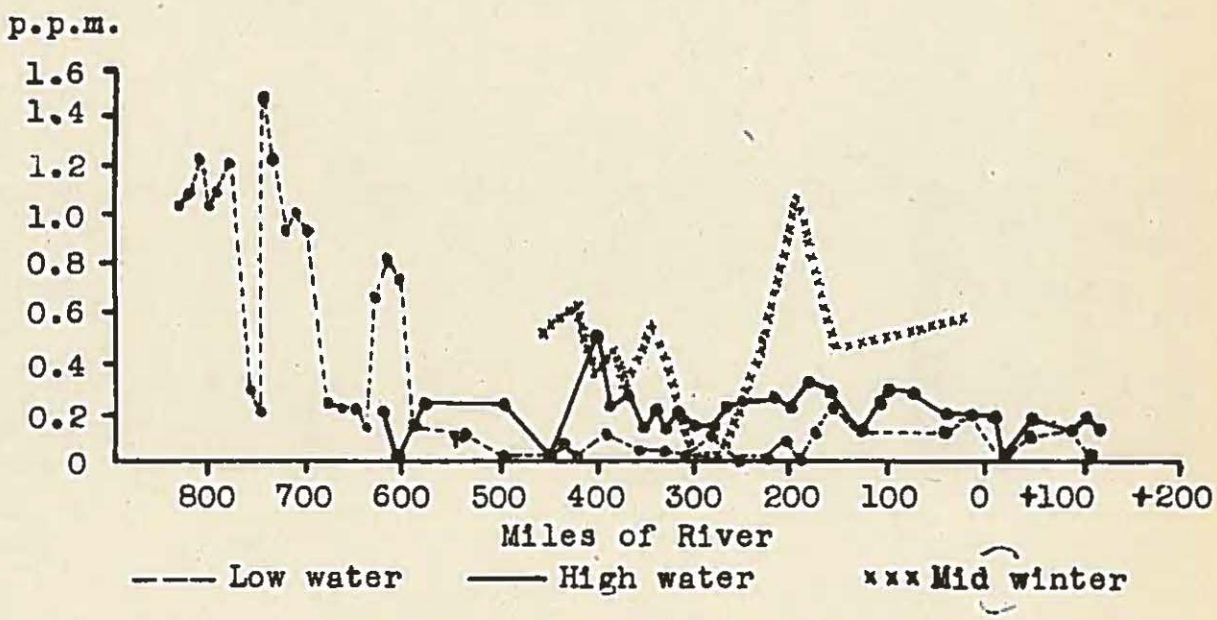


FIGURE 12.— Ammonia (NH_3) in the Mississippi River

Though the tributaries of the Mississippi (table 7-9-11) have variable amounts of ammonia, certain generalizations can be made. The rivers entering the Mississippi from the west have less ammonia than those from the east. This may be due to higher industralization along the rivers on the eastern side of the River. The Illinois and Missouri rivers showed a definite increase in the amount of ammonia in midwinter .

The amounts of ammonia found in the samples collected at the cross-sectional areas studies between Clarksville, Mo., and Louisiana, Mo., (tables 18, 19, 20, 21, 22, and 23) are slightly lower on the Missouri, than on the Illinois side.

The barrow pit shows a high value of ammonia. This is probably due to decaying vegetation. Since the water here was mostly stagnant this is not surprising.

Phosphates

Phosphates were determined by Deniges (1920) method, using stannous chloride as a reducing agent to develop the blue phos-phomolybdous acid. Fresh ammonium-molydate reagent was made whenever the zero concentration did not check. The method was adapted for use with a photelometer and the calculations were made by preparing a curve from standard solutions of phosphate.

Examination of figure 13 shows that the amount of phosphate in the Mississippi River varies with the seasons. During December the phosphate ranged from 0.03 p.p.m. to 0.20 p.p.m. with an average value of 0.13 p.p.m. Although the water stage in the river in December was about the same as during the low-water period of August and September, the phosphate content for this latter period ranged from 0.20 to 0.40 p.p.m. and averaged 0.31 p.p.m. The phosphate content of the river during high water ranged from 0.20 p.p.m. to 3.30 p.p.m. and averaged 0.25 p.p.m.

The tributaries varied in the same manner as the Mississippi River for the three seasons, that is, they had high phosphate during low-water, low phosphate in midwinter, with intermediate values for the high-water period. The phosphate content, in general, was much higher in the tributaries than in the main river. TheTrempealeau River, for instance, contained 0.55 p.p.m., the Illinois River, 0.47 p.p.m., and the Des Moines River 0.42 p.p. . during the low-water period.

Beside the tributaries as sources of phosphate for the Mississippi River such bodies of water as the barrow pit which was included in the cross-section study at mile 275, contained 3.90 p.p.m. This would also be a good source of phosphates.

It was of particular interest to find that McGregor Lake had a phosphate content of 0.40 p.p.m. while the channel of the Mississippi River at McGregor, Iowa, mile 633.8, contained only 0.32 p.p.m. Although this difference is not great, it indicates that one would expect to find more phosphate in sloughs and lakes than in the main channel (tables 24 and 25).

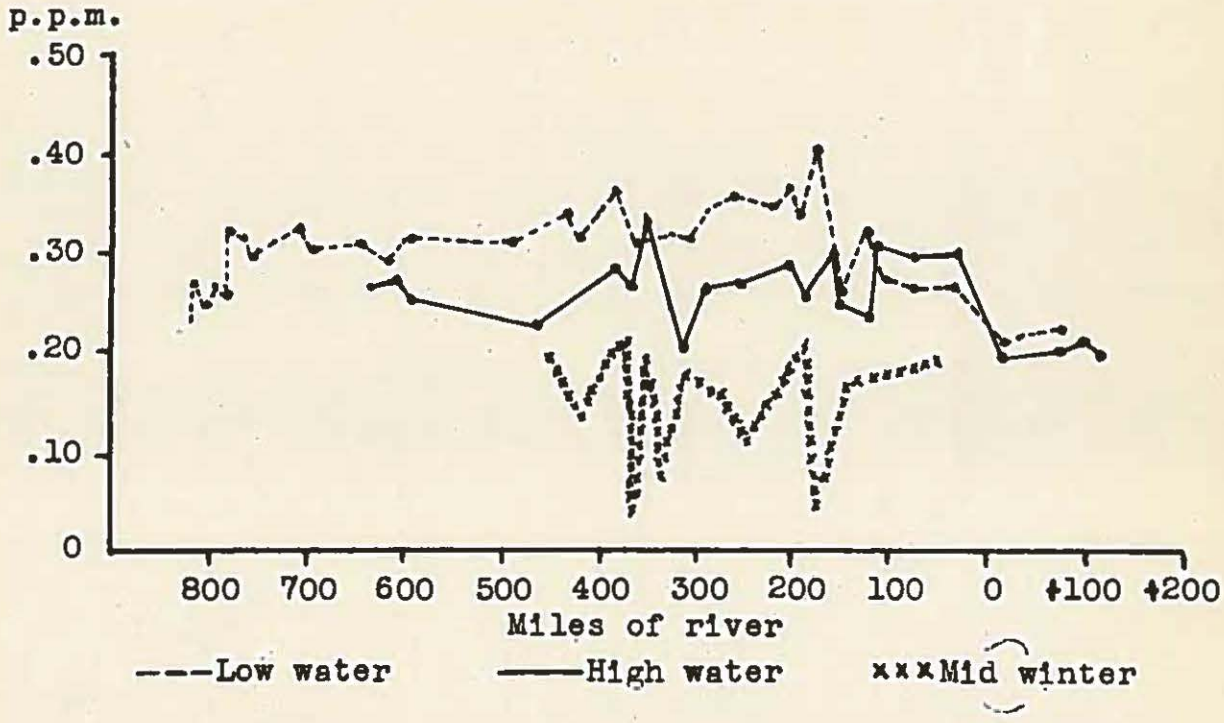


FIGURE 13.— Phosphates (PO_4) in the Mississippi River.

Table 24.--Physical characteristics of McGregor Lake, McGregor, Iowa, August 12, 1944

Station	Turbidity p.p.m.	Per cent sedimentation (60 min.)	Water temp. °C	Air temp. °C	Time	Lake depth feet	Sample depth feet	Bottom
East shore of lake	74	---	30.9	26.0	1:00 p.m.	6.0	3.0	black mud
Center of lake	75	Trace	29.0	26.0	1:15 p.m.	8.0	4.0	do .

Table 25.--Chemical analysis of samples of water collected at McGregor Lake, McGregor Iowa, August 12, 1944

Stations	Sp. cond. mho x 10^{-6} @ 25°C	pH	Dis-solved O_2	O_2 con-sumed	HCO_3	CO_3	CO_2	Total	NH_3	PO_4	Cl	SO_4	Ca
East shore of lake	291.0	8.75	6.68	----	84.5	11.40	0.00	---	---	---	--	---	---
Center of Lake	296.0	8.59	7.95	19.0	81.3	9.60	0.00	3.30	---	0.43	2.38	--	38.8

Note: Zinc, iron, fluoride, manganese, and copper were not detected by methods used.

Chlorides

The Volhard method for the determination of chlorides as described by Kolthoff and Sandell (1938), with Calfwell's modification, was employed.

Chlorides enter the Mississippi River, in part at least from human contamination, but largely from the western tributaries. Excluding the Illinois River which was always high in chlorides, about 69 percent of all the chloride from the tributaries come from the western side, and only 30 percent comes from the eastern.

The Illinois River was found to contain more chloride than any of the other rivers studied. During the period of low water it carried 23.3 p.p.m. chloride, during higher water 16.6 p.p.m. and in the midwinter 26.3 p.p.m. All of these values are about about twice as high as those for any of the other tributaries for the same periods (tables 6, 7, 8, 9, 10, and 11).

The chlorides in the Mississippi River accumulate down stream (see figure 14). In the upper river from mile 400 to mile 817 the amount of chloride during the low-water period ranged from zero to 4.0 p.p.m. and averaged 2.2 p.p.m., while in the lower section it ranged from 2.8 to 7.0 p.p.m., with an average of 4.8 p.p.m. for the same period.

Chloride values for the high-water period were the lowest, ranging from zero to 3.1 p.p.m. and averaging 1.9 p.p.m.

The midwinter period showed a surprising increase in the amounts of chloride, these ranging from 0.79 p.p.m. at Fairport, Iowa, mile 463.2 to 18.5 p.p.m. at St. Louis, Mo., mile 172; the average was 7.0 p.p.m.

The Sny River which was included in the Clarksville-Louisiana, Mo., cross-section studies had an exceptionally high chloride content of 103.2 p.p.m. This however may have been resulted from sewage.

Evidence of a density current of chlorides along the west bank of the Mississippi River appears in the LaGrange (figure 15, tables 26 and 27) cross-section, mile 335.6 where the chlorides were 2.0 p.p.m. as compared to the east bank of 1.7 p.p.m. This same density current appears at the Montrose-Nauvoo section, mile 376.

Sulfates

The volumetric benzidine method of Schroeder (1935) was used for the quantitative determination of sulfates.

The sulfates enter the Mississippi River in part, as a result of industrialization and human contamination, but a great deal of the sulfate comes largely from the western tributaries, principally from the Des Moines and Missouri Rivers which flow through gypsum beds. However, the Illinois and Ohio Rivers on the eastern side of the Mississippi also contribute.

During the low-water period of August and September, sufates were not found in the upper part of the river north of mile 340, but south of this point increased repidly until a peak of 51.1 p.p.m. was reached at mile 44.0, (figure 16).

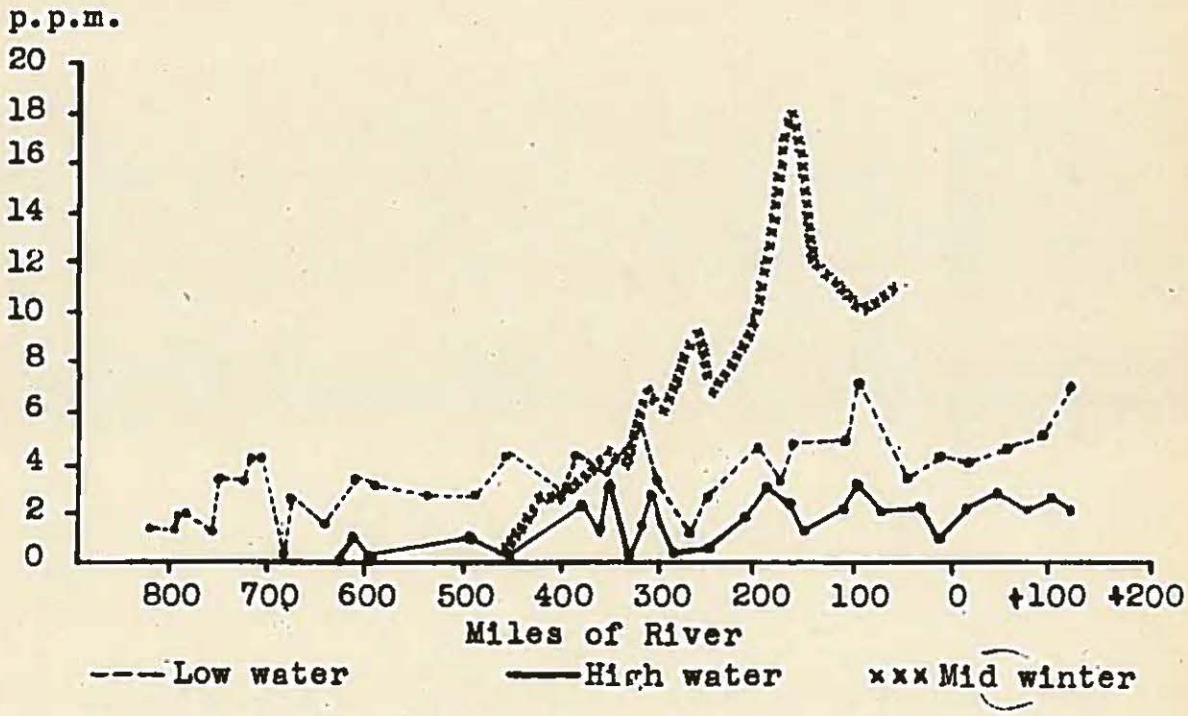


FIGURE 14.— Chlorides (Cl^-) in the Mississippi River.

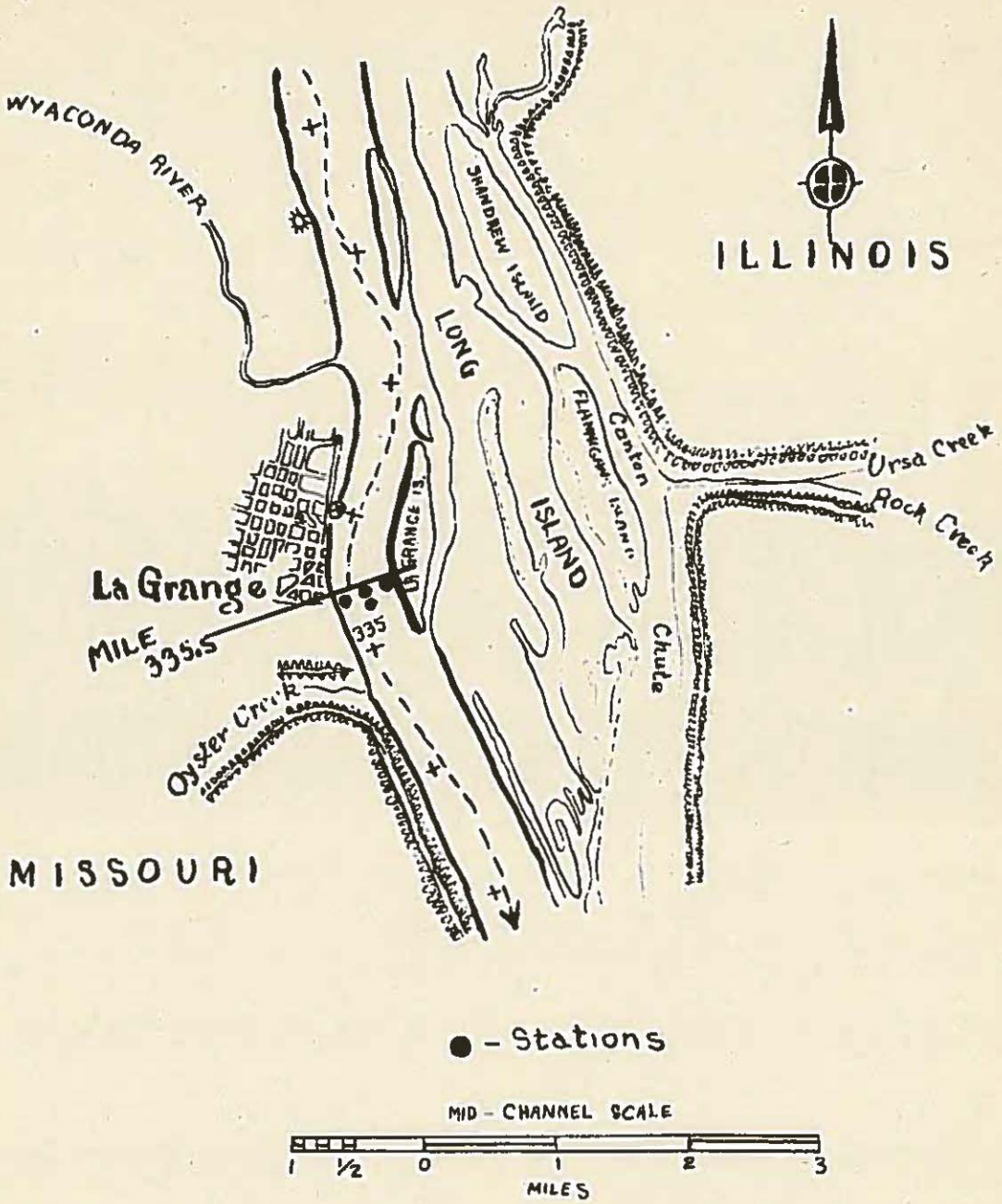


FIGURE 15.--Cross-section sampling of the Mississippi River at La Grange, Missouri.

Table 26.--Physical characteristics of Mississippi River at stations established across the river at La Grange, Mo., June 13, 1944

MILE 335.6

Stations	Date	Turbidity p.p.m.	Percentage sedimentation (60 min.)	Water temp. °C	Air temp. °C	Time	Sample depth in feet	Bottom
EAST BANK	June 13	745	0.10	22.0	24.0	10:00 a.m.	6.0	mud, sticks
CHANNEL, SURFACE	do	1080	0.05	21.4	24.0	10:10 a.m.	5.0	mud
CHANNEL, CENTER	do	1080	0.05	21.4	24.0	10:30 a.m.	10.0	mud
WEST BANK	do	1540	0.10	20.8	24.0	10:45 a.m.	4.0	mud

Table 27.--Chemical analysis of water samples collected across the Mississippi River at La Grange, Mo., June 13, 1944

MILE 335.6

	Sp. cond. mho x 10^{-6} @ 25°C	pH	Parts per million											
			Dis-solved O_2	Oxy-gen con-sumed	HCO_3	CO_3	CO_2	Total	NH_3	PO_4	Cl	Ca	SO_4
EAST BANK	596.0	8.01	5.90	20.50	165.0	0.00	Trace	0.48	0.17	0.25	1.70	34.0	33.6
CHANNEL, SURFACE	600.0	8.00	5.90	19.50	156.0	0.00	do	0.48	0.17	0.24	1.70	34.0	29.8
CHANNEL, CENTER	608.0	7.95	8.40	29.00	156.0	0.00	do	0.48	0.19	0.19	1.70	34.0	----
WEST BANK	612.0	7.95	6.30	26.50	158.0	0.00	do	0.34	0.19	0.19	2.00	34.0	----

Iron, zinc, flouride, manganese and copper were not detected by methods used.
Trace of CO_2 indicates 1.0 p.p.m. or less.

The Missouri River, which contained 62.4 p.p.m. of sulfate, was primarily responsible for this rapid indrease. South of the Ohio River (mile 0.0), however, the sulphates in the Mississippi River declined rapidly. This may be due to dilution by the Ohio River which was comparatively low in sulphates (24.2 p.p.m.) at this time of the year.

The high-water period however presents an entirely different picture. At this time, the Mississippi River seems to get most of its sulphate from the Des Moines and Illinois Rivers while the Missouri River contributes relatively little.

In midwinter the Mississippi was primarily affected by the Des Moines River, which contained 114.1 p.p.m. sulphate. The Iowa and Skunk Rivers during this same period contained 32.5 p.p.m. and 65.6 p.p.m., respectively.

A study of sloughs, bayous, and waters adjacent to the Mississippi indicate that these places contributed very little sulphate to the river.

Thus from the foregoing review of data it may be said that most of the sulphate ions enter the Mississippi River from the tributaries.

The particular effect of each tributary depends largely upon the season of the year and its volume of water as well as the stage of the Mississippi River.

Calcium

Calcium has long been considered as an important constituent in fishing waters, and was so stressed at one time that the classification of waters was based chiefly upon the quantity of calcium present.

Calcium in the Mississippi River water is usually in the form of carbonate or bicarbonate. The similarity of figures 17 and 20 especially for the high water period shows that most of the calcium was combined as bicarbonates.

In the Mississippi River the calcium content during the high-water period ranged from 24 to 54 p.p.m. The largest amount of calcium, averaging 45 p.p.m. was found between mile 370 and mile 250. Above and below these two points the calcium content was slightly lower with an average of 33 p.p.m. for the section north of mile 370 and 32 p.p.m. for the section south of mile 250.

The low-water period had calcium values that were more uniform than those for the high water period. The range was 33 to 49 p.p.m. with an average of 40 p.p.m. A tendency for calcium to accumulate in the lower stream during the low-water period is evident from data plotted in figure 17.

The calcium content of the western tributaries during low-water averaged 53 p.p.m.; with the exception of the Illinois River which had a value of 45.7 p.p.m., the eastern tributaries, averaged 24 p.p.m.

The Sny River, section mile 275, had a value of 39 p.p.m. The calcium content of water in a series of islands as at section mile 275 was slightly higher than in the main channel of the river.

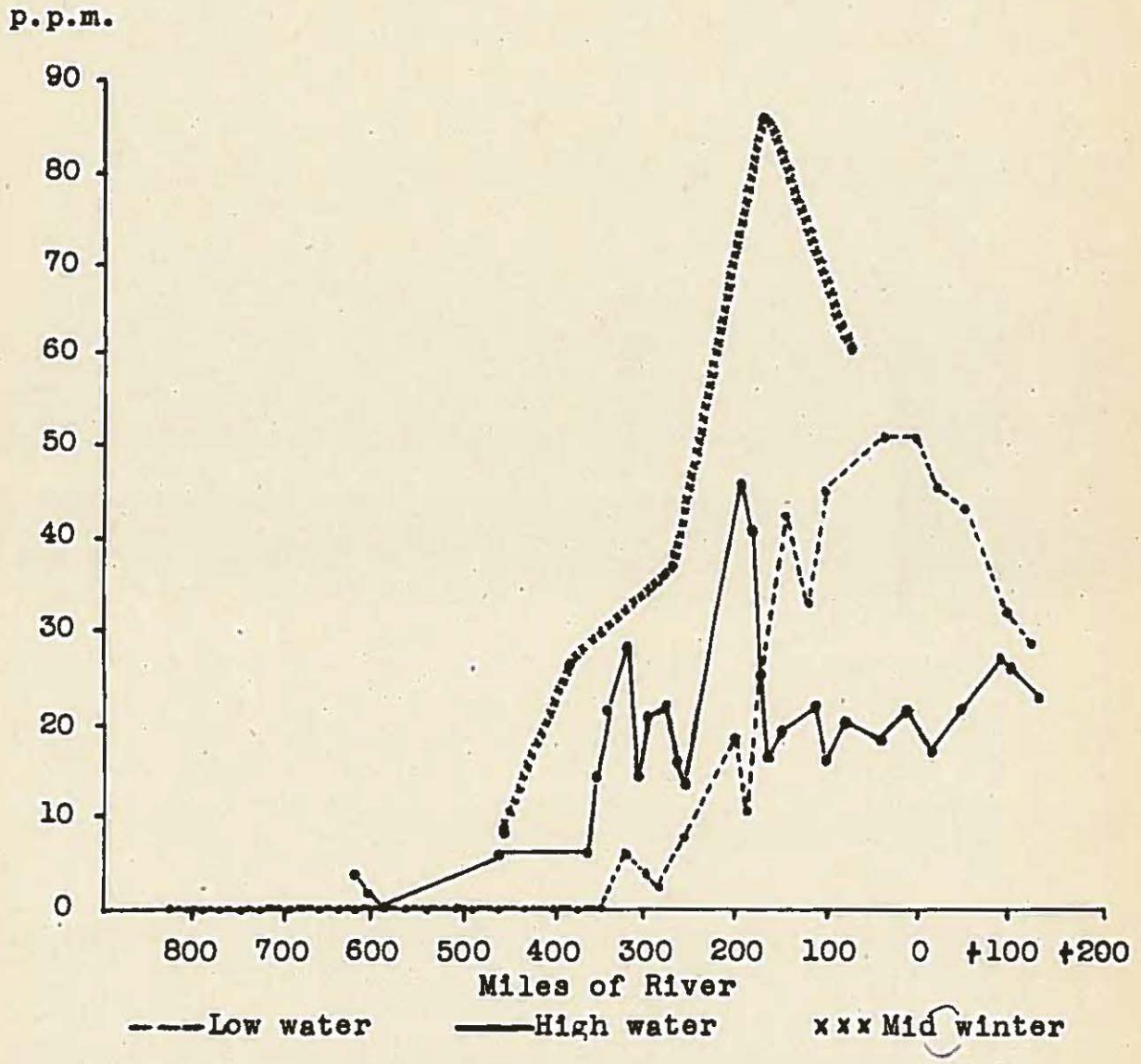


FIGURE 16.— Sulphates ($SO_4^{=}$) in the Mississippi River.

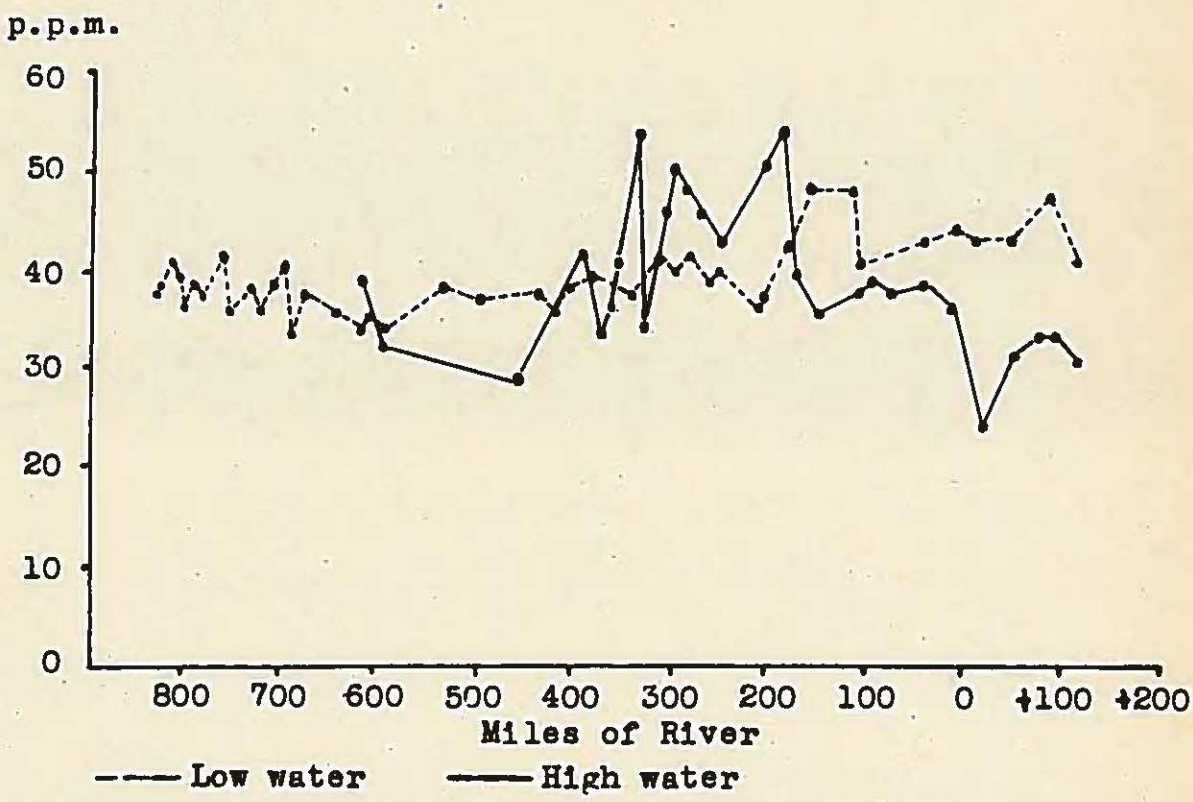


FIGURE 17. — Calcium (Ca^{++}) in the Mississippi River.

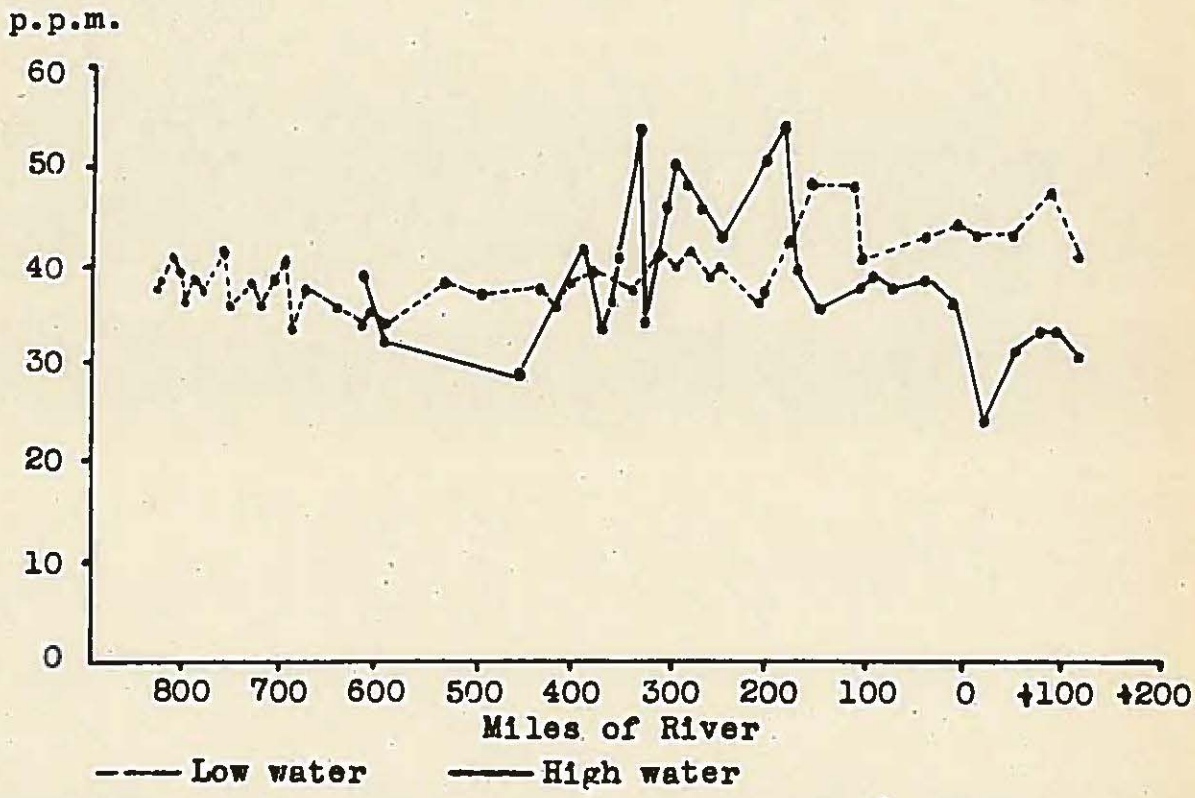


FIGURE 17. — Calcium (Ca^{++}) in the Mississippi River.

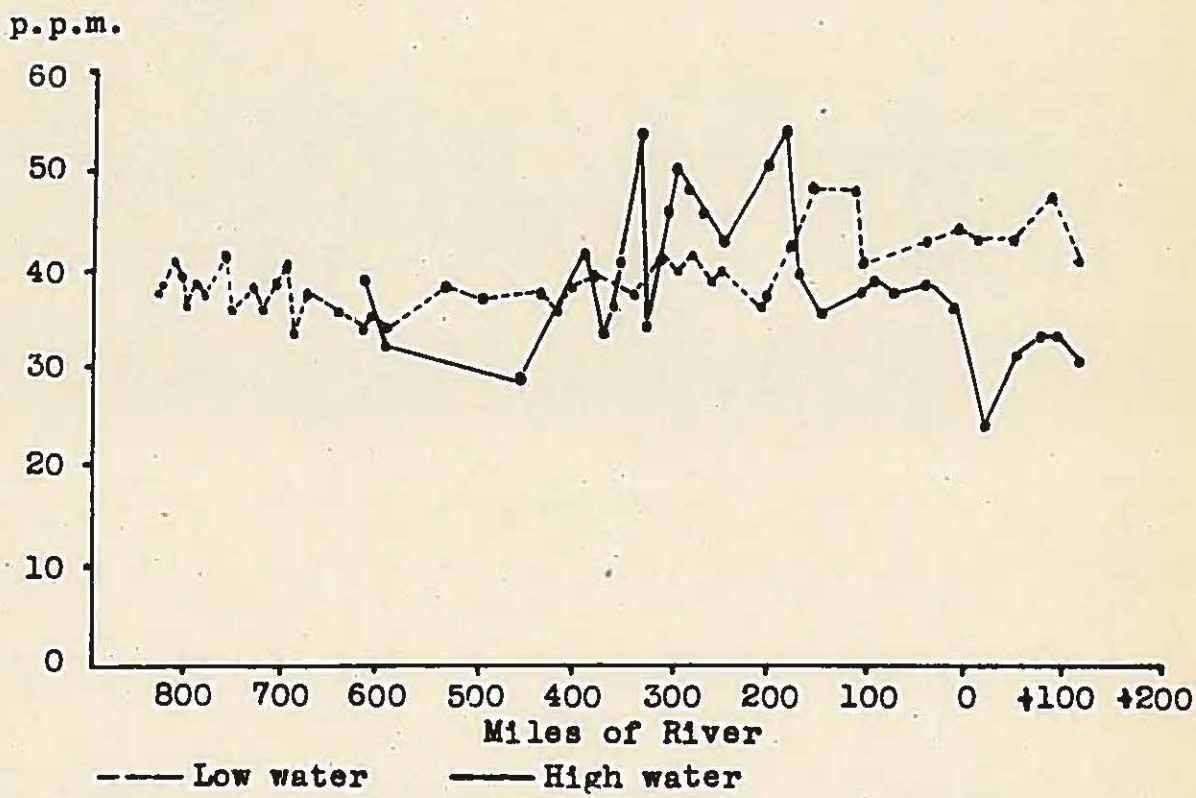


FIGURE 17. — Calcium (Ca^{++}) in the Mississippi River.

The lower end of Lake Pepin had an increase in the amount of calcium of 10 p.p.m., as compared to the upper end. However more stations would have to be sampled before any significance could be attached to this finding.

Carbonates

The Mississippi River during the low water period contained carbonates that ranged from 1.2 p.p.m. to 4.9 p.p.m. having an average of 3.4 p.p.m. (Figure 18). This condition changed completely at mile 150, where carbonates almost disappeared.

The high-water and midwinter periods were conspicuous by the complete absence of carbonates south of mile 360.

This same condition also existed in the tributaries. Both the western and eastern tributaries were devoid of carbonates. The Illinois and Ohio Rivers did not contain any carbonates during the low-water period but the other tributaries contained carbonates varying in amount from 17.3 p.p.m. in the White Water River to 2.04 p.p.m. in the Chippewa River (table 9).

The carbonate contents of the sloughs were slightly higher than in the Mississippi channel. For example, Harper's Slough contained 6.0 p.p.m., while the river contained only 4.2 p.p.m. (figure 19 and tables 28 and 29).

The cross-section studies at mile 275 revealed that certain wooded areas covered with water and water near island groups contained more carbonate than the main channel of the Mississippi River.

Bicarbonates

The method of Seyler as described by Kemmerer, Bovard, and Boorman (1923) and the American Public Health Association (1936) was used in the determination of bicarbonates, carbonates, and carbon dioxide.

The bicarbonates in the Mississippi River are present chiefly as calcium bicarbonate. A comparison of figures 17 and 20 on the calcium and bicarbonate content of the river shows that both have the same general outline.

The amount of bicarbonates in the Mississippi River during low water was quite uniform. The values ranged from 64 to 87 p.p.m. with an average of 79 p.p.m. They were generally higher in that part of the river north of mile 196 than in the section below mile 196. This difference seems to be caused by the Missouri River.

The high-water period had a range of from 51 p.p.m. to 112 p.p.m.; this latter value was found below the Illinois River, which had a moderately high bicarbonate content of 89.4 p.p.m.

A similar reduction in bicarbonate ions occurred below the Missouri River during this period as in the low-water period.

The midwinter survey indicated an increase in the amount of bicarbonate as compared to the low-and high-water surveys. The range in midwinter was from 110 to 135 p.p.m., with an average of 115 p.p.m. The presence of larger

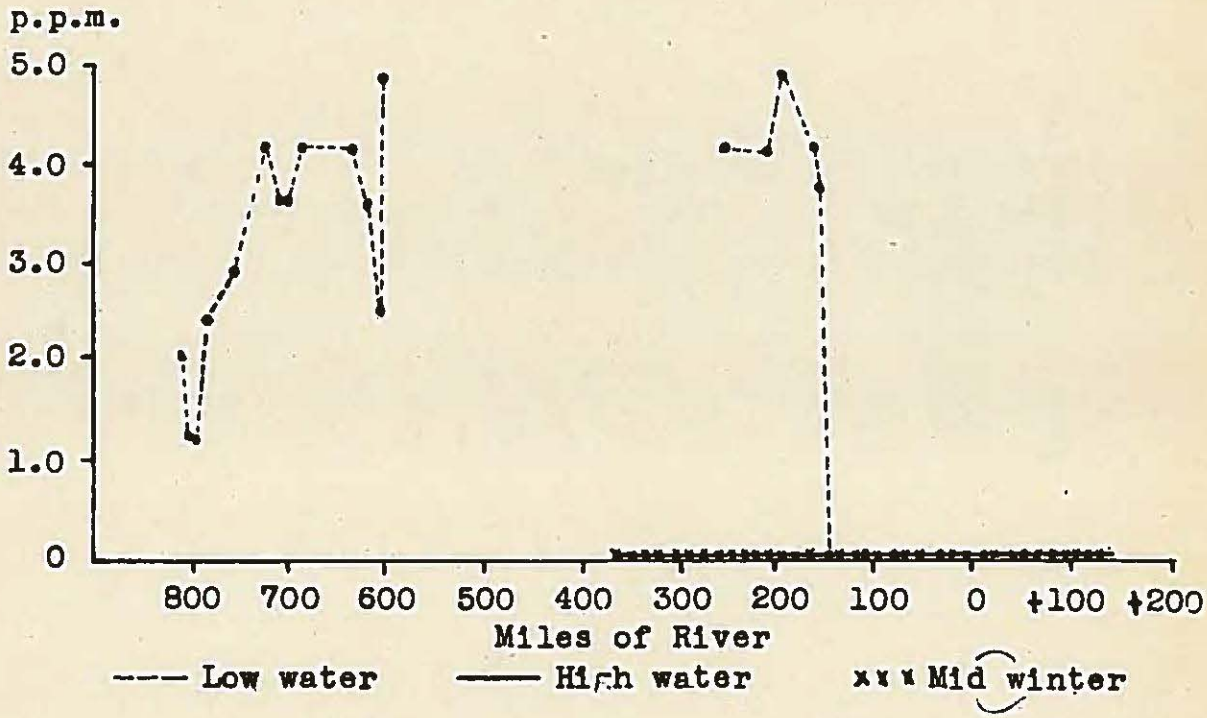


FIGURE 18.—Carbonates (CO_3) in the Mississippi River

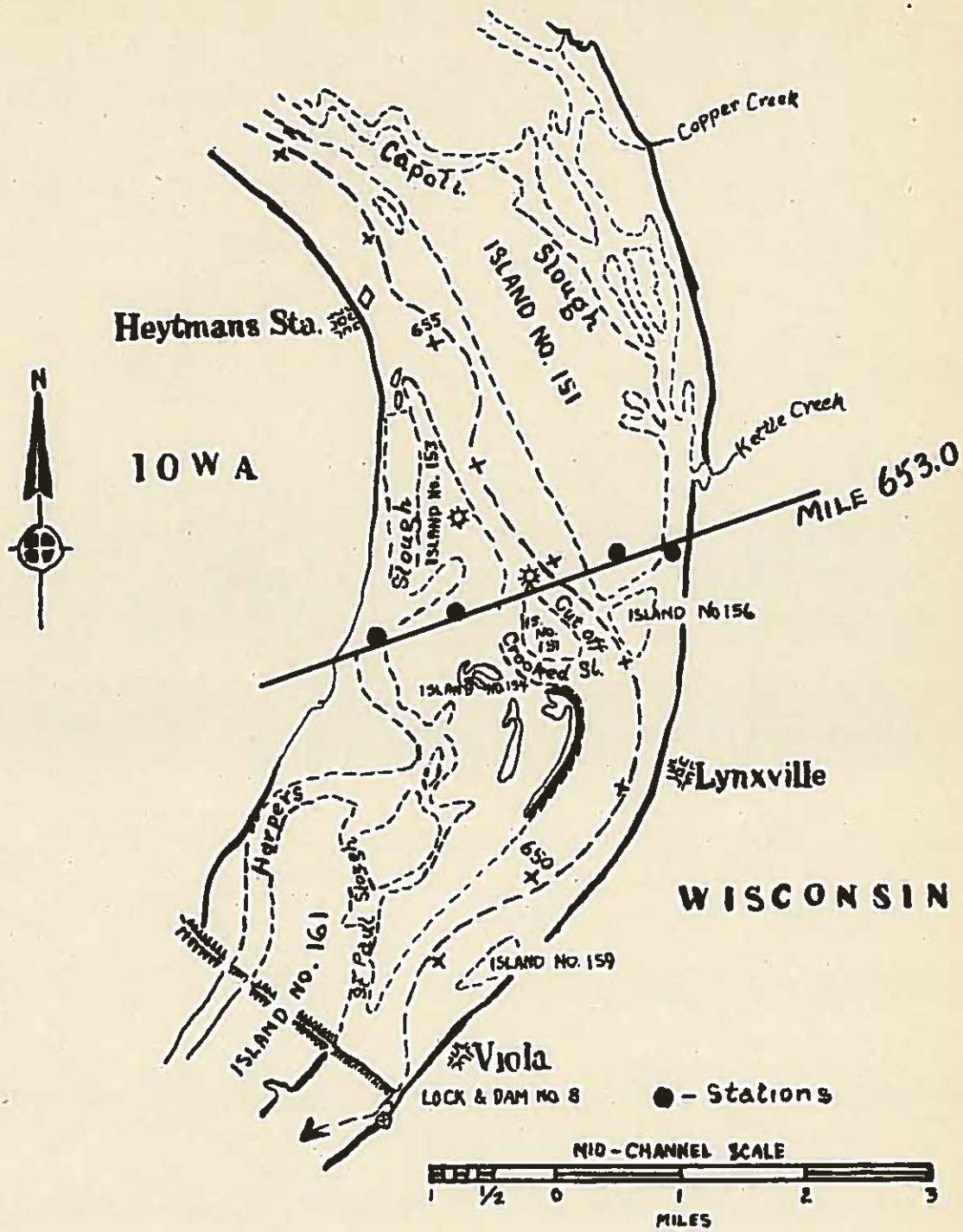


FIGURE 19.—Stations in Capoli Slough, Harper's Slough, and over submerged islands.

Table 28.--Physical characteristics of water collected from sloughs adjacent to the Mississippi River channel (August 13, 1944)

MILE 653.0

Stations	Turbidity p.p.m.	Percentage sedimentation	Water temp. °C	Air temp. °C	Time	Depth in feet	Sample depth in feet	Bottom
Capoli slough	62	0.08	25.8	24.0	8:50 a.m.	18.0	9.0	mud, empty shells
Head of island 151	94	0.09	26.2	24.0	9:00 a.m.	4.0	2.0	mud
West of Crooked slough	97	0.09	26.0	24.0	10:15 a.m.	9.0	4.0	mud
Harpers slough	85	0.07	26.8	24.0	10:30 a.m.	1.5	1.0	mud

Table 29.--Chemical analysis of water samples collected from sloughs adjacent to the Mississippi River channel (August 13, 1944)

MILE 653.0

Stations	Sp. cond. mho x 10^{-6} @ 25°C	pH	Dissolved O_2	HCO_3	CO_3	CO_2
Capoli slough	287.0	8.29	3.42	80.7	3.00	0.00
Head of island 151	283.0	8.15	3.12	80.7	4.20	0.00
West of crooked slough	292.0	8.15	3.84	82.0	3.60	0.00
Harpers slough	288.0	8.20	3.65	81.5	6.00	0.00

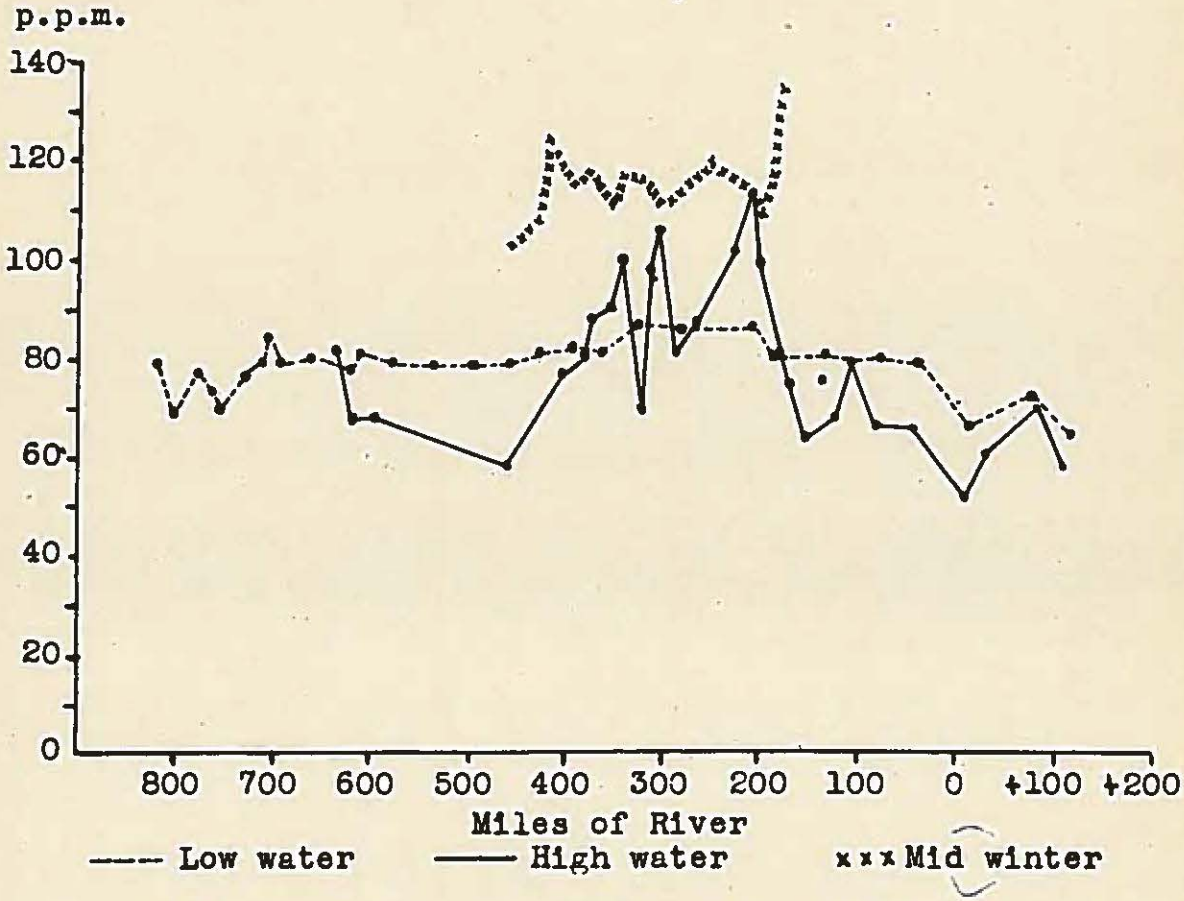


FIGURE 20.- Bicarbonates (HCO_3^-) in the Mississippi River.

amounts of bicarbonate in midwinter would indicate a better buffering power of the river against acids or alkalis.

The western tributaries exceeded the eastern tributaries, in bicarbonate content (table 9). The White River Water was comparatively high with 135.8 p.p.m. of bicarbonate. The Ohio River contained the lowest amount, the value being 30.9 p.p.m. which occurred during the low-water period.

Sloughs and bayous showed little difference in bicarbonate content from that found in the main channel of the Mississippi River.

The Sny River and a small impoundment (table 23) which is reached by flood waters of the Mississippi both had a bicarbonate content slightly higher than most of the Mississippi River.

Carbon Dioxide

The method used for the determination of carbon dioxide was sensitive to 1.0 p.p.m. The word "trace" is given where the amount of carbon dioxide appeared to be less.

The Mississippi River contained very little carbon dioxide during the low-water period. There was no carbon dioxide found in the river north of mile 612.5. However, that section south of mile 270 contained a trace. During the high-water period the amount of carbon dioxide i the lower section that is, south of mile 364 was on an average 1.0 p.p.m.

In midwinter the values of carbon dioxide in the main channel rose to an average of 1.5 p.p.m. and the increase appeared to be general. Samples collected from the Iowa, Skunk, Des Moines, Missouri, and Illinois Rivers all showed more than 2.0 p.p.m. carbon dioxide as compared to those representing low-and high-water periods, which showed no carbon dioxide or only a trace.

Carbon dioxide in the barrow pit and the 1903 break-through was rather high, being 15.0 and 8.8 p.p.m., respectively. In the month of September, the Sny River contained 3.5 p.p.m. at section mile 275 and 5.3 p.p.m. at section mile 280.

The sloughs and bayous connected with the Mississippi River had approximately the same carbon dioxide content as that found in the main channel.

Hydrogen-ion Concentration

Hydrogen-ion measurements were made with a glass electrode pH meter. All the pH readings were made in the field within a short time after collecting the water samples.

The Mississippi River becomes progressively more acid downstream, (figure 21). The average pH reading in the lower section (mile 150 to mile 112) was found to be 7.90, whereas in the upper section it was 8.25.

At the time of the high-water survey the average pH was slightly lower than it was during either the low-water or the midwinter periods. The midwinter samples were more alkaline than those taken during low-or high-water periods. This difference in pH may be correlated with the amount of bicar-

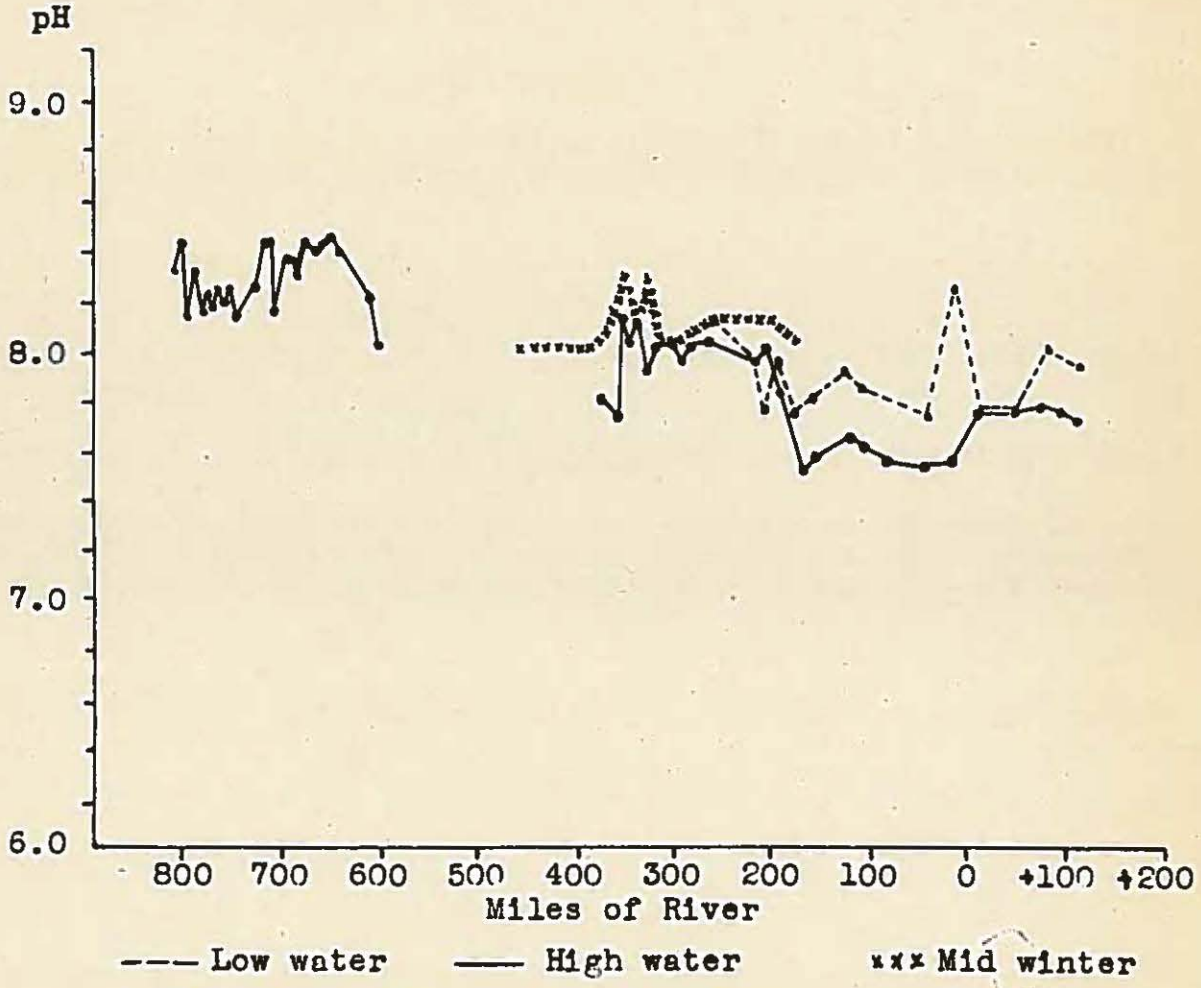


FIGURE 21.-- Hydrogen ion concentration (pH) in the Mississippi River.

bonate present (figure 20). There seem to be more bicarbonate ions in mid-winter which would give a greater buffering power to the water.

Ionizable Salts (Specific Conductance)

The amounts of salts in solution was determined by an apparatus alrady described under boat and field equipment. For convenience, the data are expressed as specific conductance in mho x 10^{-6} at $25^{\circ}C$.

The amount of ionizable salts in the Mississippi River increased steadily downstream in each of the three periods (figure 22). This increase was particularly noticeable during low water. The upper section of the river during that period had a specific conductance between 200 and 350 mho x 10^{-6} at $25^{\circ}C$ as compared to the lower section (below mile 200) which had a specific conductance from 380 to 410 mho.

The specific-conductance data for the high-water period varied considerably, from 140 to 470 mho. The greatest increase was found to be below tributaries especially the Iowa, Des Moines, Illinois, and Missour rivers.

The effect of the Missouri River is particularly evident during the mid-winter period when the specific conductivity rises from 380 mho just above its confluence with the Mississippi River to 750 mho about 50 miles below. The samples of midwinter generally had a specific conductivity that was higher than for those of either the low-or high-water periods, the average value being 450 mho

Data on specific-conductance measurements of the tributaries agree with statements made previously, that the western tributaries have a higher salt content than the eastern tributaries except those of the Illinois River (table 8). The average value for the western tributaries was found to be 372 mho and for the eastern tributaries (including the Illinois River) was 247 mho.

That there is density current of ionizable salts along the west bank of the Mississippi River is evident. Cross-section studies at LaGrange, Mo., (table 26) and at Montrose, Iowa, (table 14) showed that such a density current could be detected. The sloughs which were sampled at mile 653.0 showed no difference in conductivity measurement from those found in the Mississippi River.

However, the Sny River, which was part of the sections at mile 280 and mile 275, had a specific conductance of 660 mho. Local residents reported that until recently the Sny River was an excellent fishing site for crappie but withing the past two years the catch was rather poor. It would have been interesting to study correlation of this change with chemical data.

Trace Elements

The roles of various trace elements in the physiological processes of aquatic animals and plants are in most cases still far from clear. However, iron is known to be an essential component of haemaglobin in the vertebrate animals, and iron, manganese, and copper individually have been found in respiratory pigments of invertebrates. Zinc has recently been placed in the essential list of trace elements required in nutrition of higher vertebrates and may therefore play a similar part in the nutrition of aquatic animals.

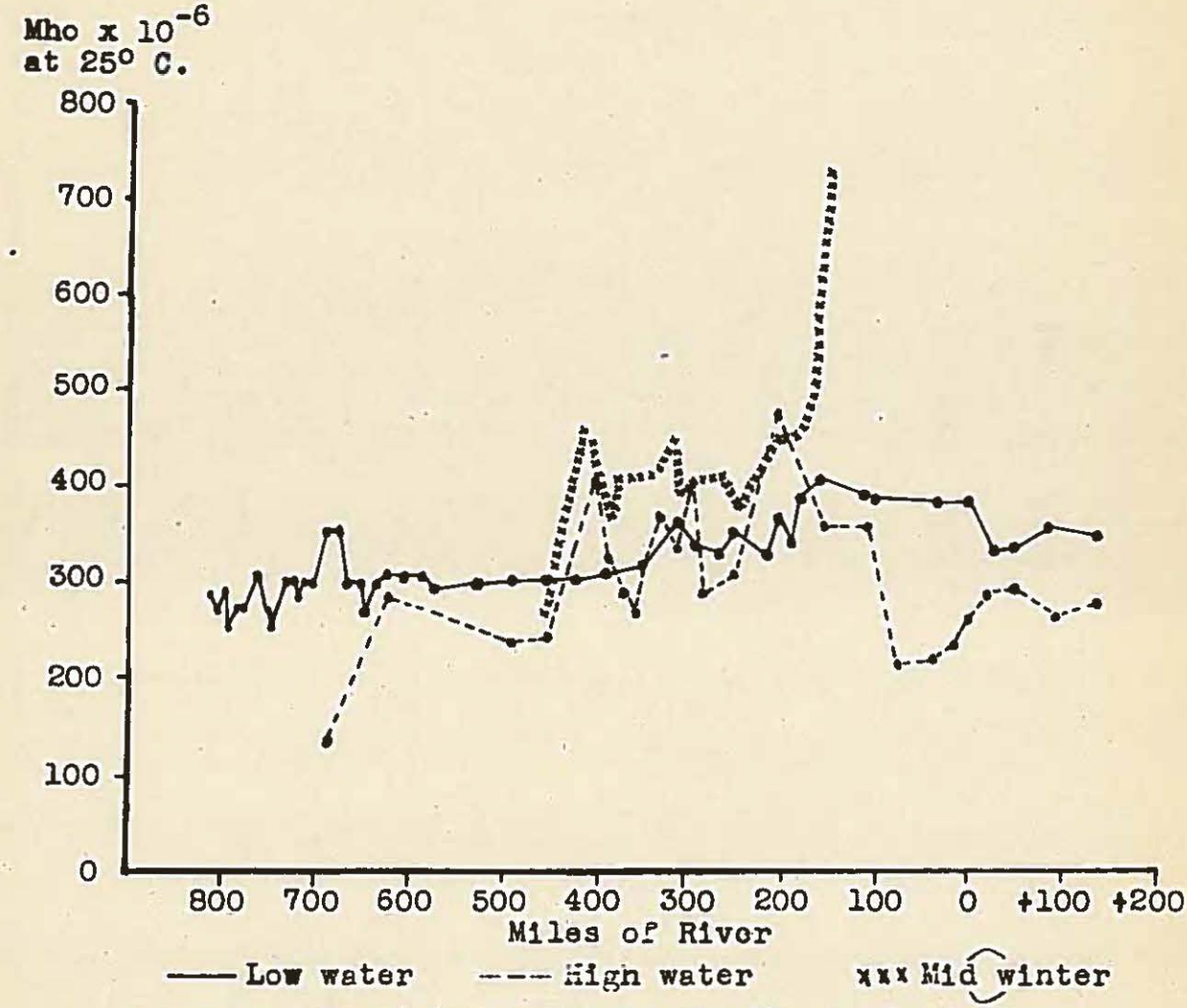


FIGURE 22.-Ionizable salts in the Mississippi River. (Specific conductance as mho x 10^{-6} at 25°C.)

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The suggestion has been made that iron, besides its function in haemoglobin, probably acts as a catalyst in the formation of chlorophyl and may be involved also in respiratory activity. Manganese may, under certain conditions, act as a partial substitute for iron. Iron has further been found to be important in that it combines with phosphates, being thus precipitated and removed.

Consequently, iron, manganese, copper, and zinc were determined for a considerable proportion of the samples of water studied in this survey.

Iron

The determination of iron was carried out according to the method described by Theroux, Eldridge, and Malman, (1943).

The presence of ferric iron in solution in the Mississippi River (excluding silt) was almost negligible. In Lake Pepin only a trace of iron was found during the low-water period. The lower section of the river, that is, south of the Missouri River contained slightly more iron but there also it could only be reported as a trace, the method used being only reliable to 0.1 p.p.m.

The tributaries did not contain iron in excess of 0.1 p.p.m. at any season studied in this survey.

The presence of iron in the cross-sections at mile 275, mile 278, and mile 280 should be explained. All of the samples collected in these sections were preserved with 1.0 ml. of concentrated sulphuric acid, being intended primarily for total nitrogen determinations, but in our usual routine of analysis trace elements were also determined. It was then discovered that the acid used to preserve the sample had leached out these elements from the silt. Acid-preserved samples which contained no silt were not altered. All other determinations for trace elements were completed on samples which were not preserved in any way.

Manganese

Manganese was determined, using a method described by Koltoff and Sandell (1938). Manganese was absent in the main channel of the Mississippi River; some, however, was found in the western tributaries. These were: Iowa River, 0.22 p.p.m.; Skunk River, 0.17 p.p.m.; Des Moines River 0.10 p.p.m. and Root River, 0.05 p.p.m. in high water. No manganese was found in any of the eastern tributaries.

The presence of manganese in the samples collected at section, mile 275, mile 278, and mile 280 should be regarded with reservations because the samples were acidified.

Copper

The method used to determine copper was that of Snell (1936), which has a reported sensitivity to 0.01 p.p.m. By concentration of samples this sensitivity was extended. No samples studied from any portion of the Mississippi River or its tributaries contained copper in excess of 0.0078 p.p.m., a proportion found during high water at mile 172.5, St. Louis, Mo. It may

be stated, therefore, that the copper content of the Mississippi River water was very small (Snell and Shell, 1936).

Zinc

Zinc determinations were made according to Sandell's method (1944). Zinc was detected in the Mississippi River below St. Louis at mile 172.5 during high water. The amount found was 0.0075 p.p.m. Zinc was also found immediately below Burlington, Iowa, the value being 0.0009 p.p.m.

The following tributaries contained zinc: Skunk River, 0.03 p.p.m.; Chippewa River, 0.03 p.p.m.; Illinois River, 0.024 p.p.m. during low water and 0.04 p.p.m. during high water.

Fluorine

The method used to determine fluorides was published by Sanchis (1934). They were not detected in the main channel of the Mississippi River. The tributaries which contained fluorides were all on the western side with the usual exception of Illinois River. Skunk River had the highest value found which was 0.14 p.p.m. The Iowa and Des Moines Rivers each had 0.045 p.p.m.

POLLUTION

From a critical review of all of the physical and chemical data collected during this survey of the Mississippi River, the existing pollutions, that is, the sums of all polluting effluents now entering the Mississippi River in the sector studied, are not creating conditions seriously unfavorable to fish and other aquatic life, except in local areas below particular plants or cities. The presence of specific areas of pollution near industrialized sections cannot be discounted but as a result of the large volume of water in the Mississippi River and the carrying power of this stream, the immediately dangerous effects of these pollutants are restricted largely to portions of the river a few miles below the entrace of particular effluents. However, the cumulative effects of these collective pollutions must be considered as slowly deteriorating the general quality of the Mississippi River water for production of fish and other aquatic organisms.

Many small, as well as some large, communities located on the river still use it as a convenient means for the disposal of sewage. Although each offense seems small and becomes insignificant a few miles from its source, the total effect produced must be considered.

Even though the volume of water is large enough and the dilution is great enough to render these pollutants harmless to the present fish fauna of the Mississippi River, one must remember that each small amount of material narrows the safety margin of the river.

It has been shown in previous surveys, as well as in the present one, that the oxygen content in the upper section of the Mississippi River during the low water period was below that found in ideal fishing water. However, this low oxygen condition may result from the gross effect of all the material which enters the stream and may not be caused by any individual pollutant.

Most natural bodies of water have a certain buffer value, and when this

is destroyed by pollutants, the plant and animal life, essential to normal stream balance, quickly die. Thus, in the Mississippi River, the water becomes more acid downstream. This acidity expressed in pH has an average value of 8.20 at mile 700 and pH 7.80 at mile 100. Regardless of the causes of this change, one must concede that the river at mile 100 would require less acid to reach a point lethal to fish than at mile 700.

Another fact may be given regarding the salinity of the Mississippi River. A limit usually accepted as tolerable by most fishes should not exceed 1,000 mho x 10^{-6} at 25° C. In the Mississippi River from mile 500 to mile 800 the mhos average 280 while the section below mile 300 averages 410 mho. Thus, the concentration of ionizable salts in the lower section would only have to be slightly more than doubled to reach a condition intolerable to fish, while the ionizable salts in the upper section would have to be more than tripled to reach the same condition. The values mentioned above for the Mississippi River are not considered harmful at present. However, an increase in industrialization in the post-war years may further narrow the margin of safety on which the river depends in keeping its natural balance

As the water quality of a stream changes from time to time, it is necessary to re-examine the stream occassionally to re-evaluate its condition.

The Mississippi River was not in a critical condition at the time of this survey. Considering the river froman over-all point of view, it may be concluded that the upper section of the river, that is, the section above mile 420, maintained a more favorable position with respect to fish production than the section below mile 420. Comparing the water quality of the Mississippi River with waters producing good fish fauna, it would be rated as good

DISCUSSION AND CONCLUSION

Study at three different seasons of the year showed that the chemical constituents of the Mississippi River are by no means constant. Not only were seasonal variations obvious but daily and hourly changes were constantly taking place.

Probably one of the most striking variations as a result of seasonal changes was in the dissolved oxygen content. The midwinter period, which was studied when most of the river was covered with several inches of ice, had an oxygen content 8 times greater than that found during the low-water period.

The midwinter period also had a greater amount of ionizable salts. This increase in electrolytes was partly due to the increase in sulfates, chlorides bicarbonates, and ammonia. The increase in bicarbonates and ammonia reflects on the hydrogen-ion content of the water; thus the alkalinity was found to be greater during this period.

The midwinter period did not show an increase in all of the constituents determined; the phosphates, for instance, were considerably lower. However, the decrease in metabolic activity of plankton during this period, for which this element has been demonstrated to be seesntial (Wiebe, 1930a, and others) probably did not suffer much from this reduction.

Seasonal rise in the water level in the Mississippi River, after periods of thaw and rain is particularly evident from March and June. The flood waters bring with them silt and detritus and cause marked changes in the chemical compostion of the water.

During these periods of high water the total nitrogen content of the Mississippi River increased to seven time the low-water and midwinter values, but the chlorides, carbonates, and sulfates in turn decreased to a point which was below the low-water and midwinter periods. In most cases the high water produced a reduction of electrolytes in the Mississippi River.

Following the period of high water comes that of least change in physical environmental conditions. The low-water period was characterized by higher phosphate and carbonate values but a low sulfate and dissolved oxygen content.

The tributaries of the Mississippi River are primarily responsible for many of the chemical and physical changes which take place. The western tributaries bring into the Mississippi more electrolytes than are contributed by the eastern streams.

The amount and kind of material depends upon geological surroundings, age, soil, and vegetation cover of the drainage. The Missouri and Des Moines Rivers, for example, were high in sulfates and chlorides, the Root, Vermillion, and White Water rivers contained much bicarbonate, whereas the Iowa, Skunk, and Des Moines rivers contained some manganese. All of the tributaries contained more or less of a majority of the constituents reported in this paper.

A study of cross-sections, sloughs, bayous, and waters adjacent to the main channel revealed that the chemical characteristics were different on whether these areas were intimately connected with the river or isolated and only reached in periods of high water.

The barrow pit and 1903 break-through, just such bodies of water, were characterized by high bicarbonates and phosphates.

The barrow pit was also high in total nitrogen, ammonia, and carbon dioxide, but very low in oxygen content. The Sny River was unusually high in chlorides.

The physical factors reported in this paper were originally assumed to be of a secondary importance, but the increased attention recently given to the study of light penetration and its consideration as a critical factor expecially in phyto-plankton production, has shown that ecological and limnological studies of plankton should be correlated with the light-transmission data as well as the chemical and physical characteristics of the water.

The full significance of these analytical findings can only be known when they are correlated with the biological and ecological data which other units of this cooperative survey have collected.

SUMMARY

The physical and chemical data here reported, presented study of the Upper Mississippi River from 2 miles above Lock and Dam No. 2 in the Hastings Pool, Minne., to Caruthersville, Mo., during the year 194 .

1. The mean oxygen content of the River during the period of low-water was 5.0 p.p.m.; in high water averaged 7.6 p.p.m.; and in midwinter, 13.6 p.p.

2. Oxygen-consumed values during the period of high water ranged from 7.8 to 43 p.p.m., with an average of 25 p.p.m. The upper section of the river from mile 280 to mile 600 averaged 22 p.p.m. During low-water the average was 22 p.p.m. from mile 170 to mile 800, while that below the Missouri River was 36 p.p.m. In Midwinter the average was 34 p.p.m.

3. Total nitrogen values were low in midwinter, averaging less than 1.0 p.p.m. The low-water average was 1.7 p.p.m., while that of high water averaged 5.5 p.p.m.

4. The ammonia values from mile 590 to mile 817 averaged 0.59 p.p.m. while the lower section south of mile 590 averaged 0.05 p.p.m. for the low-water period; high-water values averaged 0.2 p.p.m.; and in midwinter the average was 0.4 p.p.m.

5. Phosphate content was low in midwinter, high in low water and intermediate during the high-water period.

6. Chlorides tended to accumulate downstream. They were low during the high-water period, high in midwinter, and intermediate during the low-water period.

7. Sulfates were high in midwinter. During the low-water period they were absent from mile 350 to 817 but increased steadily below the Missouri River. During high water the sulfates had an intermediate value from mile 200 to mile 600 but fell below the low-water value south of mile 220.

8. Calcium for both high and low water averaged 40 p.p.m., with considerable variation during high water.

9. Carbonates during low-water averaged 3.4 p.p.m., but were absent according to the high-water and midwinter surveys.

10. Carbon dioxide was usually less than 1.0 p.p.m. Higher values were found in waters adjacent to the Mississippi River.

11. The Mississippi River became more acid downstream. Midwinter values were higher than those of either low-or high-water periods.

12. Ionizable salts were more dominant during midwinter and least so in the high-water period.

13. Bicarbonates were highest in midwinter.

14. The percentage of sedimentation increased during high water.

15. The western tributaries of the Mississippi River generally contained more salts than did the eastern tributaries.

16. Sloughs and bayous intimately connected with the Mississippi River had the same chemical characteristics as those of the main channel.

BIBLIOGRAPHY

American Public Health Association. 1936. Standard Methods for the examination of water and sewage. Ed. 8, 309 pp. New York.

Birge, E. A. and C. Juday. 1930. Solar radiation and inland lakes. Trans. Wis. Acad. Sci., Report 2, vol. 25, pp. 285. Madison, Wisconsin.

Chambers, J. 1910. The Mississippi River and its wonderful valley; twenty-seven hundred and seventy-five miles from source to sea. 308 pp. G. P. Putnam's Sons. New York and London.

Clarke, F. W. 1908. The data of Geochemistry. U. S. Geological Survey Bulletin, No. 330, 716 pp. Washington.

Clarke, F. W. 1924. The data of Geochemistry. U. S. Geological Survey Bulletin, No. 770, Ed. 5, 841 pp. Washington.

Clarke, G. L. 1934. Factors affecting the vertical distribution of copepods. Ecological Monographs, vol. 4, pp. 530,

Clarke, G. L. 1939. Utilization of solar energy by aquatic organisms. Problems of Lake Biology. The Science Press, 142 pp. Lancaster, Pennsylvania.

Coker, R. E. 1929. Keokuk Dam and the Fisheries of the Upper Mississippi River. Bull. of the Bureau of Fisheries, vol. 45, pp. 87-139. Bureau of Fisheries Document 1063. Washington.

Deniges, G. 1920. Reaction de coloration Extremement sensible des phosphates et des arsentiates. Ses applications. Comptes Rendus de l'academie des Sciences. Tome 171, pp. 802-804. Paris.

Ellis, M. M. 1931. A survey of conditions affecting fisheries in the Upper Mississippi River. U. S. Dept. Commerce, Bureau of Fisheries, Fishery Circular No. 5, pp. 1-18. Washington.

Ellis, M. M. 1936. Erosion silt as a factor in aquatic environments. Ecology, vol. 17, No. 1, pp. 29-42.

Ellis, M. M. 1937. Detection and measurement of stream pollution. Bull. of Bureau of Fisheries, vol. 48, Bulletin 22, pp. 365-437. Washington.

Galtsoff, P. S. 1924. Limnological observations in the Upper Mississippi, 1921. Bull.of the Bureau of Fisheries, vol. 39, 1923-24, pp. 347-438. Bureau of Fisheries Document No. 958. Washington.

Hoover, E. E. and H. E. Hubbard. 1937. Modification of the sexual cycle in

trout by control of light. Copeia, No. 4 pp. 206-210.

Johnson, W. H. 1938. The effect of light on the vertical movements of Acartia clausi (Giesbrecht). Biol. Bull., vol. 75, pp. 106-118.

Kemmerer, G., J. F. Bovard and W. R. Boorman. 1923. Northwestern lakes of the United States: Biologica and chemical studies with reference to possibilities in production of fish. Bull. U. S. Bureau of Fisheries, vol. 39, 1923-24, pp. 51-140. Washington.

Koch, F. C. and T. L. McMeekin. 1924. A new direct nesslerization micro Kjeldahl method and a modification of the Nessler-Folin reagent for ammonia. Jour. Amer. Chem. Soc., vol. 46, p. 2066.

Kothoff, I. M. and E. B. Sandell. 1938, Textbook of Quantitative Inorganic Analysis. 454 pp. MacMillan Co. New York.

Manning, W. M. 1938, Photsynthesis. Jour. Physical Chem., vol. 42, p. 815.

McHargue, J. S. and A. M. Peter. 1921. The removal of mineral plant-food by natural drainage water. Kentucky Agricultural Experiment Station. Bull. No. 237.

Peters, J. P. and D. D. Van Slyke. 1932. Quantitative Clinical Chemistry. Methods. Vol. 2, 516 pp. The Williams and Wilkins Co., Baltimore.

Rawson, D. S. 1939. Some physical and chemical factors in the metabolism of lakes. Problems of Lake Biology, 142 pp. The Science Press, Lancaster, Pennsylvania.

Rideal, S. and G. G. Stewart, 1901. The determination of dissolved oxygen in waters in the presence of nitrites and of organic matter. Analyst, vol. 26, pp. 141-148.

Sanchis, J. M. 1934. Determination of fluorides in natural waters. Industrial and Engineering Chemistry, Analytical Edition, vol. 6, pp. 134-135.

Sandell, E. B. 1944. Colorimetric Determination of Trace Metals. 487 pp. Interscience Publishers, Inc. New York.

Schroeder, W. C. 1933. Direct titration for sulfate. Industrial Engineering Chemistry, Analytical Edition, vol. 5, pp. 6, 403.

Snell, F. D. and C. T. Snell. 1936. Colorimetric Methods of Analysis. Ed. 2, vol. 1, 766 pp. D. Van Nostrand Co., Inc. New York.

Steiger, G. 1914. The relative abundance of several metallic elements. Jour. Washington Acad. Science, vol. 4, pp 59-62.

Straub, L. G. 1942. Mechanics of rivers. Physics of the Earth. IX. Hydrology 12 pp. McGraw-Hill Book, Inc. New York.

Theroux, F. R. and E. F. Eldridge, and W. L. Mallmann. 1943. Laboratory Manual for Chemical and Bacterial Analysis of Water and Sewage. Ed. 3, 274 pp. McGraw-Hill Book Co. New York and London.