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A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE UPPER MISSISSIPPI RIVER

SURVEYS AND LABORATORY STUDIES

U. S. TREASURY DEPARTMENT
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A STUDY OF THE POLLUTION AND NATURAL PURIFICATION OF THE UPPER MISSISSIPPI RIVER

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SECTION I

INTRODUCTION

The deficiency in rainfall on the upper Mississippi River basin, beginning about 1922, depleted reservoir and ground-water storage to such an extent that in the summer of 1925 the flow in the river through Minneapolis and St. Paul became insufficient to properly dilute the sewage and industrial wastes discharged from the Twin City metropolitan area without creating objectionable conditions in the river.

Numerous complaints, brought to the attention of the Minnesota and Wisconsin State Legislatures in the summer of 1925, resulted in each legislative body appointing an interim committee with instructions to study conditions in the river through Minneapolis and St. Paul, and in the St. Croix and Mississippi Rivers, which form the boundary between Minnesota and Wisconsin, and to submit recommendations to the 1927 State legislatures on methods of improving the condition of these waters. A joint interim committee, including three members from each of the State committees, was then organized to study, without duplication of effort, conditions in the watercourses and to present a concordant report of the steps necessary by each State to remedy conditions. This joint committee, at a meeting held in October, 1925, decided, inasmuch as the problem was one involving an interstate stream, to request the United States Public Health Service to assist them in the study. Pursuant to this decision, a request was transmitted to the Surgeon General of the Public Health Service, who detailed an officer to confer with the committee and to make a preliminary report.

At a subsequent meeting a joint report was presented to the committee by sanitary engineers representing the Minnesota and Wisconsin State health organizations and the United States Public Health Service outlining the kind and extent of the survey deemed necessary, the kinds of data to be collected, and the cost of such an investigation, to cover a period of approximately one year.

The funds necessary for making the required study were made available from allotments already appropriated by the State legislatures to the Minnesota Game and Fish Commission and the Wisconsin Conservation Commission, under whose supervision such studies would ordinarily be made. Additional funds, appropriated for a less extensive study of the river by the cities of Minneapolis and St. Paul, were also made available for the general and more extensive study of the problem. The Public Health Service furnished the necessary laboratory equipment and supplies to operate a chemical and bacteriological laboratory and detailed the writer of this report to have general supervision of the investigation.

The data were collected, therefore, primarily to determine sanitary conditions in the river due to the discharge of untreated sewage and industrial wastes from the Twin City metropolitan area, especially during periods of low water; the distance downstream that the effects of pollution were noticeable; and the probable further effect of increasing sewage loads. An attempt was also made to estimate from the data obtained the effect to be anticipated from the discharge of sewage and industrial wastes from St. Paul and South St. Paul into a pool to be created by the construction of a second navigation dam near Hastings.

The investigation was made during the 15-month period June, 1926, to August, 1927, inclusive, and covered approximately 137 miles of river channel from above Minneapolis to above Winona, Minn. During the study samples of river water were collected for chemical and bacteriological analysis at regular intervals from sampling points established on the main stream and on tributaries near their mouths. At the same time information was secured relative to existing sources of pollution on the watershed and the necessary hydrometric data were obtained.

The data collected during the summer and fall of 1926, when extremely low flows were recorded in the Mississippi River through the Twin Cities and when conditions in the river became extremely objectionable, were made the subject of a preliminary report to the joint interim committee in January, 1927. This report was used as the basis of the committee's recommendations to the 1927 State legislatures. As a result of the preliminary report, the Minnesota Legislature created the Metropolitan Drainage Commission of Minneapolis and St. Paul to study methods of collecting and treating the sewage from the Twin City metropolitan area and to recommend methods for financing such construction as was deemed necessary.

In January, 1928, after the close of the investigation, all the data collected were summarized in tabulated form in a second report which was submitted through the Surgeon General of the Public Health Service to the State health authorities and the Drainage Commission for their immediate use.

In the present report the data collected during the investigation have been reassembled and retabulated, and an endeavor made to analyze them from the standpoint of a study of stream pollution and natural-stream purification, similar to previous studies of the Illinois and Ohio Rivers made by the United States Public Health Service.

In such a presentation of the data it was necessary to estimate rates of stream discharge; times of flow; sewered population; pollution due to industrial wastes; the per capita contributions of bacteria and oxygen demand to the stream, from the chemical and bacteriological results above and below the sewer outlets; and rates of purification taking place in the stream, as shown by the satisfaction of oxygen demand and decrease in bacteria, in a relatively long section of the river free from additional pollution, in which times of flow could be calculated.

While the data were collected for studies other than those of natural stream-purification phenomena, one section of the river offered an opportunity to estimate the rates of purification taking place in the upper Mississippi River, for a comparison with the rates observed during studies of the Ohio and Illinois Rivers.

The present report, therefore, contains data relative to the physical features of the upper Mississippi River watershed and the river channel; summaries of total and sewered population, with estimates of sewered population equivalent to the industrial waste pollution; estimates of discharge and times of flow; and a summary of the chemical and bacteriological findings at various points on the section of the river under investigation. These data are presented in a series of basic tabulations, condensed to the form of monthly averages, with a discussion of the salient features of each.

Such success as was attained by the investigation was made possible by the assistance of the various State and municipal legislative bodies, by many local organizations, and by numerous individuals. Acknowledgment is due the Joint Interim Committee of the Minnesota and Wisconsin State Legislatures, through whose efforts the appropriations were obtained from their respective States to assist in conducting the investigation; to the City Councils of Minneapolis and St. Paul for the appropriation of additional funds used during the study; to the State health organizations of Minnesota and Wisconsin, from whose records was obtained much valuable information pertinent to the investigation; to the Minnesota Game and Fish Commission and the Wisconsin Conservation Commission, through whose organizations the funds appropriated by the States were disbursed; and to the Minnesota Drainage Commission and the Wisconsin Railroad Commission, who assisted, in cooperation with the United States Geological Survey, in the collection of the hydrometric data.

Individual acknowledgments are made to Mr. H. A. Whittaker, director, division of sanitation, State Department of Health of Minnesota; to Mr. N. W. Elsburg and Mr. George M. Sheppard, city engineers of Minneapolis and St. Paul, respectively, for supplying much valuable data used in the preparation of this report; to Mr. J. A. Childs, chief engineer, Metropolitan Drainage Commission of Minneapolis and St. Paul, for information collected subsequent to the present investigation which has been used in the final report; and to Mr. H. A. Bailey, chemist and bacteriologist in immediate charge of the special field laboratory throughout the entire period of the survey.

During the progress of the field work and in the preparation of the basic data contained in this report the personnel of the United States Public Health Service stream pollution investigations organization has rendered much assistance. Special acknowledgments are due to Bacteriologist C. T. Butterfield for establishing the field laboratory at Minneapolis and inaugurating the bacteriological technique used throughout the investigation, and to Chemist E. J. Theriault for assistance and advice relative to the chemical technique used during the studies. Consultant W. H. Frost, of the Public Health Service, in charge of stream pollution investigations at the time the study of the upper Mississippi River was made, has reviewed the manuscript of the report and offered many valuable suggestions which have contributed to its final form of presentation.

SECTION I

FEATURES OF THE UPPER MISSISSIPPI RIVER AND ITS WATERSHED

GENERAL FEATURES

The Mississippi River system above the Minnesota-Iowa State line drains portions of the States of Minnesota, Wisconsin, South Dakota, Iowa, and a few square miles in the State of Michigan. The source of the river is in Lake Itasca, in southeastern Clearwater County, Minn., 2,550 miles from the mouth of the Mississippi at the Gulf of Mexico. From its source the river flows northerly for a short distance, then easterly and southerly to the mouth of the Crow Wing River; and after covering a distance of 350 miles is then only about 75 miles from its source. From the Crow Wing River to the Gulf of Mexico the course of the Mississippi is quite consistently toward the south or southeast.

GEOLOGY AND GLACIAL HISTORY

The extensive mantle of glacial deposits covering the entire watershed gives evidence of several invasions of the ice sheet from the north at widely separated times and from different directions. The earlier invasions brought down from Manitoba the limestones which are found imbedded in the lower part of the drift, while later ice movements, from the northeast, brought down the stony red drift from the Superior Basin as far as Mille Lacs Lake and Saint Paul. The older drift deposits were eroded by the early drainage systems, which became so extensive that very few lakes and undrained basins remained upon them. The younger drift deposits still retain their lakes and poorly drained areas, which the present river systems have not yet reached. The younger drift formation, on the upper part of the main river basin, accounts for the numerous lakes and swampy areas on this part of the watershed, while to the west, on the Minnesota River Basin, and to the south, which is of the older drift formation, not covered by the later ice invasion, lakes and swampy areas are almost entirely lacking.

The drift sheet covering the watershed varies in thickness from 100 to 300 feet, forming an undulating plain with comparatively slight irregularities which form long low swells and hollows, with no outlets, giving rise to the lakes and swamps. The bulk of the drift is composed of blue till, a compressed mixture of sand, clay, and gravel; but to the eastward this is replaced by the red till. In the southwestern part of the basin, in Minnesota, the till is covered by a layer of loam, separated from it by a distinct line of demarcation. Along the valleys of the Mississippi and most of the larger tributaries flowing southerly there are deposits of a mixture of stratified sand and gravel covered with fine sand. The same formation is also found in isolated plains in some of the counties. Extensive lenticular beds of stratified gravel and sand constitute a large portion of the till in the rolling or broken tracts, including the Leaf Hills in the northwestern section of the basin and the Coteau des Prairies in the southwestern part.

PRESENT DRAINAGE SYSTEM

The outline of the watershed of the Mississippi River and its tributaries above Winona, Minn., as shown in Figure 1, is somewhat leaf-shaped, due to extensions of the main stream in the central part of the watershed and to the headwaters of the Minnesota and Chippewa Rivers on the west and east, respectively. The main stream divides the watershed about equally and forms the central vein of the leaf. The maximum length of the watershed from north to south is 250 miles, and from east to west 280 miles. The drainage area of the stream above Winona is estimated at 59,230 square miles, of which 15,020 square miles, or 25 per cent, lie within the State of Wisconsin; 1,870 square miles, equal to about 3 per cent, in the State of South Dakota; and 400 square miles, or somewhat less than 1 per cent, in the State of Iowa. The remainder of the watershed, amounting to 41,940 square miles, or 71 per cent of the total area above Winona, is within the State of Minnesota.

In the northern portion of the watershed there are many lakes, the more important of which are Bemidji, Cass, Winnibigoshish, and Leech. From its source to the Falls of St. Anthony, in Minneapolis, the channel of the Mississippi River is narrow in places, forming rapids along its course, and is broad in others, where the current becomes sluggish. At the Falls of St. Anthony the river drops 70 feet within half a mile as it passes from between its relatively low banks to flow between bluffs of lime and sandstone which continue for a considerable distance downstream, increasing in height to 500 feet as the river bed sinks below the general prairie level.

The Minnesota River enters the Mississippi about 8 miles below the Falls of St. Anthony, and the width of the main stream then averages about a thousand feet, with fertile flats between the river and the foot of the bluffs. The larger tributaries of the upper Mississippi River are the St. Croix, Chippewa, and Black Rivers entering from Wisconsin, and the Minnesota, Cannon, Zumbro and Root Rivers entering from Minnesota. Sand carried by the Chippewa River has been deposited in the main stream, forming a dam across the Mississippi

River. The body of water created above this obstruction is known as Lake Pepin. This lake is approximately 22 miles in length, has an average width of about 2 miles and a maximum width of nearly 3 miles. The water surface at normal river stage is estimated at about 40 square miles. The upper end of the lake is comparatively shallow, the depth increasing to a maximum of nearly 60 feet just above the outlet. The average depth throughout the lake is probably about 30 feet.

The total distance from the source of the river to the point where it leaves the State of Minnesota, at the Minnesota-Iowa State line, is 660 miles. The St. Croix River and the main channel of the Mississippi River below the mouth of the St. Croix form the boundary line between the States of Minnesota and Wisconsin.

TOPOGRAPHY

The topography of the upper Mississippi Basin is flat or slightly rolling over a large portion of the central area, with more abrupt slopes toward the watershed divide. The surface elevation is 620 feet above sea level where the Mississippi River leaves the southeastern corner of Minnesota, and reaches a maximum of about 1,750 in the Leaf Hills near the headwaters. Other areas of over 1,500 feet elevation are found in the rocky ranges in the northeast section and in the plateau southwest from Coteau des Prairies.

PRESENT RIVER CHANNEL

The course of the main river channel from its source to the Minnesota-Iowa State line is shown in Figure 1. Figure 2, a profile of the river at low-water stages, shows river distances below its source and the elevation of the water surface at various points.

During the first 30 miles of flow, to Lake Bemidji, the fall of the Mississippi River is quite rapid, averaging over 4 feet per mile. In the next 290 miles, from Bemidji to Brainerd, the slope is flatter, averaging about 0.5 foot per mile. From Brainerd to Minneapolis, a distance of about 150 miles, there is a continuous and rapid descent of the stream, amounting to 430 feet, or 2.9 feet per mile. Below Minneapolis to the Iowa State line the slope again becomes more gradual, amounting to 113 feet in 175 miles, an average of about 0.6 foot per mile. The fall along the river has been utilized for power development by the construction of dams in the vicinity of Bemidji, Brainerd, Little Falls, St. Cloud, at the Falls of St. Anthony, and just above the mouth of the Minnesota River in Minneapolis.

The Mississippi River has been made navigable as far as the Falls of St. Anthony by the construction of many wing dams to confine the low-water flows to a well-defined navigation channel, and by a lock-and-dam, operated by the Federal Government, on the main stream

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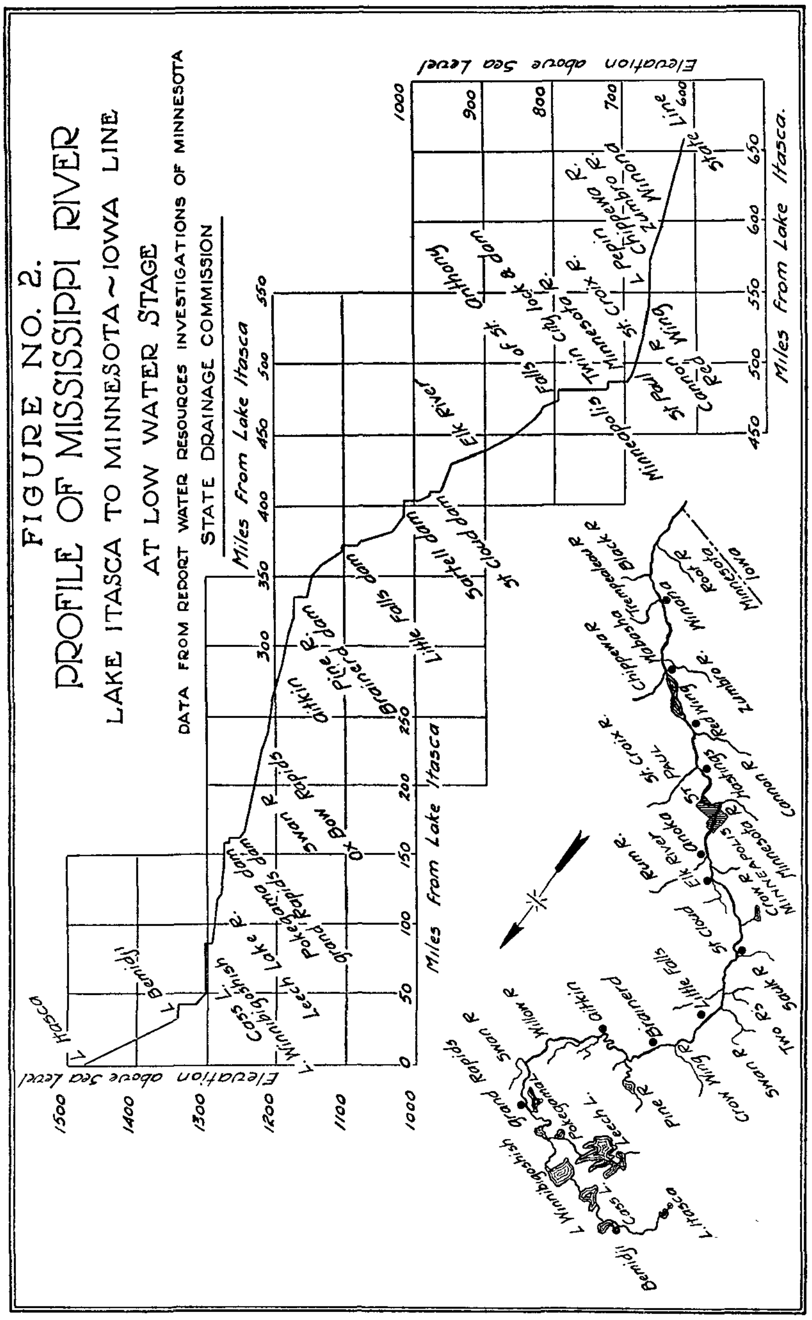

FIGURE NO. 2.
PROFILE OF MISSISSIPPI RIVER
LAKE ITASCA TO MINNESOTA ~ IOWA LINE
AT LOW WATER STAGE
DATA FROM REPORT WATER RESOURCES INVESTIGATIONS OF MINNESOTA
STATE DRAINAGE COMMISSION

just above the mouth of the Minnesota River, which forms a pool extending upstream to the head of navigation. An additional dam is to be constructed by the Federal Government just above Hastings, which will form a second pool extending to the foot of the present dam. Sufficient depth is to be provided to eliminate to a large extent regulation of summer flows by the reservoir system on the headwaters of the Mississippi, now operated by the Engineer Corps of the United States Army.

PRECIPITATION ON THE WATERSHED

Records of precipitation are available at 66 stations on the upper Mississippi River watershed, above Winona, at which observations have been made for 12 years or longer. These records have been summarized in Table 1 to show the average monthly and annual precipitation on the entire watershed, above Winona, and its major subdivisions. The actual monthly precipitation on the watershed and its major subdivisions for the period of the investigation, June, 1926, to August, 1927, inclusive, is indicated in Table 2. The data of these tables have been brought together, graphically, in Figure 3, which shows the relation between the actual monthly precipitation during the months of the investigation and the mean monthly precipitation as determined from the entire record at the various stations.

TABLE 1.—*Average monthly and annual precipitation, in inches, on the upper Mississippi River watershed and its major subdivisions*

Watershed	Number of stations	Length of record years	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Mississippi River above Minnesota River	24	12-50	0.67	0.69	1.10	1.89	3.05	4.23	3.55	3.31	2.73	1.92	1.03	0.69	24.86
Minnesota River	*18*	*12-47*	*.80*	*.80*	*1.30*	*2.36*	*3.40*	*4.44*	*3.36*	*3.21*	*2.78*	*1.77*	*1.09*	*.75*	*26.06*
St. Croix River	9	16-56	.95	.90	1.35	2.10	3.60	4.26	3.87	3.27	3.09	2.37	1.40	.97	28.13
Cannon River	6	12-36	.84	.87	1.36	2.25	3.54	4.58	3.44	3.37	3.26	2.20	1.17	.81	27.69
Chippewa River	13	15-37	1.13	1.00	1.57	2.29	3.78	4.44	4.10	3.59	3.59	2.84	1.69	1.16	31.18
Zumbro River	5	12-39	.98	.95	1.43	2.43	3.92	4.86	3.51	3.21	3.48	2.21	1.42	1.03	29.43
Mississippi River above Winona	66	12-56	.85	.83	1.29	2.16	3.40	4.41	3.63	3.32	3.02	2.12	1.26	.85	27.14

TABLE 2.—*Average monthly precipitation, in inches, on the upper Mississippi River watershed and its major subdivisions during the period June, 1926–August, 1927*

Watershed	1926							1927							
	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August
Mississippi River above Minnesota River	2.98	3.23	4.09	5.74	2.21	1.30	0.72	0.62	0.67	1.34	2.05	3.26	3.57	2.76	2.74
Minnesota River	2.76	2.90	4.23	6.11	1.29	1.30	1.17	.59	.58	1.84	3.49	3.47	3.48	2.41	1.39
St. Croix River	4.06	3.50	4.66	5.51	3.00	2.01	1.46	.56	.68	1.76	2.11	3.22	3.63	3.27	2.18
Cannon River	2.83	2.57	2.86	7.56	1.70	1.82	1.73	.73	.39	2.15	2.98	3.53	3.84	1.64	1.11
Chippewa River	3.88	4.84	5.22	7.29	2.86	3.00	1.64	.65	.66	2.34	1.49	3.96	3.27	4.69	1.59
Zumbro River	3.06	3.12	3.65	6.49	1.95	2.18	1.66	.59	.39	1.85	2.50	4.36	3.40	2.04	1.49
Mississippi River above Winona	3.29	3.43	4.35	6.26	2.21	1.84	1.22	.62	.63	1.78	2.43	3.57	3.42	3.08	1.97

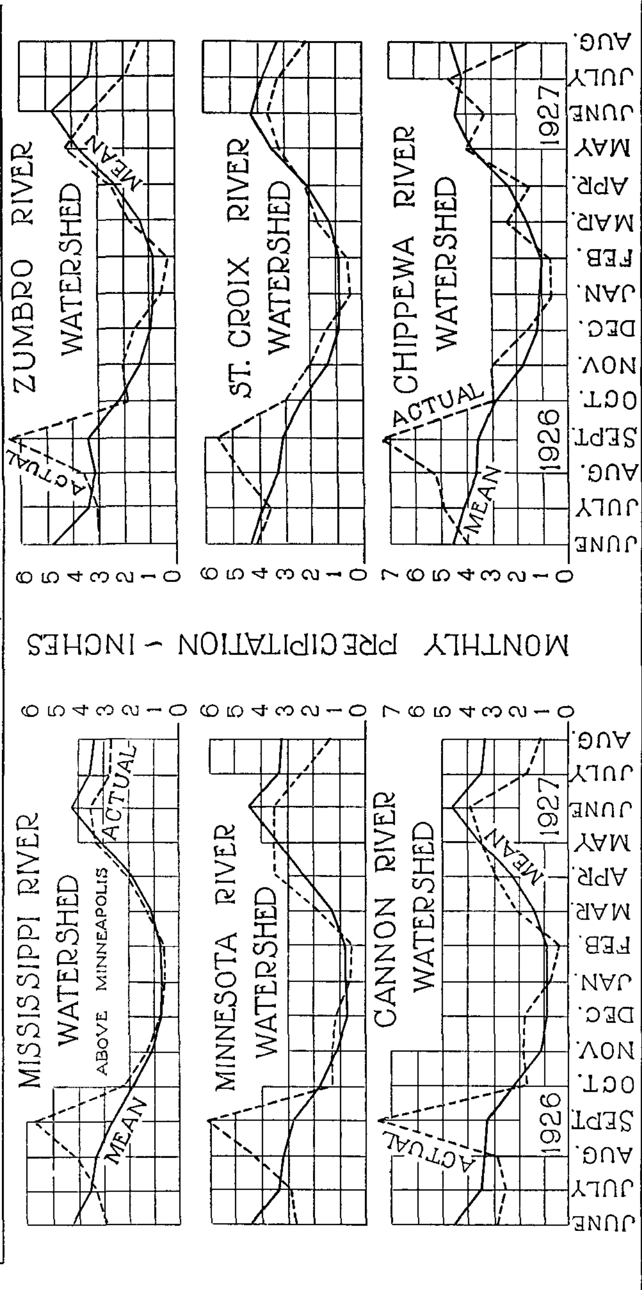

FIGURE NO. 3. MEAN MONTHLY PRECIPITATION ON THE UPPER MISSISSIPPI RIVER WATERSHED, BY TRIBUTARIES, AND THE ACTUAL MONTHLY PRECIPITATION DURING JUNE, 1926, — AUGUST, 1927.

The annual average precipitation on the upper Mississippi River watershed is about 27 inches, of which from 2 to 4 inches is in the form of snow and remains on the watershed during the winter period. June is the month of highest precipitation, with an average of 4.4 inches. Precipitation in the form of snow during the months of December, January, and February is quite uniform and averages 0.84 inch per month during these three months.

The geographical distribution of the monthly and annual precipitation shows an increase from the northwest to the southeast, the precipitation being from one-quarter to one-third greater at stations along the eastern border of the watershed than at those along the western border.

During the period of the investigation the actual precipitation on the entire watershed was about normal during the summer of 1926, the winter of 1926 and 1927, and the spring of 1927. It was below normal in the summer of 1927, and above normal in the fall of 1926. While the precipitation of the summer of 1926 was of average amount, it came at the close of an extended dry period and was utilized to increase reservoir and ground-water storage, producing but little effect on stream flow. The precipitation in the fall period was above the average, due to the high September rainfall, and stream flows approached the normal for that season. The summer precipitation, in 1927, was below the average and less than that of the preceding summer; but as a result of the high fall and normal winter precipitation, it produced higher stream flows than those recorded during the preceding summer.

VARIATIONS IN STREAM FLOW

The mean monthly discharge of the Mississippi River at St. Paul, Minn., is approximately 10,000 second-feet, while its maximum monthly discharge, observed in April, 1897, has been estimated at 60,000 second-feet. The lowest discharge usually occurs in the winter months, when the precipitation, in the form of snow, is held on the upper watershed; and monthly averages of less than 2,500 second-feet are frequent in winter. The low winter flows are followed by a spring peak in April, May, or early June, when the snow leaves the basin, after which the discharge diminishes quite consistently through the summer. Average monthly flows of less than 5,000 second-feet have occurred, during the months of July, August, or September, in 9 of the 28 years from 1900 to 1927. The minimum monthly average discharge for a summer month was recorded in July, 1926, as 2,590 second-feet. From April, 1922, when the average monthly discharge was 34,100 second-feet as measured at the St. Paul gaging station, the flow of the river was consistently low until April, 1927, when the discharge reached 27,000 second-feet.

The average monthly flows at the St. Paul gaging station for the period January, 1922, to September, 1927, inclusive, are summarized in Table 3.

TABLE 3.—*Average monthly discharge, in second-feet, of the Mississippi River, as measured at St. Paul, Minn., during the period January, 1922–September, 1927, inclusive*

Month	1922	1923	1924	1925	1926	1927
January	2,850	2,630	2,120	1,650	1,880	2,950
February	3,050	2,500	2,380	1,700	1,680	2,850
March	12,500	3,370	2,680	5,240	5,620	18,900
April	34,100	7,570	5,480	6,060	7,150	27,000
May	15,300	9,030	5,770	5,320	3,650	19,700
June	7,420	5,300	4,830	10,400	2,850	16,000
July	5,020	5,720	4,860	8,550	2,590	7,090
August	4,200	3,640	6,880	3,820	2,810	5,440
September	4,030	3,860	5,920	4,400	8,630	6,210
October	3,760	4,060	6,630	4,370	9,970	----------
November	4,560	3,170	4,040	2,990	5,150	----------
December	2,950	2,560	2,190	2,470	3,770	----------
Average	8,310	4,450	4,480	4,750	4,650	----------

Figure 4 shows the average monthly discharge of the Mississippi River at St. Paul and the discharge at gaging stations on the larger tributaries during the period from June, 1926, to August, 1927, inclusive, as compared with the mean monthly discharge during the entire period for which discharge records are available at each of the gaging stations.

It will be observed that the investigation of the pollution in the Mississippi River was conducted during a period which included months of extremely low summer flow in 1926; a fall-and-winter period of nearly average stream-flow conditions; a spring period with flows somewhat above the average; and a second summer period in 1927, in which the flow was again below the average but in excess of that of the preceding summer. The Chippewa River was an exception, the flow being above the average during the period from August, 1926, to March, 1927, inclusive, and then below the average for the remainder of the period of the investigation.

A marked difference exists between the yield of the Mississippi River Basin above the mouth of the Minnesota River and that of the Minnesota River Basin. Table 4 gives a comparison, for the period from October, 1925, to September, 1927, between the average monthly discharge from 14,600 square miles of watershed above Elk River, Minn., on the upper Mississippi River, and the discharge from 14,900 square miles of watershed on the Minnesota River above Mankato. The monthly discharge of the Mississippi River, as indicated by the table, varies from 0.93 to 19.2 times that of the Minnesota River. During this period the average monthly flow in the Mississippi River was nearly six times that in the Minnesota River from the same watershed area.

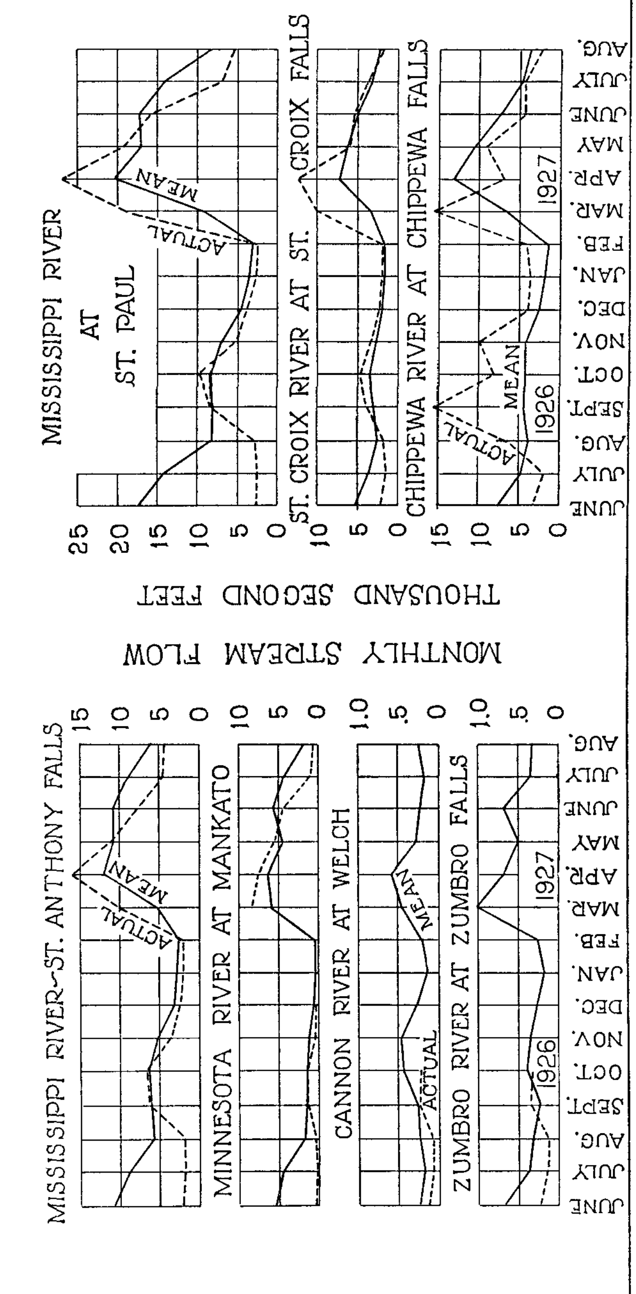

FIGURE NO. 4. MEAN MONTHLY STREAM FLOW, SECOND FEET, AT GAGING STATIONS ON THE UPPER MISSISSIPPI RIVER WATERSHED, BY TRIBUTARIES, AND THE ACTUAL MONTHLY STREAM FLOW DURING JUNE, 1926, — AUGUST, 1927.

TABLE 4.—*Ratio of the average monthly discharge, in second-feet, of the Mississippi River at Elk River, Minn., to that of the Minnesota River at Mankato, Minn., during the period October, 1925–September, 1927, inclusive*

Month	Mississippi River at Elk River, Minn., watershed 14,600 square miles	Minnesota River at Mankato, Minn., watershed 14,900 square miles	Ratio of the discharge, Mississippi River to Minnesota River	Month	Mississippi River at Elk River, Minn., watershed 14,600 square miles	Minnesota River at Mankato, Minn., watershed 14,900 square miles	Ratio of the discharge, Mississippi River to Minnesota River
1925				1926			
October	2,990	345	8.7	October	5,750	1,720	3.3
November	2,140	305	7.0	November	3,170	799	4.0
December	1,550	315	4.9	December	2,210	[3] 668	3.3
1926				1927			
January	1,060	[1] 247	4.3	January	1 900		
February	947			February	1,790		
March	3,900	[2] 2,630	1.5	March	7,840	[4] 8,430	.93
April	3,820	1.150	3.3	April	13,600	7,790	1.7
May	2,230	551	4.1	May	9,490	5,420	1.8
June	2,160	296	7.3	June	6,320	4,570	1.4
July	2,150	132	16.3	July	4,920	1,190	4.1
August	2,050	236	8.7	August	5,380	470	11.5
September	5,110	1,510	3.4	September	6,320	329	19.2

[1] January 1 to 11, inclusive.
[2] March 16 to 31, inclusive.
[3] December 1 to 12, inclusive.
[4] March 7 to 31, inclusive.

The increased yield of the upper Mississippi River is due in part to the numerous lakes and extensive swampy areas on this portion of the watershed, which act as a natural reservoir for steadying the flow of the river. Lakes and swampy areas are almost entirely lacking on the Minnesota River Basin. Of greater importance than the natural regulation of the upper Mississippi River is the regulation by an artificial reservoir system constructed and operated to increase water depths in the navigable channel between St. Paul and Lake Pepin. This system, started in 1884, now consists of six reservoirs, with a combined available capacity, between high and low water stages, of nearly 94,000,000,000 cubic feet. They are operated to maintain, in so far as possible, a depth of 6 feet in the navigable portion of the Mississippi River below Minneapolis, comparable with a gage reading of about 1.5 feet above low water at St. Paul. During the winter, or nonnavigable season, the reservoirs are drawn down to make available, on about the first of April, a storage capacity of 40,000,000,000 cubic feet, in which to store the excess water during the spring period of high run-off. If the preceding year was dry and the storage depleted, only the normal minimum winter flow, as determined prior to the construction of the storage reservoirs, is allowed to pass down the river, the remainder going to storage. If the preceding navigation season did not draw heavily upon the stored water, the winter flow in the river is increased by a sufficient amount to make available the required storage capacity on April 1. During the navigation season the stored water is held until the St. Paul gage reaches a stage of about 1.5 feet, after which water is drawn from storage in an attempt to hold the river at this reading on the gage.

For the purpose of designating sampling stations and other points of reference along that portion of the Mississippi River channel under examination, all such points have been referred to their distance

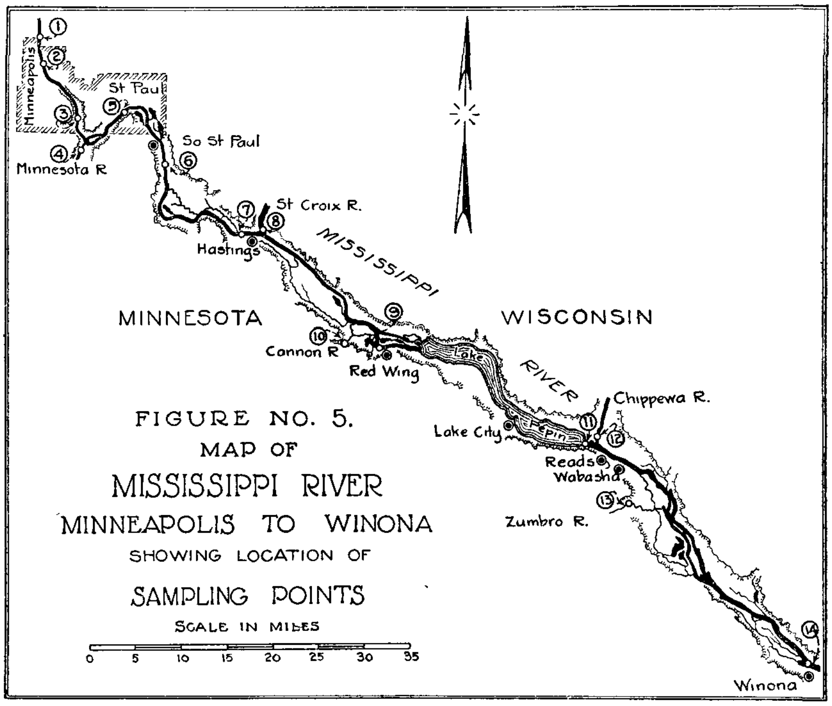

FIGURE NO. 5.
MAP OF
MISSISSIPPI RIVER
MINNEAPOLIS TO WINONA
SHOWING LOCATION OF
SAMPLING POINTS

below the Camden Avenue bridge in Minneapolis, the location of the uppermost sampling station on the river which is above all sources of pollution from the city of Minneapolis. The locations of the more important points along the river between Minneapolis and Winona are summarized in Table 5 and shown in Figure 5.

TABLE 5.—*Distance, in miles, along the channel of the Mississippi River from the Camden Avenue Bridge, Minneapolis, to designated points below*

Points below Camden Avenue Bridge	Sampling point	Miles below Camden Avenue Bridge, Minneapolis	Remarks
Camden Avenue Bridge, Minneapolis	1	0	Minneapolis water works intake.
Plymouth Avenue Bridge, Minneapolis	2	3.1	
Hennepin Avenue Bridge, Minneapolis		3.8	
Falls of St. Anthony, Minneapolis		4.6	Lower dam.
Washington Avenue Bridge, Minneapolis		5.5	Head of pool, Minneapolis; limit of navigation.
Franklin Avenue Bridge, Minneapolis		6.6	
Marshall Avenue Bridge, Minneapolis		8.1	
Intercity Bridge, Minneapolis-St. Paul		10.1	
Government lock and dam	3	10.5	End of pool, Minneapolis.
Mouth of Minnehaha Creek		11.0	Watershed area, 192 square miles.
Mouth of Minnesota River, Fort Snelling	4	12.9	Watershed area, 16,750 square miles.
Roberts Street Bridge, St. Paul	5	19.2	
South St. Paul Stockyard district		24.7	Population, 6,860.
Newport, Minn		27.6	Population, 453.
Invergrove Bridge	6	28.2	Population, 363.
St. Paul Park, Minn		28.7	Population, 900.
Hastings Bridge	7	45.0	Population, 4,571.
Mouth of St. Croix River	8	47.4	Watershed area, 7,610 square miles.
Prescott, Wis		47.5	Population, 892.
Mouth of Cannon River	10	66.1	Watershed area, 1,520 square miles.
Red Wing Bridge	9	68.3	Population, 8,637.
Upper end of Lake Pepin		73.3	
Maiden Rock, Wis		79.8	Population, 293.
Frontenac, Minn		80.8	
Stockholm, Wis		85.7	Population, 207.
Lake City, Minn		87.2	Population, 2,846.
Pepin Village, Wis		92.7	Population, 555.
Outlet of Lake Pepin	11	95.1	
Mouth of Chippewa River	12	96.2	Watershed area, 9,600 square miles.
Reads, Minn		96.7	
Wabasha, Minn		99.7	Population, 2,249.
Alma, Wis		107.6	Population, 970.
Mouth of Zumbro River	13	109.9	Watershed area, 1,420 square miles.
Mouth of Whitewater River		117.8	Watershed area, 343 square miles.
Minneiska, Minn		118.0	Population, 208.
Fountain City, Wis		129.5	Population, 880.
Winona, Minn	14	136.8	Population, 19,143

SECTION II

HYDROMETRIC MEASUREMENTS

PURPOSE OF HYDROMETRIC STUDIES

The collection of certain hydrometric data was necessary in order to interpret the results of the chemical and bacteriological analyses; to determine the effect of pollution in the river below the metropolitan area; and to estimate rates of natural purification taking place in the stream.

The hydrometric data have been reduced to the following basic tabulations, which give:

(*a*) Estimates of the monthly mean discharge at sampling points at the mouth of each of the larger tributaries.

(*b*) Estimates of the monthly mean discharge at sampling points on the main river.

(*c*) Estimates of monthly mean times of flow between certain sampling points on the main river, during low-water stages, when the available data would permit of such calculations with a reasonable degree of accuracy.

DATA FROM WHICH CALCULATIONS WERE MADE

The hydrometric calculations and related data were compiled from maps of the entire watershed of the Mississippi River above Winona, Minn.; from large-scale maps of the river channel on which soundings were given; and from river gage heights and discharge estimates made by the United States Geological Survey working in cooperation with the Minnesota Drainage Commission and the Wisconsin Railroad Commission.

MAPS

A map of the entire drainage basin of the Mississippi River, above the Minnesota-Iowa State line, on a scale of 1:500,000, prepared by the United States Geological Survey, was used to compute drainage areas above gaging stations and sampling points on the main river and its tributaries. Larger-scale maps of the river channel in the section under investigation were also available from which measurements of cross sectional areas were obtained. The maps of the Mississippi River Commission, on a scale of 1:20,000, made in 1897, showed the river channel and soundings taken at intervals of about 800 feet, together with the topography to the top of the bluffs on either side of the stream. Later surveys, made in 1921, 1925, and 1926 by the Engineer Corps of the United States Army, on a scale of 1 inch to 400 feet, showed low-water soundings taken about every 200 feet, but indicated practically none of the topography above the elevation of the water surface on the days soundings were made. Elevations on the Missipississippi River Commission maps are referred to the Memphis datum, while those of the Army Engineer Corps are referred to the Cairo datum. Weather Bureau gage elevations are above mean sea level.

The relation between the various datum planes, to which elevations on the upper Mississippi Valley are referred, is given in Table 6.

TABLE 6.—*Relation of various datum planes of the Mississippi River Valley*

Datum	Elevation in feet above—			
	Cairo	Memphis	Gulf level	Sandy Hook
Cairo	0.00	−13.13	−21.26	−21.31
Memphis	13.13	0.00	−8.13	−8.18
Gulf level	21.26	8.13	0.00	−0.05
Sandy Hook	21.31	8.18	0.05	0.00

NOTE.—From Appendix A, Public Health Bulletin No. 171.

RIVER GAGES

River gages, from which daily water-surface elevations were obtained when the river was not frozen, were maintained by the United States Weather Bureau at four points on the section of the upper Mississippi River under investigation. Gages of the Army Engineer Corps were read less frequently or were used only for reference during the course of river surveys. Gages on the larger tributaries, maintained by the United States Geological Survey in cooperation with the States of Minnesota and Wisconsin, were usually read daily.

Data relative to river gages, watershed areas, and the various prisms through which discharge estimates and times of flow have been made are summarized in Table 7.

TABLE 7.—*Summary and description of Mississippi River prisms*

Prism	Extent				Length of prism	Reference gage			Watershed area			Tributary streams		
	From—	To—	From mile[1]—	To mile—		At mile—	Zero[2] elevation	Place	Above upper station	Above lower station	Directly tributary to prism—	Name	Enters at mile—	Watershed area above mouth
					Miles				*Square miles*	*Square miles*	*Square miles*			*Square miles*
a	Station No. 1	Station No. 2	0.0	3.1	3.1				19,440	19,490	50			
b	Station No 2	Head of pool, Minneapolis.	3.1	5.5	2.4				19,490	19,560	70			
c	Head of pool, Minneapolis	Station No. 3	5.5	10.5	5.0				19,560	19,580	20			
d	Station No 3	Minnesota River	10.5	12.9	2.4				19.580	19.780	200			
e	Minnesota River	Station No. 5	12.9	19.2	6.3				36,530	36,570	40	Minnesota	12.9	16,750
f	Station No. 5	Station No. 6	19.2	28.2	9.0	18.6	680.2	St. Paul	36,570	36,680	110			
g	Station No. 6	Station No 7	28.2	45.0	16.8	18.6	680.2	St. Paul	36,680	36,820	140			
h	Station No. 7	St. Croix River	45.0	47.4	2.4	18.6	680.2	St. Paul	36,820	36,830	10			
i	St. Croix River	Cannon River	47.4	66.1	18.7	66.6	664.6	Red Wing	44,440	44,850	410	St Croix	47.4	7,610
j	Cannon River	Station No. 9	66.1	68.3	2.2	66.6	664.6	Red Wing	46,370	46,370		Cannon	66.1	1,520
k	Station No 9	Lake Pepin (inlet)	68.3	73.3	5.0	66.6	664.6	Red Wing	46,370	46,460	90			
l	Lake Pepin (inlet)	Lake Pepin (outlet)	73.3	95.1	21.8	97.5	663.7	Reads	46,460	46,940	480			
m	Lake Pepin (outlet)	Chippewa River	95.1	96.2	1.1	97.5	663.7	Reads	46,940	46,950	10			
n	Chippewa River	Zumbro River	96.2	109.9	13.7	97.5	639.9	Reads	56,550	57,000	450	Chippewa	96.2	9,600
o	Zumbro River	Station No. 14	109.9	136.8	26.9	137.0	639.9	Winona	58,420	59,230	810	Zumbro	109.9	1,420

[1] Miles below Camden Avenue bridge, Minneapolis.

[2] Above mean sea level.

RATING STATIONS

Rating stations for estimating the discharge of the Mississippi River were located on the main stream at Elk River and St. Paul, Minn., and were maintained under the supervision of the United States Geological Survey. In addition to these estimates of discharge, the St. Anthony Falls Water Power Co. made calculations of the flow of the main river at Minneapolis as the water passed the Falls of St. Anthony, where it was distributed for power purposes; and another estimate of discharge was made at the Government lock and dam a short distance above the mouth of the Minnesota River, by the Ford Motor Co., lessee of the power developed at this point. The discharge of the Mississippi River at Elk River was calculated from gage heights read twice daily; at St. Paul from continuous gage readings, and at St. Anthony Falls and at the Government lock and dam from power-house records.

Rating stations previously established on tributaries by the Geological Survey were located on the Minnesota River at Mankato, on the St. Croix River at St. Croix Falls, and at two points on the Chippewa River, one at Chippewa Falls, Wis., and the other on the Red Cedar River, at Menomonie, Wis., a tributary of the Chippewa River. Rating stations had previously been established by the United States Geological Survey, but later discontinued, on the Cannon and Zumbro Rivers. These stations were reopened, under the direction of the Minnesota Drainage Commission, during the summer and fall of 1926, and then again discontinued.

Discharge of tributary streams was calculated from continuous-gage readings at Mankato, Chippewa Falls, and Menomonie; from power-house records at St. Croix Falls; and from gage readings taken twice daily at Welch and Zumbro Falls, on the Cannon and Zumbro Rivers, respectively. During times of ice cover, the relationship between gage reading and discharge was affected and the estimates of run-off were less reliable.

METHODS OF CALCULATING DISCHARGE

DISCHARGES FROM RATED TRIBUTARIES

Daily rates of discharge of tributaries have been supplied by the United States Geological Survey from the gage height-discharge correlations determined by current-meter readings at the rating sections, or from the quantity of water passing the wheels or flowing over the dams in the case of power stations. In most instances rating stations on tributaries were located at considerable distances above their mouths. The run-off from tributaries below rating sections was assumed to be proportional to that above the section. The discharge at the mouth was calculated by multiplying the discharge at the rating section by a factor obtained by dividing the total watershed area, by the area above the point where the measurements were made. The factors so determined for the five larger tributaries of the Mississippi River are given in Table 8.

TABLE 8.—*Data relative to watershed areas, above and below gaging stations, on the principal tributaries of the upper Mississippi River*

Tributary	Area of watershed in square miles	Area of watershed above the rating station	Station of confluence with Mississippi	Location of gaging station	Ratio of total watershed to that above rating station
Minnesota River	16,750	14,900	12.9	Mankato	1.12
St. Croix River	7,610	6,190	47.4	St. Croix Falls	1.23
Cannon River	1,520	1,390	66.1	Welch	1.09
Chippewa River	9,600	7,460	96.2	Chippewa Falls and Menomonie	1.29
Zumbro River	1,420	1,140	109.9	Zumbro Falls	1.25

The monthly average rates of discharge, expressed in cubic feet per second (second-feet), at the mouths of the tributaries on the upper Mississippi River watershed, calculated from the factors of Table 8, are given in Table 9. The discharge from the Cannon and Zumbro Rivers, after the rating stations were closed on the first of November, 1926, until the end of the investigation, was assumed to be the same per square mile of watershed as the run-off from the Minnesota River above Mankato, the nearest rated tributary.

TABLE 9.—*Monthly average rates of discharge, in second-feet, of the tributaries oj the upper Mississippi River at their mouths*

Month	Minnesota River	St. Croix River	Cannon River	Chippewa River	Zumbro River
1926					
June	400	2,900	134	5,500	272
July	213	2,100	95	3,600	154
August	375	2,520	97	9,500	163
September	2,040	4,800	293	23,400	454
October	2,380	6,050	276	12,600	474
November	1,110	4,300	256	15,500	238
December	830	2,940	214	6,840	200
1927					
January	625	2,420	126	6,500	118
February	610	2,260	132	7,130	124
March	9,120	12,600	570	24,500	530
April	9,270	15,400	1,220	11,100	1,130
May	6,680	7,700	1,030	13,500	965
June	5,910	6,700	1,100	7,500	1,030
July	1,450	4,650	212	7,260	197
August	369	2,470	46	4,170	43
AVERAGES					
Yearly	3,260	5,820	450	11,810	465
Summer 1926	329	2,510	109	6,200	196
Summer 1927	2,580	4,610	453	6,310	423
Winter	688	2,540	157	6,820	147
Fall	1,840	5,050	275	17,200	389
Spring	8,360	11,900	940	16,400	875

Yearly average=July, 1926 to June, 1927, inclusive.
Summer average=June, July, August.
Winter average=December, January, February.
Fall average=September, October, November.
Spring average=March, April, May.

RATES OF DISCHARGE AT SAMPLING STATIONS

In calculating the discharge at sampling stations below St. Paul, it was necessary to extend the discharge measurements from the St. Paul rating station, with modifications, downstream to Winona, as no other rating section had been established on the Mississippi River in the section under investigation.

The flow of the Mississippi River below St. Paul during the summer months is controlled for navigation purposes by the storage reservoirs already referred to, near the headwaters of the stream.

In order to eliminate the effects of increased flow due to the operation of the reservoir system, the normal run-off from the watershed was estimated by deducting from the discharge at St. Paul the combined discharges of the Mississippi River at Elk River and the Minnesota River at Mankato, and determining the yield, per square mile, of the 7,040 square miles of watershed between these points. As an example, the average discharge of the Mississippi River at St. Paul during the month of July, 1926, was 2,590 second-feet from 36,570 square miles. During the same month the average discharge of the Mississippi River at Elk River was 2,150 second-feet from 14,630 square miles of watershed, and of the Minnesota River at Mankato 132 second-feet from 14,900 square miles of drainage area. The normal discharge from the 7,040 square miles of watershed below Elk River and Mankato and above St. Paul for this month was, therefore, assumed to be 308 second-feet, or 0.044 second-foot per-square mile of watershed. The estimated normal yield per square mile of watershed for the other months of the investigation is tabulated in Table 10. The figures were assumed to represent the yield of the watershed adjacent to the river, between the mouths of tributaries, from St. Paul to Winona.

TABLE 10.—*Estimated normal monthly discharge, in second-feet per square mile, from 7,040 square miles of watershed on the upper Mississippi River, between the Elk River, Mankato, and St. Paul gaging stations, June 1, 1926, to August 31, 1927.*

Month	Total yield in second-feet from 7,040 square miles	Yield, cubic feet per second, per square mile	Month	Total yield in second-feet from 7,040 square miles	Yield, cubic feet per second, per square mile
1926			1927		
June	394	0.056	January	580	0.083
July	308	.044	February	610	.087
August	524	.075	March	2,630	.374
September	2,010	.286	April	5,610	.798
October	2,500	.355	May	4,790	.680
November	1,181	.168	June	5,110	.725
December	990	.141	July	980	.139
			August	211	.030

The total area of the Mississippi River watershed, above Winona, has been estimated from the Geological Survey maps as 59,230 square miles. Of this area, 52,750 square miles, or about 89 per cent of the area of the watershed, is above the rating station at St. Paul or above those on tributaries. By extending the rates of run-off from the rating stations on tributaries, to their mouths, as already explained, this area is increased to 56,720 square miles, or to about 96 per cent of the total area of the watershed, leaving 2,510 square miles of watershed area directly tributary to the main stream, to which the calculated yields of Table 10 were applied.

The monthly average rates of discharge, in second-feet, of the upper Mississippi River at the various sampling stations, and above and below the mouths of the larger tributaries, are summarized in Table 11.

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TABLE 11.—*Monthly average rates of discharge, in second-feet, of the upper Mississippi River at sampling stations and above and below the mouths of tributaries*

MONTHLY MEAN DISCHARGE, SECOND-FEET, AT POINTS ON THE UPPER MISSISSIPPI RIVER

Month	Station No. 1	Station No. 2	Station No. 3	Above mouth Minnesota River	Below mouth Minnesota River	Station No. 5	Station No. 6	Station No. 7	Above mouth St. Croix River	Below mouth St. Croix River	Above mouth Cannon River	Below mouth Cannon River	Station No. 9	Above mouth Chippewa River	Below mouth Chippewa River	Above mouth Zumbro River	Below mouth Zumbro River	Station No. 14
1926																		
June	2,430	2,430	2,440	2,450	2,850	2,850	2,860	2,860	2,860	5,760	5,790	5,920	5,920	5,960	11,500	11,500	11,800	11,800
July	2,360	2,360	2,370	2,380	2,590	2,590	2,600	2,600	2,600	4,700	4,720	4,810	4,810	4,840	8,440	8,640	8,610	8,650
August	2,410	2,410	2,420	2,440	2,810	2,810	2,820	2,830	2,830	5,350	5,380	5,480	5,480	5,520	15,000	15,100	15,200	15,300
September	6,480	6,500	6,520	6,580	8,620	8,630	8,660	8,700	8,700	13,500	13,600	13,900	13,900	14,100	37,500	37,600	38,100	38,300
October	7,460	7,480	7,510	7,580	9,960	9,970	10,000	10,100	10,100	16,100	16,300	16,600	16,600	16,700	29,300	29,500	30,000	30,300
November	3,980	3,990	4,000	4,030	5,140	5,150	5,170	5,190	5,190	9,490	9,560	9,820	9,820	9,920	25,400	25,500	25,700	25,900
December	2,890	2,890	2,910	2,940	3,770	3,770	3,790	3,810	3,810	6,750	6,810	7,020	7,020	7,100	13,900	14,000	14,200	14,300
1927																		
January	2,300	2,300	2,310	2,330	2,950	2,950	2,960	2,970	2,970	5,390	5,430	5,560	5,560	5,600	12,100	12,100	12,200	12,300
February	2,210	2,210	2,220	2,240	2,850	2,850	2,860	2,870	2,870	5,130	5,170	5,300	5,300	5,350	12,500	12,500	12,600	12,700
March	9,640	9,660	9,690	9,770	18,900	18,900	18,900	19,000	19,000	31,600	31,800	32,400	32,400	32,500	57,000	57,200	57,700	58,000
April	17,400	17,500	17,500	17,700	27,000	27,000	27,100	27,200	27,200	42,600	42,900	44,100	44,100	44,600	55,700	56,100	57,200	57,900
May	12,800	12,800	12,900	13,000	19,700	19,700	19,800	19,900	19,900	27,600	27,900	28,900	28,900	29,300	42,800	43,100	44,100	44,600
June	9,810	9,850	9,910	10,100	16,000	16,000	16,100	16,200	16,200	22,900	23,200	24,300	24,300	24,700	32,200	32,500	33,500	34,100
July	5,590	5,590	5,610	5,640	7,090	7,090	7,110	7,120	7,120	11,800	11,800	12,000	12,000	12,000	19,300	19,400	19,600	19,800
August	5,100	5,100	5,090	5,080	5,450	5,440	5,440	5,450	5,450	7,920	7,930	7,980	7,980	7,990	12,200	12,200	12,200	12,200
AVERAGES																		
Yearly	6,650	6,660	6,690	6,760	10,020	10,030	10,060	10,110	10,110	15,930	16,060	16,500	16,500	16,700	28,490	28,650	29,090	29,400
Summer, 1926	2,400	2,400	2,410	2,420	2,750	2,750	2,760	2,760	2,760	5,270	5,300	5,400	5,400	5,440	11,650	11,750	11,870	11,920
Summer, 1927	6,830	6,850	6,870	6,940	9,510	9,510	9,550	9,590	9,590	14,210	14,310	14,760	14,760	14,900	21,230	21,370	21,770	22,030
Winter	2,470	2,470	2,480	2,500	3,190	3,190	3,200	3,220	3,220	5,760	5,800	5,960	5,960	6,020	12,830	12,870	13,000	13,100
Fall	5,970	5,990	6,010	6,060	7,910	7,920	7,940	8,000	8,000	13,030	13,150	13,440	13,440	13,570	30,730	30,870	31,270	31,500
Spring	13,280	13,320	13,360	13,490	21,870	21,870	21,930	22,030	22,030	33,930	34,200	35,130	35,130	35,470	51,830	52,130	53,000	53,500

Yearly average=July, 1926, to June, 1927.
Summer average=June, July, August.
Winter average=December, January, February.
Fall average=September, October, November.
Spring average=March, April, May.

TIME OF FLOW CALCULATIONS

Computations of times of flow in the section of the river under investigation were limited by the hydrometric data available and by the character of the surveys giving soundings in the river channel. Rates of discharge at St. Paul, with correction for stream control, were extended downstream to Winona and are, in the absence of a lower rating station upon which to check results, undoubtedly subject to considerable error. During December, January, and February when the river was frozen, gage readings were discontinued at many of the main river gages. At the St. Paul rating section increased velocities usually prevent the river from freezing, and daily gage readings were obtained throughout the year, but the relationship between gage height and discharge was affected by the ice cover above and below the station. Winter estimates of stream discharge are, therefore, subject to considerable error. The estimation of water slope, in the various prisms along the river, was limited to gage readings, when available, at St. Paul, Red Wing, Reads, and Winona. The water-surface slope between successive gages was assumed as uniform, which probably was not altogether true. Surveys of the river between Minneapolis and Winona, with soundings, were made on four occasions by the Engineer Corps of the United States Army. The survey of 30 years ago, made in 1897, for the Mississippi River Commission, was the most extensive and shows the topography between the top of the bluffs on either side of the river, the river channel, and the soundings as of that date. The construction of the Federal lock and dam at Minneapolis, about 1914, and the improvement in the low-water channel below St. Paul by the construction of many more wing dams and cut-off walls, together with frequent dredging operations, has probably altered channel conditions and water slopes to such an extent that the older survey is of little value in calculating cross-sectional areas at the present time. Later surveys of the river were made in 1921, between St. Paul and the mouth of the St. Croix River; in 1926 between the St. Croix River and the upper end of Lake Pepin; and in 1925 between the outlet of Lake Pepin and Winona. These recent surveys, made primarily for the purpose of obtaining depths in the navigation channel under low-water conditions, show soundings, usually from bank to bank or in the channel between wing dams, at low river stages, with no attempt to indicate probable cross-sectional areas as the river approaches flood stages. At times of low water the wing dams and cut-off walls confine the flow to a definite channel, but with increasing stages the dams become submerged and the water spreads out over the flood plain to the foot of the bluffs, making computation of the cross-sectional areas exceedingly difficult. Further difficulties arise in attempting to estimate the effect on the mean velocity of flow through a prism, due to the submergence of the wing dams, which act as baffles, of varying height, above the bottom of the river. Because of the limitations in the data, estimates of times of flow were confined to that section of the Mississippi River below Roberts Street, St. Paul, Station No. 5, where data from recent surveys were obtainable and were made only for the summer and winter periods, when river stages were more nearly comparable to those at the time soundings were taken in the river.

Estimates of times of flow though the various prisms into which the river was divided, Table 7, were based on the following fundamental relationship: Q, the discharge in second-feet, is equal to V, the velocity of flow in feet per second, times A, the cross-sectional area in square feet.

$$Q = V.\ A \text{ or } V = \frac{Q}{A}$$

By dividing the estimated mean discharge through the prism by its mean cross-sectional area, the estimated velocity of flow from the upper to the lower limit was obtained. The time of flow was then computed from the length of the section and the mean velocity of flow. To determine the mean areas of wetted cross section in the selected prisms with respect to the reference gage, the following procedure was employed.

Large-scale maps, supplied by the U. S. Army Engineer Corps, gave water-surface elevations at the reference gages on the days that soundings were made in the river. From the soundings, three to four or more representative cross sections along the river, per mile of channel, were plotted to scale on cross section paper.

The slope of the water surface was assumed to be uniform between reference gages. Water-surface elevations at the selected cross sections were calculated for the days on which soundings were taken, and then indicated on the plots of representative river sections.

A correlation of gage heights, at reference gages, above and below those of the dates on which soundings were made, indicated changes in water slopes with changing river stages. Elevations at the selected sections were then calculated and plotted on the cross-sectional areas for several corresponding changes at the reference gages.

Planimeter measurements were made of the areas below water-surface elevations, on the cross-sectional plots, corresponding to known readings on the reference gages. These areas were weighted by the distance to the next section above and gave a relationship between reference gage readings and mean cross sectional areas of the prism.

At reference gages below St. Paul an approximate relationship was first established between reference-gage readings and corresponding volumes of flow, which was used with the reference gage reading, mean cross-sectional area relationship to estimate velocity of flow through the various prisms between reference gages.

Prisms were selected so that all main tributaries entered at the upper end. The increase in flow between the upper and lower end of a prism, from the area immediately adjacent to the river, was assumed to enter uniformly along the prism and the mean volume of flow was assumed as that entering the prism, to which was added one-half of the increase between the upper and lower limits.

The mean velocity of flow through the various prisms was next computed from the mean discharge and the mean cross-sectional area, at corresponding gage heights, and the time of flow by dividing the length of the prism by the mean velocity of flow through it. Curves showing the relation between gage height and mean cross-sectional area and gage height and mean time of flow were then constructed from these data.

Times of flow between points of the main river, from St. Paul to the head of Lake Pepin, and from the outlet of the lake to Winona, were calculated by the above method. In Lake Pepin, for which no recent survey was available, the older maps of the Mississippi River Commission were used, and the volume in the lake calculated from 5-foot contours, below the reference gage at the outlet. Monthly mean times of flow through the lake were assumed as the mean capacity, during the month, divided by the monthly mean discharge at the outlet of the lake.

In Tables 12 and 13 there are assembled, where the data would permit of calculation, the monthly mean times of flow, during the summer and winter periods, through designated prisms on the Mississippi River, between St. Paul and Winona. The data of Table 12 show the time of flow through each of the designated prisms, that of Table 13 the cumulative time of flow, for the same months, to successive sampling stations below Station No. 5 at St. Paul.

TABLE 12.—*Monthly mean time of flow, in hours, of the Mississippi River between consecutive sampling stations and the mouths of tributaries, from St. Paul to Winona, Minn., during the summer and winter months*

Time of flow between—	Length of section	Mean time of flow, in hours										
		1926			1927		Average for summer months	1926		1927		Average for winter months
		June	July	August	July	August		November	December	January	February	
	Miles											
Station No 5 and Station No. 6	9.0	9.5	10 0	9.5	6.2	7.0	8.4	7.2	8.2	9.3	9.5	8.5
Station No. 6 and Station No. 7	16.8	16.4	17.2	16.4	9.5	11.0	14.1	11.5	13.9	16.0	16.4	14.5
Station No. 7 and St. Croix River	2.4	5.0	5.4	5.0	2.7	3.2	4.3	3.3	4.1	4.8	5.0	4.3
St. Croix River and Cannon River	18.7		23.2	21.9	17.3	20.4	20.7	16.4	20.6	22.5	23.0	20.6
Cannon River and Station No. 9	2.2		2 3	2.2	1.5	2.0	2.0	1.4	2.0	2.3	2.3	2.0
Station No 9 and inlet to Lake Pepin	5.0		8.9	8.2	6.0	7.6	7.7	5.5	7.6	8.5	8.8	7.6
Inlet and outlet of Lake Pepin	21.8		1,300.0	1,150.0	600.0	840.0	970.0	750.0	950.0	1,100.0	1,200.0	1,000.0
Outlet Lake Pepin and Zumbro River	14.8		16.6	14.7			15.7					
Zumbro River and Station No. 14, Winona	26.9		25.4	24.4			24.9					

TABLE 13.—*Cumulative monthly mean time of flow, in hours, of the Mississippi River from Station No. 5, St. Paul, to consecutive sampling stations and the mouths of tributaries, during the summer and winter months*

Cumulative time of flow from Station No. 5, St. Paul, to—	Distance in miles from Station No. 5	Cumulative time of flow, in hours										
		1926			1927		Average for summer months	1926		1927		Average for summer months
		June	July	August	July	August		November	December	January	February	
Station No. 6, Invergrove Bridge	9.0	9.5	10.0	9.5	6.2	7.0	8.4	7.2	8.2	9.3	9.5	8.5
Station No. 7, Hastings	25.8	25.9	27.2	25.9	15.7	18.0	22.5	18.7	22.1	25.3	25.9	23.0
Mouth of St. Croix River	28.2	30.0	32.6	30.9	18.4	21.2	26.8	22.0	26.2	30.1	30.9	27.3
Mouth of Cannon River	46.9		55.8	52.8	35.7	41.6	46.5	38.4	46.8	52.6	53.9	47.9
Station No. 9, Red Wing	49.1		58.1	55.0	37 2	43 6	48.5	39.8	48.8	54.9	56.2	49.9
Upper end of Lake Pepin	54.1		67.0	63.2	43.2	51.2	56.1	45.3	56.4	63.4	65.0	57.5
Outlet of Lake Pepin	75.9		1,367.0	1,213.2	643.2	891.2	1,028.7	795.3	1,006.4	1,163.4	1,265.0	1,057.5
Mouth of Zumbro River	90.7		1,383.6	1,227.9			1,305.8					
Station No. 14, Winona	117.6		1,409.0	1,252.3			1,330.7					

SECTION III

POPULATION AND SOURCES OF POLLUTION ON THE UPPER MISSISSIPPI RIVER WATERSHED

PRESENTATION OF DATA

The pollution of a river system at any given point along its course depends upon the amount and composition of all the wastes discharged into it above the point, the volume of the water into which they are diffused, and the direction and extent of the changes which the wastes have undergone between the point of entry and the point of observation.

Polluting material enters a watercourse with the surface run-off which carries portions of the eroded land surface and wastes of various kinds resulting from the activities of the rural population on the basin; as wastes from the more highly developed centers of population, collected in artificial sewerage systems, either of the combined or separate type; and as the wastes from industrial and manufacturing processes. In highly developed industrial centers the pollution contributed by these manufacturing wastes may be far in excess of that contributed as domestic sewage. In terms of polluting effect, the wastes contributed as domestic sewage from different communities are generally proportionate to the respective number of persons contributing to the sewers. The contributions from different communities may, therefore, be summed up and compared in terms of sewered population. It is also possible, to a limited extent, to summarize the wastes from certain industrial processes in terms of sewered population which would contribute equivalent pollution, in the form of domestic sewage, and then to obtain a rough quantitative estimate of the combined domestic and industrial waste pollution from a series of urban communities. The amount and character of the wastes derived from unsewered rural areas vary to such an extent with the topography, character of the surface formations, extent of agricultural operations, distribution of rainfall, and other indeterminate factors that they can not be estimated with any degree of accuracy or in any significant quantitative terms.

Sources of pollution on the upper Mississippi River are, therefore, presented as estimates of population; total, urban and rural, on the watershed and its various subdivisions; summaries of the sewered population contributing to the various watercourses; and as estimates of the industrial waste pollution in terms of equivalent sewered population.

POPULATION

Statistics of population used in this study were derived from the Federal census enumerations of 1910 and 1920, redistributed according to drainage areas, and extended to the year 1927 by assuming an arithmetical rate of increase since 1910.

As tabulated in the census reports, the populations of the States are distributed primarily by counties, and the population of each county further distributed according to the civil subdivisions which are included within the county area. Within the State of Minnesota these minor civil divisions consist of organized and unorganized townships, villages, and cities. In Wisconsin the county area is divided into minor civil divisions consisting of "towns," which are the equivalent of townships in most other States, cities, and unincorporated villages.

In the classification of the Census Bureau the population resident in incorporated places having 2,500 or more inhabitants is classed as "urban," and the remainder of the population, residing in the county and in incorporated places of less than 2,500 inhabitants, is classed as "rural." This classification has been followed in the present report.

In order to regroup the population according to drainage areas, each watershed was outlined on State maps on which were indicated the boundaries of the civil divisions of the population enumerations of the census. Watershed boundaries were adjusted in accordance with topographic maps of the United States Geological Survey where available, or, in their absence, from maps of the State Drainage or Conservation Commissions.

Counties lying wholly within a single watershed required only simple summation of the populations, classified as rural and urban, respectively. In apportioning the population of counties intersected by the watershed boundary, the proportion of the county area lying within the watershed was first determined by planimeter measurement. The population of all incorporated places was next deducted from the total county population, and the remainder prorated, allocating to the watershed a fraction of this population proportionate to the fraction of the county area included in the watershed as indicated by planimeter measurement. The prorated population added to the population of all incorporated places of less than 2,500 inhabitants within the watershed, as shown from the maps, gave the total rural population. The urban population was the sum of all incorporated places of 2,500 or more inhabitants lying in that portion of the county included in the watershed.

In the densely populated areas, in the vicinity of Minneapolis and St. Paul, population estimates were made with somewhat greater precision by using city maps, on which ward boundaries were indicated, or maps showing sewerage districts for which population estimates were available.

The Mississippi River investigation was conducted during the period from June 1, 1926, to August 31, 1927; and since January 1, 1927, represented approximately the mid-point of the study, estimates of population on the entire watershed above Winona, Minn., and on the various major subdivisions, as well as above sampling points, were made for 1910 and 1920 and these estimates extended to January 1, 1927.

Statistics of population for the upper Mississippi River Basin, above Winona, are summarized in Tables 14 and 15. Table 14 shows the total, urban, and rural populations in 1910 and 1920 and the estimated populations as of January 1, 1927, by major subdivisions and for the entire watershed. The estimated populations on January 1, 1927, have been rearranged in Table 15 to show the total, urban, and rural populations above the various sampling stations on the main river and its tributaries.

TABLE 14.—*Total, urban, and rural population on the Mississippi River watershed above Winona, Minn., by tributary areas, in 1910 and 1920, and the estimated population on January 1, 1927*

Watershed	Area, square miles	Population in 1910			Population in 1920			Population Jan. 1, 1927		
		Total	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural
Mississippi above Minneapolis	19,440	345,528	56,939	288,589	404,528	70,219	334,309	442,327	79,780	362,547
Minnesota River	16,750	404,460	47,439	357,021	438,879	60,384	378,495	463,659	69,705	393,954
St. Croix River	7,610	128,632	14,461	114,171	148,137	13,042	135,095	162,181	12,021	150,160
Cannon River	1,520	54,868	17,924	36,944	57,978	22,364	35,614	60,218	25,561	34,657
Chippewa River	9,600	181,382	43,206	138,176	211,545	48,431	163,114	233,263	52,193	181,070
Zumbro River	1,420	43,783	7,844	35,939	50,429	13,722	36,707	55,215	17,954	37,261
Mississippi, direct, Minneapolis to Winona	2,890	642,793	544,850	97,943	749,762	649,460	100,302	831,384	724,878	106,506
Total	59,230	1,801,446	732,663	1,068,783	2,061,258	877,622	1,183,636	2,248,247	982,092	1,266,155

TABLE 15.—*Estimated total, urban, and rural population, as of January 1, 1927, above sampling stations on the upper Mississippi River*

Population above points on the Mississippi River and tributaries	Watershed area, square miles	Population Jan. 1, 1927		
		Total	Urban	Rural
Above Minneapolis:				
Station No. 1	19,440	442,327	79,780	362,547
Station No. 2	19,490	505,933	136,653	369,280
Above lock and dam, Minneapolis, Station No. 3	19,580	922,376	549,391	372,985
Above the mouth of Minnesota River	19,780	954,136	566,813	387,323
Minnesota River watershed above station No. 4	16,750	463,659	69,705	393,954
Above St. Paul, Station No. 5	36,570	1,417,795	636,518	781,277
Above Invergrove, Station No. 6	36,680	1,650,586	858,395	792,191
Above Hastings, Station No. 7	36,820	1,661,672	863,389	798,283
St. Croix River watershed above Station No. 8	7,610	162,181	12,021	150,160
Mississippi River above the mouth of Cannon River	44,850	1,835,923	875,410	960,513
Cannon River watershed above Station No. 10	1,520	60,218	25,561	34,657
Mississippi River above the Chippewa, Station No. 11	46,950	1,924,680	911,945	1,012,735
Chippewa River watershed above Station No. 12	9,600	233,263	52,193	181,070
Mississippi River above the Zumbro River	57,000	2,173,023	964,138	1,208,885
Zumbro River watershed above Station No. 13	1,420	55,215	17,954	37,261
Above Winona, Station No. 14	59,230	2,248,247	982,092	1,266,155

The distribution, by States, of the estimated total, urban, and rural populations on the watershed, as of January 1, 1927, is indicated in the following tabulation, Table 16.

TABLE 16.—*Estimated total, urban, and rural population, as of January 1, 1927, on the Mississippi River watershed, above Winona, Minn., arranged by States*

State	Total population	Urban population	Rural population
Minnesota	1,856,819	923,840	932,979
Wisconsin	353,678	58,252	295,426
South Dakota	28,729		28,729
Iowa	9,021		9,021
Total	2,248,247	982,092	1,266,155

The estimated total population on the upper Mississippi River watershed, above Winona, on January 1, 1927, was 2,248,247, of which 1,266,155, or 56 per cent, was classed as rural, and 982,092, or 44 per cent, as urban. Of the total population on the watershed, approximately 82 per cent was within the State of Minnesota and 16 per cent in the State of Wisconsin. The urban population of the watershed, 982,092, was divided between the States of Minnesota and Wisconsin, 94 per cent residing in the former and only 6 per cent within the latter. Within the metropolitan area of the Twin Cities, in Minnesota, there was an urban population of 708,910, equivalent to approximately 72 per cent of the total urban population on the entire watershed.

The population on the watershed of the main river, above Minneapolis, and on the tributaries, was largely rural in character, as indicated in the following tabulation, which shows the percentage of watershed population classed as rural, on the larger tributaries.

TABLE 17.—*Percentage of the population classed as rural on the tributaries of the upper Mississippi River and on the main stream, above Minneapolis. Population estimates as of January 1, 1927*

Watershed	Per cent of watershed population classed as rural	Watershed	Per cent of watershed population classed as rural
Mississippi River above Minneapolis	82	Cannon River	57
Minnesota River	85	Chippewa River	78
St. Croix River	93	Zumbro River	67

With the exception of Minneapolis and St. Paul, there were but 19 communities on the upper Mississippi River watershed, above Winona, with populations of 5,000 or over. Of these, 16 were in Minnesota and 3 in Wisconsin. Five communities in Minnesota and one in Wisconsin had populations in excess of 10,000.

SEWERAGE AND SEWAGE TREATMENT

Sewerage systems had been installed in approximately 182 communities on the Mississippi River watershed above Winona. Data relative to the population contributing to sewerage systems, methods of sewage treatment, and industrial-waste pollution were secured by visits to the communities comprising the metropolitan area of the Twin Cities and to those located directly on the main stream, between the metropolitan district and Winona. Information for the remaining places, comprising a large number of small communities, scattered over the entire watershed, was obtained by circular letter addressed to the health officer, mayor, or other local official, supplemented by data from the records of the State health organizations.

SEWERAGE

Table 18 presents in summarized form the data collected relative to the number of sewered communities on the entire watershed, above Winona, and by tributary areas; the total population residing in these communities; the population actually contributing sewage; the number and types of sewage-treatment plants; and the population contributing to each type of treatment plant.

TABLE 18.—*Summary of sewered population and sewage-treatment data on the Mississippi River watershed above Winona, Minn., by watershed divisions*

Watershed	Number of sewered communities	Number of sewage-treatment plants: Primary treatment only	Number of sewage-treatment plants: Primary and secondary treatment	Total population of sewered communities Jan. 1, 1927	Estimated actual sewered population
Mississippi River above Minneapolis	58	22	2	120, 880	76, 770
Minnesota River	58	25	1	121, 590	75, 140
St. Croix River	21	3	0	31, 270	19, 350
Vermillion River	1	1	0	1, 760	1, 500
Cannon River	4	0	0	26, 830	22, 150
Isabelle Creek	1	0	1	1, 070	800
Chippewa River	20	3	1	68, 050	43, 080
Zumbro River	9	4	2	25, 620	17, 830
Buffalo River	1	0	0	1, 720	1, 000
Whitewater River	1	1	0	1, 490	1, 300
Mississippi River, directly, Minneapolis to Winona	8	0	0	717, 100	696, 360
Total	182	59	7	1, 117, 380	955, 280

Watershed	Per cent of population in sewered communities contributing sewage	Population contributing untreated sewage	Population contributing sewage after primary treatment	Population contributing sewage after primary and secondary treatment	Estimated population discharging the equivalent of untreated sewage [1]
Mississippi River above Minneapolis	63. 5	49, 810	24, 920	2, 040	66, 930
Minnesota River	61. 7	46, 480	28, 300	360	65, 440
St. Croix River	62. 2	16, 910	2, 440		18, 540
Vermillion River	85. 5		1, 500		1, 000
Cannon River	82. 4	22, 150			22, 150
Isabelle Creek	74. 7			800	200
Chippewa River	63. 3	40, 430	1, 850	800	41, 860
Zumbro River	69. 5	2, 440	2, 430	12, 960	7, 300
Buffalo River	58. 1	1, 000			1, 000
Whitewater River	87. 3		1, 300		900
Mississippi River, directly, Minneapolis to Winona	97. 2	696, 360			696, 360
Total	85 7	875, 580	62, 740	16, 960	921, 680

[1] Based on 33⅓ per cent reduction for primary treatment and 75 per cent reduction for primary and secondary treatment.

SEWERED POPULATION

In order to estimate the population discharging the equivalent of untreated sewage, it was assumed that primary treatment, consisting in most cases of sedimentation in septic or Imhoff tanks, would reduce the sewage load by about one-third, and that primary and secondary treatment would cause a reduction of 75 per cent in the sewage load. The last column of Table 18 indicates, therefore, for various subdivisions of the watershed, the estimated population discharging the equivalent of untreated sewage.

The data of Table 18 have been rearranged in Table 19 to show the population discharging the equivalent of untreated sewage, by 50-mile zones, above each of the sampling stations on the main stream and its larger tributaries.

TABLE 19.—*Estimated population discharging untreated sewage, by 50-mile zones, above sampling stations on the upper Mississippi River*

Sampling station	50-mile zone					
	0–50	50–100	100–150	150–200	200–250	250–300
1	3, 420	22, 510	19, 140	6, 550	2, 200	1, 080
2	54, 890	22, 510	16, 640	8, 720	2, 530	1, 080
3	462, 910	19, 770	9, 870	18, 230	3, 330	1, 080
Minnesota River	3, 100	5, 430	17, 150	10, 200	10, 700	11, 090
5	598, 160	21, 770	26, 800	28, 630	17, 230	14, 290
6	684, 580	21, 270	27, 020	26, 580	17, 440	15, 310
7	682, 080	7, 230	41, 460	23, 810	17, 900	11, 820
St. Croix River	10, 690	3, 230	2, 320	2, 300		
9	286, 570	437, 310	24, 860	28, 170	31, 430	15, 730
Cannon River	6, 650	15, 500				
11	13, 400	708, 660	18, 920	42, 190	26, 500	17, 900
Chippewa River	3, 500	28, 610	6, 800	2, 950		
Zumbro River		6, 780	520			
14	1, 680	38, 690	725, 810	24, 630	46, 300	29, 130

Sampling station	50-mile zone						Total population discharging untreated sewage
	300–350	350–400	400–450	450–500	500–550	550–600	
1	7, 230		4, 800				66, 930
2	7, 230		4, 800				118, 400
3	7, 230		4, 800				527, 220
Minnesota River	5, 820	1, 950					65, 440
5	11, 850	3, 330	4, 800				726, 860
6	12, 420	5, 030	100	4, 700			814, 450
7	15, 020	9, 880	450	4, 800			814, 450
St. Croix River							18, 540
9	12, 290	13, 850	3, 330	4, 800			858, 340
Cannon River							22, 150
11	11, 820	14, 770	10, 130	450	4, 800		869, 540
Chippewa River							41, 860
Zumbro River							7, 300
14	15, 470	13, 220	15, 020	6, 730	300	4, 700	921, 680

The estimated total sewered population on the upper Mississippi watershed, above Winona, is 955,280, equivalent to about 86 per cent of the total population in all the sewered communities. Omitting the sewered population of Minneapolis and St. Paul, which is equivalent to about 94 per cent of the total population within these two cities, about 68 per cent of the remaining urban population on the watershed contributes to sewerage systems. Similar calculations for the Ohio River drainage area, made in 1915, indicated a sewered population equivalent to about 72 per cent of the entire urban population; and on the Illinois River basin, in 1922, excluding the urban population of Chicago, which was practically 100 per cent sewered, the sewered population on the remainder of the watershed was 76 per cent of the total urban population.

Of the estimated total population of 921,680 discharging untreated sewage on the Mississippi watershed above Winona, 868,490, or about 94 per cent, are within the State of Minnesota and 53,190, or about 6 per cent, within the State of Wisconsin. The distribution of the population discharging untreated sewage by various subdivisions of the watershed is shown in Table 20.

TABLE 20.—*Distribution of the estimated population discharging untreated sewage, on the upper Mississippi River watershed, by tributary areas*

Watershed division	Estimated population discharging untreated sewage	Per cent of total population discharging untreated sewage
Mississippi River, above Minneapolis	66, 930	7. 3
Minnesota River	65, 440	7. 1
Mississippi River, in metropolitan area	682, 060	74. 0
St. Croix River	18, 540	2. 0
Cannon River	22, 150	2. 4
Chippewa River	41, 860	4. 5
Zumbro River	7, 300	. 8
Mississippi River, below metropolitan area	17, 400	1. 9
Total above Winona, Minn	921, 680	100 0

It will be observed from Table 20 that 74 per cent of the total estimated population discharging untreated sewage on the entire watershed contributes to the Mississippi River within the metropolitan area of the Twin Cities in Minnesota. Sewage from this area is discharged from about 75 main sewer outlets, located on both sides of the river along a distance of 25 miles.

At the time of the investigation practically all of the sewage from Minneapolis, and some from St. Paul, entered the main river above the Government lock and dam. Sedimentation of sewage solids took place in the pool behind the dam, forming sludge deposits along the sides and bottom. Decreased rates of stream flow combined with high water temperatures, in the summer months, produced septic conditions in this pool the effects of which were noticeable downstream as far as Hastings.

SEWAGE TREATMENT

Of the 182 sewered communities on the Mississippi River watershed above Winona, 66 treated their sewage before discharging it into the various watercourses. In 59 communities, in which the estimated total sewered population was 62,740, or 6.6 per cent of the total sewered population on the entire watershed, treatment consisted of sedimentation in various types of tanks. In the remaining seven communities, with an estimated sewered population of 16,960, or 1.8 per cent of the total sewered population on the entire watershed, the sewage received more or less complete treatement in primary and secondary sewage treatment works. In the communities having primary treatment works, the population contributing the equivalent of untreated sewage was assumed as two-thirds of the actual sewered population, and in communities having both primary and secondary treatment, as one-quarter of the actual sewered population. On this basis sewage treatment on the upper Mississippi River basin caused a reduction in pollution equivalent to the sewage from a population of 33,600 persons.

At the close of the field work of this investigation studies were in progress toward the collection and disposal of the sewage from the metropolitan area of the Twin Cities, to improve conditions in the Mississippi River through and below this area.

POLLUTION DUE TO INDUSTRIAL WASTES

In the questionnaire sent to local government officials concerning sewerage, sewered population, and sewage treatment, there was included a request for information relative to the number and types of manufacturing establishments discharging industrial wastes into the watercourses. Through these inquiries, a total of 107 possible waste-producing industries were reported on the watershed, outside of the metropolitan district. Included in this number were 68 creameries; 18 canning plants and a beet-sugar factory, operating only a portion of the year; 6 slaughtering and rendering establishments; 7 pulp and paper mills; 4 poultry-dressing establishments; a malting plant; a vinegar factory; and a woolen mill. This list, undoubtedly incomplete, indicated in a general way that the predominating types of industry on the watershed were those engaged in the production of milk products, canned goods, and paper. The data further indicated, from the distribution of the plants on the watershed, that the Chippewa River received the largest amounts of industrial-waste pollution, there having been reported on this watershed 6 pulp and paper mills, 12 canning plants, 2 milk condenseries, and 11 butter and cheese factories.

During the year 1928 the Minnesota State Department of Health made a study of the sewage and industrial waste pollution of the tributaries of the Mississippi River in Minnesota. By taking into consideration the reduction in the strength of part of the sewage by treatment and the increase in strength due to industrial wastes a population estimate was derived which indicated the number of persons on each watershed that would produce, in terms of domestic sewage, pollution equivalent to that of the domestic sewage and the industrial wastes reaching the stream. These population estimates, designated as the total sewered population equivalents, were 150,000 on the Mississippi River watershed above Minneapolis, 100,000 on the Minnesota River watershed, 22,800 on the Cannon River watershed, and 20,000 on the Zumbro River watershed. If from these figures there is deducted the estimated population on the same watersheds discharging the equivalent of untreated sewage as given in Table 20, a rough approximation is obtained of the population necessary to produce, in terms of domestic sewage, pollution equivalent to that of the industrial wastes. The population equivalent to the discharge of industrial wastes derived in this manner was 83,070 on the Mississippi River watershed above Minneapolis, 34,560 on the Minnesota River watershed, 650 on the Cannon River watershed, and 12,700 on the Zumbro River watershed. In other words, the pollution from industrial wastes on the Mississippi River watershed above Minneapolis and on the Zumbro River watershed appeared to be greater than the pollution by domestic sewage, on the Minnesota River watershed the pollution by industrial wastes was about half the pollution by domestic sewage, and the pollution of the Cannon River by industrial wastes seemed to be of no great significance.

In the absence of detailed information as to the points of discharge of the various polluting wastes entering the tributaries and the nature and extent of the changes taking place in the streams, the chemical and bacteriological samples collected at the mouths of the tributaries were assumed to be indicative of the final effects of all the pollution entering above the sampling point, after the operation of such natural purification agencies as existed between the source of pollution and the mouth.

The Metropolitan Drainage Commission of Minneapolis and St. Paul, in its investigation of methods of collecting and treating the sewage from this area, has made extensive measurements of the flow from nearly all of the 75 or more larger sewer outlets into the river and has collected many composite samples of sewage and industrial wastes, from the same outlets, for chemical analysis. The flow data and the 5-day biochemical oxygen demand determinations were utilized to estimate the total daily oxygen requirements, in pounds.

of the combined sewage and industrial wastes from each of the sewer outlets.

Assuming that the 5-day biochemical oxygen demand of domestic sewage is 0.163 pound per capita per day [1] the total oxygen requirements of the combined sewage and industrial wastes from each sewer outlet were converted into terms of a sewered population which would contribute pollution, in the form of domestic sewage, equivalent to that of the sewage and industrial wastes. This calculated population was designated as the total sewered population equivalent.

The actual sewered population contributing to each outlet was next estimated from the population of the sewer district and the extent of the sewerage system, and this figure checked roughly by measuring the volume of flow and collecting samples for analysis on Sundays when industrial plants were not in operation. By deducting the estimated actual sewered population from the total sewered population equivalent, there remained the number of persons necessary to produce pollution, in terms of domestic sewage, equivalent to the industrial-waste pollution. This population was designated as the sewered population equivalent to industrial wastes.

Estimates of the actual sewered population, sewered population equivalent to industrial wastes, and the total sewered population equivalent, as determined for each of the sewer districts, have been supplied through the courtesy of the chief engineer of the Metropolitan Drainage Commission. These data have been summarized in Table 21 and show the distribution of these populations between the various sampling stations within the metropolitan area.

TABLE 21.—*Summary of the actual sewered population on the upper Mississippi River, between sampling stations within the metropolitan area of Minneapolis and St. Paul, with estimates of population equivalent to industrial wastes*

Mississippi River between—	Actual sewered population (1)	Total sewered population equivalent (2)	Population equivalent to industrial wastes (2)−(1)
Station No. 1 and Station No. 2	51, 460	51, 460	----------
Station No. 2 and Station No. 3	408, 820	606, 360	197, 540
Station No. 3 and Station No. 5	134, 200	198, 545	64, 345
Station No. 5 and Station No. 6	87, 610	450, 125	362, 515
Total within metropolitan area	682, 090	1, 306, 490	624, 400

Table 21 indicates that the total population, equivalent to all the organic industrial wastes, in the metropolitan area is 624,400, or approximately 92 per cent, of the actual sewered population; that is, industrial wastes are responsible for nearly as much pollution as that attributed to domestic sewage. Ratios of industrial waste to sewage

[1] The Oxygen Demand of Polluted Waters. E. J. Theriault. Public Health Bulletin No. 173, page 54.

pollution, similarly calculated during the study of the Ohio River, for the metropolitan areas of Pittsburgh, Pa.; Wheeling, W. Va.; Cincinnati, Ohio; and Louisville, Ky., ranged from 48 to 59 per cent. The pollution of the Illinois River by industrial wastes from Chicago was estimated as being about 52 per cent of the pollution from domestic sewage.

Nearly two-thirds of the industrial-waste pollution of the Mississippi River within the metropolitan area of Minneapolis and St. Paul is attributable to the discharge of untreated wastes from the large packing establishments in South St. Paul. Deducting the population represented by these wastes, the pollution of the river from the remaining more diversified industrial establishments within the metropolitan area is equivalent to about 44 per cent of the pollution by domestic sewage, a figure more nearly comparable to those derived for the other metropolitan areas.

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SECTION IV

METHODS OF PROCEDURE IN FIELD AND LABORATORY STUDIES

The investigation of the upper Mississippi River was made primarily at the request of the States of Minnesota and Wisconsin and the cities of Minneapolis and St. Paul, to determine (a) the extent of pollution in the river through these cities; (b) the condition of the boundary waters between the States below the junction of the St. Croix River; (c) the probability of future recurrences of the objectionable conditions which existed in the river from Minneapolis to Hastings, in the summer months of 1925 and 1926, during the low stream flows of these years; and (d) to obtain data as to the necessity for sewage-treatment works in Minneapolis and St. Paul to relieve the sewage load in the river.

The collection of data was, therefore, planned with these main purposes in view, keeping in mind at the same time the possibility of locating sampling points and collecting other necessary data to make the investigation profitable for a more general study of stream pollution and natural stream purification, to compare the results with those obtained in similar studies which had previously been made by the United States Public Health Service on the Ohio and Illinois Rivers.

SELECTION OF SAMPLING POINTS

Sampling stations were located at accessible points which were indicative of conditions at the more important points along the river. Selection of sampling points was limited, to a certain extent, by express service for the shipment of samples from points below South St. Paul. It was necessary to collect samples early in the day, between 4 and 7 a. m., and from points accessible by automobile from the larger communities. Accordingly sampling stations were located in the vicinity of Hastings, Red Wing, Wabasha, and Winona, Minn. These communities were located near the entrance of tributaries so that, in most instances, one sample collector could collect two samples—one from the main river, above the local sewer outlets, and above the entrance of a tributary, showing the condition of the main stream before the admixture of tributary water; and another from the tributary, indicating the condition of the inflowing water in relation to that of the main stream. It was found impracticable to collect samples below the confluence of tributaries to indicate conditions after the mixing of the two waters.

Six sampling stations were selected along the river within the metropolitan area and indicated the condition of the river as it entered the district; the effect of the sewage of Minneapolis and some from St. Paul in the pool above the Government lock and dam; the condition of the Minnesota River, at its mouth, entering the main stream between Minneapolis and St. Paul; the condition of the river at St. Paul; and the effect of all the sewage and industrial wastes as the river left the metropolitan area. Sampling points below the metropolitan area indicated successive changes in the condition of the river as a result of the inflow of tributaries and natural purification in the passage downstream.

Sampling stations were numbered, in order of their location, downstream from Station No. 1, at the Camden Avenue bridge in Minneapolis, to Winona. Fourteen regular stations were maintained on the Mississippi River and the more important tributaries during the period of the investigation. The following summary shows the location of the sampling points selected on the main river and its tributaries and gives, for each station, information as to the character of the river channel, conditions of flow, and other related data.

DESCRIPTION OF MISSISSIPPI RIVER SAMPLING STATIONS

STATION NO. 1

Camden Avenue Bridge, Minneapolis.—Located just below the city waterworks intake. Width of river section about 800 feet; depth over 15 feet at low water. River flows between banks with very little change in the width of cross section at high water. Main channel was between the central bridge abutments, with perceptible current. The sampling point was above all of the Minneapolis sewer outlets and samples represented the water entering the metropolitan area. Samples taken from the bridge during open-water conditions; from the waterworks intake well, located just above the bridge, during periods of ice cover on the river.

STATION NO. 2

Plymouth Avenue Bridge, Minneapolis.—Located 3 miles below Station No. 1 and about a mile above the Falls of St. Anthony. Width of section about 1,000 feet; maximum depth at low water 10 feet. Very little change in river section during periods of high water. Island at east end of the bridge divided the river, but the main channel was between the central bridge abutments where the current was usually fairly rapid. At the Falls of St. Anthony the water dropped about 70 feet over the falls or through the turbines to the pool formed by the lock and dam at sampling station No. 3. Samples from this station were discontinued during periods of ice cover.

STATION NO. 3

Government lock and dam, Minneapolis.—Sampling station located just below the Intercity bridge between Minneapolis and St. Paul at the dam, 7.5 miles below Station No. 2. Width of river section 1,000 feet under all conditions of discharge. Depth of water at the dam about 30 feet. The pool formed by the dam extended upstream for about 5 miles to the head of navigation on the Mississippi River at the Washington Avenue bridge, Minneapolis. The capacity of the pool was estimated at 340,000,000 cubic feet. The flow through the pool was sluggish. Most of the sewage of Minneapolis, and some from St. Paul, entered the pool above the dam. Bottom and sides were covered with sewage material and the pool became septic during low summer stream flows and high water temperatures. Samples were collected at the east end of the dam, in the channel leading to the turbines. Below the sampling point the water dropped 30 feet over the dam or through the turbines and flowed 2.4 miles to the mouth of the Minnesota River.

STATION NO. 5

Roberts Street Bridge, St. Paul.—Located 6.3 miles below the entrance of the Minnesota River and 8.7 miles below Station No. 3. Bank-to-bank width of the section 800 feet. The low-water flow was restricted to a navigation channel about 200 feet wide with a depth of 16 feet. Current through the section usually swift. Sewage from a part of St. Paul entered the river above this station.

STATION NO. 6

Invergrove Bridge.—Located 9 miles below Station No. 5 and about 3.5 miles below the stockyard sewer outlets at South St. Paul and vicinity. Low-water bank-to-bank section about 950 feet. Main flow was confined to a navigation channel about 200 feet wide with a depth of 7 feet. From Station No. 5 the river was confined to a navigation channel during periods of low stream flow by about 85 wing dams. Samples were indicative of the condition of the water as it left the metropolitan area of the Twin Cities.

STATION NO. 7

Hastings, Minn —Located about 1,000 feet above the highway bridge over the river, and above the Hastings sewer outlets. This station was 16.8 miles below Station No. 6. Width of the low-water section, 500 feet; maximum depth, 15 feet. The flood plain of the Mississippi River reached a width of a mile just above the station. During periods of high water, considerable ponding and backwater occurred on the flood plain. Between this station and the one above, there were about 160 wing dams, confining the water to a navigation channel during low river stages. The St. Croix River entered 2.4 miles below the station.

STATION NO. 9

Red Wing, Minn.—Located about 1,000 feet above the highway bridge over the Mississippi River at Red Wing, 23.3 miles below Station No. 7. Width of low-water section, 800 feet; maximum depth, over 15 feet. The flood plain of the main river reached a width of 4.5 miles between bluffs above the station and contained many sloughs, pools, and swampy areas. At high water ponding occurred above the sampling point. From the station next above there were 125 wing dams to assist navigation during periods of low stream flow. The St. Croix River entered 20.9 miles and the Cannon River 2.2 miles above the station. About 5 miles below the station the river entered Lake Pepin.

STATION NO. 11

Outlet of Lake Pepin at Reads, Minn.—Located 0.3 mile above the mouth of the Chippewa River and 26.8 miles below Station No. 9. Lake Pepin is formed by an expansion of the main channel due to sand deposits brought down by the Chippewa River. The lake has a length of about 22 miles and a maximum depth of 56 feet, average depth probably about 30 feet. The lake occupies the entire flood plain between bluffs and has a maximum width of about 3 miles. Width at the sampling section, 2,000 feet. Current usually swift, making sampling difficult at the station and at Station No. 12 on the Chippewa River.

STATION NO. 14

Winona, Minn.—Located 1,500 feet above the highway bridge over the Mississippi River at Winona and above the local sewer outlets. The station was 41.7 miles below Station No. 11, at the outlet of Lake Pepin, 41.4 miles below the mouth of the Chippewa River and 27 miles below the mouth of the Zumbro River. Width of low-water section, 800 feet; maximum depth, 13 feet. The channel above the section winds across the flood plain, which had a maximum width of 5 miles and on which there were numerous sloughs, ponds, and swampy areas. About 400 wing dams had been constructed between Stations No. 11 and 14.

DESCRIPTION OF TRIBUTARY SAMPLING STATIONS

STATION NO. 4

Minnesota River at its mouth.—Located opposite Fort Snelling just above Pike Island. Width of low-water section, 500 feet; depth about 30 feet. The flow in the lower stretches of the river was very sluggish. Sampling at this station irregular during periods of ice cover. The Minnesota River entered between Stations No. 3 and 5 on the main river.

STATION NO. 8

St. Croix River at its mouth.—Located opposite Prescott, Wis., below the highway bridge. The sampling point was in the restricted section of the sand bar at the outlet of Lake St. Croix, an expansion of the lower portion of the main channel which extended upstream a distance of some 20 miles and which had a depth of nearly 50 feet in its lower section. The current through the sampling section was usually swift. The St. Croix River entered the Mississippi River 2.4 miles below Station No. 7 at Hastings.

STATION NO. 10

Cannon River near its mouth.—Located at the bridge over Highway No. 3, about 6 miles from Red Wing. Width of section 200 feet with a fairly rapid current. The sampling station was above the point where the Cannon River starts meandering and dividing on the flood plain of the Mississippi River and was above backwater from the main river. The Cannon River entered the Mississippi River 2.2 miles above Station No. 9 at Red Wing.

STATION NO. 12

Chippewa River at its mouth.—Located on the Wisconsin side of the river opposite Reads. The river entered through a restricted artificial channel constructed to increase its velocity and prevent the deposition of sand in the main river. The sampling section had a width of 500 feet. Current usually swift through the section. With the river in flood there was considerable backing up of water from the Chippewa River through Station No. 11 into Lake Pepin. Samples discontinued during the winter months on account of the inaccessibility of the station. The mouth of the river was 0.3 mile below Station No. 11 at the outlet of Lake Pepin.

STATION NO. 13

Zumbro River at Kellogg, Minn.—Located at the bridge over the river on Highway No. 3. Low-water section width 100 feet. Sampling station above the point where the Zumbro River entered the flood plain of the Mississippi River and began to divide and meander across it to the main river channel. The Zumbro River entered the Mississippi River 27 miles above Station No. 14 at Winona.

COLLECTION OF WATER SAMPLES

Samples from all of the stations selected were taken at a single point, located in the center of the channel, at mid-depth. During the first summer and fall of the investigation, samples were taken from all the stations five times each week, i. e., each day from Monday to Friday, inclusive; and during the winter and second summer, three times a week, on Monday, Wednesday, and Friday.

Samples were obtained in a special galvanized-iron collector [2] used during the Illinois River investigation and patterned after one previously used by the Sanitary District of Chicago. This type of collector permitted the filling, simultaneously, of two bottles for the dissolved-oxygen determinations and one for the bacteriological analysis.

Samples for the oxygen determinations were taken in 350 c c bottles, which were filled through tubes in the cover of the sample collector, extending to the bottom of the sample bottles. The first water entering these bottles overflowed into the collector and several changes of water took place before the sample was obtained. Bacteriological bottles of 250 c c capacity were filled through a sterile glass tube, placed in the top of the collector before each sample was taken. Air bubbles were excluded from the oxygen samples, but an air space was purposely left in the bacteriological sample bottles. Temperature readings, made on the larger volume of water in the collector, were recorded as the temperature of the sample at the time of collection. Immediately after collecting each set of samples, the following information was noted on a label which was attached to each bottle: Date of collection, time of day, sampling-station number, temperature of the water, and name of the sample collector.

DELIVERY OF WATER SAMPLES

The laboratory for the examination of all water samples was located in space made available by the division of sanitation of the Minnesota State Department of Health on the campus of the University of Minnesota, in Minneapolis. All examinations were made under comparable conditions with the single exception that there were considerable differences in the time between the collection of the samples from different stations and their arrival at the laboratory. Samples from Stations Nos. 1 to 6, inclusive, located on the highly polluted section of the river, were transported by automobile and delivered immediately to the laboratory for examination, the maximum time between collection and arrival for analysis not exceeding 2.5 hours. All down-river samples arrived in Minneapolis on the same train and reached the laboratory about noon on the day of

[2] Diagram in Public Health Bulletin No. 171, page 58.

sampling. The time between collection and arrival at the laboratory depended chiefly on the distance of the sampling station from the shipping point. For Stations Nos. 7 to 13, inclusive, this period varied from 4 to 7 hours, while for Station No. 14, the farthest away from Minneapolis, it was between 7 and 9 hours. Samples from Stations Nos. 7 and 8 were collected by the same sample collector, using a boat, and were shipped from Hastings. Samples at Stations Nos. 9 and 10 were also collected by one sample collector, using an automobile, from Red Wing for the Cannon River sample. Three samples were shipped from Wabasha, two collected by boat, from Reads, at Stations Nos. 11 and 12, and one from the Zumbro River at Kellogg; all three of these being brought to Wabasha by automobile. The sample at Station No. 14 was collected from a boat and shipped from Winona.

Samples were shipped in special metal-lined shipping cases, with an inner circular compartment, in which the sample bottles were supported by a perforated metal disk, with space for eight bottles. During the summer months, the space beneath and around the sample bottles shipped by express was packed with ice.

CHEMICAL METHODS

Routine chemical analyses made on each sample as received at the laboratory comprised the determination of turbidity, alkalinity, dissolved oxygen present upon arrival at the laboratory, and the 5-day biochemical oxygen demand at 20° C. For a period of five months, hydrogen-ion concentration determinations were made on all samples.

TURBIDITY

Turbidities of less than 25 parts per million were read from bottle standards of standard silica suspension, while turbidities in excess of 25 parts per million were determined by the standard candle turbidimeter. The excess water from the bacteriological samples was used for turbidity readings and for alkalinity determinations.

ALKALINITY

Alkalinity, using methyl orange as an indicator, was determined on a portion of the water from each sampling station.

DISSOLVED OXYGEN

The dissolved oxygen present in all samples was determined immediately upon arrival at the laboratory. To eliminate the interference of any nitrites that might be present in the samples, the permanganate modification of the Winkler method for the determination of dissolved oxygen was adopted as routine procedure.

BIOCHEMICAL OXYGEN DEMAND

The difference between the amount of dissolved oxygen originally present in the sample and the amount remaining at the end of five days' incubation at 20° C. was taken as the measure of the 5-day biochemical oxygen demand. The high organic content of the water from several of the sampling stations necessitated dilution, before incubation, to prevent the depletion of the oxygen. The dilution water used was made up of 75 per cent distilled water and 25 per cent Minneapolis tap water, stored two weeks before use. During periods of cold weather, samples arrived at the laboratory supersaturated with oxygen. These samples were warmed to 20° C. and shaken until the oxygen content was reduced to about 9 parts per million or less, after which the initial dissolved oxygen, prior to incubation, was determined.

The laboratory procedure for the dissolved oxygen and the biochemical oxygen demand determinations was inaugurated by Bacteriologist C. T. Butterfield, of the United States Public Health Service, at the beginning of the investigation, and verified by Chemist E. J. Theriault during the progress of the laboratory work. The technique used was similar to that employed during the Illinois River study and is outlined by Chemist E. J. Theriault in Public Health Bulletin No. 151.[3]

BACTERIOLOGICAL METHODS

Routine bacteriological examination of samples consisted in determining the number of colonies per cubic centimeter of sample, developing on standard agar plates in 24 hours at 37° C. and in 48 hours at 20° C., and an estimate of the number of B. coli present in the sample as indicated by the results of fermentation tests, using standard lactose bouillon.

CULTURE MEDIA

The culture media used throughout the investigation of the upper Mississippi River were prepared from dehydrated stock, a quantity of each kind of stock sufficient to last through the entire period of the survey having been purchased prior to starting the work. It was specified that each kind of dehydrated stock should be from, or prepared as, a single lot, in order to eliminate any variations that might occur in the manufacture of the media when prepared in separate lots. For routine examinations three kinds of culture media were used—nutrient agar, Endo's agar, and lactose broth. All media were prepared and sterilized in accordance with the instructions of the manufacturer, to insure the proper final hydrogen-ion concen-

[3] The Determination of Dissolved Oxygen by the Winkler Method. E. J. Theriault, Public Health Bulletin No. 151, Washington, D. C.

tration. Sterility controls were made, on the media used each day, and of the water used for dilution. The media used were comparable to those utilized in the previous studies of the Ohio and Illinois Rivers, with the exception that agar instead of gelatin was used to determine the 20° C. plate count.

STERILIZATION OF BOTTLES

Wide-mouthed ground-glass stoppered bottles were used in collecting the bacteriological samples. The stopper and bottle neck were covered with paper, tied in place, and the entire bottle protected by wrapping in heavy paper. The bottles thus prepared were sterilized, by baking in hot air for two hours, after the temperature had reached 170° C. At the time of sample collection and during shipment, adequate precautions were taken to prevent contamination.

PLATE COUNTS

The methods employed in making plate counts on agar at the two incubation temperatures were substantially those of Standard Methods, 1925 edition. In planting samples, amounts of 1.0 or 0.1 cubic centimeter of the water were added directly to the plates from calibrated pipettes. Amounts smaller than 0.1 cubic centimeter were measured by diluting 1 cubic centimeter of the sample in 99 cubic centimeters of sterile dilution water, so that 1.0 and 0.1 cubic centimeter of the mixture represented 0.01 and 0.001 cubic centimeter of the mixture represented 0.01 and 0.001 cubic centimeter, respectively, of the original sample. For further dilution, when required, 1 cubic centimeter from the first dilution bottle was added to a second, containing 99 cubic centimeters.

Three agar plates were prepared for incubation at each of the two incubation temperatures. Two of the three plates were planted as duplicates, with a sufficient amount of the sample to give ordinarily between 25 (unless the total count from 1 cubic centimeter of the undiluted sample was less than that number) and 400 colonies per plate, preferably not more than 200. The third plate of the series was inoculated with one-tenth or ten times the amount of the duplicates, depending on whether it was more probable that too many or too few colonies, respectively, would develop on the two duplicate plates. One set of agar plates was incubated at 20° C. for 48 hours, and the other at 37° C. for 24 hours. The glass-covered plates were inverted in the 37° C. incubator during the period of incubation.

The colonies developing at the end of incubation were counted with a standard reading lens in a special illuminated counting device. The rules adopted in counting the series of three plates and recording results were as follows:

(*a*) When duplicate plates of the series gave more than 25 and less than 400 colonies per plate and the third plate less than 25 or more than 400 colonies, the third plate was disregarded in the average. If, however, the number of colonies on the third plate fell between the number of those on the duplicate plates it was included in the average.

(*b*) When duplicate plates fell outside of the allowable range of 25 to 400 colonies, the third plate was considered as the representative count.

(*c*) When one duplicate plate gave an obviously incorrect result it was disregarded in determining the average result.

DETERMINATION OF B. COLI

The partially confirmed test was employed in the estimation of the number of B. coli present in the samples. Three or more graduated portions of each sample were planted, the amounts being selected so that the largest would show gas production and the smallest none. Lactose-broth medium, in Durham fermentation tubes, was used to record gas production, the amount of the medium being at least three times that of the volume of water planted and more often ten or more times. Fermentation tubes were incubated at 37° C. for 48 hours, and gas production was recorded at the end of 24 and 48 hours.

At the end of 48 hours' incubation an Endo plate was streaked from the tube, showing gas, which had been inoculated with the least amount of the sample, unless this was a doubtful tube which had shown no gas at the end of 24 hours, in which case an additional Endo plate was made from the positive tube containing the next larger portion of the sample. Endo plates were incubated for from 18 to 24 hours at 37° C.; and, if typical lactose-fermenting colonies developed, the partially confirmed test was considered completed. From Endo plates showing no typical colonies at the end of 24 hours a colony most nearly resembling the B. coli group was picked, and a lactose-broth tube inoculated with the culture. At the same time a second Endo plate was made from the original broth tube and the plate incubated as before. If the atypical colony from the first Endo plate produced gas in amounts equivalent to 10 per cent or more at the end of 24 or 48 hours, or if the second Endo plate from the original tube showed colonies typical of the group at the end of 48 hours, the partially confirmed test was considered completed.

In estimating the numbers of B. coli present in the samples, the methods prescribed in the 1925 edition of Standard Methods, of the American Public Health Association, were used. Since the media and methods used were the same as during previous studies, the results of the upper Mississippi River survey are fully comparable with those obtained in the Ohio and Illinois River studies.

SECTION V

RESULTS OF CHEMICAL ANALYSES

PRESENTATION OF DATA

Chemical examinations of the water from the sampling stations were made to determine the effect of the gross pollution entering the river through the metropolitan area of the Twin Cities and the subsequent changes taking place in the river below the zone of pollution due to the inflow of tributaries and to processes of natural stream purification.

During the course of the investigation a total of 2,732 water samples, from the 14 regular sampling stations, were analyzed in the field laboratory at Minneapolis. The results of the chemical determinations, together with data relative to water temperatures and rates of stream discharge, are presented in Table 22 as monthly averages of the daily observations. The results are summarized by sampling stations and give the averages of the various determinations for each month and season.

TABLE 22.—*Summary of monthly average results of chemical analyses for each sampling station on the upper Mississippi River, arranged by months*

STATION NO. 1.—MISSISSIPPI RIVER AT CAMDEN AVENUE BRIDGE, MINNEAPOLIS

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(p*H*) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
June	2,430	18.3	169	9	8.05	1.50	84.9	--------
July	2,360	23.0	155	5	6.13	1.06	70.7	--------
August	2,410	21.9	141	5	6.59	1.03	74 4	--------
September	6,480	16.4	139	5	7.96	1.23	80.7	--------
October	7,460	9.5	142	4	9.23	1.47	80.5	--------
November	3,980	1.4	143	2	12.62	1.96	89.8	--------
December	2,890	0	193	3	8.79	1.12	60.1	--------
1927								
January	2,300	0	198	2	7.19	1.11	49 1	--------
February	2,210	0	197	2	5.68	1.09	38.9	--------
March	9,640	1.0	136	26	10.63	2.79	74 7	--------
April	17,400	7.2	117	15	10.55	2.13	87.1	7.7
May	12,800	12.8	136	21	9.25	2 09	86.7	7.8
June	9,810	18.6	153	19	7.75	1.87	82.3	8 0
July	5,590	22 4	162	11	6.58	1.13	75 2	8.1
August	5,100	19.9	155	6	6.89	.84	75.0	8.0
AVERAGES								
Summer, 1926	2,400	21.1	155	6	6.92	1.20	76.7	--------
Fall	5,970	9.1	141	4	9 94	1.55	83.7	--------
Winter	2,470	0	196	2	7.22	1.11	49.4	--------
Spring	13,280	7.0	130	21	10.14	2.34	82.8	7.8
Summer, 1927	6,830	20.3	157	12	7.07	1.28	77.5	8.0
Yearly	6,650	9.3	154	9	8.53	1.58	73.0	--------

TABLE 22.—*Summary of monthly average results of chemical analyses for each sampling station on the upper Mississippi River, arranged by months*—Continued

STATION NO. 2.—MISSISSIPPI RIVER AT PLYMOUTH AVENUE BRIDGE, MINNEAPOLIS

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(p*H*) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
June	2,430	18.1	169	10	7.25	1.39	76.1	-------
July	2,360	23.4	155	6	5.42	1.28	62.9	-------
August	2,410	22.0	141	7	6.08	1.13	68.9	-------
September	6,500	16.1	137	5	7.65	1.19	77.1	-------
October	7,480	9.5	142	4	9.21	1.47	80 3	-------
November	3,990	1.4	142	3	12.59	1.84	89.5	-------
December	2,890	0	175	2	11.82	1.37	80.8	-------
1927								
January	2,300	0	201	6	6.52	4.20	44.5	-------
February	2,210	0	204	9	4.44	4.35	30.4	-------
March	9,660	2.2	109	25	12.24	2.76	88.9	-------
April	17,500	7.2	117	15	10.73	2.09	88.7	7.7
May	12,800	12.8	134	20	9.26	1.84	86.7	7.8
June	9,850	18.6	152	18	7.74	1.97	82 2	8.0
July	5,590	22.4	159	11	6.19	1.09	70.8	8.0
August	5,100	19.9	156	6	6.68	.88	72.9	8.1
AVERAGES								
Summer, 1926	2,400	21.2	155	8	6.25	1.27	69.3	-------
Fall	5,990	9.0	140	4	9.82	1.50	82.3	-------
Winter	2,470	0	193	6	7.59	3.31	51.9	-------
Spring	13,320	7.4	120	20	10.74	2.23	88.1	7.8
Summer, 1927	6,850	20 3	156	12	6.87	1.31	75.3	8.0
Yearly	6,660	9 4	151	10	8.64	2.12	73.4	-------

STATION NO. 3.—MISSISSIPPI RIVER AT GOVERNMENT LOCK AND DAM, MINNEAPOLIS

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(p*H*) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
June	2,440	19.4	174	21	0.74	5.84	8.0	-------
July	2,370	24 3	161	14	.43	3.96	5.1	-------
August	2,420	23.0	148	8	.67	3.31	7.7	-------
September	6,520	16.9	140	8	5.27	2.90	54.0	-------
October	7,510	9.8	146	5	7.92	4.38	68.8	-------
November	4,000	1.6	143	7	11.57	6.90	82 6	-------
December	2,910	0	194	8	9.30	5.56	63.5	-------
1927								
January	2,310	0	200	12	6.74	9 31	46.1	-------
February	2,220	0	207	14	5.87	10.05	40.2	-------
March	9,690	1.2	139	22	11.00	5.33	77.7	-------
April	17,500	7.4	120	13	10 66	3.25	88.3	7.7
May	12,900	12.7	137	23	9.12	3.14	85.6	7.8
June	9,910	18.6	156	17	6.41	3.13	67.9	7.9
July	5,610	22.9	164	9	3.77	3.35	43 4	7.7
August	5,090	20 3	157	7	4.15	3.13	45.5	7.7
AVERAGES								
Summer, 1926	2,410	22.2	161	14	0.61	4.37	6.9	-------
Fall	6,010	9.4	143	7	8.25	4.73	68.5	-------
Winter	2,480	0	200	11	7.30	8.31	49.9	-------
Spring	13,360	7.1	132	19	10.26	3.91	83.9	7.8
Summer, 1927	6,870	20.6	159	11	4.78	3.20	52.3	7.8
Yearly	6,690	9.6	158	13	7.08	5.10	57.3	-------

TABLE 22.—*Summary of monthly average results of chemical analyses for each sampling station on the upper Mississippi River, arranged by months*—Continued

STATION NO. 4.—MINNESOTA RIVER AT FORT SNELLING

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
June	400	19.4	244	89	4.84	2.62	52.2	-------
July	213	23.7	244	86	5.75	3.39	67.1	-------
August	375	22.6	218	90	5.70	3.10	65.2	-------
September	2,040	17.2	182	81	6.79	2.88	70.0	-------
October	2,380	10.1	219	70	10.06	2.59	88.9	-------
November	1,110	1.8	244	28	12.92	5.46	92.8	-------
December	830	0	298	14	9.67	2.86	66.1	-------
1927								
January	625	0	341	9	6.72	1.81	45.9	-------
February	610	0	356	9	6.15	2.15	42.1	-------
March	9,120	2.4	150	218	10.89	3.38	79.5	-------
April	9,270	7.9	187	70	10.34	2.36	86.8	8.0
May	6,680	13.6	230	40	10.03	2.73	96.1	8.1
June	5,910	18.4	223	176	7.20	1.94	76.2	8.1
July	1,450	22.7	262	65	6.92	2.81	79.4	8.1
August	369	20.6	257	50	8.29	3.76	91.7	8.2
AVERAGES								
Summer, 1926	329	21.9	235	88	5.43	3.04	61.5	-------
Fall	1,840	9.7	215	60	9.92	3.64	83.9	-------
Winter	688	0	332	11	7.51	2.27	51.4	-------
Spring	8,360	8.0	189	109	10.42	2.82	87.5	8.1
Summer, 1927	2,580	20.6	247	97	7.47	2.84	82.4	8.1
Yearly	3,260	9.8	241	74	8.52	2.89	73.1	-------

STATION NO. 5.—MISSISSIPPI RIVER AT ROBERTS STREET BRIDGE, ST. PAUL

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
June	2,850	19.3	195	26	1.53	8.32	16.5	-------
July	2,590	23.5	177	19	.54	5.25	6.3	-------
August	2,810	22.1	160	14	.87	3.67	9.9	-------
September	8,630	16.5	147	10	5.19	3.55	52.8	-------
October	9,970	10.0	161	12	8.46	4.03	74.5	-------
November	5,150	1.4	169	9	12.09	5.07	85.9	-------
December	3,770	0	208	23	9.57	9.83	65.4	-------
1927								
January	2,950	0	214	15	6.24	8.38	42.6	-------
February	2,850	0	223	17	5.77	7.09	39.4	-------
March	18,900	1.2	133	100	10.66	4.86	75.4	-------
April	27,000	7.8	134	30	10.37	4.82	86.7	7.8
May	19,700	13.3	160	30	8.68	3.15	82.3	7.9
June	16,000	18.8	181	91	6.30	2.92	67.1	8.0
July	7,090	22.8	188	27	4.35	2.81	50.0	7.9
August	5,440	20.7	172	11	3.77	2.16	41.8	7.9
AVERAGES								
Summer, 1926	2,750	21.6	177	20	0.98	5.75	10.9	-------
Fall	7,920	9.3	159	10	8.58	4.22	71.1	-------
Winter	3,190	0	215	18	7.19	8.43	49.1	-------
Spring	21,870	7.4	142	53	9.90	4.28	81.5	7.9
Summer, 1927	9,510	20.8	180	43	4.81	2.63	53.0	7.9
Yearly	10,030	9.6	172	31	7.06	5.22	57.4	-------

TABLE 22.—*Summary of monthly average results of chemical analyses for each sampling station on the upper Mississippi River, arranged by months*—Continued

STATION No. 6.—MISSISSIPPI RIVER AT INVERGROVE BRIDGE

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
June	2,860	18.9	192	29	1.22	6.23	13.0	-------
July	2,600	23.3	175	24	.26	5.95	3.0	-------
August	2,820	21.9	162	22	.51	4.04	5.8	-------
September	8,660	16.4	148	13	4.99	3.23	50.6	-------
October	10,000	9.8	165	13	8.04	4.36	70.7	-------
November	5,170	1.4	171	11	11.14	7.74	79.3	-------
December	3,790	0	207	17	9.03	10.32	61.7	-------
1927								
January	2,960	0	223	14	5.75	9.30	39.3	-------
February	2,860	0	222	17	5.65	8.45	38.6	-------
March	18,900	1.2	135	97	10.26	5.10	72.4	-------
April	27,100	7.8	139	29	10.05	3.28	84.2	7.8
May	19,800	13.3	160	31	8.62	3.65	81.8	7.9
June	16,100	18.8	178	77	6.16	3.00	65.6	7.9
July	7,110	22.8	188	30	3.87	3.02	44.4	7.8
August	5,440	20.6	172	14	2.96	2.28	32.7	7.8
AVERAGES								
Summer, 1926	2,760	21.4	176	25	0.66	5.41	7.3	-------
Fall	7,940	9.2	161	12	8.06	5.11	66.9	-------
Winter	3,200	0	217	16	6.81	9.36	46.5	-------
Spring	21,930	7.4	145	52	9.64	4.01	79.5	7.9
Summer, 1927	9,550	20.7	179	40	4.33	2.77	47.6	7.8
Yearly	10,060	9.5	174	30	6.71	5.70	54.4	-------

STATION No. 7.—MISSISSIPPI RIVER ABOVE HASTINGS, MINN.

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
July	2,600	23.6	181	20	0.16	8.40	1.9	-------
August	2,830	22.4	170	12	.39	4.19	4.4	-------
September	8,700	17.4	151	10	3.36	2.74	34.8	-------
October	10,100	11.7	163	8	6.37	3.82	58.4	-------
November	5,190	2.8	167	15	9.20	6.16	67.8	-------
December	3,810	0	212	20	5.41	7.72	37.0	-------
1927								
January	2,970	0	231	18	3.95	7.74	27.0	-------
February	2,870	0	223	22	4.46	8.90	30.5	-------
March	19,000	2.5	136	88	9.02	4.26	66.1	-------
April	27,200	7.6	145	28	9.29	2.90	77.2	7.7
May	19,900	14.5	168	17	7.63	2.59	74.5	7.8
June	16,200	18.9	185	52	5.70	2.87	60.9	7.8
July	7,120	23.9	192	30	3.81	2.90	44.6	7.8
August	5,450	22.2	180	19	3.49	3.22	39.7	7.8
AVERAGES								
Summer, 1926	2,720	23.0	176	16	0.28	6.29	3.2	-------
Fall	8,000	10.6	160	11	6.31	4.24	53.7	-------
Winter	3,220	0	222	20	4.61	8.12	31.5	-------
Spring	22,030	8.2	150	44	8.65	3.25	72.6	7.8
Summer, 1927	9,590	21.7	186	34	4.33	3.00	48.4	7.8
Yearly	10,110	10.1	178	26	5.41	5.19	45.0	-------

TABLE 22.—*Summary of monthly average results of chemical analyses for each sampling station on the upper Mississippi River, arranged by months*—Continued

STATION NO. 8.—ST. CROIX RIVER AT PRESCOTT, WIS.

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
July	2,100	22.9	98	12	8.20	1.82	94.4	-------
August	2,520	22.7	103	6	7.10	1.31	81.4	-------
September	4,800	18.8	97	6	7.38	.81	78.7	-------
October	6,050	13.1	82	5	7.23	1.14	68.3	-------
November	4,300	4.1	76	4	9.55	1.34	72.8	-------
December	2,940	0	95	6	11.80	1.45	80.6	-------
1927								
January	2,420	0	101	6	9.96	1.34	68.1	-------
February	2,260	0	110	6	8.62	1.36	58.9	-------
March	12,600	2.6	96	20	9.13	1.71	66.9	-------
April	15,400	7.4	55	6	9.99	1.82	82.9	7.2
May	7,700	15.0	64	6	8.72	1.75	85.9	7.3
June	6,700	18.8	76	10	7.38	1.00	78.7	7.6
July	4,650	24.2	82	6	6.57	1.19	77.2	7.7
August	2,470	22.7	88	4	6.14	1.12	70.4	7.7

AVERAGES

Period	Discharge, second-feet	Water temperature, °C.	Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.	Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
Summer, 1926	2,310	22.8	100	9	7.65	1.57	87.9	-------
Fall	5,050	12.0	85	5	8.05	1.10	73.3	-------
Winter	2,540	0	102	6	10.13	1.38	69.2	-------
Spring	11,900	8.3	72	11	9.28	1.76	78.6	7.3
Summer, 1927	4,610	21.9	82	7	6.70	1.10	75.4	7.7
Yearly	5,820	10.5	88	8	8.76	1.40	76.5	-------

STATION NO. 9.—MISSISSIPPI RIVER ABOVE RED WING, MINN.

Month	Discharge, second-feet	Water temperature, °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
July	4,810	22.6	149	15	2.13	2.90	24.4	-------
August	5,480	21.4	152	13	2.25	1.68	25.2	-------
September	13,900	18.7	136	26	4.27	1.89	45.3	-------
October	16,600	20.4	140	13	6.51	2.74	71.5	-------
November	9,820	1.0	144	9	10.10	3.71	70.8	-------
December	7,020	0	192	6	8.01	3.86	54.6	-------
1927								
January	5,560	0	182	6	7.52	3.21	51.4	-------
February	5,300	0	189	7	7.71	2.62	52.7	-------
March	32,400	1.9	150	33	8.63	2.83	62.2	-------
April	44,100	7.3	152	15	10.10	2.51	83.6	7.8
May	28,900	14.8	157	14	8.17	2.69	80.2	7.8
June	24,300	18.3	168	66	6.05	2.11	63.8	7.8
July	12,000	22.9	156	22	4.99	2.72	57.5	7.8
August	7,980	22.3	154	13	5.17	1.97	58.8	7.8

AVERAGES

Period	Discharge, second-feet	Water temperature, °C.	Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.	Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
Summer, 1926	5,150	22.0	150	14	2.19	2.29	24.8	-------
Fall	13,440	13.4	140	16	6.96	2.78	62.5	-------
Winter	5,960	0	188	6	7.75	3.23	52.9	-------
Spring	35,130	8.0	153	21	8.97	2.68	75.3	7.8
Summer, 1927	14,760	21.2	159	34	5.40	2.27	60.0	7.8
Yearly	16,500	10.5	160	19	6.79	2.73	57.1	-------

TABLE 22.—*Summary of monthly average results of chemical analyses for each sampling station on the upper Mississippi River, arranged by months*—Continued

STATION NO. 10.—CANNON RIVER AT RED WING, MINN.

Month	Discharge, second-feet	Water temperature °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
July	95	20.8	202	10	7.09	1.75	78.5	--------
August	97	19.7	196	100	7.43	1.35	80.6	--------
September	293	18.5	196	37	8.52	1.65	90.2	--------
October	276	20.6	198	6	9.86	1.42	108.5	--------
November	256	1.6	204	3	12.68	1.57	90.6	--------
December	214	0	240	4	10.58	2.64	72.3	--------
1927								
January	126	0	290	6	10.19	1.44	69.7	--------
February	132	0	265	5	9.48	1.73	64.8	--------
March	570	1.8	155	107	9.59	2.86	68.8	--------
April	1,220	7.5	195	14	10.83	2.58	90.2	8.0
May	1,030	14.7	205	20	8.76	4.21	85.6	8.2
June	1,100	18.2	194	259	7.73	2.51	81.4	8.1
July	212	22.0	216	19	7.05	1.56	79.8	8.2
August	46	21.7	217	40	7.99	1.69	89.9	8.2
AVERAGES								
Summer 1926	96	20.3	199	55	7.26	1.55	79.6	--------
Fall	275	13.6	199	15	10.35	1.55	96.4	--------
Winter	157	0	265	5	10.08	1.94	68.9	--------
Spring	940	8.0	185	47	9.73	3.22	81.5	8.1
Summer 1927	453	20.6	209	96	7.59	1.92	83.7	8.2
Yearly	450	10.3	212	48	9.40	2.14	81.8	--------

STATION NO. 11.—MISSISSIPPI RIVER AT OUTLET OF LAKE PEPIN

Month	Discharge, second-feet	Water temperature °C.	Constituents in parts per million				Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
			Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.		
1926								
July	4,840	22.6	152	4	5.84	0.99	66.8	--------
August	5,520	22.0	128	5	5.37	.87	60.8	--------
September	14,100	19.3	121	4	6.92	.87	74.4	--------
October	16,700	13.9	132	2	8.89	1.17	85.5	--------
November	9,920	3.5	118	3	11.04	2.57	82.9	--------
December	7,100	0	150	3	10.96	.87	74.9	--------
1927								
January	5,600	0	172	3	4.39	1.18	30.1	--------
February	5,350	0	182	4	2.48	1.55	17.0	--------
March	32,500	1.4	161	21	4.91	2.56	34.9	--------
April	44,600	6.9	118	10	9.82	3.48	80.4	7.7
May	29,300	13.6	134	5	8.77	4.12	83.8	7.7
June	24,700	18.1	149	9	8.32	2.28	87.4	7.9
AVERAGES								
Summer 1926	5,180	22.3	140	5	5.60	0.93	63.8	--------
Fall	13,570	12.2	124	3	8.95	1.54	80.9	--------
Winter	6,020	0	168	3	5.94	1.20	40.7	--------
Spring	35,470	7.3	138	12	7.83	3.39	66.4	7.7
Summer 1927	24,700	18.1	149	9	8.32	2.28	87.4	7.9
Yearly	16,700	10.1	143	6	7.31	1.88	64.9	--------

TABLE 22.—*Summary of monthly average results of chemical analyses for each sampling station on the upper Mississippi River, arranged by months*—Continued

STATION NO. 12.—CHIPPEWA RIVER AT MOUTH

Month	Discharge, second-feet	Water temperature °C.	Constituents in parts per million: Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C	Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
1926								
July	3, 600	22. 6	66	41	6. 59	2. 78	75. 4	-------
August	9, 500	21. 8	59	10	6. 26	1. 68	70. 6	-------
September	23, 400	18. 2	67	9	7. 00	1. 20	73. 7	-------
October	12, 600	12. 6	55	5	8. 70	1 57	81. 3	-------
November	15, 500	6. 5	47	3	10. 71	1. 60	86. 7	-------
1927								
June	7, 500	19. 2	53	14	7. 83	2. 97	84. 2	7. 4
AVERAGES								
Summer 1926	6, 550	22. 2	63	26	6. 43	2. 23	73. 0	-------
Fall	17, 200	12. 4	56	6	8. 80	1. 46	80. 6	-------
Summer 1927	7, 500	19 2	53	14	7. 83	2. 97	84. 2	7. 4

STATION NO. 13.—ZUMBRO RIVER AT KELLOGG, MINN.

Month	Discharge, second-feet	Water temperature °C.	Constituents in parts per million: Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.	Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
1926								
July	154	21. 0	222	52	7. 70	1. 80	85. 7	-------
August	163	19. 9	219	82	8. 08	2. 41	88. 0	-------
September	454	16. 9	186	289	8. 71	2. 05	89. 2	-------
October	474	9. 9	196	41	9. 85	1. 14	86. 8	-------
November	238	2. 1	210	14	12. 39	1. 02	89. 7	-------
December	200	0	246	22	12. 03	1. 31	82. 3	-------
1927								
January	118	0	260	16	11. 61	1. 02	79. 5	-------
February	124	0	255	33	12. 00	1. 19	82. 0	
March	530	2. 4	170	178	11. 58	2. 75	84. 4	-------
April	1, 130	7. 2	207	42	10. 65	1. 30	87. 9	7. 9
May	965	13. 5	220	130	9. 20	1. 64	87. 8	8. 0
June	1, 030	18. 3	211	196	8. 12	1. 97	85. 6	8. 1
AVERAGES								
Summer 1926	159	20. 5	221	67	7. 89	2. 11	86 9	-------
Fall	389	9. 6	197	115	10. 32	1. 40	88. 6	-------
Winter	147	0	254	24	11. 88	1. 17	81. 3	-------
Spring	875	7. 7	199	117	10. 48	1. 90	86. 7	8. 0
Summer 1927	1, 030	18. 3	211	196	8. 12	1. 97	85. 6	8. 1
Yearly	465	9 3	217	91	10. 16	1. 63	85 7	-------

TABLE 22.—*Summary of monthly average results of chemical anlayses for each sampling station on the upper Mississippi River, arranged by months*—Continued

STATION NO. 14.—MISSISSIPPI RIVER ABOVE WINONA

Month	Discharge, second feet	Water temperature °C.	Constituents in parts per million: Alkalinity	Turbidity	Initial dissolved oxygen	5-day oxygen demand at 20° C.	Initial dissolved oxygen, per cent saturation	(pH) Hydrogen-ion concentration
1926								
July	8,650	22.0	139	26	6.02	3.51	68.1	-------
August	15,300	23.3	106	17	5.99	3.49	69.5	-------
September	38,300	21.7	98	16	7.30	2.44	82.2	-------
October	30,300	13.0	127	5	9.79	1.87	92.3	-------
November	25,900	3.2	118	5	11.47	1.83	85.3	-------
December	14,300	0	148	5	11.44	1.82	78.3	-------
1927								
January	12,300	0	156	4	10.34	1.73	70.7	-------
February	12,700	0	160	7	10.21	2.43	69.6	-------
March	58,000	2.2	139	26	10.17	2.47	73.8	-------
April	57,900	7.4	123	8	10.64	2.44	88.3	7.9
May	44,600	12.0	136	10	8.95	2.06	82.6	7.8
June	34,100	18.8	148	25	7.11	2.24	75.8	7.9
AVERAGES								
Summer 1926	12,000	22.7	123	22	6.00	3.50	68.8	-------
Fall	31,500	12.6	114	9	9.52	2.05	86.6	-------
Winter	13,100	0	155	5	10.66	1.99	72.9	-------
Spring	53,500	7.2	133	15	9.92	2.32	81.6	7.9
Summer 1927	34,100	18.8	148	25	7.11	2.24	75.8	7.9
Yearly	29,400	10.3	133	13	9.12	2.36	78.0	-------

Summer averages of 1926, for Stations Nos. 1 to 6, inclusive, based on the months of June, July, and August, 1926. Summer average of 1926, for Stations Nos. 7 to 14, inclusive, based on the months of July and August, 1926. Summer averages of 1927 for Stations Nos. 1 to 10, inclusive, based on the months of June, July, and August, 1927. Summer averages of 1927, for Stations Nos. 11 to 14, inclusive, based on the month of June only. Fall averages at all stations based on the months of September, October, and November, 1926. Winter averages at all stations based on the months of December, 1926, January and February, 1927. Spring averages at all stations based on the months of March, April, and May, 1927. Yearly average at all stations based on the 12-month period July, 1926, to June, 1927, inclusive.

Seasonal averages in Table 22 are based on a summer period consisting of the months of June, July, and August; a fall period comprising the months of September, October, and November; a winter period including the months of December, January, and February; and a spring period consisting of the months of March, April, and May. Such a grouping gives a comparison between the summer period of 1926, with exceptionally low stream flow and water temperatures, averaging over 20° C., and the normal winter period of 1926–27, when stream flows were nearly the same as those of the summer period of 1926, but with water temperatures at 0° C., and the surface covered with ice. A further comparison has been possible between a more nearly normal summer period, represented by the summer of 1927, and a normal winter period. During the fall and spring periods average water temperatures were nearly the same, 10.5° and 7.4° C., respectively, but the spring run-off, due to melting ice and snow, was from two to four times that of the fall period at main river sampling stations.

For purposes of comparison there is presented the relation between the average stream flow in the main river, at the St. Paul gaging station, for the seasons covered by the investigation, and the flow on the day of minimum and maximum discharge, respectively, during each of the seasonal periods.

Season	Discharge, second-feet, at St. Paul		
	Seasonal average	Day of minimum discharge	Day of maximum discharge
Summer of 1926	2,750	1,820	4,470
Winter of 1926-27	3,190	2,340	4,620
Fall of 1926	7,920	3,380	13,100
Summer of 1927	9,510	4,320	19,700
Spring of 1927	21,900	3,800	33,700

DISCUSSION

ALKALINITY

Alkalinity determinations are summarized in Table 23 to show monthly and seasonal averages, in parts per million, at each of the sampling stations.

TABLE 23.—*Summary of average monthly and seasonal alkalinity, in parts per million, at sampling stations on the upper Mississippi River, June, 1926, to August, 1927, inclusive*

Sampling station	Monthly averages															Seasonal averages					Yearly average
	1926							1927													
	June	July	Aug	Sept	Oct	Nov.	Dec	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Summer, 1926	Fall	Winter	Spring	Summer, 1927	
1	169	155	141	139	142	143	193	198	197	136	117	136	153	162	155	155	141	196	130	157	154
2	169	155	141	137	142	142	175	201	204	109	117	134	152	159	156	155	140	193	120	156	151
3	174	161	148	140	146	143	194	200	207	139	120	137	156	164	157	161	143	200	132	159	158
Minnesota River	244	244	218	182	219	244	298	341	356	150	187	230	223	262	257	235	215	332	189	247	241
5	195	177	160	147	161	169	208	214	223	133	134	160	181	188	172	177	159	215	142	180	172
6	192	175	162	148	165	171	207	223	222	135	139	160	178	188	172	176	161	217	145	179	174
7	------	181	170	151	163	167	212	231	223	136	145	168	185	192	180	176	160	222	150	186	178
St. Croix River	------	98	103	97	82	76	95	101	110	96	55	64	76	82	88	100	85	102	72	82	88
Cannon River	------	202	196	196	198	204	240	290	265	155	195	205	194	216	217	199	199	265	185	209	212
9	------	149	152	136	140	144	192	182	189	150	152	157	168	156	154	150	140	188	153	159	160
11	------	152	128	121	132	118	150	172	182	161	118	134	149	------	------	140	124	168	138	149	143
Chippewa River	------	66	59	67	55	47	------	------	------	------	------	------	53	------	------	63	56	------	------	53	------
Zumbro River	------	222	219	186	196	210	246	260	255	170	207	220	211	------	------	221	197	254	199	211	217
14	------	139	106	98	127	118	148	156	160	139	123	136	148	------	------	123	114	155	133	148	133

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period July, 1926, to June, 1927, inclusive.

The alkalinity of the tributaries entering from the west, or Minnesota, side of the watershed, was approximately three times that of the tributaries entering from the east, or Wisconsin, side. The yearly average for the Mississippi River, above Minneapolis, 154 parts per million, falls about midway between the yearly average of 220 parts per million for the Minnesota, Cannon, and Zumbro Rivers and that of 70 parts per million for the St. Croix and Chippewa Rivers.

The higher alkalinity of the Minnesota River caused a temporary increase in the alkalinity of the main river below its confluence. At Red Wing, below the entrance of the St. Croix and Cannon Rivers, and again at Winona, below the Chippewa and Zumbro Rivers, the alkalinity of the main stream decreased. The final effect of the inflow of tributaries from the east, with higher rates of discharge but lower concentration of alkalinity, was a decrease in the concentration of alkalinity in the Mississippi River between Minneapolis and Winona amounting on an average to about 20 parts per million.

With the exception of the spring period, seasonal averages of alkalinity show similar decreases, through the section of the river under observation. The highest concentration of alkalinity occurred during the winter period and the lowest during the fall and spring periods. In the two summer periods the concentration was approximately the same.

TURBIDITY

Average monthly and seasonal turbidities, in parts per million, at the various sampling stations, are assembled in Table 24.

TABLE 24.—*Summary of average monthly and seasonal turbidity, in parts per million, at sampling stations on the upper Mississippi River June, 1926, to August, 1927, inclusive*

Sampling station	Monthly averages															Seasonal averages					Yearly average
	1926							1927													
	June	July	Aug	Sept	Oct.	Nov.	Dec.	Jan	Feb	Mar	Apr.	May	June	July	Aug	Summer, 1926	Fall	Winter	Spring	Summer, 1927	
1	9	5	5	5	4	2	3	2	2	26	15	21	19	11	6	6	4	2	21	12	9
2	10	6	7	5	4	3	2	6	9	25	15	20	18	11	6	8	4	6	20	12	10
3	21	14	8	8	5	7	8	12	14	22	13	23	17	9	7	14	7	11	19	11	13
Minnesota River	89	86	90	81	70	28	14	9	9	218	70	40	176	65	50	88	60	11	109	97	74
5	26	19	14	10	12	9	23	15	17	100	30	30	91	27	11	20	10	18	53	43	31
6	29	24	22	13	13	11	17	14	17	97	29	31	77	30	14	25	12	16	52	40	30
7		20	12	10	8	15	20	18	22	88	28	17	52	30	19	16	11	20	44	34	26
St. Croix River		12	6	6	5	4	6	6	6	20	6	6	10	6	4	9	5	6	11	7	8
Cannon River		10	100	37	6	3	4	6	5	107	14	20	259	19	10	55	15	5	47	96	48
9		15	13	26	13	9	6	6	7	33	15	14	66	22	13	14	16	6	21	34	19
11		4	5	4	2	3	3	3	4	21	10	5	9			5	3	3	12	9	6
Chippewa River		41	10	9	5	3							14			26	6			14	
Zumbro River		52	82	289	41	14	22	16	33	178	42	130	196			67	115	24	117	196	91
14		26	17	16	5	5	5	4	7	26	8	10	25			22	9	5	15	25	13

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period July, 1926, to June, 1927, inclusive.

In the winter and summer months of decreased stream flow, when the normal turbidity of the river was low, a slight increase in turbidity was observed between Stations Nos. 1 and 3, due apparently to the sewage discharged from Minneapolis above the lock and dam. A similar increase in turbidity was indicated in the river, from Station No. 5 to Station No. 6, between which the wastes from the stockyards are discharged. In the months of higher stream flow the normal turbidity from the watershed greatly exceeded that of the sewage and the effects of the latter on the river were not noticeable.

Minnesota River turbidities were higher, except in winter, than those of the main stream. The lower discharge of this river as compared to that in the main stream resulted in but little increase in turbidity in the Mississippi River below its confluence. The St. Croix River, entering through Lake St. Croix at its mouth, in which the normal turbidity was reduced, decreased the concentration of turbidity in the main river below its confluence and diminished the effect of the Cannon River, which at times was high in turbidity. As the water passed through Lake Pepin, the turbidity decreased during every month of observation and at the outlet was usually less than that of the water as it entered the metropolitan area. The indicated reduction in turbidity through Lake Pepin varied from 33 to 85 per cent. Below the lake, turbidities in the main river again increased with the inflow of the Chippewa and Zumbro Rivers.

The lowest concentration of turbidity was indicated in the winter period when the watershed was covered with ice and snow and when surface erosion was reduced to a minimum. Maximum turbidities resulted from the increased discharge in the spring period as the accumulation of ice and snow left the watershed. With the exception of the winter period the actual quantities of turbidity carried by the stream, calculated from the concentration and the discharge estimates, increased with increased rates of run-off from the watershed.

HYDROGEN-ION CONCENTRATION (pH)

The monthly average hydrogen-ion concentration, determined at the various sampling stations, during the five months' period April to August, 1927, inclusive, indicated concentrations corresponding to pH values of between 7.7 and 8.1 at the main river sampling stations. On the tributary streams, those entering from the west showed slightly higher concentrations (7.9 to 8.2) than those entering from the east (7.2 to 7.7).

DISSOLVED OXYGEN

Monthly and seasonal changes in concentration

The dissolved-oxygen results of the basic-data table have been rearranged in Tables 25 and 26 to show monthly and seasonal averages at each sampling station. In Table 25 the monthly and seasonal averages of dissolved oxygen are expressed in parts per million, while Table 26 shows the same averages expressed in terms of the percentage of saturation at the mean water temperature during the month. Figure No. 6 shows graphically the variation in monthly averages of dissolved oxygen, as per cent of saturation; at Station No. 1, above pollution from the Twin City metropolitan area; at Station No. 7, the point usually showing the greatest effects of the pollution from the sewers above; at Station No. 11, the outlet of Lake Pepin, at which recovery from the effects of the pollution has to a large extent taken place; and at Station No. 14, the lowest sampling station on the river.

TABLE 25.—*Summary of average monthly and seasonal initial dissolved oxygen, in parts per million, at sampling stations on the upper Mississippi River, June, 1926, to August, 1927, inclusive*

Sampling station	Monthly averages															Seasonal averages						Yearly average
	1926							1927								Summer 1926	Fall	Winter	Spring	Summer 1927		
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.							
Temperature, ° C	18.9	23.3	21.9	16.4	9.8	1.4	0	0	0	1.2	7.8	13.3	18.8	22.8	20.6	21.4	9.2	0	7.4	20.7		9.5
1	8.05	6.13	6.59	7.96	9.23	12.62	8.79	7.19	5.68	10.63	10.55	9.25	7.75	6.58	6.89	6.92	9.94	7.22	10.14	7.07		8.53
2	7.25	5.42	6.08	7.65	9.21	12.59	11.82	6.52	4.44	12.24	10.73	9.26	7.74	6.19	6.68	6.25	9.82	7.59	10.74	6.87		8.64
3	.74	.43	.67	5.27	7.92	11.57	9.30	6.74	5.87	11.00	10.66	9.12	6.41	3.77	4.15	.61	8.25	7.30	10.26	4.78		7.08
Minnesota River	4.84	5.75	5.70	6.79	10.06	12.92	9.67	6.72	6.15	10.89	10.34	10.03	7.20	6.92	8.29	5.43	9.92	7.51	10.42	7.47		8.52
5	1.53	.54	.87	5.19	8.46	12.09	9.57	6.24	5.77	10.66	10.37	8.68	6.30	4.35	3.77	.98	8.58	7.19	9.90	4.81		7.06
6	1.22	.26	.51	4.99	8.04	11.14	9.03	5.75	5.65	10.26	10.05	8.62	6.16	3.87	2.96	.66	8.06	6.81	9.64	4.33		6.71
7	------	.16	.39	3.36	6.37	9.20	5.41	3.95	4.46	9.02	9.29	7.63	5.70	3.81	3.49	.28	6.31	4.61	8.65	4.33		5.41
St. Croix River	------	8.20	7.10	7.38	7.23	9.55	11.80	9.96	8.62	9.13	9.99	8.72	7.38	6.57	6.14	7.65	8.05	10.13	9.28	6.70		8.76
Cannon River	------	7.09	7.43	8.52	9.86	12.68	10.58	10.19	9.48	9.59	10.83	8.76	7.73	7.05	7.99	7.26	10.35	10.08	9.73	7.59		9.40
9	------	2.13	2.25	4.27	6.51	10.10	8.01	7.52	7.71	8.63	10.10	8.17	6.05	4.99	5.17	2.19	6.96	7.75	8.97	5.40		6.79
11	------	5.84	5.37	6.92	8.89	11.04	10.96	4.39	2.48	4.91	9.82	8.77	8.32	------	------	5.60	8.95	5.94	7.83	8.32		7.31
Chippewa River	------	6.59	6.26	7.00	8.70	10.71	------	------	------	------	------	------	7.83	------	------	6.43	8.80	------	------	7.83		------
Zumbro River	------	7.70	8.08	8.71	9.85	12.39	12.03	11.61	12.00	11.58	10.65	9.20	8.12	------	------	7.89	10.32	11.88	10.48	8.12		10.16
14	------	6.02	5.99	7.30	9.79	11.47	11.44	10.34	10.21	10.17	10.64	8.95	7.11	------	------	6.00	9.52	10.66	9.92	7.11		9.12

Summer average, *1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.*
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12 months' period, July, 1926, to June, 1927, inclusive.

TABLE 26.—*Summary of monthly and seasonal averages of initial dissolved oxygen, expressed as the percentage of saturation, at sampling stations on the upper Mississippi River, June, 1926, to August, 1927, inclusive*

Sampling station	Monthly averages															Seasonal averages					Yearly average
	1926							1927													
	June	July	Aug.	Sept.	Oct.	Nov	Dec.	Jan.	Feb.	Mar	Apr.	May	June	July	Aug	Summer 1926	Fall	Winter	Spring	Summer 1927	
Temperature, ° C	18.9	23.3	21.9	16.4	9.8	1.4	0	0	0	1.2	7 8	13.3	18.8	22.8	20.6	21.4	9.2	0	7.4	20.7	9.5
1	84.9	70.7	74.4	80.7	80.5	89.8	60.1	49.1	38.9	74 7	87.1	86.7	82 3	75.2	75.0	76.7	83.7	49.4	82.8	77.5	73.0
2	76.1	62 9	68.9	77.1	80.3	89.5	80.8	44 5	30.4	88.9	88.7	86 7	82.2	70.8	72.9	69.3	82.3	51.9	88 1	75.3	73.4
3	8.0	5.1	7.7	54.0	68.8	82.6	63 5	46.1	40 2	77.7	88.3	85 6	67.9	43.4	45.5	6.9	68.5	49 9	83 9	52 3	57.3
Minnesota River	52.2	67 1	65.2	70.0	88.9	92.8	66.1	45.9	42.1	79.5	86.8	96.1	76.2	79 4	91.7	61 5	83.9	51.4	87.5	82.4	73.1
5	16.5	6.3	9.9	52.8	74.5	85 9	65 4	42 6	39.4	75.4	86.7	82.3	67.1	50 0	41 8	10 9	71.1	49.1	81.5	53.0	57.4
6	13.0	3.0	5 8	50.6	70.7	79.3	61 7	39 3	38 6	72.4	84 2	81.8	65.6	44 4	32.7	7.3	66.9	46.5	79 5	47.6	54.4
7	------	1.9	4.4	34.8	58.4	67.8	37 0	27 0	30.5	66 1	77 2	74.5	60.9	44.6	39 7	3.2	53.7	31 5	72.6	48.4	45.0
St Croix River	------	94.4	81.4	78.7	68.3	72 8	80 6	68.1	58 9	66.9	82.9	85.9	78.7	77.2	70.4	87.9	73.3	69 2	78.6	75.4	76.5
Cannon River	------	78.5	80.6	90 2	108.5	90 6	72.3	69.7	64.8	68.8	90.2	85.6	81 4	79.8	89.9	79.6	96.4	68.9	81.5	83.7	81.8
9	------	24.4	25.2	45.3	71.5	70 8	54.6	51.4	52 7	62.2	83 6	80.2	63.8	57.5	58.8	24.8	62.5	52.9	75.3	60 0	57.1
11	------	66.8	60.8	74.4	85.5	82 9	74.9	30.1	17 0	34.9	80.4	83.8	87.4	------	------	63.8	80 9	40 7	66.4	87.4	64.9
Chippewa River	------	75.4	70.6	73.7	81.3	86 7	------	------	------	------	------	------	84.2	------	------	73.0	80.6	------	------	84 2	------
Zumbro River	------	85.7	88 0	89.2	86.8	89.7	82.3	79.5	82.0	84.4	87.9	87.8	85.6	------	------	86 9	88 6	81.3	86 7	85.6	85.7
14	------	68.1	69.5	82.2	92.3	85 3	78 3	70 7	69.6	73.8	88 3	82.6	75.8	------	------	68 8	86.6	72.9	81.6	75.8	78.0

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period July, 1926, to June, 1927, inclusive.

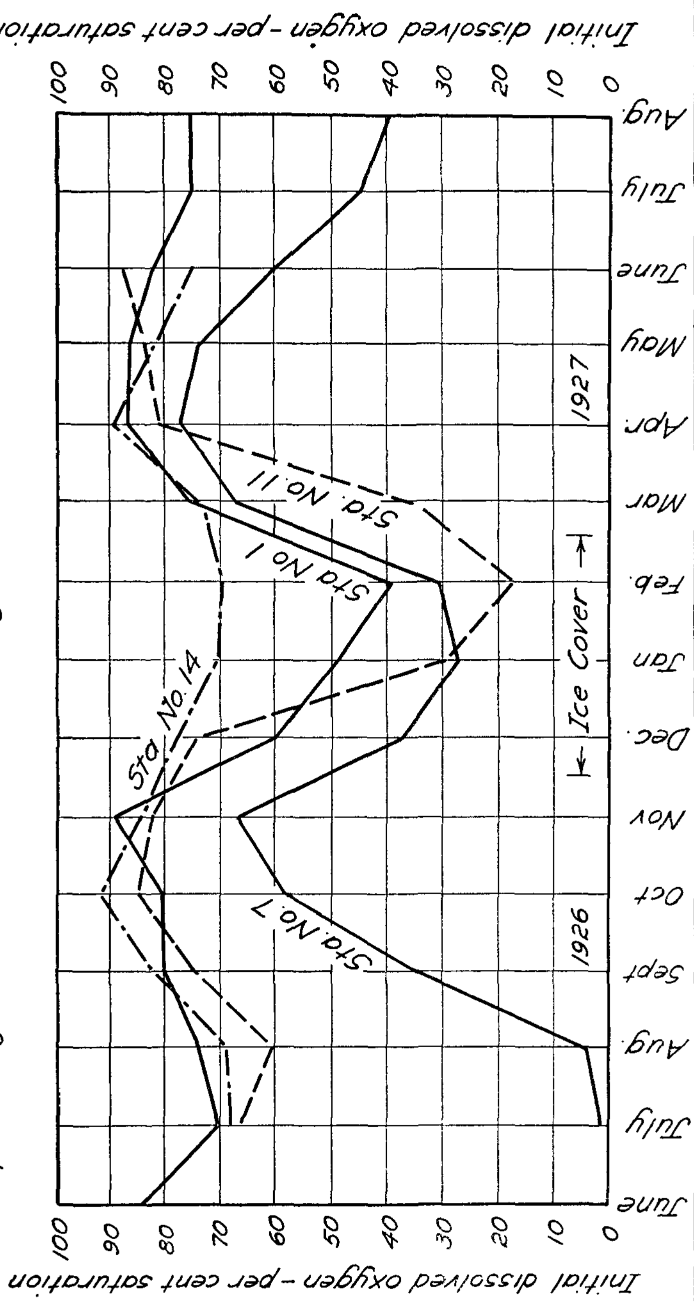

Figure No. 6. Variation in monthly averages of dissolved oxygen, in percentage of saturation, at sampling stations No. 1-7-11 and 14.

The tables and figure indicate a decrease in the dissolved oxygen in the water as it flowed downstream, from Station No. 1, and received increasing amounts of sewage and industrial wastes from the Twin City metropolitan area. Below the sewer outlets, the dissolved-oxygen increased as a result of reaeration and the inflow of tributaries. During the winter months, however, reaeration was to a large extent prevented by the ice cover and the point of minimum dissolved-oxygen concentration, which usually occurred at Station No. 7, above Hastings, was further downstream at the outlet of Lake Pepin. The effect of the ice cover was particularly noticeable in Lake Pepin between Stations No. 9 and 11 in the winter and early spring.

Two periods of high oxygen concentration were indicated, one in the spring, another in the fall. The high oxygen concentration in fall occurred just prior to the formation of the ice cover, when water temperatures approached freezing but with reaeration still in progress at the surface when the water was capable of taking up maximum amounts of oxygen. The high-dissolved oxygen concentration in the spring occurred under similar conditions immediately after the ice cover broke up and disappeared. During both periods of low-water temperatures, biological activities were decreased, less dissolved oxygen was utilized in such processes, and the greater reaeration produced an oxygen reserve.

After the winter ice cover formed, preventing reaeration, a decrease in the oxygen concentration began, which lasted until the ice disappeared in the spring. Station No. 11, at the outlet of Lake Pepin, represents changes in dissolved-oxygen concentration of the water following a long period of detention under the ice cover in winter. In October and November, 1926, with decreasing water temperatures and reaeration proceeding at the surface, the oxygen saturation percentages were 85.5 and 82.9, respectively. Ice formed on the lake at the end of November, after which the monthly average oxygen saturation percentages were: December 74.9; January, 30.1; February, 17; and March 1 to 15, inclusive, 14. Ice left the lake about the middle of March and the average oxygen saturation during the latter part of the month was 58 per cent, which increased to an average of 80 per cent during April.

In addition to the low concentration of oxygen at the end of winter, a second period of decreased oxygen concentration occurred during the summer months when water temperatures were highest, the solubility of oxygen lowest, and when biological activities were greatest.

As already indicated by the monthly averages, the lowest dissolved-oxygen concentration occurred in the summer and winter seasons, with the highest amounts present in the spring and fall. The concentration of dissolved oxygen in the larger tributaries of the Mississippi

River was greater than that of the main stream above their respective points of confluence. As a result of tributary inflow, and of reaeration, the oxygen concentration of the water at Winona was nearly as great as that of the water above Minneapolis before receiving the pollution from the metropolitan area.

Quantitative changes in dissolved oxygen

In Table 27 the seasonal averages of dissolved oxygen, in parts per million, have been converted into the actual quantities of dissolved oxygen present in the water passing the various sampling stations. Quantities of dissolved oxygen are expressed in kilograms per day, and the data of the table are arranged to show the seasonal changes in the amount of dissolved oxygen, at successive downstream sampling stations and at the mouths of tributaries. The data of this table are shown graphically in Figure 7.

TABLE 27.—*Seasonal averages of dissolved oxygen, in terms of kilograms per day, at sampling stations on the upper Mississippi River*

Station	Summer, 1926	Fall	Winter	Spring	Summer, 1927	Yearly average
1	40, 760	139, 380	44, 500	330, 300	120, 830	150, 260
2	36, 800	137, 890	48, 160	346, 710	118, 340	154, 360
3	3, 630	114, 430	45, 460	335, 480	86, 400	137, 350
Minnesota River	*4, 330*	*42, 580*	*13, 050*	*214, 110*	*45, 440*	*76, 810*
5	6, 720	156, 310	57, 930	532, 840	124, 260	208, 130
6	4, 580	147, 990	55, 050	520, 170	116, 620	201, 480
7	1, 860	115, 410	36, 870	470, 320	113, 100	174, 810
St. Croix River	43, 010	98, 190	63, 930	274, 420	77, 720	126, 400
Cannon River	1, 710	6, 910	3, 920	22, 620	8, 470	10, 380
9	27, 660	217, 720	113, 440	784, 930	202, 660	313, 650
11	70, 940	290, 370	94, 460	697, 850	503, 490	324, 450
Chippewa River	101, 910	358, 860	----------	----------	143, 880	----------
Zumbro River	3, 070	9, 450	4, 300	22, 090	20, 490	11, 180
14	176, 060	713, 200	343, 360	1, 310, 820	594, 010	670, 690

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period July, 1926, to June, 1927, inclusive.

Table 27 and Figure 7 show a decrease in the amount of dissolved oxygen as sewage and industrial wastes are discharged into the river between Stations Nos. 1 and 6, and a recovery of dissolved oxygen below the zone of pollution. During the summer of 1926, when stream flows were exceptionally low, the dissolved oxygen present in the water as it entered the metropolitan area was practically exhausted at the Government lock and dam at Minneapolis, Station No. 3, and the water remained depleted of oxygen to Station No. 7, at Hastings. The indicated average daily loss in dissolved oxygen, as the water passed through the metropolitan district in the summer of 1926, was 43,200 kilograms.

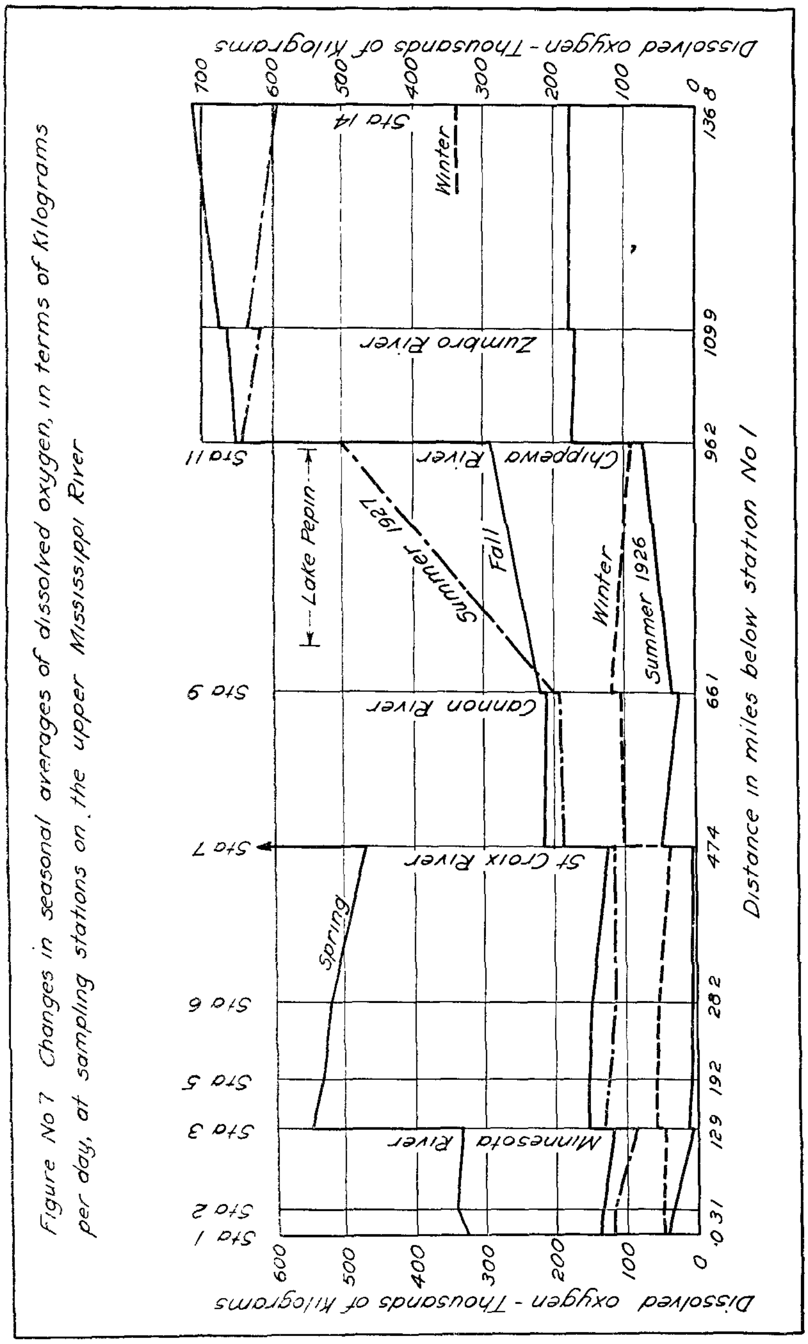

Figure No 7 Changes in seasonal averages of dissolved oxygen, in terms of kilograms per day, at sampling stations on the upper Mississippi River

During a summer of more normal stream discharge, as indicated by the 1927 data, there was a decrease in dissolved oxygen through the zone of highest pollution, but the greater amounts present in the water entering the area were sufficient to maintain a reserve through and below the zone of pollution. During the winter months of normal stream flow, when the surface of the water was covered with ice retarding reaeration, the quantity of dissolved oxygen present in the water at each sampling station was less than in the normal summer period of 1927. The data suggest that in polluted streams of this type, with long periods of ice cover, critical oxygen conditions may occur at the end of winter, rather than during the summer months.

The table and figure further indicate the loss in dissolved oxygen during the winter and early spring months as the water flowed through Lake Pepin under the ice. In the winter period the estimated time of flow through the lake was between 30 and 40 days. Water entering the lake in December, under the ice, would, therefore, have reached the outlet during January, and, similarly, the inflow during January would have appeared at the outlet in February. Taking into consideration the period of lag in passing through the lake, the average daily loss in dissolved oxygen during December, 1926, and January, 1927, was 77,500 and 69,900 kilograms, respectively. The data also indicate the smaller contributions of dissolved oxygen during the critical summer and winter periods, by the Minnesota, Cannon, and Zumbro Rivers, entering from the west through Minnesota, and the much larger contributions of dissolved oxygen by the St. Croix and Chippewa Rivers, entering from Wisconsin. The relatively large amounts of dissolved oxygen contributed by the St. Croix River in the summer and winter periods at the point of lowest oxygen content in the main stream are an important factor in improving conditions in the main channel between Hastings, Station No. 7, and Red Wing, Station No. 9.

BIOCHEMICAL OXYGEN DEMAND

Monthly and seasonal changes in oxygen demand concentration

The results of the 5-day biochemical oxygen demand determinations at 20° C. are summarized in Table 28 as monthly and seasonal averages at successive sampling stations below Station No. 1. The results at the mouths of tributaries are inserted beneath sampling stations on the main river below which the respective tributaries entered. In Figure 8, changes in monthly average demand are indicated graphically at Station No. 1, above the zone of highest pollution; at Station No. 7, below the zone of greatest sewage contamination; at Station No. 11, the outlet of Lake Pepin; and at Station No. 14, the lowest sampling station on the river.

TABLE 28.—*Summary of average monthly and seasonal 5-day biochemical oxygen demand determinations, in parts per million, at 20° C., at sampling stations on the upper Mississippi River, June, 1926, to August, 1927, inclusive*

Sampling station	Monthly averages															Seasonal averages					Yearly average
	1926							1927													
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Summer, 1926	Fall	Winter	Spring	Summer, 1927	
1	1.50	1.06	1.03	1.23	1.47	1.96	1.12	1.11	1.09	2.79	2.13	2.09	1.87	1.13	0.84	1.20	1.55	1.11	2.34	1.28	1.58
2	1.39	1.28	1.13	1.19	1.47	1.84	1.37	4.20	4.35	2.76	2.09	1.84	1.97	1.09	.88	1.27	1.50	3.31	2.23	1.31	2.12
3	5.84	3.96	3.31	2.90	4.38	6.90	5.56	9.31	10.05	5.33	3.25	3.14	3.13	3.35	3.13	4.37	4.73	8.31	3.91	3.20	5.10
Minnesota River	2.62	3.39	3.10	2.88	2.59	5.46	2.86	1.81	2.15	3.38	2.36	2.73	1.94	2.81	3.76	3.04	3.64	2.27	2.82	2.84	2.89
5	8.32	5.25	3.67	3.55	4.03	5.07	9.83	8.38	7.09	4.86	4.82	3.15	2.92	2.81	2.16	5.75	4.22	8.43	4.28	2.63	5.22
6	6.23	5.95	4.04	3.23	4.36	7.74	10.32	9.30	8.45	5.10	3.28	3.65	3.00	3.02	2.28	5.41	5.11	9.36	4.01	2.77	5.70
7		8.40	4.19	2.74	3.82	6.16	7.72	7.74	8.90	4.26	2.90	2.59	2.87	2.90	3.22	6.29	4.24	8.12	3.25	3.00	5.19
St. Croix River		1.82	1.31	.81	1.14	1.34	1.45	1.34	1.36	1.71	1.82	1.75	1.00	1.19	1.12	1.57	1.10	1.38	1.76	1.10	1.40
Cannon River		1.75	1.35	1.65	1.42	1.57	2.64	1.44	1.73	2.86	2.58	4.21	2.51	1.56	1.69	1.55	1.55	1.94	3.22	1.92	2.14
9		2.90	1.68	1.89	2.74	3.71	3.86	3.21	2.62	2.83	2.51	2.69	2.11	2.72	1.97	2.29	2.78	3.23	2.68	2.27	2.73
11		.99	.87	.87	1.17	2.57	.87	1.18	1.55	2.56	3.48	4.12	2.28			.93	1.54	1.20	3.39	2.28	1.88
Chippewa River		2.78	1.68	1.20	1.57	1.60							2.97			2.23	1.46			2.97	
Zumbro River		1.80	2.41	2.05	1.14	1.02	1.31	1.02	1.19	2.75	1.30	1.64	1.97			2.11	1.40	1.17	1.90	1.97	1.63
14		3.51	3.49	2.44	1.87	1.83	1.82	1.73	2.43	2.47	2.44	2.06	2.24			3.50	2.05	1.99	2.32	2.24	2.36

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period, July, 1926, to June, 1927, inclusive.

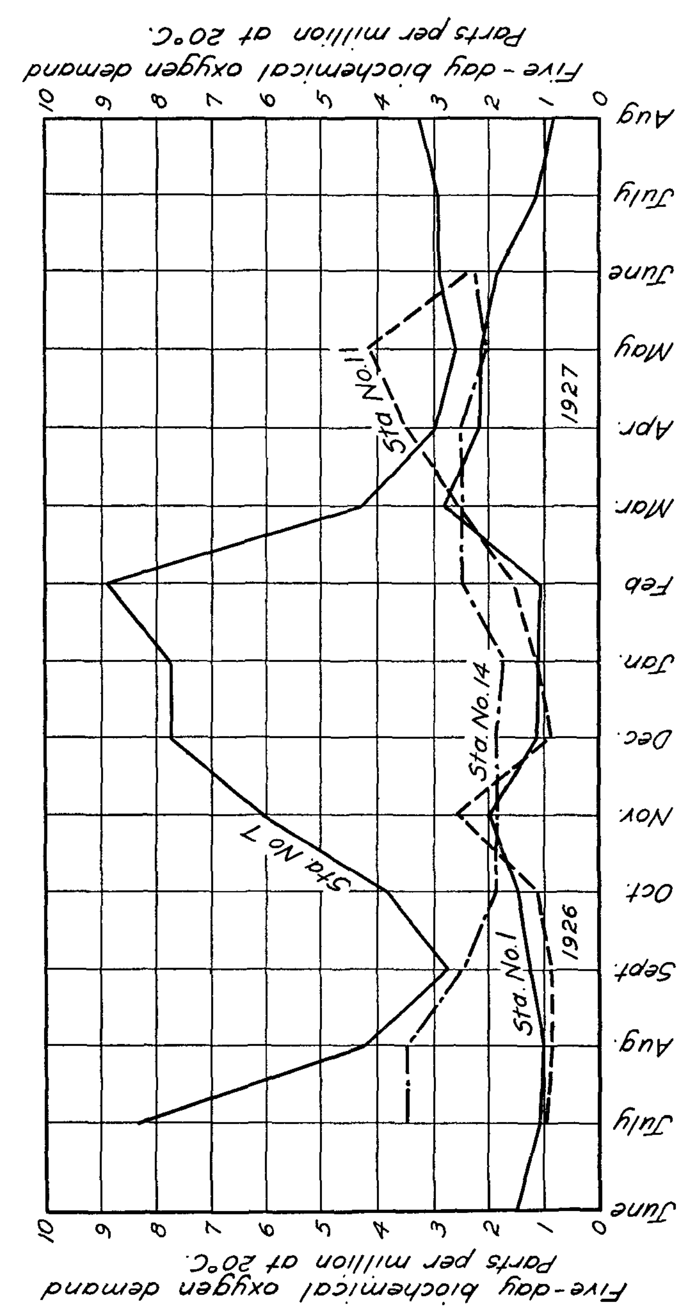

Figure No. 8 Variation in monthly averages of five day biochemical oxygen demand, parts per million 20°C, at sampling stations No. 1-7-11 and 14

Table 28 and Figure 8 indicate an increase in the oxygen demand of the river through the metropolitan area, between Stations Nos. 1 and 7, from above Minneapolis to Hastings, due to the discharge of sewage and industrial wastes. Below the zone of heavy pollution, between Hastings, Station No. 7, and Red Wing, Station No. 9, near the upper end of Lake Pepin, the river receives the inflow of the St. Croix and Cannon Rivers and but little additional contamination. The data indicate a reduction in oxygen demand in this part of the stream due to the dilution by the tributaries, reaeration, and processes of natural stream purification. In passing through Lake Pepin there was a further, and usually much greater, reduction in the oxygen demand of the water. The velocity of flow was diminished in Lake Pepin and a long period of sedimentation took place at ordinary rates of run-off. Because of the increased water surface area, reaeration was increased, except at times of ice cover, and the time interval permitted the oxidation of organic matter to take place. A marked reduction in oxygen demand, therefore, was usually observed as the water passed slowly through the lake. In the spring months of highest stream flow, when ice and snow were leaving the watershed, times of flow were decreased, there was a general flushing out of the drainage area above the lake, and under these conditions there was very little reduction in the oxygen demand between the inlet and outlet of Lake Pepin.

Between the outlet of Lake Pepin, Station No. 11, and Winona, Station No. 14, the Chippewa and Zumbro Rivers enter the main stream, and in this section of the river there was a frequent and unexpected increase in the oxygen demand. In general the increases occurred during the summer and winter months, when stream flows were the lowest, and the reduction in demand occurred in the spring months of highest stream flows.

Quantitative changes in oxygen demand

Table 29 gives the seasonal averages of the 5-day biochemical oxygen demand at 20° C., converted into the actual 5-day oxygen requirements expressed in terms of kilograms. The data are arranged as seasonal averages at successive sampling stations below Station No. 1.

TABLE 29.—*Seasonal averages of 5-day biochemical oxygen demand at 20° C., expressed as kilograms, at sampling stations on the upper Mississippi River*

Station	Summer 1926	Fall	Winter	Spring	Summer 1927	Yearly average
1	7,050	21,840	6,700	74,080	23,640	30,420
2	7,450	21,290	18,970	70,880	24,490	32,950
3	25,840	64,850	49,000	121,710	53,690	68,770
Minnesota River	2,400	14,780	3,930	57,930	13,820	21,890
5	38,890	79,160	66,960	231,970	64,020	108,940
6	36,490	91,130	74,160	210,330	67,110	109,250
7	41,280	77,090	63,650	172,610	69,160	94,710
St. Croix River	8,730	13,510	8,640	51,490	12,250	21,230
Cannon River	360	1,040	809	7,440	2,590	2,950
9	28,370	88,350	48,050	228,770	81,370	106,490
11	11,750	46,800	17,210	293,290	137,970	102,780
Chippewa River	31,810	59,340	------	------	54,570	------
Zumbro River	820	1,400	439	3,680	4,970	1,930
14	102,600	161,300	63,840	307,400	187,140	165,830

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August
Summer average, 1926, Stations Nos 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November
Winter average, all stations, based on months of December, January, and February
Spring average, all stations, based on months of March, April, and May
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period, July, 1926, to June 1927, inclusive

The data of yearly averages in Table 29 indicate changes in oxygen requirements as follows: An increase in demand through the metropolitan area to its lower limits; satisfaction of demand from Station No. 6 to the outlet of Lake Pepin; and an increase in demand from the outlet of the lake to Winona. In the seasons of lower stream flow, satisfaction of demand began below Stations Nos. 6 or 7 and continued through Lake Pepin. At times of higher stream discharge the demand remained high to points further downstream and in the spring period of highest run-off, there was an indicated increase in oxygen demand through the lake. The unexpected increase in demand below Lake Pepin is again shown during the months of lower stream discharge.

For a period of six months complete data were obtained at the sampling stations at and below the outlet of Lake Pepin. During four of these months the oxygen demand at Winona was greater than the combined demand of the water at the outlet of the lake and the water contributed by the Chippewa River. Investigation failed to reveal any pollution entering the main stream or introduced by other tributaries that would account for the increased oxygen demand at the lower station.

The greatest indicated increases in oxygen requirements occurred at the lower sampling station in the months of highest water temperatures, when the inflow of the Chippewa River was nearly twice the flow of the main stream and when the oxygen requirements of the tributary were from two to three times those of the main river at the outlet of Lake Pepin. Much smaller increases, or actual decreases in oxygen requirements, were noted at the lower station when tributary inflow was less than that of the main stream and when the oxygen requirements of both were more nearly the same. During the months of lowest stream discharge the average time of flow through Lake Pepin was approximately 40 days, while in the spring period of highest run-off the time of detention within the lake was reduced to about 10 days. The data suggest that it was the organic matter of the tributary which influenced the increase in oxygen requirements in the lower section of the stream. The organic matter of the main stream, after its long period of detention in the lake, must have reached the second or nitrification stage of the oxidation process at Station No. 11. The organic matter in the water entering the main river from the Chippewa River, in which velocities of flow were comparatively high, was presumably in the first or carbon stage of oxidation, but in its passage downstream the time interval was such that it had entered upon the second stage of oxidation at Winona, showing greater oxygen requirements than at the upper station.

The survey of the industrial-waste pollution of the river system indicated that the Chippewa River was probably the most highly polluted tributary of the Mississippi River, receiving manufacturing wastes from several paper mills, canning plants, and milk-products establishments. Industrial wastes inhibiting normal bacterial activity in the Chippewa River, and subsequent dilution by the main stream, may have been a further factor in the increased oxygen requirements in the main stream below the confluence of the tributary. Sufficient data, however, are not available from which to determine definitely the particular factors responsible for the indicated increase in oxygen demand in the lower section of the river.

OXYGEN BALANCE

A comparison between the amount of dissolved oxygen in the water at a sampling station and the oxygen requirements of the same water, as indicated by the biochemical-oxygen demand, shows the capacity of the stream at that particular time to care for the pollution previously discharged into it. Changes in the ratio of available oxygen to the oxygen required by the stream take place when polluting substances are added, which decrease the dissolved oxgyen and increase the oxygen demand, or when processes of natural stream purification are operating, tending to increase the amount of dissolved oxygen and decrease the oxygen demand.

SEASONAL CHANGES IN THE RATIO BETWEEN DISSOLVED OXYGEN AND OXYGEN DEMAND

Table 30 shows for the various sampling stations the seasonal and yearly average ratios of the quantity of dissolved oxygen to the oxygen requirements, as indicated by the 5-day demand at 20° C.

Table 30.—*Seasonal ratios of the dissolved oxygen to the 5-day biochemical oxygen demand at 20° C., at main river and tributary sampling stations on the upper Mississippi River*

Station	Summer, 1926	Fall	Winter	Spring	Summer, 1927	Yearly average
1	5.8	6.4	6.6	4.4	5.1	4.9
2	4.9	6.5	2.5	4.9	4.8	4.7
3	.14	1.8	.93	2.8	1.6	2.0
Minnesota River	1.8	2.9	3.3	3.7	3.3	3.5
5	.17	2.0	.87	2.3	1.9	1.9
6	.13	1.6	.74	2.5	1.7	1.8
7	.05	1.5	.58	2.7	1.6	1.8
St. Croix River	4.9	7.3	7.4	5.3	6.3	6.0
Cannon River	4.7	6.6	4.9	3.0	3.3	3.5
9	.98	2.5	2.4	3.4	2.5	2.9
11	6.0	6.2	5.5	2.4	3.7	3.2
Chippewa River	3.2	6.0	----	----	2.6	----
Zumbro River	3.7	6.7	10.0	6.0	4.1	5.8
14	1.7	4.4	5.4	4.3	3.2	4.0

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10 inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period July, 1926, to June, 1927, inclusive.

Table 30 shows that the dissolved oxygen carried by the tributaries was always in excess of their oxygen requirements, the amount of dissolved oxygen varying from about twice the required oxygen in the Minnesota River in summer to ten times the required oxygen in the Zumbro River in winter.

Yearly average ratios at main river sampling stations indicate a decrease in ratio due to the pollution from the Twin City Metropolitan area, between Stations Nos. 1 and 7, and an increase in ratio below the zone of pollution.

Seasonal averages show the decrease in ratio within the polluted section of the stream during all seasons. In the summer of 1926 practically no oxygen was present in the stream between Stations Nos. 3 and 7. The winter ratios, due to the prevention of reaeration, were lower than during a normal summer period as indicated by the 1927 data. In the spring and fall periods the dissolved oxygen was always in excess of the oxygen requirements of the main river. In all but the fall period an increase in ratio was indicated as the water flowed through Lake Pepin, between Stations Nos. 9 and 11. In both summer periods and in the fall period a decrease in ratio was indicated between the outlet of Lake Pepin, Station No. 11, and Winona, Station No. 14.

The data of Tables 27 and 29 have been combined to show the relationship between the actual amount of dissolved oxygen and the oxygen demand, both expressed in terms of kilograms, at designated sampling points along the main river. From these relationships calculations have been made to show the changes in the oxygen balance taking place between designated points along the stream.

Corrections have been made for the effect of tributaries within the sections below their points of entrance. These data are summarized in Table 31 as seasonal and yearly averages, expressed as kilograms, to show the decrease in oxygen balance as a result of sewage pollution, or the increase in balance resulting from processes of natural stream purification.

TABLE 31.—*Seasonal and yearly averages of the changes in oxygen balance, expressed as kilograms, between designated main river sampling stations on the upper Mississippi River*

	Summer 1926	Fall	Winter	Spring	Summer 1927	Yearly average
STATIONS NO. 1 TO NO. 3						
Total change	−55, 920	−67, 960	−42, 300	−47, 630	−64, 480	−51, 260
Per capita change [1]	−0. 085	−0. 103	−0. 064	−0. 072	−0. 098	−0. 079
STATIONS NO. 3 TO NO. 7						
Total change	−19, 140	−39, 060	−32, 360	−72, 240	−20, 390	−43, 400
Per capita change [2]	−0. 030	−0. 060	−0. 050	−0. 111	−0. 031	−0. 067
STATIONS NO. 7 TO NO. 9						
Total change	+4, 430	+6, 370	+36, 880	+35, 520	+11, 880	+21, 890
Kilograms per hour	+148	----------	+1, 280	----------	+500	----------
STATIONS NO. 9 TO NO. 11						
Total change	+59, 900	+114, 200	+11, 860	−151, 600	+244, 250	+14, 510
Kilograms per hour	+49	----------	+11	----------	+335	----------
STATIONS NO. 11 TO NO. 14						
Total change	−55, 830	+8, 810	----------	----------	−47, 960	----------
Kilograms per hour	−2, 240	----------	----------	----------	----------	----------

[1] Based on an estimated total equivalent sewered population of 657,820.
[2] Based on an estimated total equivalent sewered population of 648,670.

PER CAPITA CHANGES IN OXYGEN BALANCE WITHIN THE METROPOLITAN AREA

In the upper section of the river, between Stations Nos. 1 and 3, and also between Stations Nos. 3 and 7, the indicated total decrease in oxygen balance has been calculated in terms of kilograms per capita per day, by dividing the total decrease in balance by the estimated total equivalent sewered population between these sampling points. Assuming that the per capita oxygen demand of domestic sewage, as represented by the 5-day biochemical oxygen demand at 20° C., is 0.163 pounds, or 0.074 kilograms, the estimates of per capita decreases in the oxygen balance between stations on the upper section of the river calculated from the oxygen determinations should be of about the same order of magnitude as 0.074 kilograms, except in so far as physical conditions in the stream or processes of natural stream purification not recorded by the chemical analyses might alter the results.

Between Stations Nos. 1 and 3 the average per capita decrease in oxygen balance, Table 31, varies between a minimum of 0.064 kilogram in winter to a maximum of 0.103 kilograms in the fall. This section of the river includes the pool above the Government lock and dam at Minneapolis, in which considerable deposition of sludge takes place. It is believed that this pool accounts to some extent at least for the variation in the calculated daily average per capita decrease in oxygen balance. In the summer and early fall, the accumulated sludge increased the draft on the oxygen resources of the water, while in winter and early spring biological activities were decreased and the sedimentation of sludge, without subsequent decomposition, tended to decrease the draft on the oxygen resources of the water. In all of the calculations certain discrepancies are introduced, due to the satisfaction of oxygen demand by the dissolved oxygen introduced by reaeration not always accounted for in the chemical analyses, and by the organic matter carried in the surface run-off. Yearly averages have a tendency to balance the seasonal variations and the calculated amount of 0.079 kilogram per capita per day, during the period of a year, for the upper section of the river is in close agreement with the figure of 0.074 kilogram per capita per day, representative of the pollution contributed by domestic sewage.

Seasonal averages of the daily per capita change in balance between Stations Nos. 3 and 7 were less in each season, with the exception of spring, than in the river section immediately above, and in general were considerably lower than the estimated figure of 0.074 kilogram. In this section of the river, nearly 35 miles long, increased times of flow undoubtedly permitted processes of natural stream purification to operate, reducing the calculated per capita changes. In the summer and winter months of lowest stream discharge and lengthened times of flow, allowing greater natural purification to take place, the indicated per capita contributions were less than during the fall and spring periods, when times of flow were less.

RATES OF INCREASE IN OXYGEN BALANCE BELOW THE ZONE OF POLLUTION

Below Station No. 7 changes in oxygen balance, Table 31, are expressed as the increase or decrease in kilograms; and where times of flow were available, as rates of change in terms of kilograms per hour. Insufficient hydrometric data limited such comparisons to those taking place in the summer and winter seasons and only for certain stretches of the river.

Such data as were available show an increase in balance between Stations Nos. 7 and 9 in every season, the indicated rate of increase in winter greatly exceeding that of summer, and the summer rate in 1927 exceeding that of the summer of 1926.

Between Stations Nos. 9 and 11, which includes Lake Pepin, an increase in balance was shown during the summer, fall, and winter periods, and a decrease in balance was indicated in the spring period. When the time factor was considered, however, the rate of change in this section was very much less than in the more swiftly moving section immediately above. Also, in contrast to the section immediately above, somewhat greater rates of change were indicated in the summer period rather than in the winter period of ice cover.

RATES OF SECONDARY DECREASE IN OXYGEN BALANCE BELOW LAKE PEPIN

From Station No. 11, at the outlet of Lake Pepin, to Station No. 14, at Winona, an increase in balance was shown only in the fall period. The indicated decrease in balance in the summer of 1926 in the lower section of the river was practically the same as the decrease in the upper section between Stations Nos. 1 and 3, which received the sewage from a total equivalent sewered population of 657,820. In the summer of 1927 the indicated decrease in the lower section of the river was almost 75 per cent of that in the upper section between Stations Nos. 1 and 3.

SECTION VI

BACTERIOLOGICAL STUDIES

Observations were made of the bacteriological content of the Mississippi River and its tributaries on samples of water collected from the 14 regular sampling stations during the 15-month period June 1, 1926, to August 31, 1927, as follows:

Station number	Days of sampling each week	Period of sampling
1 to 6, inclusive	5 (Monday-Friday, inclusive)	June 1 to Oct. 31, 1926.
7 to 14, inclusive	5 (Monday-Friday, inclusive)	July 1 to Oct. 31, 1926.
1 to 10, inclusive	3 (Monday, Wednesday, Friday)	Nov. 1, 1926, to Aug. 31, 1927
11 to 14, inclusive	3 (Monday, Wednesday, Friday)	Nov. 1, 1926, to June 30, 1927

Laboratory determinations consisted of plate counts on agar after an incubation period of 48 hours at 20° C., and of 24 hours at 37° C. Quantitative estimates of B. coli were obtained from fermentation tube tests, with lactose broth, in portions of water in geometric series.

PRESENTATION OF DATA

Results of the daily bacteriological examinations are summarized as monthly arithmetical averages in the basic tabulations, Tables 32 and 33. Table 32 shows at each sampling station for every month of observation the monthly average bacterial content per cubic centimeter determined from the 20° and 37° C. agar-plate counts and the estimated number of B. coli from the fermentation-tube results. Included in the table are monthly average rates of stream discharge and water temperatures. This table, in addition, summarizes the monthly averages of the bacterial observations at each sampling station in terms of "quantity units" (bacteria per cubic centimeter multiplied by the stream discharge in thousands of second-feet). For purposes of comparison, seasonal and yearly averages of bacteria per cubic centimeter and in terms of quantity units are included.

In Table 33 the same data are grouped by months, to show for each month at all sampling stations the monthly averages of bacteria per cubic centimeter and the bacteria in terms of quantity units. Sampling stations have been arranged in consecutive order passing downstream, and the results at the mouths of tributaries have been inserted beneath the main-river sampling stations below their respective points of entrance.

A study of the actual numbers of bacteria present in the water at the various sampling stations offers a better basis for comparison than the concentration of bacteria at the several points. For this purpose a unit designated as the "quantity unit" was adopted during the studies of the Ohio and Illinois Rivers. This unit is defined as the product of 1 cubic foot discharge per second, and the concentration of 1,000 bacteria per cubic centimeter. The number of quantity units in a stream is therefore:

$$\frac{\text{Discharge in second-feet} \times \text{Bacteria per cubic centimeter}}{1{,}000}$$

This unit is convertible into actual numbers of bacteria per day by multiplying the bacteria in one quantity unit by 28,317 (cubic centimeters per cubic foot) by 86,400 (seconds per day) by 1,000. Hence one quantity unit equals 2,446,589,000 bacteria per day.

Bacterial concentration as indicated by the basic tabulations varies considerably from month to month; and it has been found advisable to still further arrange the bacteriological observations as seasonal averages, using the same groupings as in the study of the chemical results. In Table 34 the bacteriological results from the agar-plate counts and the B. coli estimates, in terms of quantity units, are presented as seasonal averages at the various sampling stations in their order downstream.

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*

STATION NO. 1.—MISSISSIPPI RIVER AT CAMDEN AVENUE BRIDGE, MINNEAPOLIS

Month	Average discharge second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
June	2,430	22	18.3	6,600	2,900	1	16,038	7,047	2
July	2,360	21	23.0	2,500	1,400	2	5,900	3,304	5
August	2,410	22	21.9	1,400	950	4	3,374	2,290	10
September	6,480	21	16.4	1,700	1,500	7	11,016	9,720	45
October	7,460	21	9.5	1,100	1,000	10	8,206	7,460	75
November	3,980	14	1.4	1,100	650	25	4,378	2,587	100
December	2,890	13	0	600	225	6	1,734	650	17
1927									
January	2,300	12	0	550	100	15	1,265	230	35
February	2,210	11	0	900	225	15	1,989	497	33
March	9,640	13	1.0	6,600	800	20	63,624	7,712	193
April	17,400	13	7.2	4,300	600	11	74,820	10,440	191
May	12,800	11	12.8	3,800	400	14	48,640	5,120	179
June	9,810	13	18.6	3,000	600	6	29,430	5,886	59
July	5,590	12	22.4	2,500	850	6	13,975	4,752	34
August	5,100	18	19.9	2,700	850	5	13,770	4,335	25
SEASONAL AVERAGES									
Summer, 1926	2,400	65	21.1	3,500	1,750	2	8,440	4,210	6
Fall	5,970	56	9.1	1,300	1,050	14	7,870	6,590	73
Winter	2,470	36	0	680	180	12	1,660	460	28
Spring	13,280	37	7.0	4,900	600	15	62,360	7,760	188
Summer, 1927	6,830	43	20.3	2,700	800	6	19,060	4,990	39
Yearly	6,650	185	9.3	2,300	700	11	21,200	4,660	79

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*—Continued

STATION NO. 2.—MISSISSIPPI RIVER AT PLYMOUTH AVENUE BRIDGE, MINNEAPOLIS

Month	Average discharge second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter × thousand second-feet): 20° C. agar	Quantity units: 37° C agar	Quantity units: B. coli
1926									
June	2,430	22	18.1	8,100	3,000	11	19,683	7,290	27
July	2,360	21	23 4	9,200	6,200	33	21,712	14,632	78
August	2,410	22	22.0	8,400	5,300	165	20,244	12,773	398
September	6,500	21	16.1	2,300	2,000	10	14,950	13,000	65
October	7,480	21	9.5	1,200	1,100	10	8,976	8,228	75
November	3,990	14	1.4	1,700	900	7	6,783	3,591	28
December	2,890	2	0	2,200	900	10	6,358	2,601	29
1927									
January	2,300	10	0	3,300	1,200	351	7,590	2,760	807
February	2,210	2	0	3,700	1,200	100	8,177	2,652	221
March	9,660	6	2.2	3,900	850	6	37,674	8,211	58
April	17,500	13	7.2	3,700	550	6	64,750	9,625	105
May	12,800	11	12.8	3,400	450	33	43,520	5,760	422
June	9,850	13	18.6	3,500	550	8	34,475	5,418	79
July	5,590	12	22.4	3,100	950	15	17,329	5,311	84
August	5,100	18	19.9	3,300	900	17	16,830	4,590	87
SEASONAL AVERAGES									
Summer, 1926	2,400	65	21.2	8,600	4,800	70	20,550	11,570	168
Fall	5,990	56	9.0	1,700	1,300	9	10,240	8,270	56
Winter	2,470	14	0	3,100	1,100	154	7,380	2,670	352
Spring	13,320	30	7.4	3,700	620	15	48,650	7,870	195
Summer, 1927	6,850	43	20.3	3,300	800	13	22,880	5,110	83
Yearly	6,660	156	9.4	3,900	1,800	62	22,930	7,440	197

STATION NO. 3.—MISSISSIPPI RIVER AT GOVERNMENT LOCK AND DAM, MINNEAPOLIS

Month	Average discharge second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter × thousand second-feet): 20° C agar	Quantity units: 37° C agar	Quantity units: B. coli
1926									
June	2,440	22	19.4	440,000	300,000	2,000	1,073,100	732,000	4,880
July	2,370	21	24.3	750,000	650,000	1,639	1,777,500	1,540,500	3,884
August	2,420	22	23.0	320,000	380,000	1,565	774,400	919,600	3,787
September	6,520	21	16.9	330,000	400,000	1,640	2,151,600	2,608,000	10,693
October	7,510	21	9.8	190,000	230,000	1,510	1,426,900	1,727,300	11,340
November	4,000	14	1.6	90,000	94,000	672	360,000	376,000	2,688
December	2,910	14	0	60,000	51,000	1,485	174,600	148,410	4,321
1927									
January	2,310	12	0	77,000	70,000	591	177,870	161,700	1,365
February	2,220	11	0	64,000	130,000	1,410	142,080	288,600	3,130
March	9,690	13	1.2	39,500	47,500	149	382,755	460,275	1,444
April	17,500	13	7.4	35,500	42,000	1,117	621,250	735,000	19,547
May	12,900	11	12.7	61,000	80,000	225	786,900	1,032,000	2,903
June	9,910	13	18 6	150,000	130,000	1,070	1,486,500	1,288,300	10,604
July	5,610	12	22.9	160,000	180,000	2,800	897,600	1,009,800	15,708
August	5,090	18	20.3	210,000	200,000	1,695	1,068,900	1,018,000	8,628
SEASONAL AVERAGES									
Summer, 1926	2,410	65	22.2	500,000	440,000	1,735	1,208,500	1,064,000	4,184
Fall	6,010	56	9.4	200,000	240,000	1,274	1,312,830	1,570,430	8,240
Winter	2,480	37	0	67,000	84,000	1,162	164,850	199,570	2,939
Spring	13,360	37	7.1	45,300	56,500	497	596,970	742,430	7,965
Summer, 1927	6,870	43	20.6	173,000	170,000	1,855	1,151,000	1,105,370	11,647
Yearly	6,690	186	9.6	181,000	192,000	1,089	855,200	940,470	6,309

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*—Continued

STATION NO. 4.—MINNESOTA RIVER AT FORT SNELLING

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
June	400	22	19.4	5,900	4,100	5	2,360	1,640	2
July	213	21	23 7	2,700	2,100	3	575	447	1
August	375	22	22.6	2,400	1,900	5	900	713	2
September	2,040	21	17.2	5,800	5,300	25	11,832	10,812	51
October	2,380	21	10.1	12,000	11,500	20	28,560	27,370	48
November	1,110	14	1 8	8,800	5,700	7	9,768	6,327	8
December	830	13	0	1,500	550	5	1,245	457	4
1927									
January	625	12	0	500	95	12	313	59	8
February	610	5	0	525	110	6	320	67	4
March	9,120	7	2.4	9,100	2 400	19	82,992	21,888	173
April	9,270	13	7.9	8,000	2,600	29	74,160	24,102	269
May	6,680	11	13.6	6,400	2,100	14	42,752	14,028	94
June	5,910	13	18.4	4,600	2,000	13	27,186	11,820	77
July	1,450	12	22 7	4,500	2,200	20	6,525	3,190	29
August	369	18	20.6	4,700	2,400	22	1,734	886	8
SEASONAL AVERAGES									
Summer, 1926	329	65	21.9	3,700	2,700	4	1,280	930	2
Fall	1,840	56	9.7	8,900	7,500	17	16,720	14,840	36
Winter	688	30	0	840	250	8	630	190	5
Spring	8,360	31	8.0	7,800	2,400	21	66,640	20,010	179
Summer, 1927	2,580	43	20 6	4,600	2,200	18	11,820	5,300	38
Yearly	3,260	173	9.8	5,200	3,000	13	23,380	9,840	62

STATION NO. 5.—MISSISSIPPI RIVER AT ROBERTS STREET BRIDGE, ST. PAUL

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C agar	Quantity units: B coli
1926									
June	2,850	20	19 3	170,000	95,000	1,130	484,500	270,750	3,221
July	2,590	21	23.5	550,000	360,000	2,500	1,424,500	932,400	6,475
August	2,810	22	22.1	170,000	160,000	2,964	477,700	449,600	8,329
September	8,630	21	16.5	190,000	190,000	1,596	1,639,700	1,639,700	13,773
October	9,970	21	10 0	120,000	110,000	1,587	1,196,400	1,096,700	15,822
November	5,150	13	1 4	63,000	64,000	2,040	324,450	329,600	10,506
December	3,770	14	0	83,000	58,000	1,485	312,910	218,660	5,598
1927									
January	2,950	12	0	71,000	72,000	692	209,450	212,400	2,041
February	2,850	12	0	65,000	86,000	475	185,250	245,100	1,354
March	18,900	13	1.2	56,000	21,500	294	1,058,400	406,350	5,557
April	27,000	13	7 8	36,500	21,000	577	985,500	567,000	15,579
May	19,700	11	13 3	100,000	56 000	181	1,970,000	1,103,200	3,566
June	16,000	13	18 8	110,000	81,000	633	1,760,000	1,296,000	10,128
July	7,090	12	22 8	68 000	50,000	618	482,120	354,500	4,382
August	5,440	18	20.7	93,000	80,000	1,050	505,920	435,200	5,712
SEASONAL AVERAGES									
Summer, 1926	2,750	63	21 6	297,000	205,000	2,198	795,570	550,920	6,008
Fall	7,920	55	9.3	124,000	121,000	1,741	1,053,520	1,022,000	13,367
Winter	3,190	38	0	73,000	72,000	884	235,870	225,390	2,998
Spring	21,870	37	7 4	64,000	33,000	351	1,337,970	692,180	8,234
Summer, 1927	9,510	43	20.8	90,000	70,000	767	916,010	695,230	6,741
Yearly	10,030	186	9 6	135,000	107,000	1,252	962,020	708,060	8,227

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*—Continued

STATION No. 6.—MISSISSIPPI RIVER AT INVERGROVE BRIDGE

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
June	2,860	21	18.9	190,000	100,000	515	543,400	286,000	1,473
July	2,600	21	23.3	550,000	390,000	1,531	1,430,000	1,014,000	3,981
August	2,820	22	21.9	430,000	310,000	795	1,212,600	874,200	2,242
September	8,660	21	16 4	130,000	130,000	1,081	1,125,800	1,125,800	9,361
October	10,000	21	9.8	130,000	110,000	1,253	1,300,000	1,100,000	12,530
November	5,170	13	1.4	79,000	74,000	515	408,430	382,580	2,663
December	3,790	14	0	64,000	48,000	2,870	242,560	181,920	10,877
1927									
January	2,960	12	0	44,000	47,000	1,442	130,240	139,120	4,268
February	2,860	12	0	78,000	90,000	700	223,080	257,400	2,002
March	18,900	13	1 2	54,000	19,000	224	1,020,600	359,100	4,234
April	27,100	13	7.8	35,500	19,500	1,055	962,050	528,450	28,591
May	19,800	11	13.3	97,000	63,000	451	1,920,600	1,247,400	8,930
June	16,100	13	18.8	72,000	50,000	385	1,159,200	805,000	6,199
July	7,110	12	22.8	90,000	59,000	625	639,900	419,490	4,444
August	*5,440*	*18*	*20.6*	*110,000*	*91,000*	*700*	*598,400*	*495,040*	3,808
SEASONAL AVERAGES									
Summer, 1926	2,760	64	21.4	390,000	267,000	947	1,062,000	724,730	2,565
Fall	7,940	55	9.2	113,000	105,000	950	944,740	869,460	8,185
Winter	3,200	38	0	62,000	62,000	1,671	198,630	192,810	5,716
Spring	21,930	37	7.4	62,200	33,800	577	1,301,080	711,650	13,918
Summer, 1927	9,550	43	20.7	90,700	66,700	570	799,170	573,180	4,817
Yearly	10,060	186	9.5	147,000	113,000	1,025	927,930	667,910	7,990

STATION No. 7.—MISSISSIPPI RIVER ABOVE HASTINGS, MINN.

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	2,600	18	23 6	1,300,000	1,200.000	9,950	3,380,000	3,120,000	25,870
August	2,830	22	22.4	750,000	750.000	3,246	2,122,500	2,122,500	9.186
September	8,700	21	17 4	290,000	320,000	520	2,523,000	2,784,000	4,524
October	10,100	18	11 7	130,000	100,000	535	1,313,000	1,010,000	5,404
November	5,190	13	2.8	110,000	63,000	345	570,900	326,970	1,791
December	3,810	13	0	35,500	22,000	385	135,255	83,820	1,467
1927									
January	2,970	13	0	50,000	34.000	685	148,500	100,980	2,034
February	2,870	12	0	130,000	54,000	393	373,100	154,980	1,128
March	19,000	13	2 5	59,000	16,500	841	1,121,000	313,500	15,979
April	27,200	13	7.6	130,000	25.000	280	3,536,000	680,000	7,616
May	19,900	11	14.5	99,000	48,000	153	1,970,100	955,200	3,045
June	16,200	13	18.9	83,000	43,000	272	1,344,600	696,600	4,406
July	7,120	12	23 9	200,000	130,000	288	1,424,000	925,600	2,051
August	5,450	11	22.2	170,000	150,000	229	926,500	817,500	1,248
SEASONAL AVERAGES									
Summer, 1926	2,720	40	23.0	1,025,000	975,000	6,598	2,751,250	2,621,250	17,528
Fall	8,000	52	10.6	180,000	161,000	467	1,468,970	1,373,660	3,906
Winter	3,220	38	0	71,800	36,700	488	218 950	113,260	1,543
Spring	22,030	37	8.2	96,000	29,800	125	2,209,030	649,570	8,880
Summer, 1927	9,590	36	21.7	151,000	108,000	263	1,231,700	813,230	2,568
Yearly	10,110	130	10.1	264,000	223.000	1,467	1,544 830	1,029,050	6,871

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*—Continued

STATION NO. 8.—ST. CROIX RIVER AT PRESCOTT, WIS.

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	2,100	18	22.9	90,000	66,000	159	189,000	138,600	334
August	2,520	22	22.7	18,500	11,500	245	46,620	28,980	617
September	4,800	18	18.8	6,000	5,200	22	28,800	24,960	106
October	6,050	17	13.1	6,100	5,000	11	36,905	30,250	67
November	4,300	13	4.1	3,600	3,300	1	15,480	14,190	4
December	2,940	6	0	--------	375	.5	---------	1,103	1
1927									
January	2,420	13	0	250	170	13	605	411	31
February	2,260	12	0	2,300	250	1	5,198	565	2
March	12,600	13	2.6	6,000	500	.4	75,600	6,300	5
April	15,400	13	7.4	4,100	650	.1	63,140	10,010	2
May	7,700	11	15.0	3,900	1,800	.4	30,030	13,860	3
June	6,700	13	18.8	5,200	700	.3	34,840	4,690	2
July	4,650	12	24.2	2,600	950	.3	12,090	4,418	1
August	2,470	11	22.7	12,000	3,600	.3	29,640	8,892	1
SEASONAL AVERAGES									
Summer, 1926	2,310	40	22.8	54,300	38,800	202	117,810	83,790	476
Fall	5,050	48	12.0	5,200	4,500	11	27,060	23,130	59
Winter	2,540	31	0	1,300	265	5	2,900	690	11
Spring	11,900	37	8.3	4,700	980	.3	56,260	10,060	3
Summer, 1927	4,610	36	21.9	6,600	1,800	.3	25,520	6,000	1
Yearly	5,820	169	10.5	13,000	8,000	38	47,840	22,830	98

STATION NO. 9.—MISSISSIPPI RIVER ABOVE RED WING, MINN.

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	4,810	19	22.6	72,000	53,000	104	346,320	254,930	500
August	5,480	22	21.4	44,000	33,000	186	241,120	180,840	1,019
September	13,900	21	18.7	17,000	15,000	52	236,300	208,500	723
October	16,600	21	20.4	48,500	28,000	70	805,100	464,800	1,162
November	9,820	12	1	81,000	34,500	159	795,420	338,790	1,561
December	7,020	6	0	28,000	7,200	40	196,560	50,544	281
1927									
January	5,560	9	0	36,500	8,100	28	202,940	45,036	156
February	5,300	11	0	26,000	11,000	26	137,800	58,300	138
March	32,400	13	1.9	21,500	2,000	13	696,600	64,800	421
April	44,100	13	7.3	11,000	2,600	21	485,100	114,660	926
May	28,900	11	14.8	29,500	8,500	20	852,550	245,650	578
June	24,300	13	18.3	16,500	6,200	38	400,950	150,660	923
July	12,000	11	22.9	27,500	17,000	26	330,000	204,000	312
August	7,980	10	22.3	27,500	13,000	9	219,450	103,740	72
SEASONAL AVERAGES									
Summer, 1926	5,150	41	22.0	58,000	43,000	145	293,720	217,890	760
Fall	13,440	54	13.4	48,800	25,800	94	612,270	337,360	1,149
Winter	5,960	26	0	30,000	8,800	31	179,100	51,290	192
Spring	35,130	37	8.0	21,000	4,400	18	678,080	141,700	642
Summer, 1927	14,760	34	21.2	24,000	12,000	24	316,800	152,800	436
Yearly	16,500	171	10.5	36,000	17,000	63	449,730	181,460	699

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*—Continued

STATION NO. 10.—CANNON RIVER AT RED WING, MINN.

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter × thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	95	19	20.8	13,000	11,000	14	1,235	1,045	1
August	97	22	19.7	15,000	11,500	12	1,455	1,116	1
September	293	20	18.5	6,500	5,700	22	1,905	1,670	6
October	276	20	20.6	4,000	3,800	13	1,104	1,049	4
November	256	11	1.6	1,300	600	11	333	154	3
December	214	6	0	1,200	325	10	257	70	2
1927									
January	126	9	0	1,800	500	4	227	63	1
February	132	11	0	12,000	2,200	1	1,584	290	0
March	570	13	1.8	13,000	1,700	2	7,410	969	1
April	1,220	13	7.5	5,000	650	3	6,100	793	4
May	1,030	11	14.7	4,700	700	16	4,841	721	16
June	1,100	13	18.2	8,900	3,800	14	9,790	4,180	15
July	212	11	22.0	3,900	1,000	4	827	212	1
August	46	11	21.7	4,100	900	3	189	41	0
SEASONAL AVERAGES									
Summer, 1926	96	41	20.3	14,000	11,300	13	1,350	1,080	1
Fall	275	51	13.6	3,900	3,400	15	1,110	960	4
Winter	157	26	0	5,000	1,000	5	690	140	1
Spring	940	37	8.0	7,600	1,000	7	6,120	830	7
Summer, 1927	453	35	20.6	5,600	1,900	7	3,600	1,480	5
Yearly	450	168	10.3	7,200	3,500	10	3,020	1,010	5

STATION NO. 11.—MISSISSIPPI RIVER AT OUTLET OF LAKE PEPIN

Month	Average discharge, second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter × thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	4,840	21	22.6	22,000	18,000	3	106,480	87,120	15
August	5,520	22	22.0	7,300	7,400	1	40,296	40,848	6
September	14,100	21	19.3	5,400	5,400	7	76,140	76,140	99
October	16,700	19	13.9	1,900	2,800	1	31,730	46,760	17
November	9,920	10	3.5	750	325	1	7,440	3,224	10
December	7,100	4	0	--------	100	.4	----------	710	3
1927									
January	5,600	5	0	450	50	.3	2,520	280	2
February	5,350	9	0	850	75	.2	4,548	401	1
March	32,500	8	1.4	2,100	400	.7	68,250	13,000	23
April	44,600	10	6.9	2,900	550	.6	129,340	24,530	27
May	29,300	10	13.6	2,400	400	2	70,320	11,720	59
June	24,700	10	18.1	2,700	1,500	.3	66,690	37,050	7
SEASONAL AVERAGES									
Summer, 1926	5,180	43	22.3	14,700	12,700	2	73,390	63,980	11
Fall	13,570	50	12.2	2,700	2,800	3	38,440	42,040	42
Winter	6,020	18	0	650	75	.3	3,530	460	2
Spring	35,470	28	7.3	2,500	450	1	89,300	16,420	36
Summer, 1927	24,700	10	18.1	2,700	1,500	.3	66,690	37,050	7
Yearly	16,700	149	10.1	4,400	3,100	1	54,890	28,480	22

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*—Continued

STATION NO. 12.—CHIPPEWA RIVER AT MOUTH

Month	Average discharge second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	3, 600	21	22. 6	27, 000	25, 500	25	97, 200	91, 800	90
August	9, 500	21	21. 8	13, 000	12, 500	21	123, 500	118, 750	200
September	23, 400	21	18. 2	6, 500	5, 200	23	152, 100	121, 680	538
October	12, 600	15	12. 6	6, 300	7, 300	18	79, 380	91, 980	227
November	15, 500	2	6. 5	1, 400	900	6	21, 700	13, 950	93
1927									
June	7, 500	8	19. 2	6, 600	2, 700	7	49, 500	20, 250	53
SEASONAL AVERAGES									
Summer, 1926	6, 550	42	22. 2	20, 000	19, 000	23	110, 350	105, 280	145
Fall	17, 200	38	12 4	4, 700	4, 500	16	84, 390	75, 870	286
Winter									
Spring									
Summer, 1927	7, 500	8	19. 2	6, 600	2, 700	7	49, 500	20, 250	53
Yearly									

STATION NO. 13.—ZUMBRO RIVER AT KELLOGG, MINN.

Month	Average discharge second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	154	21	21. 0	21, 500	17, 000	14	3, 311	2, 618	2
August	163	21	19. 9	7, 500	4, 900	10	1, 223	799	2
September	454	21	16. 9	17, 000	15, 500	173	7, 718	7, 037	79
October	474	21	9. 9	5, 300	6, 500	13	2, 512	3, 081	6
November	238	11	2. 1	3, 200	1, 700	11	762	405	3
December	200	13	0	1, 700	600	2	340	120	0
1927									
January	118	13	0	650	190	2	77	22	0
February	124	11	0	1, 400	1, 000	2	174	124	0
March	530	12	2. 4	9, 100	1, 600	4	4, 823	848	2
April	1, 130	12	7. 2	5, 400	750	1	6, 102	848	1
May	965	10	13. 5	5, 900	1, 700	6	5, 694	1, 641	6
June	1, 030	13	18. 3	8, 700	2, 400	14	8, 961	2, 472	14
SEASONAL AVERAGES									
Summer, 1926	159	42	20. 5	14, 500	11, 000	12	2, 270	1, 710	2
Fall	389	53	9 6	8, 500	7, 900	66	3, 660	3, 510	29
Winter	147	37	0	1, 250	600	2	200	90	0
Spring	875	34	7 7	6, 800	1, 350	4	5, 540	1, 110	3
Summer, 1927	1, 030	13	18. 3	8, 700	2, 400	14	8, 960	2, 470	14
Yearly	465	179	9. 3	7, 300	4, 500	21	3, 470	1, 670	10

TABLE 32.—*Summary of bacteriological observations, by stations, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet), arranged as monthly means and seasonal averages at each sampling station*—Continued

STATION No. 14.—MISSISSIPPI RIVER ABOVE WINONA, MINN.

Month	Average discharge second-feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1926									
July	8, 650	21	22. 0	320, 000	250, 000	118	2, 768, 000	2, 162, 500	1, 021
August	15, 300	19	23. 3	240, 000	240, 000	156	3, 672, 000	3, 672, 000	2, 387
September	38, 300	16	21. 7	4, 600	5, 100	18	176, 180	195, 330	689
October	30, 300	16	13. 0	2, 700	2, 500	7	81, 810	75, 750	212
November	25, 900	9	3. 2	2, 000	1, 100	17	51, 800	28, 490	440
December	14, 300	10	0	750	325	5	10, 725	4, 648	72
1927									
January	12, 300	10	0	1, 200	450	3	14, 760	5, 535	37
February	12, 700	9	0	3, 200	1, 000	38	40, 640	12, 700	483
March	58, 000	13	2. 2	5, 100	700	13	295, 800	40, 600	754
April	57, 900	12	7. 4	2, 400	475	14	138, 960	27, 503	811
May	44, 600	11	12 0	3, 400	550	6	151, 640	24, 530	268
June	34, 100	13	18. 8	5, 300	650	5	180, 730	22, 165	171
SEASONAL AVERAGES									
Summer, 1926	12, 000	40	22. 7	280, 000	245, 000	137	3, 220, 000	2, 917, 250	1, 704
Fall	31, 500	41	12. 6	3, 100	2, 900	14	103, 260	99, 860	447
Winter	13, 100	29	0	1, 720	590	15	22, 040	7, 630	197
Spring	53. 500	36	7. 2	3, 600	580	11	195, 470	30, 880	611
Summer, 1927	34, 100	13	18. 8	5, 300	650	5	180, 730	22, 170	171
Yearly	29, 400	159	10. 3	49, 000	42, 000	33	631, 920	522, 650	612

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period, July, 1926, to June, 1927, inclusive.

TABLE 33.—*Summary of bacteriological observations, by months, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet) arranged as monthly means for all sampling stations*

JUNE, 1926

Station	Average discharge (second feet)	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at— 20° C. 48 hours	Bacteria per cubic centimeter: On agar at— 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter× thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1	2, 430	22	18. 3	6, 600	2, 900	1	16, 038	7, 047	2
2	2, 430	22	18. 1	8, 100	3, 000	11	19, 683	7, 290	27
3	2, 440	22	19. 4	440, 000	300, 000	2, 000	1, 073, 600	732, 000	4, 880
Minnesota River	400	22	19. 4	5, 900	4, 100	5	2, 360	1, 640	2
5	2, 850	20	19 3	170, 000	95, 000	1, 130	484, 500	270, 750	3, 221
6	2, 860	21	18 9	190. 000	100, 000	515	543, 400	286, 000	1, 473

TABLE 33.—*Summary of bacteriological observations, by months, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet) arranged as monthly means for all sampling stations*—Continued

Station	Average discharge (second feet)	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter			Quantity units: Bacteria per cubic centimeter× thousand second-feet		
				On agar at— 20° C. 48 hours	On agar at— 37° C. 24 hours	B. coli (estimated)	20° C. agar	37° C. agar	B. coli
JULY, 1926									
1	2,360	21	23.0	2,500	1,400	2	5,900	3,304	5
2	2,360	21	23.4	9,200	6,200	33	21,712	14,632	78
3	2,370	21	24.3	750,000	650,000	1,639	1,777,500	1,540,500	3,884
Minnesota River	213	21	23.7	2,700	2,100	3	575	447	1
5	2,590	21	23.5	550,000	360,000	2,500	1,424,500	932,400	6,475
6	2,600	21	23.3	550,000	390,000	1,531	1,430,000	1,014,000	3,981
7	2,600	18	23.6	1,300,000	1,200,000	9,950	3,380,000	3,120,000	25,870
St. Croix River	2,100	18	22.9	90,000	66,000	159	189,000	138,600	334
Cannon River	95	19	20.8	13,000	11,000	14	1,235	1,045	1
9	4,810	19	22.6	72,000	53,000	104	346,320	254,930	500
11	4,840	21	22.6	22,000	18,000	3	106,480	87,120	15
Chippewa River	3,600	21	22.6	27,000	25,500	25	97,200	91,800	90
Zumbro River	154	21	21.0	21,500	17,000	14	3,311	2,618	2
14	8,650	21	22.0	320,000	250,000	118	2,768,000	2,162,500	1,021
AUGUST, 1926									
1	2,410	22	21.9	1,400	950	4	3,374	2,290	10
2	2,410	22	22.0	8,400	5,300	165	20,244	12,773	398
3	2,420	22	23.0	320,000	380,000	1,565	774,400	919,600	3,787
Minnesota River	375	22	22 6	2,400	1,900	5	900	713	2
5	2,810	22	22.1	170,000	160,000	2,964	477,700	449,600	8,329
6	2,820	22	21.9	430,000	310,000	795	1,212,600	874,200	2,242
7	2,830	22	22.4	750,000	750,000	3,246	2,122,500	2,122,500	9,186
St. Croix River	2,520	22	22.7	18,500	11,500	245	46,620	28,980	617
Cannon River	97	22	19.7	15,000	11,500	12	1,455	1,116	1
9	5,480	22	21.4	44,000	33,000	186	241,120	180,840	1,019
11	5,520	22	22.0	7,300	7,400	1	40,296	40,848	6
Chippewa River	9,500	21	21 8	13,000	12,500	21	123,500	118,750	200
Zumbro River	163	21	19.9	7,500	4,900	10	1,223	799	2
14	15,300	19	23.3	240,000	240,000	156	3,672,000	3,672,000	2,387
SEPTEMBER, 1926									
1	6,480	21	16 4	1,700	1,500	7	11,016	9,720	45
2	6,500	21	16.1	2,300	2,000	10	14,950	13,000	65
3	6,520	21	16.9	330,000	400,000	1,640	2,151,600	2,608,000	10,693
Minnesota River	2,040	21	17.2	5,800	5,300	25	11,832	10,812	51
5	8,630	21	16.5	190,000	190,000	1,596	1,639,700	1,639,700	13,773
6	8,660	21	16 4	130,000	130,000	1,081	1,125,800	1,125,800	9,361
7	8,700	21	17.4	290,000	320,000	520	2,523,000	2,784,000	4,524
St. Croix River	4,800	18	18.8	6,000	5,200	22	28,800	24,960	106
Cannon River	293	20	18.5	6,500	5,700	22	1,905	1,670	6
9	13,900	21	18.7	17,000	15,000	52	236,300	208,500	723
11	14,100	21	19.3	5,400	5,400	7	76,140	76,140	99
Chippewa River	23,400	21	18.2	6,500	5,200	23	152,100	121,680	538
Zumbro River	454	21	16.9	17,000	15,500	173	7,718	7,037	79
14	38,300	16	21.7	4,600	5,100	18	176,180	195,330	689
OCTOBER, 1926									
1	7,460	21	9.5	1,100	1,000	10	8,206	7,460	75
2	7,480	21	9.5	1,200	1,100	10	8,976	8,228	75
3	7,510	21	9.8	190,000	230,000	1,510	1,426,900	1,727,300	11,340
Minnesota River	2,380	21	10 1	12,000	11,500	20	28,560	27,370	48
5	9,970	21	10.0	120,000	110,000	1,587	1,196,400	1,096,700	15,822
6	10,000	21	9.8	130,000	110,000	1,253	1,300,000	1,100,000	12,530
7	10,100	18	11.7	130,000	100,000	535	1,313,000	1,010,000	5,404
St. Croix River	6,050	17	13.1	6,100	5,000	11	36,905	30,250	67
Cannon River	276	20	20.6	4,000	3,800	13	1,104	1,049	4
9	16,600	21	20.4	48,500	28,000	70	805,100	464,800	1,162
11	16,700	19	13.9	1,900	2,800	1	31,730	46.760	17
Chippewa River	12,600	15	12.6	6,300	7,300	18	79,380	91,980	227
Zumbro River	474	21	9.9	5,300	6,500	13	2,512	3,081	6
14	30,300	16	13.0	2,700	2,500	7	81,810	75,750	212

TABLE 33.—*Summary of bacteriological observations, by months, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet) arranged as monthly means for all sampling stations*—Continued

Station	Average discharge (second feet)	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at — 20° C. 48 hours	Bacteria per cubic centimeter: On agar at — 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter × thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
NOVEMBER, 1926									
1	3, 980	14	1. 4	1, 100	650	25	4, 378	2, 587	100
2	3, 990	14	1. 4	1, 700	900	7	6, 783	3, 591	28
3	4, 000	14	1. 6	90, 000	94, 000	672	360, 000	376, 000	2, 688
Minnesota River	1, 100	14	1. 8	8, 800	5, 700	7	9, 768	6, 327	8
5	5, 150	13	1. 4	63, 000	64, 000	2, 040	324, 450	329, 600	10, 506
6	5, 170	13	1. 4	79, 000	74, 000	515	408, 430	382, 580	2, 663
7	5, 190	13	2. 8	110, 000	63, 000	345	570, 900	326, 970	1, 791
St. Croix River	4, 300	13	4. 1	3, 600	3, 300	1	15, 480	14, 190	4
Cannon River	256	11	1. 6	1, 300	600	11	333	154	3
9	9, 820	12	1. 0	81, 000	34, 500	159	795, 420	338, 790	1, 561
11	9, 920	10	3. 5	750	325	1	7. 440	3, 224	10
Chippewa River	15, 500	2	6 5	1, 400	900	6	21, 700	13, 950	93
Zumbro River	238	11	2 1	3, 200	1, 700	11	762	405	3
14	25, 900	9	3. 2	2, 000	1, 100	17	51, 800	28, 490	440
DECEMBER, 1926									
1	2, 890	13	0	600	225	6	1, 734	650	17
2	2, 890	2	0	2, 200	900	10	6, 358	2, 601	29
3	2, 910	14	0	60, 000	51, 000	1, 485	174, 600	148, 410	4, 321
Minnesota River	830	13	0	1, 500	550	5	1, 245	457	4
5	3. 770	14	0	83, 000	58, 000	1, 485	312, 910	218, 660	5, 598
6	3, 790	14	0	64, 000	48, 000	2, 870	242, 560	181, 920	10, 877
7	3, 810	13	0	35, 500	22, 000	385	135, 255	83, 820	1, 467
St. Croix River	2, 940	6	0	--------	375	. 5	--------	1, 103	1
Cannon River	214	6	0	1, 200	325	10	257	70	2
9	7, 020	6	0	28, 000	7, 200	40	196, 560	50, 544	281
11	7, 100	4	0	--------	100	. 4	--------	710	3
Chippewa River	6, 840	0	0	--------	--------	--------	--------	--------	--------
Zumbro River	200	13	0	1, 700	600	2	340	120	0
14	14, 300	10	0	750	325	5	10, 725	4, 648	72
JANUARY, 1927									
1	2, 300	12	0	550	100	15	1, 265	230	35
2	2, 300	10	0	3, 300	1, 200	351	7, 590	2, 760	807
3	2, 310	12	0	77, 000	70, 000	591	177, 870	161, 700	1, 365
Minnesota River	625	12	0	500	95	12	313	59	8
5	2, 950	12	0	71, 000	72, 000	692	209, 450	212, 400	2, 041
6	2, 960	12	0	44. 000	47, 000	1, 442	130, 240	139, 120	4, 268
7	2, 970	13	0	50, 000	34, 000	685	148, 500	100, 980	2, 034
St. Croix River	2, 420	13	0	250	170	13	605	411	31
Cannon River	126	9	0	1, 800	500	4	227	63	1
9	5, 560	9	0	36, 500	8, 100	28	202, 940	45, 036	156
11	5, 600	5	0	450	50	. 3	2, 520	280	2
Chippewa River	6, 500	0	0	--------	--------	--------	--------	--------	--------
Zumbro River	118	13	0	650	190	2	77	22	0
14	12, 300	10	0	1, 200	450	3	14, 760	5, 535	37
FEBRUARY, 1927									
1	2, 210	11	0	900	225	15	1, 989	497	33
2	2, 210	2	0	3, 700	1, 200	100	8, 177	2, 652	221
3	2, 220	11	0	64, 000	130, 000	1, 410	142, 080	288, 600	3, 130
Minnesota River	610	5	0	525	110	6	320	67	4
5	2, 850	12	0	65, 000	86, 000	475	185, 250	245, 100	1, 354
6	2, 860	12	0	78, 000	90, 000	700	223, 080	257, 400	2, 002
7	2, 870	12	0	130, 000	54, 000	393	373, 100	154, 980	1, 128
St. Croix River	2, 260	12	0	2, 300	250	1	5, 198	565	2
Cannon River	132	11	0	12, 000	2, 200	1	1, 584	290	0
9	5, 300	11	0	26, 000	11, 000	26	137, 800	58, 300	138
11	5, 350	9	0	850	75	. 2	4, 548	401	1
Chippewa River	7, 130	0	0	--------	--------	--------	--------	--------	--------
Zumbro River	124	11	0	1, 400	1, 000	2	174	124	0
14	12, 700	9	0	3, 200	1, 000	38	40, 640	12, 700	483

TABLE 33.—*Summary of bacteriological observations, by months, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet) arranged as monthly means for all sampling stations*—Continued

Station	Average discharge (second-feet)	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at — 20° C. 48 hours	Bacteria per cubic centimeter: On agar at — 37° C. 24 hours	B. coli (estimated)	Quantity units (Bacteria per cubic centimeter × thousand second-feet): 20° C. agar	37° C. agar	B. coli
MARCH, 1927									
1	9, 640	13	1. 0	6, 600	800	20	63, 624	7, 712	193
2	9, 660	6	2. 2	3, 900	850	6	37, 674	8, 211	58
3	9, 690	13	1. 2	39, 500	47, 500	149	382, 755	460, 275	1, 444
Minnesota River	9, 120	7	2. 4	9, 100	2, 400	19	82, 992	21, 888	173
5	18, 900	13	1. 2	56, 000	21, 500	294	1, 058, 400	406, 350	5, 557
6	18, 900	13	1. 2	54, 000	19, 000	224	1, 020, 600	359, 100	4, 234
7	19, 000	13	2. 5	59, 000	16, 500	841	1, 121, 000	313, 500	15, 979
St. Croix River	12, 600	13	2. 6	6, 000	500	. 4	75, 600	6, 300	5
Cannon River	570	13	1. 8	13, 000	1, 700	2	7, 410	969	1
9	32, 400	13	1. 9	21, 500	2, 000	13	696, 600	64, 800	421
11	32, 500	8	1. 4	2, 100	400	. 7	68, 250	13, 000	23
Chippewa River	24, 500	0	---	---	---	---	---	---	---
Zumbro River	530	12	2. 4	9, 100	1, 600	4	4, 823	848	2
14	58, 000	13	2. 2	5, 100	700	13	295, 800	40, 600	754
APRIL, 1927									
1	17, 400	13	7. 2	4, 300	600	11	74, 820	10, 440	191
2	17, 500	13	7. 2	3, 700	550	6	64, 750	9, 625	105
3	17, 700	13	7. 4	35, 500	42, 000	1, 117	621, 250	735, 000	19, 547
Minnesota River	9, 270	13	7. 9	8, 000	2, 600	29	74, 160	24, 102	269
5	27, 000	13	7. 8	36, 500	21, 000	577	985, 500	567, 000	15, 579
6	27, 100	13	7. 8	35, 500	19, 500	1, 055	962, 050	528, 450	28, 591
7	27, 200	13	7. 6	130, 000	25, 000	280	3, 536, 000	680, 000	7, 616
St. Croix River	15, 400	13	7. 4	4, 100	650	. 1	63, 140	10, 010	2
Cannon River	1, 220	13	7. 5	5, 000	650	3	6, 100	793	4
9	44, 100	13	7. 3	11, 000	2, 600	21	485, 100	114, 660	926
11	44, 600	10	6. 9	2, 900	550	. 6	129, 340	24, 530	27
Chippewa River	11, 100	0	---	---	---	---	---	---	---
Zumbro River	1, 130	12	7. 2	5, 400	750	1	6, 102	848	1
14	57, 900	12	7. 4	2, 400	475	14	138, 960	27, 503	811
MAY, 1927									
1	12, 800	11	12. 8	3, 800	400	14	48, 640	5, 120	179
2	12, 800	11	12. 8	3, 400	450	33	43, 520	5, 760	422
3	12, 900	11	12. 7	61, 000	80, 000	225	786, 900	1, 032, 000	2, 903
Minnesota River	6, 680	11	13. 6	6, 400	2, 100	14	42, 752	14, 028	94
5	19, 700	11	13. 3	100, 000	56, 000	181	1, 970, 000	1, 103, 200	3, 566
6	19, 800	11	13. 3	97, 000	63, 000	451	1, 920, 600	1, 247, 400	8, 930
7	19, 900	11	14. 5	99, 000	48, 000	153	1, 970, 100	955, 200	3, 045
St. Croix River	7, 700	11	15. 0	3, 900	1, 800	. 4	30, 030	13, 860	3
Cannon River	1, 030	11	14. 7	4, 700	700	16	4, 841	721	16
9	28, 900	11	14. 8	29, 500	8, 500	20	852, 550	245, 650	578
11	29, 300	10	13. 6	2, 400	400	2	70, 320	11, 720	59
Chippewa River	13, 500	0	---	---	---	---	---	---	---
Zumbro River	965	10	13. 5	5, 900	1, 700	6	5, 694	1, 641	6
14	44, 600	11	12. 0	3, 400	550	6	151, 640	24, 530	268
JUNE, 1927									
1	9, 810	13	18 6	3, 000	600	6	29, 430	5, 886	59
2	9, 850	13	18. 6	3, 500	550	8	334, 475	5, 418	79
3	9, 910	13	18 6	150, 000	130, 000	1, 070	1, 486, 500	1, 288. 300	10, 604
Minnesota River	5, 910	13	18 4	4, 600	2, 000	13	27, 186	11, 820	77
5	16, 000	13	18 8	110, 000	81, 000	633	1, 760, 000	1, 296, 000	10, 128
6	16, 100	13	18. 8	72, 000	50, 000	385	1, 159, 200	805, 000	6. 199
7	16, 200	13	18. 9	83, 000	43, 000	272	1. 344, 600	696, 600	4, 406
St. Croix River	6, 700	13	18. 8	5, 200	700	. 3	34, 840	4, 690	2
Cannon River	1, 100	13	18. 2	8, 900	3, 800	14	9, 790	4, 180	15
9	24, 300	13	18. 3	16, 500	6, 200	38	400, 950	150, 660	923
11	24, 700	10	18. 1	2, 700	1, 500	3	66, 690	37, 050	7
Chippewa River	7, 500	8	19 2	6, 600	2, 700	7	49, 500	20, 250	53
Zumbro River	1. 030	13	18. 3	8, 700	2, 400	14	8, 961	2, 472	14
14	34, 100	13	18. 8	5, 300	650	5	180, 730	22, 165	171

TABLE 33.—*Summary of bacteriological observations, by months, in terms of bacteria per cubic centimeter and bacterial "quantity units" (bacteria per cubic centimeter ×discharge in thousands of second-feet) arranged as monthly means for all sampling stations*—Continued

JULY, 1927

Station	Average discharge (second) feet	Total days samples taken	Water temperature, ° C.	Bacteria per cubic centimeter: On agar at — 20° C. 48 hours	Bacteria per cubic centimeter: On agar at — 37° C. 24 hours	Bacteria per cubic centimeter: B. coli (estimated)	Quantity units (Bacteria per cubic centimeter × thousand second-feet): 20° C. agar	Quantity units: 37° C. agar	Quantity units: B. coli
1	5, 590	12	22 4	2. 500	850	6	13, 975	4, 752	34
2	5, 590	12	22 4	3, 100	950	15	17, 329	5, 311	84
3	5, 610	12	22 9	160, 000	180, 000	2, 800	897. 600	1, 009, 800	15, 708
Minnesota River	1, 450	12	22 7	4, 500	2, 200	20	6, 525	3, 190	29
5	7, 090	12	22 8	68, 000	50, 000	618	482, 120	354, 500	4, 382
6	7, 110	12	22 8	90, 000	59, 000	625	639, 900	419, 490	4, 051
7	7, 120	12	23. 9	200, 000	130, 000	288	1, 424, 000	925, 600	2, 444
St. Croix River	4, 650	12	24 2	2, 600	950	. 3	12, 090	4, 418	1
Cannon River	212	11	22 0	3, 900	1, 000	4	827	212	1
9	12, 000	11	22 9	27, 500	17, 000	26	330, 000	204, 000	312

AUGUST, 1927

Station	Average discharge (second) feet	Total days samples taken	Water temperature, ° C.	20° C. 48 hours	37° C. 24 hours	B. coli (estimated)	20° C. agar	37° C. agar	B. coli
1	5, 100	18	19. 9	2, 700	850	5	13, 770	4, 335	25
2	5, 100	18	19. 9	3, 300	900	17	16, 830	4, 590	87
3	5, 090	18	20. 3	210, 000	200, 000	1, 695	1, 068, 900	1, 018, 000	8, 628
Minnesota River	369	18	20 6	4, 700	2, 400	22	1, 734	886	8
5	5, 440	18	20. 7	93, 000	80, 000	1, 050	505, 920	435, 200	5, 712
6	5, 440	18	20. 6	110, 000	91, 000	70	598, 400	495, 040	3, 808
7	5, 450	11	22 2	170, 000	150, 000	229	926, 500	817, 500	1, 248
St. Croix River	2, 470	11	22. 7	12, 000	3, 600	. 3	29, 640	8, 892	1
Cannon River	46	11	21 7	4, 100	900	3	189	41	0
9	7, 890	10	22 3	27, 500	13, 000	9	219, 450	103, 740	72

TABLE No. 34.—*Summary of bacteriological observations at all sampling stations in terms of quantity units, seasonal averages of agar counts, and B. coli*

20° C. AGAR COUNT

Sampling stations	Summer, 1926		Fall		Winter		Spring		Summer, 1927		Yearly average	
	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units
1	2,400	8,440	5,970	7,870	2,470	1,660	13,280	62,360	6,830	19,060	6,650	21,200
2	2,400	20,550	5,990	10,240	2,470	7,380	13,320	48,650	6,850	22,880	6,660	22,930
3	2,410	1,208,500	6,010	1,312,830	2,480	164,850	13,360	596,970	6,870	1,151,000	6,690	855,200
Minnesota River	329	1,280	1,840	16,720	688	630	8,360	66,640	2,580	11,820	3,260	23,380
5	2,750	795,570	7,920	1,053,520	3,190	235,870	21,870	1,337,970	9,510	916,010	10,030	962,020
6	2,760	1,062,000	7,940	944,740	3,200	198,630	21,930	1,301,080	9,550	799,170	10,060	927,930
7	2,720	2,751,250	8,000	1,468,970	3,220	218,950	22,030	2,209,030	9,590	1,231,700	10,110	1,544,830
St. Croix River	2,310	117,810	5,050	27,060	2,540	2,900	11,900	56,260	4,610	25,520	5,820	47,840
Cannon River	96	1,350	275	1,110	157	690	940	6,120	453	3,600	450	3,020
9	5,150	293,720	13,440	612,270	5,960	179,100	35,130	678,080	14,760	316,800	16,500	449,730
11	5,180	73,390	13,570	38,440	6,020	3,530	35,470	89,300	24,700	66,690	16,700	54,890
Chippewa River	6,550	110,350	17,200	84,390					7,500	49,500		
Zumbro River	159	2,270	389	3,660	147	200	875	5,540	1,030	8,960	465	3,470
14	12,000	3,220,000	31,500	103,260	13,100	22,040	53,500	195,470	34,100	180,730	29,400	631,920

37° C. AGAR COUNT

Sampling stations	Summer, 1926		Fall		Winter		Spring		Summer, 1927		Yearly average	
	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units	Discharge, second-feet	Bacteria, quantity units
1	2,400	4,210	5,970	6,590	2,470	460	13,280	7,760	6,830	4,990	6,650	4,660
2	2,400	11,570	5,990	8,270	2,470	2,670	13,320	7,870	6,850	5,110	6,660	7,440
3	2,410	1,064,000	6,010	1,570,430	2,480	199,570	13,360	742,430	6,870	1,105,370	6,690	940,470
Minnesota River	329	930	1,840	14,840	688	190	8,360	20,010	2,580	5,300	3,260	9,840
5	2,750	550,920	7,920	1,022,000	3,190	225,390	21,870	692,180	9,510	695,230	10,030	708,060
6	2,760	724,730	7,940	869,460	3,200	192,810	21,930	711,650	9,550	573,180	10,060	667,910
7	2,720	2,621,250	8,000	1,373,660	3,220	113,260	22,030	649,570	9,590	813,230	10,110	1,029,050
St. Croix River	2,310	83,790	5,050	23,130	2,540	690	11,900	10,060	4,610	6,000	5,820	22,830
Cannon River	96	1,080	275	960	157	140	940	830	453	1,480	450	1,010
9	5,150	217,890	13,440	337,360	5,960	51,290	35,130	141,700	14,760	152,800	16,500	181,460
11	5,180	63,980	13,570	42,040	6,020	460	35,470	16,420	24,700	37,050	16,700	28,480
Chippewa River	6,550	105,280	17,200	75,870					7,500	20,250		
Zumbro River	159	1,710	389	3,510	147	90	875	1,110	1,030	2,470	465	1,670
14	12,000	2,917,250	31,500	99,860	13,100	7,630	53,500	30,880	34,100	22,170	29,400	522,650

B. COLI

1	2,400	6	5,970	73	2,470	28	13,280	188	6,830	39	6,650	79
2	2,400	168	5,990	56	2,470	352	13,320	195	6,850	83	6,660	197
3	2,410	4,184	6,010	8,240	2,480	2,939	13,360	7,965	6,870	11,647	6,690	6,309
Minnesota River	329	2	1,840	36	688	5	8,360	179	2,580	38	3,260	62
5	2,750	6,008	7,920	13,367	3,190	2,998	21,870	8,234	9,510	6,741	10,030	8,227
6	2,760	2,565	7,940	8,185	3,200	5,716	21,930	13,918	9,550	4,817	10,060	7,990
7	2,720	17,528	8,000	3,906	3,220	1,543	22,030	8,880	9,590	2,568	10,110	6,871
St. Croix River	2,310	476	5,050	59	2,540	11	11,900	3	4,610	1	5,820	98
Cannon River	96	1	275	4	157	1	940	7	453	5	450	5
9	5,150	760	13,440	1,149	5,960	192	35,130	642	14,760	436	16,500	699
11	5,180	11	13,570	42	56,020	2	35,470	36	24,700	7	16,700	22
Chippewa River	6,550	145	17,200	286					7,500	53		
Zumbro River	159	2	389	29	147	0	875	3	1,030	14	465	10
14	12,000	1,704	31,500	447	13,100	197	53,500	611	34,100	171	29,400	612

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average, all stations, based on months of September, October, and November.
Winter average, all stations, based on months of December, January, and February.
Spring average, all stations, based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.
Yearly average, all stations, based on 12-month period, July, 1926, to June, 1927, inclusive.

BACTERIAL POLLUTION OF THE UPPER MISSISSIPPI RIVER

A broad picture of the bacterial pollution of the upper Mississippi River, as indicated by the bacterial-plate counts at 20° and 37° C. and the B. coli estimates, is presented in Table 35, which shows the yearly average concentration of bacteria per cubic centimeter during the 12-month period July, 1926, to June, 1927, inclusive, at each sampling station on the main river and at the mouths of tributaries.

TABLE 35.—*Summary of average yearly numbers of bacteria per cubic centimeter at sampling stations on the upper Mississippi River during 12-month period, July, 1926, to June, 1927, inclusive*

MAIN RIVER SAMPLING STATIONS

Sampling station and location	Average discharge (thousand second-feet)	Average yearly bacteria per cubic centimeter		
		20° C. agar count	37° C. agar count	B. coli (estimated)
1. Camden Avenue Bridge, Minneapolis	6.65	2,300	700	11
2. Plymouth Avenue Bridge, Minneapolis	6.66	3,900	1,800	62
3. Government lock and dam	6.69	181,000	192,000	1,089
5. Roberts Street Bridge, St. Paul	10.03	135,000	107,000	1,252
6. Invergrove Bridge	10.06	147,000	113,000	1,025
7. Above Hastings	10.11	264,000	223,000	1,467
9. Above Red Wing	16.50	36,000	17,000	63
11. Outlet Lake Pepin	16.70	4,400	3,100	1
14. Above Winona	29.40	49,000	42,000	33

TRIBUTARY SAMPLING STATIONS

Sampling station and location	Average discharge (thousand second-feet)	20° C. agar count	37° C. agar count	B. coli (estimated)
4. Minnesota River at mouth	3.26	5,200	3,000	13
8. St. Croix River at mouth	5.82	13,000	8,000	38
10. Cannon River at mouth	.45	7,200	3,500	10
12. Chippewa River at mouth	11.80			
13. Zumbro River at mouth	.46	7,300	4,500	21

Yearly averages show that the bacterial concentration of the tributaries was as low or lower than the bacterial concentration of the main stream at their respective points of confluence, and, in general, the effect of tributary inflow was that of dilution. The St. Croix and Chippewa Rivers, entering from Wisconsin, contributed much larger quantities of diluting water than the Minnesota, Cannon, and Zumbro Rivers, entering from the Minnesota section of the watershed.

At the main river sampling stations the yearly averages show three zones within the section of the river under observation in which bacterial variations occurred. Between Stations Nos. 1 and 7, a distance of 45 miles, the bacterial concentrations showed a progressive increase due to the discharge of sewage and industrial wastes from the Twin City metropolitan area. From Station No. 7, at Hastings, to Station No. 11, at the outlet of Lake Pepin, a distance of 50 miles, in which the stream received but little additional pollution, there was a marked reduction in bacterial concentration due to the diluting effect of tributaries and to natural processes of stream purification which operated during the relatively long period of flow between these points. In the 42 miles of river between the outlet of Lake Pepin and Winona, Station No. 14, in which relatively little additional sewage pollution reached the river, a further reduction in bacterial concentration was to be expected. Contrary to expectation, however, a considerable increase in bacterial concentration was noted at the lower sampling station.

SEASONAL CHANGES IN BACTERIAL CONCENTRATION

Seasonal averages of bacterial concentration have been summarized in Table 36 for each of the sampling stations on the main river and its tributaries.

TABLE 36.—*Summary of seasonal averages of bacteria per cubic centimeter, at sampling stations on the upper Mississippi River*

MAIN RIVER SAMPLING STATIONS

Sampling station and location	Summer average, 1926				Winter average				Spring average				Fall average				Summer average, 1927			
	Discharge, thousand second-feet	20° C. agar count	37° C. agar count	B. coli (estimated)	Discharge, thousand second-feet	20° C. agar count	37° C. agar count	B. coli (estimated)	Discharge, thousand second-feet	20° C. agar count	37° C. agar count	B. coli (estimated)	Discharge, thousand second-feet	20° C. agar count	37° C. agar count	B. coli (estimated)	Discharge, thousand second-feet	20° C. agar count	37° C. agar count	B. coli (estimated)
1. Camden Avenue Bridge, Minneapolis	2.40	3,500	1,750	2	2.47	680	180	12	5 97	1,300	1,050	14	13.28	4,900	600	15	6.83	2,700	800	6
2. Plymouth Avenue Bridge, Minneapolis	2.40	8,600	4,800	70	2.47	3,100	1,100	154	5.99	1,700	1,300	9	13.32	3,700	620	15	6.85	3,300	800	13
3. Government lock and dam	2.41	500,000	440,000	1,735	2.48	67,000	84,000	1,162	6.01	200,000	240,000	1,274	13.36	45,300	56,500	497	6.87	173,000	170,000	1,855
5. Roberts Street Bridge, St. Paul	2.75	297,000	205,000	2,198	3 19	73,000	72,000	884	7.92	124,000	121,000	1,741	21.87	64,000	33,000	351	9.51	90,000	70,000	767
6. Invergrove Bridge	2.76	390,000	267,000	947	3.20	62,000	62,000	1,671	7.94	113,000	105,000	950	21.93	62,200	32,800	577	9 55	90,700	66,700	570
7. Above Hastings	2.72	1,025,000	975,000	6,598	3.22	71,800	36,700	488	8.00	180,000	161,000	467	22.03	96,000	29,800	425	9 59	151,000	108,000	263
9. Above Red Wing	5.15	58,000	43,000	145	5 96	30,000	8,800	31	13.44	48,800	25,800	94	35 13	21,000	4,400	18	14.76	24,000	12,000	24
11. Outlet Lake Pepin	5.18	14,700	12,700	2	6 02	650	75	.3	13.57	2,700	2,800	3	35.47	2,500	450	1	24 70	2,700	1,500	.3
14. Above Winona	12.00	280,000	245,000	137	13.10	1,720	590	15	31.50	3,100	2,900	14	53.50	3,600	580	11	34.10	5,300	650	5
TRIBUTARY SAMPLING STATIONS																				
4. Minnesota River at mouth	0.33	3,700	2,700	4	0.69	840	250	8	1.84	8,900	7,500	17	8.36	7,800	2,400	21	2 58	4,600	2,200	18
8. St. Croix River at mouth	2.31	54,300	38,800	202	2.54	1,300	265	5	5.05	5,200	4,500	11	11.90	4,700	980	.3	4 61	6,600	1,800	.3
10. Cannon River at mouth	.10	14,000	11,300	13	.16	5,000	1,000	5	.28	3,900	3,400	15	.94	7,600	1,000	7	.45	5,600	1,900	7
12. Chippewa River at mouth	6.55	20,000	19,000	23	-----	-----	-----	-----	17.20	4,700	4,500	16	-----	-----	-----	-----	7.50	6,600	2,700	7
13. Zumbro River at mouth	.16	14,500	11,000	12	.15	1,250	600	2	.39	8,500	7,900	66	.89	6,800	1,350	4	1.03	8,700	2,400	14

Summer average, 1926, Stations Nos. 1 to 6, inclusive, based on months of June, July, and August.
Summer average, 1926, Stations Nos. 7 to 14, inclusive, based on months of July and August.
Fall average at all stations based on months of September, October, and November.
Winter average at all stations based on months of December, 1926, January and February, 1927.
Spring average at all stations based on months of March, April, and May.
Summer average, 1927, Stations Nos. 1 to 10, inclusive, based on months of June, July, and August.
Summer average, 1927, Stations Nos. 11 to 14, inclusive, based on month of June only.

Seasonal averages show the same increases in bacterial concentration in the upper section of the river, but the point of maximum pollution occurred at different sampling points between Stations Nos. 3 and 7. The decrease in bacterial concentration was indicated in every season between Stations Nos. 7 and 11, as was also the secondary increase in the lower section of the river, between Stations Nos. 11 and 14. The greatest increase in bacteria below Lake Pepin occurred during the winter and the summer period of 1926, when stream flows were the lowest.

Between Stations Nos. 3 and 7 the Mississippi River received the inflow of the Minnesota River at a point 2.4 miles below Station No. 3. The Minnesota River was less heavily polluted than the main river and tended to reduce the bacterial concentration of the Mississippi River below its confluence. Because of the manipulation of the storage reservoirs on the headwaters of the main stream, for navigation purposes below the Twin Cities, the mean monthly discharge of the Mississippi River, at Minneapolis, varied from three to seven times that of the Minnesota River. At such times the effect of the Minnesota River in reducing the bacterial concentration of the main stream below its confluence was not great. In the summer months, however, the apparent effect of the Minnesota River was accentuated by that of natural purification taking place between Stations Nos. 3 and 5, a distance of 9 miles. The combination of dilution and natural purification is believed to influence, to a considerable extent, the change in the location of the point of maximum bacterial concentration in the upper section of the stream.

In the summer period of 1926 the mean discharge of the Mississippi River was practically the same as that during the winter period of 1926–27. In the winter months the water temperatures were continuously at 0° C., a large portion of the water surface was covered with ice, and surface run-off from the watershed was reduced to a minimum. In the summer period water temperatures were above 20° C.; water surfaces were exposed, allowing reaeration; and surface run-off entered the water courses. The seasonal averages for these two periods show a much lower bacterial concentration at all stations during the winter, with the point of greatest pollution occurring either at Station No. 5 or Station No. 6, rather than at Hastings, Station No. 7.

During the fall period and the summer period of 1927, which more nearly represents normal summer conditions, the point of maximum bacterial concentration occurred at Station No. 3, the outlet of the pool at Minneapolis, followed by a decrease in concentration below this station and a secondary rise at Station No. 7, Hastings.

QUANTITATIVE CHANGES IN BACTERIA

A study of the monthly and seasonal changes in the actual number of bacteria in a stream furnishes a better basis for comparison than the changes in bacterial concentration. In Tables 32 and 33 the bacterial concentrations at the various sampling stations have been expressed in terms of quantity units. As already stated, the quantity unit is the product of the number of bacteria per cubic centimeter as indicated by the plate counts and B. coli estimates and the stream flow in thousands of second-feet. The quantity unit is proportional to the actual number of bacteria carried past a given section in the river during a given period of time and is more convenient to use than the estimated actual number of organisms present in the stream.

Table 34 summarizes the data of Tables 32 and 33 as seasonal and yearly averages of the quantity units of bacteria at the various sampling stations.

Yearly averages of quantity units show the progressive increase in numbers of bacteria within the zone of pollution between Stations Nos. 1 and 7; the decrease in numbers from Station No. 7 to Station No. 11, the outlet of Lake Pepin; and the secondary increase in bacteria in the lower section of the river, between Stations Nos. 11 and 14. The smaller number of bacteria contributed by the tributaries, as compared to those present in the main stream at their points of confluence, is clearly indicated.

Seasonal averages of quantity units show the same increases in numbers of bacteria in the upper and lower sections of the river and the decrease in bacteria within the intermediate zone. During the winter period, of lowest water temperatures and surface run-off, the numbers of bacteria present at each sampling point were lower than in any other season of the year. In general, the greatest numbers of 20° C. organisms in the stream occurred in the spring months of highest stream flow, when surface run-off was greatest; the largest numbers of 37° C. organisms in the summer and fall months of 1926, when stream flows were the lowest; and the greatest number of B. coli organisms in the spring and fall months.

The table of monthly averages of quantity units indicates greater numbers of bacteria at Station No. 14, above Winona, than at Station No. 11, the outlet of Lake Pepin, during every month of the investigation. For a period of six months during the study, comprising the months of July to November, 1926, inclusive, and the month of June, 1927, complete data were available at the two lower main river sampling stations, Nos. 11 and 14, and at Stations Nos. 12 and 13, on the Chippewa and Zumbro Rivers, respectively, which enter this section of the main stream. Of these six months, an increase in quantity units of bacteria was indicated during July, August, and November, 1926, and in June, 1927. A decrease in quantity units between Stations Nos. 11 and 14 was indicated in September and October, 1926. The greatest increase at Station No. 14, amounting to from 10 to 20 times the quantity units at Station No. 11, occurred in July and August, 1926, when the flow in the main stream was only 4,800 and 5,500 second-feet, respectively, and when the inflow of the Chippewa River was 3,600 and 9,500 second-feet, respectively; or from 75 to over 100 per cent of that of the main river. During September and October, when stream flows increased, those in the main channel averaging 14,100 and 16,700 second-feet, respectively, and those in the Chippewa River 23,400 and 12,600 second-feet, respectively, tributary inflow again amounting to from 75 to over 100 per cent of the flow in the main channel, a decrease in quantity units of bacteria at Station No. 14 resulted. In November, stream discharges again decreased; the flow in the main stream averaged 9,900 second-feet. During this month another increase in quantity units of bacteria occurred at Station No. 14, but of lesser magnitude than during July and August. In June, 1927, main-river flows reached an average of 24,700 second-feet, but the Chippewa River contributed only 7,500 second-feet, or about 30 per cent of that of the main river. In this month there was an increase in the 20° C. and B. coli organisms at Station No. 14, but a decrease in the 37° C. organisms.

In the months of September and October, when the decrease in organisms at the lower station was indicated, the sum of the quantity units of bacteria contributed by the Chippewa and Zumbro Rivers added to those present at Station No. 11 was greater than the quantity units present at Station No. 14, but the actual decrease in quantity units at the lower station was much less than would be expected as a result of natural purification processes taking place in the 42 miles of river between Lake Pepin and Winona. As noted in the discussion of the chemical results, there was also an increase in the oxygen demand of the river in the lower section between these same sampling points during every month of observation, which could not be accounted for by additional pollution reaching the main stream directly or contributed by the tributaries.

During the course of the Illinois River survey, a similar increase in bacteria, not accounted for by additional pollution, was observed in the main stream below the confluence of the Kankakee River. The greatest increase in bacteria was observed when the inflow of the Kankakee River amounted to 10 per cent or more than the flow in the main stream. A study of the changes in numbers of bacteria in stored water samples conducted at the Cincinnati laboratory of the Public Health Service also gave evidence, in some cases at least, that if a sample of water reaching a state of bacterial stability was subsequently diluted, a further increase in numbers of bacteria might occur. During the course of stream-pollution investigations it has repeatedly been observed that the maximum bacterial effect of the sewage entering a stream was not immediately below the sewer outlets but at a considerable distance downstream, suggesting that dilution may be one of the factors influencing changes in bacterial numbers. One seems forced to the conclusion that under certain conditions it may be possible, in the absence of additional pollution, to have actual measurable increases in bacteria between points on a stream due to an altered relationship between inhibitive or destructive forces and growth factors.

RELATION OF BACTERIAL POLLUTION TO THE CONTRIBUTING SEWERED POPULATION

The effect of the bacterial pollution of a stream should be reflected in the increase in bacteria between sampling points above and below the sources of pollution. Such an estimate, however, does not take into consideration any indeterminate increase in bacteria which may have taken place in the stream, nor any reduction in the number of bacteria from destructive substances which might reach the stream, or from processes of natural stream purification. The total change in bacterial numbers divided by the contributing population above the point of maximum bacterial pollution should be a measure of the per capita contribution of bacteria to the river and provide a means of comparing the intensity of bacterial pollution in various sections of the same stream or in different streams.

On the upper Mississippi River the difference between the quantity units of bacteria at the point of maximum bacterial concentration below the metropolitan area and the sum of the quantity units of bacteria present at Station No. 1 above all local sources of pollution and the quantity units contributed by the Minnesota River should indicate the increase in bacteria in the river due to the pollution from the Twin City metropolitan area.

Table 37 summarizes the seasonal increases in bacteria in terms of total bacterial quantity units within the metropolitan area, calculated from those present at the point of maximum bacterial content and those present at Stations Nos. 1 and 4. In Table 38 the seasonal changes in total bacterial quantity units from Table 34 have been converted into the estimated actual daily per capita contribution of bacteria, due to the sewered population above the indicated point of greatest pollution.

TABLE 37.—*Bacterial pollution of the upper Mississippi River, in terms of quantity units, contributed by the sewered population of the Minneapolis and St. Paul metropolitan area*

Season	20° C. agar count		37° C. agar count		B. coli organisms	
	Maximum quantity units	Occur at station No.	Maximum quantity units	Occur at station No.	Maximum quantity units	Occur at station No.
Summer, 1926	2,741,530	7	2,616,110	7	17,520	7
Fall	1,444,380	7	1,563,840	3	13,258	5
Winter	233,580	5	224,740	5	5,683	6
Spring	2,080,030	7	734,670	3	13,551	6
Summer, 1927	1,200,820	7	1,100,380	3	11,608	3

TABLE 38.—*Bacterial pollution of the upper Mississippi River, expressed as quantity units per capita per day, contributed by the sewered population of the Minneapolis and St. Paul metropolitan area*

Season	20° C. agar count		37° C. agar count		B. coli organisms	
	Quantity units per capita per day	Above station No.	Quantity units per capita per day	Above station No.	Quantity units per capita per day	Above station No.
Summer, 1926	4.02	7	3.83	7	0.026	7
Fall	2.12	7	3.40	3	.022	5
Winter	.39	5	.38	5	.008	6
Spring	3.05	7	1.60	3	.020	6
Summer, 1927	1.76	7	1.39	3	.025	3

The data of Table 38 indicate that the lowest daily per capita contribution of bacteria to the upper Mississippi River occurred during the winter period. The contribution of B. coli organisms was quite consistent during the remaining periods of the year, with a tendency to be slightly higher in the summer months. The greatest per capita contribution of 20° and 37° C. organisms occurred in the summer period of 1926; the lowest in the summer of 1927; with contributions in the spring and fall lying between these extremes.

COMPARISON OF BACTERIAL POLLUTION FROM DIFFERENT METROPOLITAN AREAS

Table 39 gives, for comparison with the upper Mississippi River data, estimates of the actual average daily per capita contribution of bacteria during the summer and winter periods from metropolitan areas on the Ohio and Illinois Rivers.

TABLE 39.—*Seasonal changes in numbers of bacteria added to streams by sewered populations*

Community	Billions of bacteria per capita per diem					
	Gelatin 20° C.		Agar 37° C.		B. coli	
	Winter	Summer	Winter	Summer	Winter	Summer
Chicago	9,740	24,750	1,920	25,400	39	433
Peoria	2,130	15,800	7,650	25,600	141	231
Cincinnati	2,560	14,100	1,000	18,300	119	583
Louisville	7,360	13,600	907	15,800	193	291
Minneapolis-St. Paul:						
1926	[1] 570	[1] 6,710	550	6,400	14	43
1927		[1] 2,938		2,690		28
Pittsburgh	382	108	170	160	32	4
Wheeling		505		495		24

[1] Counts on agar at 20° C., 48 hours, not comparable to gelatin counts.

Variations in the calculated per capita contribution of bacteria from a sewered population are influenced to a considerable extent by the amount and character of the industrial wastes reaching the sewers or watercourse; those having a high bacterial content tending to increase the number, while wastes germicidal in character cause a decrease in numbers. Variations also result from the nature and amount of surface run-off reaching the stream, either directly or through the sewers; the period of detention within the sewer system, minor tributaries or the main stream; the physical and biological condition of the receiving stream; and the relation of the various sampling points to the location of the sewer outlets. Accurate measurements of the bacterial content of the river are only possible when the sewage is discharged into a comparatively narrow zone and when sampling stations are so spaced along the stream to give the actual maximum bacteria at all the stations.

The data of Table 39 indicate a much smaller contribution of bacteria in the winter months as compared to the summer months. It further indicates that the contribution of bacteria to the upper Mississippi River, below the Twin City metropolitan area, was less than the contribution from any of the other metropolitan areas so far studied, with the exception of the contributions from the Pittsburgh and Wheeling areas. Within the Pittsburgh area the bacteria contributed to the Ohio River were materially reduced by the presence of acid iron wastes, causing coagulation and precipitation in the stream through Pittsburgh. In addition the operation of the navigation dams below Pittsburgh and Wheeling during periods of low water increased the times of flow from the sewer outlets to the sampling points, allowing natural stream-purification processes to take place, tending toward a reduction in the bacteria contributed by the sewered population.

Estimates of the average daily per capita contribution of bacteria within the Twin City metropolitan area are influenced by the pool at Minneapolis, which increased times of flow and permitted sedimentation of sewage sludge which caused septic conditions in the pool during summer; by the discharge of sewage from a large number of outlets throughout the entire metropolitan area; by the inflow of the Minnesota River and by variations in times of flow from the sewer outlets to the sampling stations below the district. These factors combine to give an indicated lower per capita bacterial contribution on the upper Mississippi River than the contributions indicated from some of the other metropolitan areas, but are not entirely outside the range of previous observation and emphasize the fact that different local conditions may greatly affect the results.

RATES OF BACTERIAL PURIFICATION

Methods of making calculations

In previous studies of the rates of natural stream purification, which were made from the data secured during the Ohio and Illinois River investigations, the bacterial decreases in these watercourses could be described with fair accuracy by relatively smooth curves, showing the relation between the bacteria remaining in the water at sampling stations below the points of maximum bacterial concentration and the time of flow to these stations.

The tables which have been exhibited in the present report show similar decreases in bacteria in the upper Mississippi River as the water flows away from the zone of maximum pollution, and they also have indicated variations in the bacterial decreases during different seasons of the year. As has been previously noted, the character of the channel of the upper Mississippi River, the location of sampling stations, and the data from which to make time of flow estimates were such that studies of rates of bacterial decrease comparable in significance to those made in the Ohio and Illinois Rivers could not be undertaken. The river section between Hastings, Station No. 7, and Station No. 11, the outlet of Lake Pepin, did, however, provide an opportunity to observe rates of bacterial decrease taking place below the Twin City metropolitan area, and made possible limited comparisons between the rates observed in the upper Mississippi River with similar observations in the Ohio and Illinois Rivers.

Table 40 summarizes for the winter and summer periods the quantity units of bacteria at main-river sampling stations from Hastings, Station No. 7, to the outlet of Lake Pepin, Station No. 11, and at the sampling stations at the mouths of tributaries entering this section of the river. The table also shows the location of the sewered communities on the river below Station No. 7 and the point of entrance of the larger tributaries, together with the estimated times of flow from Station No. 7 to points downstream during the summer and winter periods.

TABLE 40.—*Bacterial pollution of the upper Mississippi River at Hastings, Minn., Station No. 7, with estimates of the pollution contributed below Hastings by sewered communities and tributary inflow, in terms of quantity units*

AVERAGE SUMMER CONDITIONS

Sampling stations on main stream with intervening tributary rivers and sewered cities	Distance from Station No. 7, miles	Time of flow from Station No. 7, hours	Quantity units of bacteria		
			Agar 20° C.	Agar 37° C.	B. coli
(1) Sampling Station No. 7	0	0	1,963,000	1,746,000	9,590
(2) City of Hastings (2,200)	.2	.3	[1] 6,300	[1] 5,600	[1] 30
(3) St. Croix River	2.4	4.1	69,300	45,000	238
(4) Cannon River	21.1	24.8	930	600	1
(5) Sampling Station No. 9	23.3	26.8	284,000	185,900	476
(6) Red Wing (10,400)	23.5	27.2	[1] 29,700	[1] 26,600	[1] 146
(7) Sampling Station No. 11	50.1	1,260.0	73,400	64,000	10

AVERAGE WINTER CONDITIONS

Sampling stations on main stream with intervening tributary rivers and sewered cities	Distance from Station No. 7, miles	Time of flow from Station No. 7, hours	Agar 20° C.	Agar 37° C.	B. coli
(1) Sampling Station No. 7	0	0	218,950	113,260	1,534
(2) City of Hastings (2,200)	.2	.4	[1] 704	[1] 836	[1] 18
(3) St. Croix River	2.4	4.6	2,900	690	11
(4) Cannon River	21.1	26.6	690	140	1
(5) Sampling Station No. 9	23.3	28.8	179,100	51,290	192
(6) Red Wing (10,400)	23.5	29.1	[1] 3,330	[1] 3,950	[1] 87
(7) Sampling Station No. 11	50.1	1,120.0	3,530	460	2

[1] Calculated on the assumption that the per capita contribution of bacteria is the same as observed for Minneapolis and St. Paul.
Summer average based on months of July and August, 1926 and 1927.
Winter average based on months of December, 1926, January and February, 1927.

The estimates of bacterial quantity units and times of flow for the summer period in Table 40 are averages for the months of July and August, 1926 and 1927, while the winter period is based on averages for the months of December, 1926, and January and February, 1927. In these particular months, bacteriological data were complete at all of the sampling stations and stream flows were such that times of flow could be estimated with a reasonable degree of accuracy. The quantity units of bacteria contributed by the sewered communities on the river below Station No. 7, as indicated in Table 40, have been calculated by assuming that in these communities the per capita contribution of bacteria from the sewered population was the same as observed from Minneapolis and St. Paul. While such an estimate was exceedingly crude, the attempted correction was of little significance, since the total contribution of bacteria by these sewered communities was usually only a fraction of the bacteria carried by the receiving water.

In estimating the rates of bacterial decrease in sections of the river where pollution was contributed to the main stream by the entrance of tributaries or was added from sewered communities the following assumptions were made: (*a*) Inasmuch as the bacterial content of the main stream tended to diminish as the water passed downstream, the pollution, brought in by a tributary or added by the sewers of a community, was assumed to decrease with the downstream flow and at the same rate as the decrease which occurred at the stations on the main river between which the added pollution entered; and (*b*) that the pollution added between stations on the main river entered immediately below the nearest sampling point.

The detailed method of calculating the rates of bacterial decrease is best illustrated by the actual computation, Table 41, of the decrease which took place in the Mississippi River below Station No. 7 during the winter period, using the bacterial quantity units derived from the agar-plate counts at 37° C.

TABLE 41.—*Calculation of the percentage of bacteria remaining in the upper Mississippi River at sampling stations below Hastings, Minn., Station No. 7, during the winter period of ice cover, based on the 37° C. agarplate counts*

Station	Quantity units	Per cent of total quantity units	Per cent remaining from Station No. 7	Time of flow, hours, below Station No. 7
Station No. 7:				
Total quantity units	113, 260	98. 7	100. 0	0
Added by Hastings	836	. 7		
Added by St. Croix River	690	. 6		
Total below Station No. 7	114, 786	100. 0		
Station No. 9.				
Total quantity units	51, 150			
Remaining from Station No. 7	50, 485	91. 4	44. 5	28. 8
Remaining from Hastings	358	. 6		
Remaining from St. Croix River	307	. 6		
Added by Cannon River	140	. 3		
Added by Red Wing	3, 950	7. 1		
Total below Station No. 9	55, 240	100. 0		
Station No. 11:				
Total quantity units	460			
Remaining from Station No. 7	420	91. 4	. 37	1, 120. 0
Remaining from Hastings	3	. 6		
Remaining from St. Croix River	3	. 6		
Remaining from Cannon River	1	. 3		
Remaining from Red Wing	33	7. 1		

Estimates of times of flow and calculations of bacterial decreases, expressed as the percentage of bacteria remaining in the water at sampling points below Station No. 7, with corrections for tributary inflow and contributions by sewered communities, have been made from the other bacteriological findings during the summer and winter periods and are summarized in Table 42, the data of which are shown graphically in Figure 9.

Figure No 9 Rates of bacterial purification in the upper Mississippi River in relation to times of flow from station No 7, Hastings, Minnesota, during the summer and winter periods

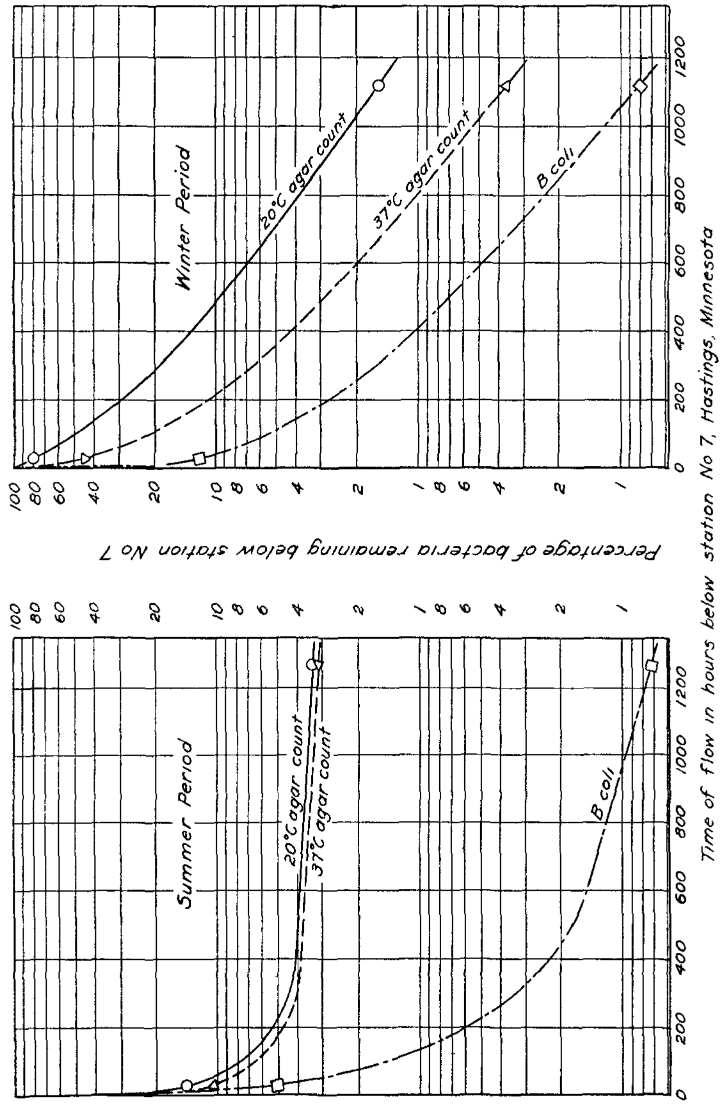

TABLE 42.—*Bacteria remaining at sampling stations on the upper Mississippi River below Hastings, Minn., Station No. 7, corrected for tributary inflow and cities, expressed in percentages of the maximum with times of flow below this maximum*

AVERAGE SUMMER CONDITIONS

Sampling station	Time of flow in hours below Station No. 7	20° C. agar—Per cent of maximum remaining, corrected for additions by tributaries and cities	Time of flow in hours below Station No. 7	37° C. agar—Per cent of maximum remaining, corrected for additions by tributaries and cities	Time of flow in hours below Station No. 7	B. coli—Per cent of maximum remaining, corrected for additions by tributaries and cities
7	0	100.0	0	100.0	0	100.0
9	26.8	14.0	26.8	10.4	26.8	4.9
11	1,260.0	3.2	1,260.0	3.1	1,260.0	.07

AVERAGE WINTER CONDITIONS

Sampling station	Time of flow in hours below Station No. 7	20° C. agar—Per cent of maximum remaining, corrected for additions by tributaries and cities	Time of flow in hours below Station No. 7	37° C. agar—Per cent of maximum remaining, corrected for additions by tributaries and cities	Time of flow in hours below Station No. 7	B. coli—Per cent of maximum remaining, corrected for additions by tributaries and cities
7	0	100.0	0	100.0	0	100.0
9	28.8	80.6	28.8	44.5	28.8	12.2
11	1,120.0	1.6	1,120.0	.37	1,120.0	.08

Summer average based on the months of July and August, 1926 and 1927.
Winter average based on the months of December, 1926, January and February, 1927.

COMPARISON BETWEEN SUMMER AND WINTER RATES OF BACTERIAL PURIFICATION IN THE UPPER MISSISSIPPI RIVER

Table 42 and Figure 9 indicate that the summer rates of disappearance of the organisms growing on agar at 20° and 37° C. were practically the same and that the rate of disappearance of the B. coli organisms was considerably greater than the rate of disappearance of the 20° and 37° C. organisms. In the winter period organisms of the B. coli group disappear from the stream at a faster rate than the 37° C. agar organisms, which in turn showed a higher rate of disappearance than the 20° C. organisms. The table and figure further indicate considerable differences in the rates of bacterial disappearance in the stream during the summer and winter periods, when the times of flow in the river were substantially the same. Under average summer conditions only 14 per cent of the 20° C. organisms which were present in the water at Station No. 7 remained at Station No. 9 after approximately 27 hours' flow. In the winter period the mean time of flow between the same stations was practically the same, 29 hours, but in this period 81 per cent of the 20° C. organisms present in the water at Station No. 7 still remained at Station No. 9.

Of the organisms growing at 37° C. and organisms of the B. coli group which were present at Station No. 7 in the summer period only 10 and 5 per cent, respectively, remained at Station No. 9 after 27 hours' flow. During the winter months, with approximately the same time of flow between the same points on the river, 45 per cent of the 37° C. organisms and 12 per cent of the B. coli organisms remained in the water at Station No. 9. The data indicate, therefore, that in the section of the river between Stations Nos. 7 and 9 the summer rate of disappearance of the 20° C., 37° C., and B. coli organisms was about 4.3, 1.6, and 1.1 times, respectively, the rate of disappearance in the winter period.

Lake Pepin, in which the average time of flow in both the summer and winter periods was in excess of 1,000 hours, is located between Stations Nos. 9 and 11. A still further reduction in bacteria occurred between these points. The data for this section of the stream appear to indicate that the winter rate of disappearance of bacteria was greater than the summer rate, the disappearance of the 20° C., 37° C., and B. coli in winter being about 7.3, 6.0, and 2.4 times the rate in summer. However, in the absence of data from additional sampling stations within the lake itself, it seems reasonable to suppose that a state of bacterial stability may have been reached in Lake Pepin during a period of flow considerably less than that indicated by the time of flow through the entire lake as given in Table No. 42. The reductions in bacteria as determined at the outlet of the lake indicate that in summer only 3 per cent or less of the organisms present at Station No. 7 were still present in the water at the outlet of Lake Pepin, while in winter the residual bacteria from Station No. 7 were only 1½ per cent or less.

COMPARISON BETWEEN RATES OF BACTERIAL PURIFICATION IN THE OHIO, ILLINOIS, AND UPPER MISSISSIPPI RIVERS

Figures 10 and 11 give curves showing a comparison between the summer and winter rates of bacterial purification in the Ohio, Illinois, and upper Mississippi Rivers. Curves for the Ohio River show the indicated decrease in bacteria in the 123 miles of river, from the point of maximum bacterial concentration below Cincinnati, Ohio, to Louisville, Ky. The Illinois River curves include a section in the upper portion of the river, 126 miles long, between Lockport and Peoria, and a section in the lower portion of the stream, 160 miles long, from Peoria to Kampsville. The data for the upper Mississippi River are for the 50 miles of river between Hastings, Station No. 7, and the outlet of Lake Pepin, Station No. 11. Data for the Ohio and Illinois Rivers were obtained from river sections in which velocities of flow were comparatively high, while the Mississippi River section includes Lake Pepin, in which velocities of flow are extremely low, particularly in the winter and summer periods to which the curves apply. The data of the Mississippi River are therefore not entirely comparable to those from the other two rivers.

Rates of purification in Figures 10 and 11 are expressed in terms of the percentage of bacteria remaining below the point of maximum bacterial concentration on the Ohio and Illinois Rivers and below Station No. 7 on the Mississippi River, which is usually the point of

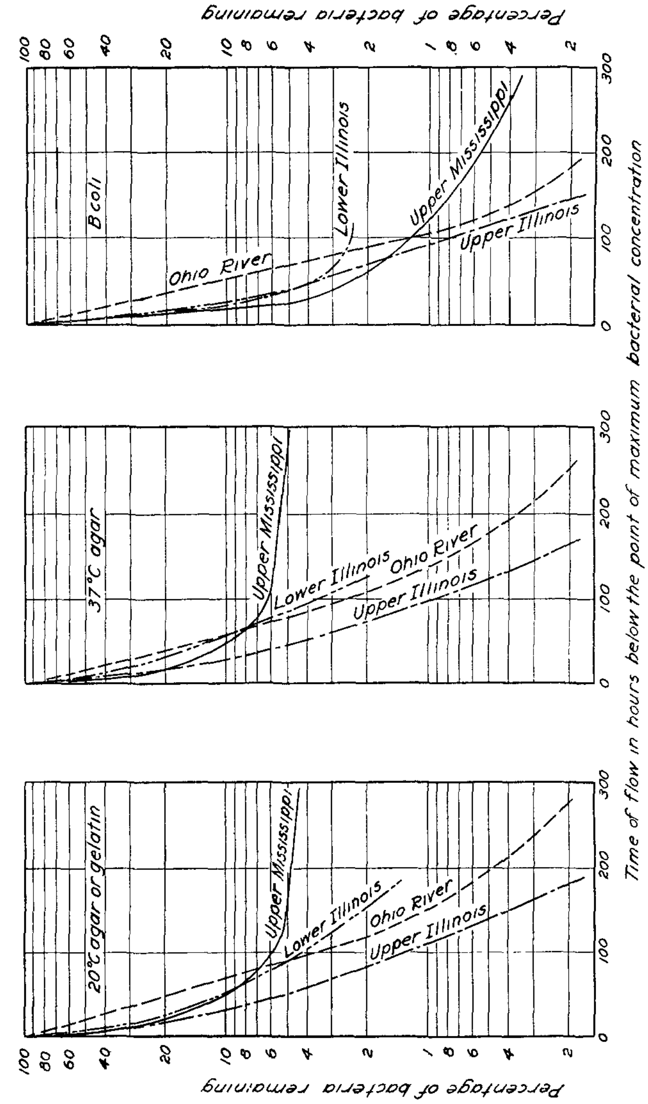

Figure No 10 Comparison of summer rates of bacterial purification in the Ohio, Illinois and upper Mississippi Rivers in relation to time of flow from the zone of maximum pollution.

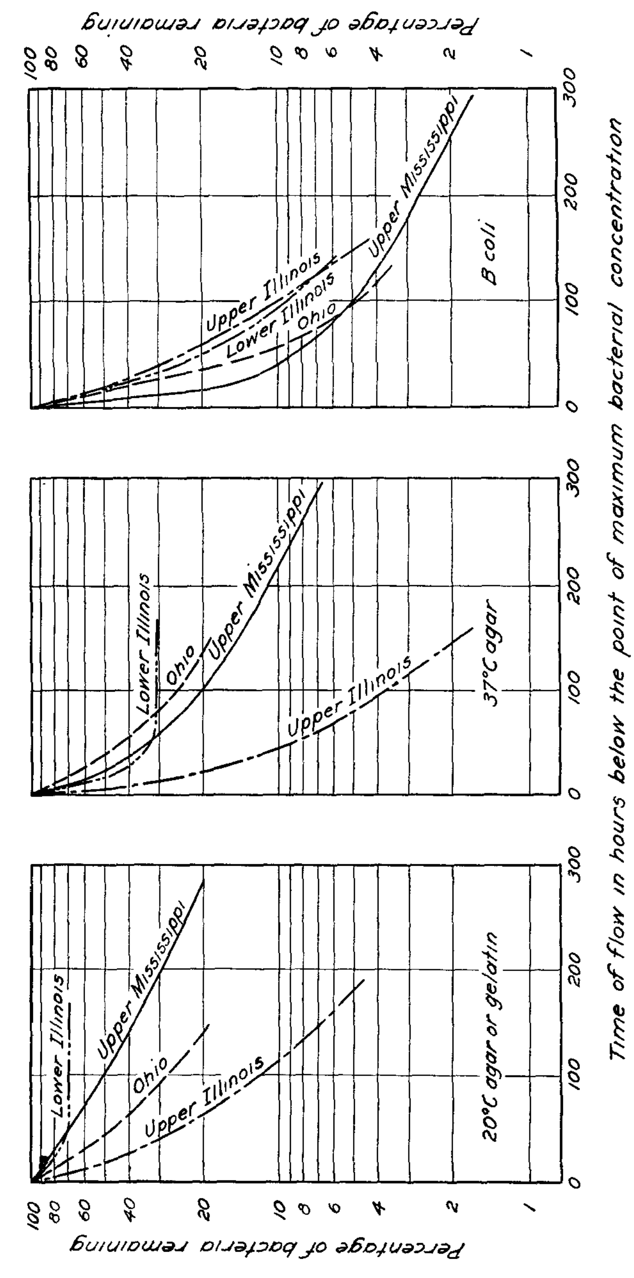

Figure No 11 Comparison of winter rates of bacterial purification in the Ohio, Illinois and upper Mississippi Rivers in relation to times of flow from the zone of maximum pollution maximum pollution, and the corresponding times of flow below the points of highest pollution.

While the data for the upper Mississippi River are extremely limited, they do however appear to indicate, as shown in Figure 10, that the summer rates of bacterial disappearance in the more rapidly moving section of the river, between Station No. 7 and the inlet to Lake-Pepin, are in general comparable with the rates observed in the Ohio and Illinois Rivers.

The summer rate of bacterial disappearance in the upper Mississippi River during the first 30 hours of flow appears to follow somewhat more closely the rates of disappearance in the Illinois rather than those in the Ohio River. After about 30 hours' flow there is a marked flattening of the 20° and 37° C. curves for the upper Mississippi River, indicating much lower rates of purification than those observed in the Ohio and Illinois Rivers. The lower portion of the Mississippi River curve is based on times of flow through Lake Pepin, which are extremely uncertain. Had a condition of bacterial stability been reached within the lake at any considerable distance above the outlet, the time factor would have been reduced, and the Mississippi River curves would then approach more closely those of the Ohio and Illinois Rivers during the later stages of purification. The flattening of the lower part of the Mississippi River curve of B. coli disappearance is less marked than in the curves for the agar counts, indicating rates of B. coli disappearance in the lake more nearly comparable to those in the Ohio and Illinois Rivers but somewhat greater than those observed in the lower Illinois River.

Winter curves of bacterial purification, given in Figure 11, show quite consistent rates of B. coli disappearance in the three river sections, the indicated rate in the upper section of the Mississippi River being somewhat higher than in the other rivers. In the winter period, during the first 20 hours of flow, rates of decrease of the 20° C. organisms were less in the upper Mississippi River than in the other river sections. After about 20 hours' flow the rates in the upper Illinois and Ohio Rivers greatly exceeded the indicated rate in the upper Mississippi River, which in turn showed a higher rate of reduction in 20° C. organisms than that observed in the lower Illinois River. The winter rate of disappearance of the 37° C. organisms was greatest in the upper Illinois River. During the first 30 hours' flow, below the point of maximum pollution, the rates of disappearance of 37° C. organisms in the lower Illinois, Ohio, and Mississippi Rivers were quite consistent. After 30 hours' flow the rates of reduction in the Ohio and Mississippi Rivers were more nearly comparable and were greater than the rate in the lower Illinois River.

In the preceding comparisons, defining average rates of bacterial purification in the Ohio, Illinois, and Mississippi Rivers, the curves were started, in each instance, from the point of maximum bacterial concentration, no account being taken of the initial numbers of bacteria present at the upper station of the river section. In the three rivers studied, the greatest bacterial concentration occurred in the upper Illinois River, and, in the order of decreasing bacterial pollution, followed the Mississippi, lower Illinois, and Ohio Rivers. Table 43 shows the variation in the average initial number of bacteria per cubic centimeter at the points of greatest pollution in the Ohio, Illinois, and Mississippi Rivers in the summer and winter seasons.

TABLE 43.—*Comparison between the initial numbers of bacteria, per cubic centimeter, in the Ohio, Illinois, and upper Mississippi Rivers during the summer and winter periods*

River	Initial number of bacteria per cubic centimeter	
	Summer period	Winter period
20° C. COUNT ON AGAR OR GELATIN		
Upper Illinois River	3,310,000	751,000
Upper Mississippi River	605,000	71,800
Lower Illinois River	281,000	29,000
Ohio River	84,400	28,600
37° C. AGAR COUNT		
Upper Illinois River	3,420,000	142,000
Upper Mississippi River	558,000	36,700
Lower Illinois River	254,000	9,440
Ohio River	99,300	8,300
B. COLI		
Upper Illinois River	57,100	3,030
Upper Mississippi River	3,430	490
Lower Illinois River	3,730	180
Ohio River	2,220	121

A further comparison between the rates of bacterial decreases in the three river systems was attempted by adjusting the coordinates of the lower Illinois, Ohio, and Mississippi Rivers to those of the upper Illinois River, so that comparisons could be made between the rates of bacterial disappearance below points of equal bacterial concentration, rather than below the same origin of 100 per cent, representing the point of maximum pollution in each case. The maximum concentration of bacteria growing on agar at 37° C., on the upper Illinois River in summer was 3,420,000 bacteria per cubic centimeter, while the corresponding concentrations on the Mississippi, lower Illinois, and Ohio Rivers were 558,000, 254,000, and 99,300 bacteria per cubic centimeter, respectively. The concentrations in the Mississippi, lower Illinois, and Ohio Rivers were therefore 16.3, 7.4, and 2.6 per cent, respectively, of the concentration on the upper Illinois River, as represented by the 37° C. agar count. Therefore, the 100 per cent point of the Mississippi River curve was moved to the 16.3 per cent point on the upper Illinois River curve and proportionate changes made on the other points of the Mississippi River curve. In a similar manner the curves of the lower Illinois and Ohio Rivers were adjusted to the 7.4 and 2.6 per cent points on the upper Illinois River curve.

In some instances such an adjustment of the curves indicated somewhat more comparable rates of bacterial decrease in the sections of the watercourses studied, showing the varying effect of initial density on the rate of bacterial purification. In other instances the divergence in the adjusted curves was more pronounced than when comparisons were made on the basis of maximum concentration On the whole the coincidence of the adjusted curves was not particularly striking and leads one to believe that the degree of bacterial pollution in these streams could in general be more accurately indicated by a series of curves having the maximum points at a common origin with respect to time, and at ordinates corresponding to the bacterial density at such maximum.

SECTION VII

GENERAL SUMMARY

Sewage and industrial wastes discharged from the metropolitan area of Minneapolis and St. Paul create objectionable conditions in the upper Mississippi River between Minneapolis and Hastings during the summer months of low stream flow.

The necessity for sewage treatment to improve conditions in the river through and below the Twin Cities has previously been discussed in unpublished preliminary reports to local and State authorities and in the published reports of the Metropolitan Drainage Commission of Minneapolis and St. Paul created in 1927 to continue observations along the river and to formulate plans for collecting and treating the sewage from this district.

In the present report an attempt has been made to analyze the various data collected during the investigation from the standpoint of a study of the factors involved in processes of natural stream purification. An extensive analysis of the data has not been possible due to lack of sufficient information from which to estimate times of flow in the river, because of the physical characteristics of the river channel affecting uniform conditions of flow and because of the difficulty in determining rates of purification in Lake Pepin, a large body of water located a comparatively short distance below the metropolitan area. The data obtained during the Mississippi River investigation have, however, indicated conditions not encountered during previous studies of stream pollution and in some instances have assisted in interpreting data collected during the earlier investigations.

The point of maximum pollution in the upper Mississippi River varies to some extent in the different seasons as a result of dilution by tributary inflow and natural processes of stream purification, but usually occurs in the vicinity of Hastings, Minn., about 20 miles by river below the lower sewer outlets of the metropolitan area. During the summer and winter periods of decreased stream flow Hastings is approximately 15 hours' flow below the lowest sources of pollution from the Twin Cities. Thus the results from the upper Mississippi River are in agreement with observations of previous studies, the point of maximum pollution occurring in the Ohio River after a flow of from 10 to 15 hours below the Cincinnati sewers, and in the Illinois River after a period of flow varying from 10 to 25 hours below the sources of pollution.

The results of the chemical analyses indicate a decrease in dissolved oxygen as sewage and industrial wastes enter the river from the metropolitan area, and an increase in dissolved oxygen below the zone of pollution due to tributary inflow and to reaeration. In the winter months of ice cover, reaeration is retarded, the dissolved oxygen in the water is lower at all points along the river than in other seasons, and the point of minimum dissolved oxygen content is found at points farther downstream. Data for the upper Mississippi River suggest that critical oxygen conditions in polluted streams having a long period of ice cover may occur toward the end of winter rather than in the summer months, and that the effects of pollution may be noticeable in winter at points considerably farther downstream than in summer.

The oxygen requirements of the upper Mississippi River, indicated by the 5-day biochemical oxygen demand, increase, as would be expected, with the addition of pollution from the Twin City metropolitan area and are usually greatest at Hastings, about 20 miles below the lower sewer outlets. The oxygen requirements of the stream decrease between Hastings and the outlet of Lake Pepin as the organic matter in the water is oxidized during the long period of flow within the lake. In the lower section of the river, from the outlet of Lake Pepin to Winona, which receives but little additional pollution, a further reduction in the oxygen requirements of the stream would be expected. Contrary to expectation, however, an increase in oxygen requirements is frequently observed in this section of the river. Increased oxygen requirements occur when times of flow from sources of pollution on the main river are greatest and when the flow of the Chippewa River, which enters below Lake Pepin, is as great or greater than the flow in the main channel. The data suggest that the indicated increases are due either to the relatively fresh pollution in the tributary which reaches the transitional period between the first and second stages of oxidation at the lower station or to changes in the biological balance of the stream after the industrial waste-polluted water of the Chippewa River mixes with the water of the main stream.

The oxygen balance in the main river, as represented by the ratio of the dissolved oxygen to the oxygen demand at various points along the river, shows a progressive decrease through the metropolitan area as far downstream as Hastings, due to the added pollution. In periods of open water the balance begins to increase below Hastings; but during the season of ice cover when reaeration is retarded, recovery in oxygen balance begins at points considerably farther downstream. Below Lake Pepin a secondary decrease in oxygen balance is indicated, due to the increased oxygen requirements at the lower station. Changes in the relation between the dissolved oxygen and the oxygen demand within the pool at Minneapolis during the summer months show a draft on the oxygen resources of the stream in excess of that to be expected from the sewered population. Increased summer drafts result from the sludge accumulated during periods of low water temperatures, when biological activities are lowest, which remains to exert its influence in the months of higher water temperatures. The indicated reduction in oxygen balance in the lower section of the river, in which but little actual sewage pollution is discharged into the stream, is equivalent to a sewered population almost as great as that discharging sewage into the pool above the dam at Minneapolis.

The results of the bacteriological analyses show a progressive increase in numbers of bacteria from above Minneapolis to Hastings as increasing amounts of sewage and industrial wastes reach the river. From Hastings to the outlet of Lake Pepin there is a decrease in numbers of bacteria, due to the dilution by tributary inflow and to processes of natural stream purification during the long period of flow through the lake. In the lower section of the stream, between the outlet of Lake Pepin and Winona, in which the oxygen demand increased, there is also at times an unexpected increase in bacteria not accounted for by additional pollution. An increase in bacteria in the Illinois River below the Kankakee comparable to that in the Mississippi River below the Chippewa had previously been observed during the Illinois River investigation. Laboratory studies have since indicated the possibility of bacterial increases due to the disturbance of biological conditions as a result of dilution. Increases in the bacterial content of streams during a considerable time of flow below the sewer outlets have been consistently indicated in all of the stream-pollution studies. It does not seem entirely without the range of possibility that actual measurable increases in bacteria may occur in a watercourse as a result of changes which influence biological activities and alter the balance between destructive forces and growth factors.

The indicated per capita contribution of bacteria from the sewered population of the Twin City metropolitan area above the point of maximum pollution on the upper Mississippi River is lower than the observed per capita contribution of bacteria from metropolitan areas on the Ohio and Illinois Rivers, with the exception of the contributions from the Pittsburgh and Wheeling areas on the upper Ohio River. The lower per capita contribution to the upper Mississippi River, while not outside the range of previous observations, emphasizes the fact that local conditions influence results to a considerable extent. The indicated bacterial purification in the Mississippi River between the point of maximum bacterial pollution and the outlet of Lake Pepin varies in the different seasons from 97 to 98.5 per cent during the long period of flow through the lake.

Rates of bacterial decrease were determined in the summer and winter periods in the upper Mississippi River between Hastings and the outlet of Lake Pepin. This river section includes 28 miles of relatively narrow river channel above Lake Pepin, representing a time of flow of about 21 hours and 22 miles of lake in which seasonal times of flow are usually in excess of 1,000 hours. Inaccessibility of sampling stations along the lake and the difficulty of collecting representative samples from such a large body of water made the determination of rates of purification within the lake impracticable. The rate of disappearance of B. coli organisms between Hastings and the inlet of Lake Pepin during the summer months is greater than the rate of disappearance of the 20° and 37° C. agar organisms, which have rates practically the same. In winter, B. coli is also eliminated from this section of the river at a rate greater than are the 37° C. organisms, which in turn have a greater rate of decrease than the 20° C. organisms. A comparison between seasonal rates of bacterial disappearance indicates that all three types of organisms in the river above Lake Pepin disappear in summer at rates varying from 1.1 to 4.3 times the winter rates, showing, as in the case of the Ohio and Illinois Rivers, the effect of seasonal temperatures on rates of natural stream purification.

Rates of bacterial decrease in the upper Mississippi River are influenced by conditions in Lake Pepin and are not entirely comparable with the rates of decrease observed in the more rapidly flowing portions of the Ohio and Illinois Rivers. During a period of about 21 hours' flow in the more swiftly moving section of the river above the lake rates of bacterial decrease appear to be intermediate between the rates determined in the upper and lower Illinois River and greater than the rates observed in the Ohio River. The concentration of bacteria at the point of maximum bacterial pollution in the upper Mississippi River is also intermediate between the concentration of bacteria at the points of greatest pollution in the upper and lower Illinois River, suggesting that the initial concentration of bacteria may influence to some extent rates of bacterial disappearance in streams.

Of special significance in the upper Mississippi River is the effect of the winter ice cover, which reduces the dissolved oxygen content of the entire river system, so that critical oxygen conditions are approached toward the end of the winter period at points further downstream from the sources of pollution, the reversal of conditions in the lower section of the river producing an increase in the oxygen demand and the bacterial concentration in the absence of additional sewage pollution.

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