Water-Supply and Irrigation Paper No. 194 Series L, Quality of Water, 20

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

POLLUTION OF ILLINOIS AND MISSISSIPPI RIVERS BY CHICAGO SEWAGE

A DIGEST OF THE TESTIMONY TAKEN IN THE CASE OF THE STATE OF MISSOURI V. THE STATE OF ILLINOIS AND THE SANITARY DISTRICT OF CHICAGO

BY

MARSHALL O. LEIGHTON

WASHINGTON
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POLLUTION OF ILLINOIS AND MISSISSIPPI RIVERS BY CHICAGO SEWAGE.

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INTRODUCTION.

OBJECT OF THE PAPER.

The testimony taken in the suit of the State of Missouri against the State of Illinois and the sanitary district of Chicago comprises the best symposium on river pollution, its biological and chemical aspects, and its general and special sanitary significance that has ever been assembled. The contentions of both parties to the suit are supported by the most eminently qualified men in the United States. The evidence presented and the discussions recorded are therefore of unique importance. The final record of testimony occupies 8,000 printed pages, much of which is irrelevant. This digest of testimony is the result of an attempt to recover the valuable material and present it in concise form. A consistent endeavor has been made by the reviewer to eliminate all personal opinions with reference to the issue and to make an impartial presentation of so much of the testimony as in his opinion appears to be relevant and of scientific importance. It will be well to remember in this connection that any digest of so large a volume of testimony must be the result of a final exercise of personal opinion by the reviewer as to those parts which may best be excluded. Naturally opinions will differ on this point; therefore it will be strange if many of those familiar with the case do not find that certain portions of testimony which they consider most important are passed over in this digest without reference. Controversies between counsel, objections to the admission of testimony, legal technicalities and quibbles, badgering cross-examination, and in general all the testimony introduced for purposes of mere corroboration have been disregarded. The object has been to present a faithful statement of the scientific phases of the testimony to the exclusion, if need be, of the legal aspect of the case.

Many of the averages contained in the tables of the official record appear to be incorrect. It does not appear whether this is due to typographical errors or to mistakes by the original computers. Such tables as are reproduced in this digest are copied from the record without correction.

STATEMENTS OF PARTIES TO THE SUIT.

This is a proceeding in equity instituted by the State of Missouri on January 17, 1900, against the State of Illinois and the sanitary district of Chicago, praying for an injunction against the defendants from draining into Mississippi River the sewage and drainage of said sanitary district by way of the Chicago drainage canal and the channels of Desplaines and Illinois rivers.

BILL OF COMPLAINT.

The bill of complaint alleges in substance as follows:

That the complainant is a State lying on the west bank of Mississippi River with a frontage thereon of over 400 miles;

That the States of Illinois and Missouri have concurrent jurisdiction over the waters of Mississippi River, each having exclusive territorial jurisdiction over that portion adjacent to its shores, the boundary having been declared at the middle of the main channel;

That Illinois River joins the Mississippi at a point above St. Louis;

That on the banks of the Mississippi below its confluence is a large population that uses the water of the Mississippi for domestic, agricultural, and manufacturing purposes;

That the said water is indispensable to the life, health, and happiness of many thousands of inhabitants in Missouri;

That the construction of the Chicago drainage canal is such that its contents finally empty into Mississippi River about 43 miles above the city of St. Louis;

That such construction was done under the sanction and authority of the State of Illinois;

That the channel of said canal is cut through the natural watershed dividing the drainage area of Lake Michigan from that of Illinois River;

That the defendants propose to drain through said channel the sewage matter from nearly the whole of the city of Chicago and a portion of Cook County;

That for many years the city of Chicago had discharged into Lake Michigan large quantities of sewage which has accumulated upon the beds of Chicago River and of Lake Michigan;

That if such plan is carried out it will cause such sewage matter to flow into Mississippi River past the homes and waterworks systems of the inhabitants of the complainant;

That the amount of such undefecated sewage matter would be about 1,500 tons daily, and that it will poison the waters of the Mississippi and render them unfit for domestic use, amounting to a direct and continuing nuisance that will endanger the health and lives and irreparably injure the business interests of inhabitants of the complainant;

That the complainant is without remedy except in a court of equity, and

That it prays for an injunction restraining the defendants from doing the acts herein alleged.

In a supplemental bill of complaint, made subsequent to the opening of the drainage canal, the complainant alleged—

That the water of the canal had destroyed the value of the water of the Mississippi for drinking and domestic purposes, and had caused much sickness to persons living along the banks of said river in the State of Missouri;

That, under the law authorizing the construction of the canal, it was required that said sewage be diluted with not less than 20,000 cubic feet of water per minute for each 1,000 inhabitants of the sanitary district, and

That the defendants had reduced this amount to about 10,000 cubic feet per 1,000 inhabitants and, acting under the authority of the Secretary of War, proposed thereafter to limit the maximum dilution to that amount.

ANSWER OF THE DEFENDANTS.

The State of Illinois united with the codefendant in general admissions, denials, and allegations, and further contended that the sanitary district was not subject to the control of the executive department of the State of Illinois, and that all acts of the State and its executive department were performed prior to January 17, 1900, the date at which the complainant moved for permission to file this bill of complaint.

The sanitary district admitted the character of the complainant, its population and location with reference to Mississippi River, and the jurisdiction of each party with reference to said stream as alleged in the bill of complaint.

It further admitted that Illinois River empties into the Mississippi at a point above the city of St. Louis, and that a large population of said plaintiff relies on the waters of Mississippi River for their water supply for domestic, agricultural, and manufacturing purposes.

In reference to the question as to whether or not the said waters are indispensable to the life, health, and happiness of the said inhabitants, and whether or not said inhabitants are compelled to use such waters for the aforesaid purposes, the defendant neither admitted nor denied, but left the complainant to make proof thereof.

The defendant admitted the passage of the law creating the sanitary district and all the complainant's allegations with reference to the geographic situation of Lake Michigan and of the various rivers and the canal forming the drainage system of the defendant.

The construction of the drainage canal as alleged in the bill of complaint was admitted, and the allegation that the sewage of the district has been caused to flow through such canal into Desplaines River.

The defendant denied that the sewage of said district flows into Chicago River and Lake Michigan, but averred that the greater portion thereof had for many years been discharged into Desplaines and Illinois rivers, the same having been pumped from Chicago River into the Illinois and Michigan Canal and through this conducted to said rivers.

It was further denied that large quantities of sewage matter had accumulated upon the beds of Chicago River and Lake Michigan, and further that the plans adopted would loosen such matter and cause it to flow into Desplaines River.

It was further denied that the waters of the Mississippi will be poisoned and polluted by the completion of the plans above noted and that the adaptability of said waters for domestic and other uses will be destroyed.

It was further denied that the discharge of sewage through the canal will injure the property and business of the cities of the complainant or that it will create a direct and continuing nuisance.

The defendant averred that the turning into Desplaines River of such sewage, together with 300,000 cubic feet per minute of the pure water of Lake Michigan, will greatly improve the quality of the water of the Mississippi.

The defendant made numerous allegations concerning the discharge by means of pumps of nearly all the sewage of Chicago through the Illinois and Michigan Canal, and further alleged that the acts of the defendant with reference to the construction of the canal and the plans in relation thereto are open and notorious and largely matters of record.

That during the nine years since the institution of the work the defendant had expended more than $33,000,000.

That the complainant had notice of such work, and that said complainant, having delayed this complaint until the completion of said work, had been guilty of laches and was therefore estopped to further urge this cause.

It was further averred that the distance by water from Robey street, Chicago, to the mouth of Illinois River is 322 miles, and that on the various tributaries that unite to form Illinois River and on the main stream there was a population of not less than 1,500,000, exclusive of the sanitary district of Chicago, and that a large number of cities drained into the said rivers, and that the sewage of said cities had for a great length of time flowed by way of said rivers to Mississippi River.

That Mississippi River and its tributaries form the natural drainage system of a vast region of country and that the additional amount of sewage discharged through the canal is trifling in amount as compared with the enormous volume received from cities on the Mississippi drainage area above St. Louis.

That by natural laws governing running water in large bodies the sewage was deprived of all its deleterious qualities by processes of vaporization, attrition, and chemical conversion.

In answer to the supplemental bill of complaint, the sanitary district admitted the opening of the canal, but denied that the sewage had polluted the waters of the Mississippi or that the same had or will hereafter cause sickness to persons living upon the banks of said river in the State of Missouri.

It was averred that the defendant would prove, if permitted, that the turning into Illinois River of said sewage, together with the pure waters of Lake Michigan, does not in any way impair the value of the waters of the Mississippi.

It was further averred that suburban towns and villages having a population of 50,000 discharged their sewage into Mississippi River opposite said city, which caused a much greater pollution of the waters of said river than can possibly be produced by the waters coming from Illinois River; that the natural flow of Mississippi and Missouri rivers, the latter entering a short distance above the city of St. Louis, caused a pressing of the Illinois waters upon the east bank of Mississippi River lying along Illinois River and prevented them from mixing with the waters flowing along the west bank of said stream and into the intake of the waterworks of the city of St. Louis.

WITNESSES AND COUNSEL.

The principal witnesses called to testify in behalf of the parties to this suit were as follows:

In behalf of the plaintiff: Benezette Williams, Amand Nicholas Ravold, Edward H. Keiser, William C. Teichmann, J. L. Van Ornum, George Chandler Whipple, William Thompson Sedgwick, Gardner Stewart Williams, George W. Fuller, Allen Hazen, Edward W. Saunders, Washington E. Fischel, Ludwig Bremer, Albert E. Taussig, Charles H. Goodman, Herbert E. Smith, John W. Alvord, and Ernest E. Lochridge.

In behalf of the defendants: John H. Long, F. Robert Zeit, Adolph Gehrmann, D. B. Bisbee, Arthur W. Palmer, Thomas J. Burrill, Edwin Oakes Jordan, Henry L. Russell, Isham Randolph, Ludwig Hektoen, E. G. Hastings, Erastus G. Smith, Jacob A. Harman, Robert Spurr Weston, William Pitt Mason, Rudolph Hering, George Dock, Lewellys F. Barker, Theobald Smith, Victor C. Vaughan, Leonard P. Kinnicutt, William S. Thayer, and John W. Hill.

The principal counsel participating in the examination were the following:

In behalf of the plaintiff: Edward C. Crow, attorney-general of the State of Missouri; Samuel B. Jeffries and William F. Woerner, of counsel.

In behalf of the defendants: H. J. Hamlin, attorney-general of the State of Illinois; James Todd, solicitor for the sanitary district of Chicago; William M. Springer, John G. Drennan, and W. C. Johns, of counsel.

The examination was conducted before Frank S. Bright, commissioner of the Supreme Court of the United States.

TYPHOID FEVER IN THE MISSISSIPPI VALLEY.

During the course of the testimony there were introduced, through various witnesses, the records of deaths from typhoid fever at numerous cities in the Mississippi basin above St. Louis. In order that this record may be more comprehensive, the figures have been combined in the following table,. and will be referred to in connection with the deductions of certain witnesses for both parties to the suit.

Table 1.—*Deaths from typhoid fever in designated cities in Mississippi basin above St. Louis, Mo., 1893–1902.*

	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	Population in 1900.
Mississippi basin above mouth of Illinois River:											
Minneapolis, Minn	134	107	88	60	148	86	71	79	121	66	202,718
St. Paul, Minn	51	32	38	37	22	43	30	36	24	23	163,055
Dubuque, Iowa	6	6	12	8	12	10	12	7	8	10	36,297
Burlington, Iowa	8	10	8	13	3	4	8	13	12	11	23,201
Keokuk, Iowa	8	14	3	3	7	10	9	10	4	7	14,641
Des Moines, Iowa	22	29	30	14	20	17	13	7	22	21	62,139
Quincy, Ill	22	33	24	13	15	6	7	9	12	18	36,252
Hannibal, Mo	7	7	6	8	10	8	4	3	3	2	12,780
Davenport, Iowa	5	6	4	3	5	2	12	14	11	11	35,254
Rock Island, Ill	15	13	3	13	......	......	10	14	28	5	19,493
Moline, Ill	7	9	8	11	3	5	20	22	16	7	17,248
Winona, Minn	2	2	1	2	2	2	5	5	1	4	....
Red Wing, Minn	5	2	2	3	0	4	0	3	2	3	....
Fort Madison, Iowa	......	......	......	......	......	......	......	5	......	1	....
La Crosse, Wis	15	2	5	0	3	8	7	7	5	4	....
Louisiana, Mo	......	......	......	......	......	......	......	4	2	7	....
Clinton, Iowa	10	5	3	7	5	7	7	10	12	5	....
Muscatine, Iowa	4	8	5	5	2	25	2	13	8	5	....
	321	285	240	200	257	237	217	271	291	210	....

TABLE 1.—*Deaths from typhoid fever in designated cities in Mississippi basin above St. Louis, Mo., 1893–1902*—Continued.

	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	Population in 1900.
Missouri River basin:											
Lincoln, Nebr.	33	21	23	15	14	12	13	4	13	10	40,169
Omaha, Nebr.	22	40	29	18	22	32	26	24	23	20	102,555
Council Bluffs, Iowa	5	7	6	8	8	6	8	11	6	8	25,802
St. Joseph, Mo.	20	22	31	19	15	19	37	20	12	13	102,979
Kansas City, Mo.	59	37	34	29	38	49	52	49	58	58	163,752
St. Charles, Mo.	......	......	......	......	......	......	22	5	6	14	....
	139	127	123	89	97	118	158	113	118	123	....
Illinois River basin:											
Chicago, Ill.	670	491	518	751	437	636	442	339	509	801	[a]1,500,000
Joliet, Ill.	12	14	0	12	12	15	15	13	13	21	29,353
Ottawa, Ill.	2	5	2	2	4	4	3	3	5	2	10,588
Elgin, Ill.	5	3	5	14	......	4	5	15	15	8	22,433
Aurora, Ill.	6	12	19	10	5	10	4	17	11	2	24,147
Peoria, Ill.	......	......	......	13	18	18	12	33	15	18	56,100
Pekin, Ill.	......	......	......	......	......	......	......	2	1	2	8,420
Decatur, Ill.	5	7	2	1	7	5	7	11	5	4	20,754
Bloomington, Ill.	12	14	15	9	10	10	9	15	9	15	23,286
Springfield, Ill.	......	......	......	......	......	......	......	20	10	8	34,159
Havana, Ill.	3	7	2	5	......	......	......	......	1	2	....
	45	62	45	66	56	66	55	129	85	82	....
St. Louis, Mo.	215	178	106	106	125	95	130	168	198	222	575,238

[a] Tributary to Chicago drainage canal.

TESTIMONY FOR PLAINTIFF.

BENEZETTE WILLIAMS.

DIRECT EXAMINATION.

Benezette Williams, a consulting engineer of Chicago, formerly chief engineer of the sanitary district, and for a number of years connected with the sewer department of that city, was called as a witness in behalf of the complainant and testified to certain geographic and engineering facts concerning the city of Chicago, the sanitary district, and the drainage canal. The examination was somewhat digressive and the witness was frequently not allowed to finish his testimony concerning one point before he was diverted to another; therefore the following paragraphs are presented without reference to the order in which they were related by the witness:

The city of Chicago has an area of about 190.6 square miles and extends along the southwestern shore of Lake Michigan for about 20 miles. The eastern boundary is therefore the lake itself, except for a distance of 4½ miles where it is coincident with the western boundary of Indiana; the southern boundary is a line running at right angles from the State boundary; the northern boundary is parallel to and 24 miles distant from the southern boundary.[a]

Chicago lies very low, the elevation running from lake level to 25 feet above. During the construction of the city it was necessary to

[a] The western boundary is irregular; in general it is at a distance of 8 miles from the eastern boundary.—M. O. L.

raise the grades in order to cover the sewers and elevate the city out of the mire. A considerable portion of the city has been built out into the lake, the mouth of Chicago River, for example, being more than one-half mile farther out than formerly. As a whole, the city lies too low to afford sufficient gradient for the discharge of the sewers by gravity, and therefore trunk sewers have been laid below the lake level and pumps have been installed to raise the sewage from them.

One of the most important, as well as the most troublesome natural features about Chicago is Chicago River. The main stream was originally not over a mile long from the lake back to the confluence of two forks. The northern fork (called North Branch) is the larger of the two, rises in Wisconsin, and runs in a southeasterly direction across the northern portion of the city. The southern fork (called South Branch) divides at a distance of about 5 miles from the lake into two forks, which are locally known as West Fork and South Fork. South Fork drains a very small territory and originally was merely a ditch, dry except during floods. West Fork also drains a small territory, the area adjoining that of Desplaines River. Formerly, during floods, Desplaines River would break over the divide and come down West Fork into Lake Michigan, making the fork at such times a comparatively large stream. Throughout the greater length of Chicago River and its branches in the city the channel has been dredged and docked for commercial purposes, and a considerable depth of water is maintained.

From the time of the initial development of Chicago the river has been commonly utilized for the discharge of sewage. With the growth of the city the danger occasioned by this practice became more and more acute until it was necessary to provide means for purifying the stream. The readiest means at hand was the dilution of the river water by that from Lake Michigan, and this was accomplished for several decades, both by the actual pumping of the lake water into the river through conduits and by the pumping of river water into the Illinois and Michigan Canal, allowing the lake water to take the place of that so discharged. The character of these conduits and pumping works is briefly as follows:

In 1879 a 12-foot conduit was completed, running from the lake along Fullerton avenue to North Branch. The pumps there installed had a working capacity of 15,000 cubic feet per minute. This amount of fresh water from the lake had the effect of flushing the impurities gathered in North Branch either into the lake or down South Branch, according as the current ran toward one place or the other.

Another conduit was excavated along Lawrence avenue, circular in cross section and 16 feet in diameter. The conduit had not been completed at the date of the testimony. It was designed to take away by means of a system of intercepting sewers the sewage then discharged into the lake along the north shore, as well as to supply water from the lake to North Branch.

South Fork of South Branch has its origin about 3 miles south of its confluence with South Branch and was at first merely a storm-water drain. At this time it is dredged for shipping purposes and extends to the Chicago stock yards. A conduit has been built into what is known as the east arm of South Fork, an arm merely dredged out for docks. This conduit, 20 feet in diameter, with a capacity of 120,000 cubic feet per minute, was constructed to divert the sewage entering the lake along the south shore and to supply fresh water to flush South Fork.

The city of Chicago more than thirty years ago established a pumping station at the head of South Branch near Ashland avenue and Twenty-sixth street for the purpose of turning the foul water of the stream into the Illinois and Michigan Canal, thereby relieving the river of much of its impurity. This plan was efficient for a time, but with the unexampled growth of the city and the consequent increasing foulness of Chicago River the pumping necessary to the purification of the river soon increased beyond the capacity of the plant. These pumps were operated by the city until 1900 and had the effect of reversing the normal course of the current in South Branch. In the year mentioned, however, the works were turned over to the sanitary district of Chicago and finally to the commissioners of the Illinois and Michigan Canal. At present they are used only for keeping up the level of the canal for navigation purposes. The Chicago drainage canal was the result of the increased pollution of Chicago River and was built to divert all the sewage of the city from the lake into Desplaines River.

The Chicago drainage canal begins at Robey street, Chicago, about one-fourth of a mile north of Thirty-first street, and is parallel with the old Illinois and Michigan Canal as far as Lemont—that is, to the range line just east of Summit. This stretch of the canal is 41,100 feet in length. The elevation of the bottom of the channel at Robey street is 24.45 feet below Chicago datum, this datum being the lake level at low-water mark in 1847. From Robey street to Willow Springs, a distance of 13.2 miles, the grade is 1 foot in 40,000, so that at Willow Springs the elevation of the canal bottom is −26.2 feet. The section from Robey street to the range line at Summit is dug in glacial drift 110 feet wide on the bottom, with slopes of 2 to 1, making the width at water line about 200 feet. From the range line at Summit to Willow Springs the canal is in glacial drift except for a short distance, where it strikes some rock. The canal is built in the manner above described throughout this second stretch. From Willow Springs to a point within about 4,000 feet of the controlling works at

Lockport the channel is 160 feet wide on the bottom, with vertical sides formed by excavating the rock which extended most of the distance between the two points. Along this stretch there is a fall of 1 foot in 20,000. At a point within 4,000 feet of the controlling works the canal widens out in fan shape, and just above the works the width becomes considerable. The grade is maintained the same, the elevation of the bottom at the works being −30.1 feet, which gives a total fall of the canal between Robey street and the controlling works of 5.55 feet. The distance between the two points is 28.01 miles.

As originally designed, according to the prescription of law, the canal is intended to carry 600,000 cubic feet per minute, with the water in the lake as datum. This capacity was provided for in all rock excavations, but in the first section, between Robey street and Summit, the canal was made smaller, with a view to widening in the future as the demand should arise. The canal was commenced in the fall of 1892, and it was accepted by the governor of Illinois January 17 1900.

The flow from the canal to Desplaines River during the early periods is as follows:

Flow from Chicago drainage canal to Desplaines River, January 20, 1900, to March 31, 1901.

	Cubic feet per minute.
January 20 to March 31, 1900	179,741
March 31 to June 30, 1900	211,577
June 30 to September 29, 1900	210,317
September 29 to December 29, 1900	250,635
December 29, 1900, to March 31, 1901	303,736
Maximum flow, March 16, 1901	356,723

The rate of flow in the canal, as reported June 20, 1900, by Major Willard, United States Engineer Corps, was as follows: Whenever there was a discharge of 150,000 to 210,000 cubic feet per minute the average velocity was 1.79 feet per second, or 1.22 miles per hour; when the discharge was from 270,000 to 310,000 cubic feet per minute the average velocity was 2.72 feet per second, or 1.85 miles per hour.

For the purpose of showing the population tributary to Chicago River in the city, and thereby indicating the great amount of polluted matter discharged into it, the witness stated that he had made for the whole city a distribution of the population according to the points of watercourse to which it is tributary and had represented that distribution of the city into districts by a map, which he introduced in evidence. These districts are numbered from 1 to 12, inclusive, and were fixed according to the sewer map of Chicago, showing the main sewers, each district being tributary to one of them. Based on these districts, the total population of the sanitary district—that is, north of Eighty-seventh street—was, in 1900, 1,639,546. Consolidating certain districts in accordance with the drainage system, the witness found that the population tributary to the main portion of Chicago River and to South Branch was 791,677; that tributary to the lake on the south shore, which the witness explained will ultimately be discharged into South Branch, was 175,182; tributary to South Fork of South Branch, 282,655; tributary to West Fork within the city limits, 74,899; tributary to North Branch, 555,789; tributary to the lake on the north shore, 28,878. Aside from the districts here enumerated there was in the southern part of the sanitary district a population of 18,827 that had not up to that time been provided with a sewerage system; and in what is known as the Calumet district, lying south of Eighty-seventh street and discharging into Calumet River, there was a population of 70,636.

Summarizing these, the witness stated that there drained into the main river, South Branch, and various tributaries a total population of 1,705,020. To this there would ultimately be added, through the Lawrence avenue and Thirty-ninth street conduits, under construction, the drainage from a population of 204,060. After these conduits are put into operation, the sewage intercepted and turned into the river, there will be distributed directly into the main river, South Branch, and the drainage canal the sewage from a population of 800,829; into South Fork that from 476,664; into West Fork that from 74,899; and into North Branch that from 584,664. The foregoing figures are based on the school census, which was in excess of the Federal census by about 16 per cent. Witness stated that the sewage from about 200,000 people was discharged directly into Lake Michigan.

CROSS-EXAMINATION.

On cross-examination the witness stated that the pumps which were used in South Branch of Chicago River to deliver polluted water to the Illinois and Michigan Canal had operated most of the time since their installation up to 1900, or for a period of about thirty years, usually at their full capacity, not far from 45,000 cubic feet per minute, and that this water eventually reached Illinois River through the foot of the canal at La Salle and from various waste weirs between the two points.

REDIRECT EXAMINATION.

The testimony of the witness was closed with a description of the controlling works of the Chicago drainage canal at Lockport. He stated that at these works there were seven sluice gates operated by mechanical appliances, each gate having an opening 30 feet wide. They are held as a reserve until the time comes when they will be needed. The main appliance relied on at present for controlling the flow from the canal is known as the Bear Trap dam; it is 160 feet long and has a vertical oscillation of 17 feet. This dam is a steel caisson, the upper edge of which points upstream and can be lowered or raised by water power. When the dam was completely lowered, there would pass over it an amount of water which the witness estimated as from 800,000 to 1,000,000 cubic feet per minute, or more than equal to the capacity of the intake of the canal at Chicago River; while when the dam is raised to its maximum height, the flow of water from the canal can be shut off completely.

The testimony of this witness occupies pages 480 to 543 of the record.

J. L. VAN ORNUM.

J. L. Van Ornum, called as a witness in behalf of the complainant, qualified by making the following statements: He is a civil engineer by profession, having graduated from the University of Wisconsin in 1888; for about ten years thereafter was engaged in the general practice of the profession of civil engineering in different parts of the country, the work including municipal, railway, and river and harbor investigations, together with that on the Mexican boundary survey; at the time of testimony and during four years previous thereto had been professor of civil engineering at Washington University, St. Louis, Mo. (1733–1734)[a].

The witness stated that in March, 1903, he was engaged by the city of St. Louis to determine the time required for water to flow from Chicago, through the drainage canal and Desplaines, Illinois, and Mississippi rivers, down to the water intake at Chain of Rocks. The investigation was divided into three sections; one covered the distance from Chicago to Peoria, the second from Peoria to Grafton, and the third from Grafton to Chain of Rocks. It had been the intention to carry on the work in all these sections simultaneously and continue the observations day and night, but this was found impracticable by reason of adverse conditions which made it impossible to follow the floats at night. Therefore they were taken out of the water at night and replaced in the same positions on the following morning. (1734.)

The floats were of the submerged type, the lower portion consisting of metal-plate vanes set into each other in such a way that in whatever direction the current should turn there would be a considerable area exposed. Each plate was 12 by 12 inches in area. It was connected to the buoyant part of a float by a chain, the length of which varied in different floats according to the depth of the water in which it was used. The part of the float which gave buoyancy consisted of

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[a] Figures in parentheses throughout this paper refer to pages of the official record of testimony.

two cones with bases superimposed at the periphery. The cones had a diameter at the base of 12 inches, while the axis of the double cone was about 8 inches in length, the idea being to so regulate this size that the buoyant part of the submerged float would be made to sink to about half its height by the weight which it was supporting. Extending down through the center of this cone was a cylindrical tube into which was set a stiff wire which supported a metal flag 4 by 4 inches. This flag was numbered and painted a certain color in order that the observers might readily distinguish the various floats. The whole idea of float construction was to get as closely as practicable the velocity of water on and below the surface, rather than merely that at the surface, so that there might be derived from the observations a more accurate idea of the velocities of the stream. The length of the chains supporting the vanes was set at 1, 2, and 3 feet for those used on Illinois River, while those on Mississippi River were regulated to 2, 4, and 6 feet. (1735–1736.)

The testimony of the witness with reference to the intervals noted during the investiagtion is collected in Table 2. (1737–1742.)

TABLE 2.—*Rate of flow of Chicago drainage canal and Desplaines, Illinois, and Mississippi rivers from Chicago to St. Louis, March, 1903.*

FIRST SECTION—CHICAGO TO PEORIA.

Day.	Measuring points.	Interval. Hr.	Interval. min.	Remarks.
	Head of canal			
	Western Avenue Bridge, Chicago		40	Estimated.
15	C. and C. T. Ry. bridge	7	59	
16–17	Cook County line	19	4	
16	Desplaines River at Bear Trap dam	6	43	34 hours 26 minutes in canal.
16	Joliet, Ill	2	15	River at flood stage.
17	Designated flag station	3	36	
18	1 mile above Dupage River	3	6	
19	Morris	7	54	
20	Seneca	5	2	
20	Marseilles	2	15	
21	Ottawa	2	7	
21	Utica	3	36	
22	La Salle	2	28	
22	Peru		58	
22	Marquette	5	6	
22	Depue	1	1	
23	Hennepin	4	15	
23	Twin Island	7	5	
[a]24				
25	Henry	8	36	
25	Flag station at small island	1	49	
26	Chillicothe	11	18	
25	Rome	2	26	Observations by special party sent ahead.
25	Blazed tree on bank	9	48	
26	Peoria main highway	17	45	Lockport to Peoria, 102 hours 26 minutes.

[a] No observation by reason of storm.

TABLE 2.—*Rate of flow of Chicago drainage canal and Desplaines, Illinois, and Mississippi rivers from Chicago to St. Louis, March 1903*—Continued.

SECOND SECTION—PEORIA TO GRAFTON.

Day.	Measuring point.	Interval.	Remarks.
		Hr. min.	
	Peoria		
14	Pekin	4 30	River at flood stage.
15	Kingston	3 17	
15	Banner	7 43	
16	Liverpool	8 58	
17	Havana	10 40	
18	Sheldons Grove	10 37	
19	Beardstown	10 51	
20	Lagrange	6 22	
20	Flag station on tree	3 33	
21	Naples	5 19	
18	Florence	4 15	Observations by special party sent ahead.
18	Bedford	3 35	
19	Pearl	2 45	
19	Kampsville	5 15	
19	Designated beacon	1 40	
20	Hardin	3 50	
20	Government light	5 15	
21	Grafton	4 2	Peoria to Grafton, 102 hours 27 minutes.

THIRD SECTION—GRAFTON TO CHAIN OF ROCKS.

Day.	Measuring point.	Interval.	Remarks.
	Grafton		
18	Alton	6 36	River at half stage.
18	Intake tower, Chain of Rocks	4 34	Grafton to Chain of Rocks, 11 hours 10 minutes.

Total time, Chicago to St. Louis, 10 days, 10 hours, 29 minutes.

The witness stated that although the work was all done under his supervision, none of it was conducted personally except that between Grafton and Chain of Rocks. The assistant engineers employed to make the observations between Chicago and Grafton submitted field notes properly certified. These notes included records of velocity and direction of wind, velocity of floats, condition of the weather and stream, the general course taken by the floats, and every incident or fact having any bearing on the work. The instructions given to assistant engineers making the observations were that the floats should be placed in the stream along the cross section and allowed to take their own course. Whenever one of the floats would go ashore or become entangled in a snag, it would be removed and carried forward to the position of the most advanced float. (1743–1744.)

In reply to a question concerning the side of the river taken by the floats during the observations made from Grafton to Chain of Rocks, the witness stated that the floats were placed in the lower end of Illinois River in such a way that they went across the river, one in the center, one about half way from the center to the right bank, and the third half way from the center to the left bank. As they floated into Mississippi River they moved closer to the Illinois shore, and from Illinois River to a point below the mouth of the Missouri they were more or less close to the Illinois shore. At a point about 2 miles above the waterworks intake, the floats were fairly close to the Illinois shore, perhaps about 50 feet from it, but from this point down to the intake the floats rapidly left the Illinois shore, reaching the middle of Mississippi River, and finally passing the intake between it and the Missouri shore. (1745–1746.)

On being recalled to the witness stand, Professor Van Ornum testified that he had taken samples from Mississippi and Missouri rivers and sent the same to George C. Whipple at Brooklyn for examination. The samples were taken along the sections across the rivers as follows: Section B in Missouri River above its confluence with the Mississippi; section M in Mississippi River above the mouth of the Missouri; section C in Mississippi River below the mouth of the Missouri; and section I in Mississippi River close to the intake at Chain of Rocks. A chart showing these locations was presented and discussed. The samples taken were numbered from 1 to the highest number, No. 1 always being toward the right bank of the river. Eight points were located along each of sections M and C, twelve along section I, and three along section B. At each sampling point on section B one sample was taken at a depth of 10 feet; at each point on sections C and I three samples were taken at depths of 6 inches, 10 feet, and 30 feet or at the bottom, being designated, according to the depth of the water, a, b, and c, respectively. (1882–1884.)

AMAND NICHOLAS RAVOLD.

DIRECT EXAMINATION.

Dr. Amand Nicholas Ravold was called as a witness on behalf of the complainant and qualified as an expert by stating that he had been a practicing physician since 1881 and a professional bacteriologist since 1885. From 1887 he had been connected with the medical department of Washington University, during most of which period he had held the professorship of bacteriology. In 1894 he entered the employ of the health department of the city of St. Louis, as consulting bacteriologist. The testimony occupies pages 2–480, volume 1 of the record.

After relating at some length the history of bacteriology and its development and discussing briefly various epidemic diseases and methods of sewage disposal, the witness was directed to the subject in hand. (7 et seq.)

The bacteriological investigation carried on by the city of St. Louis to determine the effect of the water from the Chicago drainage canal was divided into three periods, the first extending from August to December, 1899; the second from January to December, 1900, and the third from September to November, 1901, each inclusive. Besides this, from January to April, 1902, the witness engaged in special investigations, and from June to September of the same year carried on experiments to determine the longevity of *Bacillus typhosus* in water under various conditions. The witness further stated that all methods used in these investigations conformed with the recommendations of the committee on standard methods in water analyses appointed by the American Public Health Association, except such special procedure as he had devised during the investigations for original work. (57–76.)

Previous to the beginning of this investigation a temporary bacteriological laboratory was established at Chain of Rocks, and August 10, 1899, numerous samples of the water were taken from the river in the intake and in the uptake, which is at the end of the 1,500 feet of channel running from the intake tower to the Missouri shore. As the results are simply preliminary in character and not especially significant, the tables will not be given in this review. It is sufficient to state that from August 10 to September 25, 1899, the number of bacteria in Mississippi River above the intake varied from 275 to 3,600 per cubic centimeter; the four water samples taken at the intake from August 10 to 23 showed a content of 375 to 950 bacteria per cubic centimeter, and in the samples taken at the uptake from August 10 to September 11 the number of bacteria varied from 150 to 1,500. The results, as a whole, show an unmistakable decrease in the number of bacteria between the river above the intake and the end of the tunnel at the shore. (76–81.)

Following this five series of samples were taken from a boat along Illinois, Mississippi, and Missouri rivers at various points, the results of which are not here recorded. (81–85.)

Commencing January 23, 1900, six days after the opening of the Chicago drainage canal, a systematic bacteriological survey was started, daily samples being taken from the following points:

Lake Michigan.
Chicago drainage canal.
Desplaines River at Joliet and Lockport.
Illinois River at Peoria, Beardstown, and Grafton.
Mississippi River at Grafton, Alton, and Hartford.
Missouri River at Fort Bellefontaine.
Mississippi River opposite St. Louis water-supply intake at three points on cross section, Missouri shore, midriver, and Illinois shore.

These samples were transported to St. Louis, and throughout the remainder of the year the number of bacteria per cubic centimeter and the presence or absence of *Bacillus coli communis* were determined. The results of the determinations on Lake Michigan samples are given in Table 3. (93–96.)

TABLE 3.—*Bacteriological examination of seventeen samples of water from Lake Michigan in 1900.*

Date.	Place.	Bacteria per cubic centimeter.	B. coli communis.[a]
July 23, 11.45 a. m	4-mile crib	1,600	+
July 30, 11.30 a. m	Carter Harrison crib	12,300	+
Aug. 9, 4.00 p. m	10 miles out from Chicago	16,300	+
Aug. 31, 10.30 a. m	Carter Harrison crib	21,400	+
Sept. 7, 11.30 a. m	Lake View crib	5,200	—
Sept. 15, 10.30 a. m	2-mile crib	909,700	+
Sept. 15, 11.45 a. m	3-mile crib	111,500	+
Sept. 22, 2.00 p. m	2-mile crib	61,000	—
Sept. 22, 11.15 a. m	68th street crib	44,000	—
Oct. 11, 12.15 p. m	2-mile crib	1,100	—
Oct. 11, 11.30 a. m	3-mile crib	1,000	+
Oct. 19, 11.00 a. m	2-mile crib	4,400	+
Oct. 19, 10.30 a. m	3-mile crib	1,100	—
Oct. 26, 11.45 a. m	4-mile crib	90,000	—
Oct. 26, 12.30 a. m	68th street crib	157,500	—
Nov. 9, 11.30 a. m	do	3,300	—
Nov. 9, 11.00 a. m	4-mile crib	2,900	—

[a] + indicates presence of *B. coli communis;* — indicates absence of *B. coli communis.*

The witness then read into the record the results of the daily examinations made at the various other points above mentioned. The complete statement occupies pages 100–211, inclusive, of the official record of testimony. The results, condensed into weekly averages with the per cent of samples containing *B. coli communis*, are included in Table 4.

In connection with report of these investigations the witness discussed the work of identification of bacterial flora in samples taken from seven points. The results are combined in Table 5.

TABLE 4.—*Weekly averages of results of bacteriological examinations January 23 to October 9, 1900, on samples taken from designated points.*

[Numbers of bacteria expressed in thousands per cubic centimeter; of *B. coli communis* in per cent.]

Week beginning—	Drainage canal at Lockport.		Desplaines River at Joliet.		Illinois River 3 miles above Peoria.		Illinois River 3 miles above Grafton.		Mississippi River 3 miles above Grafton.		Mississippi River above Alton.	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Jan. 23	....	.....	....	.....	170	100	116	40	41	57	120	40
Jan. 30	....	.....	....	.....	360	71	189	30	46	20	115	0
Feb. 6	....	.....	....	.....	91	57	258	33	43	30	100	0
Feb. 13	....	.....	....	.....	622	66	222	83	161	17	296	33
Feb. 20	....	.....	....	.....	378	66	222	71	105	33	250	29
Feb. 27	....	.....	....	.....	374	66	223	83	55.5	83	157	60
Mar. 6	1,010	80	2,792	71	210	43	268	43	125	71	215	43
Mar. 13	10,339	83	9,208	66	579	86	277	86	490	86	312	57
Mar. 20	16,233	57	13,308	86	536	83	204	57	434	66	156	57
Mar. 27	4,921	71	4,860	71	276	50	159	57	142	40	90	43
Apr. 3	2,490	100	5,602	86	310	43	143	71	37.5	0	59.5	29
Apr. 10	2,391	83	6,250	57	65	16	24	50	69	57	23.5	60
Apr. 17	621	71	934	71	65	43	9	71	18.5	57	9.5	43
Apr. 24	191	60	236	57	20	0	2.5	0	11	71	10	29
May 1	821	100	211	83	5	80	2.5	25	2	67	7	20
May 8	323	86	581	83	78	86	12.5	66	7	71	13.5	71
May 15	140	71	354	30	462	30	6	43	6.5	57	16.	43
May 22	1,232	100	783	66	623	83	6	80	6.5	100	8	75
May 29	634	83	213	86	62	16	9.5	100	5.5	30	7	29
June 5	939	100	169	86	268	71	6.5	86	7	57	12.5	83
June 12	1,951	71	461	60	188	57	6	66	20	83	9	57
June 19	2,201	71	103	14	344	100	31	71	12	57	5.5	83
June 26	406	100	127	71	1,766	57	6.5	43	14.5	86	6	57
July 3	1,225	100	121	100	304	66	17	86	15.5	83	3.5	83
July 10	181	71	90	71	791	100	15	71	24	43	3.5	29
July 17	211	100	94	57	1,549	71	11.5	57	9	57	18	57
July 24	479	83	168	43	335	100	18	100	12	86	5	43
July 31	346	100	450	100	489	100	9	100	20	100	2.5	100
Aug. 7	209	100	110	100	1,425	100	14	100	12.5	100	1	100
Aug. 14	312	100	90	100	1,513	100	12.5	86	18	100	2	100
Aug. 21	1,671	100	208	100	373	100	15.5	100	36.5	100	3	100
Aug. 28	255	100	74	100	330	100	26.5	100	32	100	7	100
Sept. 4	261	100	651	100	903	100	29	100	17	100	1.5	100
Sept. 11	1,669	100	1,068	100	215	100	7.5	100	8	100	1	100
Sept. 18	115	100	508	100	313	100	3	100	8.5	100	2	100
Sept. 25	1,104	100	696	100	288	100	3	100	14.5	100	4	100
Oct. 2	183	100	125	100	306	100	16.5	100	20.5	100	2	100

Week beginning—	Mississippi River at Hartford.		Missouri River at Fort Bellefontaine.		Mississippi River at Chain of Rocks, Missouri shore.		Mississippi River at Chain of Rocks, intake tower.		Mississippi River at Chain of Rocks, Illinois shore.		Outlet of reservoir, St. Louis waterworks.		Tap in laboratory, St. Louis.	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Jan. 23	88	25	213	50	240	25	154	60	155	50	49.8	67	....	.....
Jan. 30	147	33	141	0	147	0	135	0	76	75	110	29	....	.....
Feb. 6	106	0	63	0	58	0	75	0	106	0	28.3	0	....	.....
Feb. 13	233	25	52	0	98	29	133	100	224	25	92.2	0	....	.....
Feb. 20	267	83	70	0	77	50	112	66	192	100	106.3	33	....	.....
Feb. 27	193	40	63	80	50.5	60	53	50	77	100	53.1	60	....	.....
Mar. 6	209	14	176	43	177	75	177	33	174	100	69.8	29	....	.....
Mar. 13	320	86	435	71	485	57	485	50	374	86	253	83	....	.....
Mar. 20	228	71	271	43	315	57	512	57	254	43	349.5	71	....	.....
Mar. 27	60.5	14	139	50	70	29	118	29	76	86	76.8	29	....	.....
Apr. 3	58	43	140	29	76	57	118	43	47.5	14	41	43	....	.....
Apr. 10	34	33	66	50	62.5	100	90	67	37	0	35.5	40	....	.....
Apr. 17	16	71	49	57	21	57	37	57	14.5	71	84.7	71	....	.....
Apr. 24	7.5	29	49	50	11.5	43	12	57	9	16	9.8	43	....	.....
May 1	11.5	100	16.5	80	10.5	60	7	80	2.5	100	7.1	75	....	.....
May 8	15.5	86	22	43	46	43	23.5	100	21.5	57	23.3	43	10.5	.....
May 15	18	50	45.5	33	43	67	13.5	14	24	43	14.5	33	3.5	0
May 22	6	100	40.5	50	29.5	83	4	100	9	67	4.2	100	3.6	20
May 29	8	71	52	100	25	86	17	86	20	86	7.6	100	2.1	100
June 5	6	43	55.5	43	22.5	57	23.5	71	26	100	4.7	100	2.1	57
June 12	5	86	63.5	57	38.5	57	26.5	57	21.5	86	12.3	71	1.6	43
June 19	5	50	112	67	38.5	29	17	50	20.5	71	9.2	67	1.3	71
June 26	4.5	83	105	57	17	57	13	57	10.5	100	7.7	43	.9	100
July 3	3.5	57	29.5	86	1	86	14	80	10.5	100	4.8	100	1	100
July 10	7	100	27.5	100	20.5	100	19	71	8	57	5.4	86	.9	33
July 17	4	16	21	83	17.5	33	13	33	7.5	71	3.6	71	.6	67
July 24	3	50	10.5	57	10	71	7	83	4.5	57	2.7	100	1	86
July 31	1.5	100	10.5	100	6.5	100	4.5	100	5	100	3.6	100	1.1	100
Aug. 7	1.5	100	7	100	10	100	8.5	100	4.5	100	2.1	100	.8	100
Aug. 14	2	100	5.5	100	10	100	6.5	100	5.5	100	3.3	100	.8	100
Aug. 21	3.5	100	14	100	10.5	100	14	100	3.5	100	2.1	100	.9	100
Aug. 28	3.5	100	12.5	100	12	100	6.5	100	8.5	100	3.9	100	1.9	100
Sept. 4	2.5	100	6.5	100	5.5	100	4.5	100	2	100	2.6	100	1	100
Sept. 11	1	100	40.5	100	24	100	30.5	100	1.5	100	4.1	100	.7	100
Sept. 18	2.5	100	36	100	30.5	100	25.5	100	8	100	4.1	100	1.1	100
Sept. 25	4	100	36	100	30	100	25.5	100	13	100	10.7	100	1.7	100
Oct. 2	2.5	100	24	100	23.5	100	17	100	6	100	3.5	100	1.6	100

TABLE 5.—*Bacterial flora in Desplaines, Illinois, Mississippi, and Missouri rivers at designated points.*

Species.	Desplaines River at Joliet.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River at Hartford.	Mississippi River at Chain of Rocks.	Missouri River at Fort Bellefontaine.	Laboratory tap, St. Louis.
Bacillus albus	+	......	......	+	......	+	......
B. antenniformis	......	......	......	......	+	+	......
B. aquatilis sulcatus I	+	......	+	......	......	......	......
B. aquatilis sulcatus III	......	......	+	+	......	+	......
B. aquatilis sulcatus V	+	+	+	......	+	......	......
B. arborescens	......	......	+	+	......	+	+
B. aurescens	......	+	+	+	+	+	......
B. aureus	......	+	+	+	......	......	......
B. brunneus	......	......	......	+	......	......	......
B. candicans	......	......	......	......	......	......	+
B. cereus	......	+	+	+	+	+	+
B. cloacæ	+	+	+	+	+	+	+
B. coli communis	+	+	+	......	......	......	+
B. delicatulus	+	+	......	+	+	......	+
B. desidiosus	......	+	......	......	......	......	+
B. fluorescens incognitus	......	......	......	+	......	+	......
B. fluorescens liquefaciens	......	......	+	+	+	+	......
B. fluorescens tenuis	+	+	......	+	......	......	+
B. fluorescens termo	......	......	+	+	......	......	......
B. fulvus	......	......	......	......	......	+	+
B. helvolus	+	......	+	+	+	......	+
B. iridescens	+	......	......	+	+	......	......
B. lactiviscosus	+	+	+	......	+	......	+
B. lactis erythrogenes	......	......	......	+	......	......	......
B. liquefaciens	+	+	+	......	......	+	+
B. liquidus	......	......	......	......	+	......	......
B. megaterium	......	+	......	+	+	+	+
B. mesentericus vulgatus	......	+	......	+	......	......	......
B. nubulis	......	......	......	......	......	+	......
B. ocraceus	+	+	+	......	......	......	......
B. plicatus	......	+	......	......	......	......	......
B. proteus mirabilis	+	+	......	+	......	......	+
B. proteus zenkeri	+	......	+	+	......	+	+
B. proteus zaearei	......	+	......	......	......	......	......
B. rubefaciens	......	......	......	......	......	......	+
B. stellatus	+	+	......	+	+	+	+
B. subflavus	......	+	......	......	......	......	......
B. subtilis	......	......	......	......	+	......	......
B. superficialis	+	......	......	+	......	......	......
B. ubiquitus	......	+	......	......	+	......	......
B. ureæ	......	+	......	......	......	......	......
B. viridis	......	+	+	......	+	+	+
Micrococcus cremoides	......	......	......	......	......	......	+
M. flavus liquefaciens	......	......	......	......	......	......	+
Sarcina lutea	+	......	......	......	......	+	+

A third series of examinations extended throughout the period from August 26 to December 1, 1901. The plan of procedure involved the establishment of temporary laboratories equipped with the necessary apparatus at the following points: Joliet, Ill., in charge of Dr. W. C. G. Kirchner; Peoria, Ill., in charge of Dr. William H. Rush; Grafton, Ill., in charge of Leon G. Tedesche; 1141 Market street, St. Louis, with five assistant bacteriologists under the charge of Dr. Ravold.

Samples were collected from the following points:

Sampling points, August 26 to December 1, 1901.

	Number of samples.
Desplaines River at Lockport, above junction with drainage canal	40
Bear Trap dam, drainage canal	52
Illinois and Michigan canal, at Ninth Street Bridge, Lockport	34
Desplaines River at Ninth Street Bridge	41
Desplaines River at Ruby street, Joliet	51
Desplaines River at Brandon's bridge, Joliet	49
Illinois River at Averyville	54
Illinois River at railroad bridge, Pekin	57
Illinois River at Kingston, 3 miles below Pekin	55
Illinois River above Grafton	56
Mississippi River above Grafton	56
Mississippi River 1 mile above Alton	52
Mississippi River at Hartford	51
Missouri River at Bellefontaine	55
Mississippi River at Chain of Rocks, near Illinois shore	74
Mississippi River at Chain of Rocks, near Missouri shore	72
Mississippi River at intake tower	70
Reservoir at Chain of Rocks	75
Reservoir at Bissells Point	72
Laboratory tap, 1141 Market street, St. Louis	69
Tap at residence 5946 Garfield avenue, St. Louis	49

Besides the above, seven samples were collected from Illinois River at Lasalle, and twenty-four at Beardstown. These samples were sent to Peoria.

The witness explained that the purpose of taking the series of samples from a tap on Garfield avenue, St. Louis, was to show the difference in the condition of the water in the high service from that in the low. In addition to the seventy-hours sedimentation period afforded by the reservoirs at Chain of Rocks, the water diverted to the low service had the benefit of further storage in the reservoirs at Bissells Point. No further sedimentation period is afforded to the high service after leaving Chain of Rocks, but the effect of the long distance traveled by the water in the mains must be taken into account. Between the Chain of Rocks reservoirs and the Garfield avenue tap, 10 miles of pipe intervene, 6 miles of this lying between the reservoirs and the Compton Hill standpipe, and 4 miles between the standpipe and the Garfield avenue house.

The results of the third series of examinations were then read into the record by Dr. Ravold, and are reported on pages 222–275, inclusive. Table 6 contains the weekly averages of these determinations, together with the proportion of samples in each week containing *Bacillus coli communis*. These results are fairly representative of the daily figures and may be accepted in connection with all interpretations necessary to this testimony without important error.

TABLE 6.—*Weekly averages of results of bacteriological examinations, September 14 to November 30, 1901, on samples from designated points.*

Numbers of bacteria expressed in thousands per cubic centimeter; of *B. coli communis* in per cent.]

Week beginning—	Desplaines River above junction with Chicago drainage canal.		Bear Trap dam, Chicago drainage canal, Lockport.		Illinois and Michigan Canal at Ninth Street Bridge, Lockport		Desplaines River at Ninth Street Bridge, Lockport.		Desplaines River at Ruby street, Joliet.		Desplaines River at Brandon's bridge, Joliet.		Illinois River, 3 miles above Peoria	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Sept. 21..	....	.....	950	50	496	50	....	.....	471	100	344	.....	....	.....
Sept. 28..	....	.....	824	60	282	60	84	50	317	67	221	100	1.74	75
Oct. 5....	42.3	20	487	75	665	50	317	25	224	100	442	100	.34	86
Oct. 12...	4.2	40	764	60	1,077	33	366	25	581	83	69	67	1.16	100
Oct. 19...	25.3	60	348	100	532	33	193	100	453	100	343	75	.27	86
Oct. 26...	1.7	0	371	.....	1,080	.....	284	25	438	.....	346	.....	.66	71
Nov. 2...	4.2	.....	533	.....	....	.....	621	.....	249	.....	200	.....	.30	86
Nov. 9...	2.0	.....	495	.....	....	.....	441	.....	274	.....	299	.....	1.6	86
Nov. 16..	4.0	.....	3,429	.....	....	.....	3,572	.....	2,153	.....	210	.....	3.2	71
Nov. 23..	4.2	.....	5,000	.....	....	.....	6,000	.....	2,990	.....	3,045	.....	3.6	100

Week beginning—	Illinois River above railroad bridge at Pekin.		Illinois River at Kingston, 3 miles below Pekin.		Illinois River above Grafton.		Mississippi River, 2 miles above Grafton.		Mississippi River, 1 mile above Alton.		Mississippi River opposite Hartford.		Missouri River opposite Fort Bellefontaine.	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Sept. 28..	36.5	100	....	.....	....	.....	....	.....	....	.....	....	.....	....	.....
Oct. 5....	20.4	100	387	100	1.4	57	0.82	29	0.56	100	0.74	100	11.1	100
Oct. 12...	202	100	385	100	1.1	57	.79	71	.67	100	1.5	100	31.8	100
Oct. 19...	81.7	100	221	100	2.1	43	.68	0	1.6	100	2.6	86	37.9	71
Oct. 26...	9.2	71	481	100	2.6	57	.68	43	1.9	100	3.5	57	33.6	100
Nov. 2...	5	100	275	86	7.1	43	1.2	43	1	50	2.5	50	21.7	75
Nov. 9...	7.0	100	41	100	1.8	14	.99	71	1.5	86	3.5	71	49.2	86
Nov. 16..	4.3	100	21.1	100	4.8	29	2.7	57	1.5	57	1.5	29	30.4	50
Nov. 23..	3.3	.....	15.8	.....	3.7	.....	5.3	100	2.2	43	4.9	50	53.3	100

Week beginning—	Mississippi River at Chain of Rocks, near Illinois shore.		Mississippi River at Chain of Rocks, near Missouri shore.		Mississippi River at intake tower, Chain of Rocks.		Reservoir at Chain of Rocks.		Reservoir at Bissells Point.		Laboratory tap, 1141 Market street, St. Louis.		Tap at residence, 5946 Garfield avenue, St. Louis.	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Sept. 14..	0.59	67	1.1	75	1.8	50	0.46	67	0.14	.....	0.61	50	....	.....
Sept. 21..	5.3	86	3.5	67	3.5	83	1.2	83	.47	83	.34	100	....	.....
Sept. 28..	1.9	83	4.3	100	4.7	83	2.2	100	.49	67	.42	67	....	.....
Oct. 5....	8.5	100	7.7	100	6.8	83	1.75	100	.67	100	.91	100	0.31	86
Oct. 12...	2.1	100	10.5	86	14.5	86	3.0	100	.63	86	.94	100	.38	100
Oct. 19...	2.7	86	33.1	100	40	86	5.6	100	1.98	100	2.3	100	.53	100
Oct. 26...	1.7	100	25.5	100	34.9	100	7.4	100	1.4	86	1.9	100	.40	100
Nov. 2...	3.2	50	17.0	75	23.5	75	5.8	100	2.3	100	1.1	43	3.1	100
Nov. 9...	2.4	86	40.9	86	45	86	7.1	100	2.8	100	2.5	86	3.9	100
Nov. 16..	2.2	86	52	71	53.7	57	10	100	2.6	100	3.2	71	2.9	83
Nov. 23..	5.2	71	32.9	100	39.2	86	7.8	71	2.9	83	2.9	80	1	100

Summing up the results of the third period of examination, the witness stated the percentage of samples taken at the various points along Mississippi River below Illinois River in which *Bacillus coli communis* was found, as shown in Table 7. (275–277.)

TABLE 7.—*Proportion of samples of water from designated points in which Bacillus coli communis was found, September to November, 1901.*

Sampling point.	September.	October.	November.	Average.
Mississippi River at Alton	....	100	77	88.6
Mississippi River at Hartford	....	86.4	56	70
Missouri River at Fort Bellefontaine	....	92.6	80	86.2
Chain of Rocks, Missouri shore	76.9	97	84.6	88.4
Chain of Rocks, Illinois shore	76.9	97	77	81.7
Chain of Rocks intake	76.9	90	77	80
Bissells Point reservoir	86.4	94.04	93.8	91.41
Tap in old city hall, St. Louis	85.7	97	80	87.5

Discussing the percentage of the removal of bacteria per cubic centimeter at various sampling points in the St. Louis water-supply system, the witness gave the evidence set forth in Table 8. (277–279.)

TABLE 8.—*Percentage of removal of bacteria per cubic centimeter at various sampling points in the St. Louis water-supply system, September to November, 1901, the number in Mississippi River being designated as 100 per cent.*

Sampling point.	September.	October.	November.	Average.
Chain of Rocks reservoir	48.43	85.6	81.5	71.84
Bissells Point	86.05	90	93.5	90
Tap in old city hall	88.83	95.9	93.2	92.64
Tap on Garfield avenue	....	98	92.7	95.3

In discussing further the number of bacteria found at various sampling points in the river, the witness called attention to the fact that the average number of bacteria in Mississippi River above Grafton, as shown by the investigations during the third period, was 717 and 2,290 during October and November, respectively, while in Illinois River above Grafton there were 1,780 and 3,050 during the same months, showing that the water of the Illinois contains the larger number. (279.)

Doctor Ravold then considered the results of the investigations of the bacterial flora and testified concerning the physical and cultural characteristics of the various bacteria isolated during the entire investigation. The characteristics of the following organisms are set forth in volume 1 of the record, pages 280–307, inclusive:

Bacteria discussed by Dr. A. N. Ravold.

Bacillus albus.
B. antenniformis.
B. aquatilis sulcatus I.
B. aquatilis sulcatus III.
B. aquatilis sulcatus V.
B. arborescens, chromogenic, orange.
B. aurescens.
B. aureus.
B. brunneus.
B. candicans.
B. cloacæ.
B. coli communis.
B. delicatulus.
B. desidiosus.
B. fluorescens incognitis.
B. fluorescens liquefaciens.
B. fluorescens tenuis.
B. fluorescens termo.
B. fulvus.
B. helvolus.
B. hyalinus.
B. iridescens.
B. lactiviscosus.
B. lactis erythrogenes.
B. liquefaciens.
B. liquidus.
B. megaterium.
B. mesentericus vulgatus.
B. nubilis.
B. ocraceus.
B. plicatus.
B. proteus mirabilis.
B. proteus zenkeri.
B. pyocyaneus.
B. rubefaciens, chromogenic, red.
B. stellatus.
B. subflavus.
B. subtilis.
B. subtilis cereus.
B. superficialis.
B. ubiquitus.
B. ureæ.
B. viridis.
Micrococcus cremoides.
M. flavus liquefaciens.
Sarcina alba.
S. lutea.

The witness gave extended definitions of bacteriological terms and a somewhat minute description of general methods of bacteriological procedure. (307–312.)

He then testified concerning microscopic organisms (algæ, etc.), describing the Sedgwick-Rafter method of procedure, and stated that two series of examinations had been made according to this method in connection with the investigations carried on by the city of St. Louis. He further stated that the object of this work was to discover the micro-organisms connected with sewage pollution, and also to attempt to trace the forms found in Lake Michigan water which are distinctive from those existing in Illinois, Mississippi, and Missouri rivers. Two sets of investigations were made—one by George A. Johnson, at the St. Louis laboratory, and one by George C. Whipple, of Brooklyn, N. Y. The long statement which Doctor Ravold then made concerning the number and genera of the organisms found in the water at chosen points is reproduced in condensed form in Table 9. (312–351.)

TABLE 9.—*Number of micro-organisms found in water at designated points.*

Family and genus.	Lake Michigan.					Drainage canal at Bear Trap dam.				
	4-mile crib.	Carter Harrison crib.	10 miles out.	Lake View crib.	2-mile crib.		June.			
	July 23.	July 30.	August 9.	September 7.	September 15.	May 27	3.	10.	17.	25.
Diatomaceæ:										
Asterionella	100	42	10	84	100	71	73	18	120	40
Cyclotella	19	12		4	16	8	2	1		
Cymbella									14	20
Diatoma	33	65	3	31	14	32	22	4	23	
Fragilaria	6		12				6			
Himantidium						2	4			1
Meridion									6	10
Navicula	11	4	14			4	6	1		
Nitzschia	60	93	86	47	62	23	7		1	14
Stephanodiscus								1	1	
Synedra	680	400	290	100	200	313	116	101	180	96
Tabellaria	30	12	26			55	16	5	16	3
Cyanophyceæ:										
Anabæna										2
Chroococcus	3			6					4	
Cœlosphærium										1
Lyngbya									1	
Oscillaria	30	20			15	15	22	38	4	
Chlorophyceæ:										
Arthrodesmus							2	1		4
Closterium	1	1		1		5				1
Eudorina							1			
Hydrodictyon						12	19			6
Pandorina									3	
Pediastrum	6	9	2	12	9				2	2
Protococcus						2	4		1	
Raphidium	4	16		4		17	7	2		
Scenedesmus	10	4	4	3						5
Spirogyra	1			4	1				4	
Ulothrix	22	10	6	14	6	15	11	16	10	
Schizomycetes:										
Beggiatoa						2		4		
Crenothrix	6	3		12	1	6		3		2
Leptothrix								6		
Protozoa:										
Amœba	2		6		1	23				
Cryptomonas	2		1							
Dinobryon	25	31	14		6		2			
Glenodinium	15	6	8	2	4					
Monas	6	15	9	12	19	32	19	21	6	47
Paramæcium						13		14	12	38
Peridinium	10	3								
Phacus								2		2
Protomonas							8	12	2	
Synura	2	6	4		1	19	6	3		1
Trachelomonas							8			
Vorticella	1	2	1			7	4	4		6
Rotifera:										
Anuræa	4	1	3	1			2			
Polyarthra		1	2							1
Rotifer	2	4	1	2	1			2		2
Crustacea:										
Bosmina						1		1		
Daphnia		1	1			1			1	
Miscellaneous	25	13	14	17	16	3	27	10	1	14
Total organisms	1,117	774	517	256	472	681	394	270	412	318
Total genera	31	26	23	19	18	25	25	24	21	25

TABLE 9.—*Number of micro-organisms found in water at designated points*—Continued.

Family and genus.	Drainage canal at Bear Trap dam.					Desplaines River at Joliet.					
	July.			August.		May 17.	June.				July 11.
	11.	20.	30.	10.	18.		3.	10.	17.	25.	
Diatomaceæ:											
Asterionella	10	6	128	130	39	34	82	96	38	138	80
Cyclotella	4	.....	16	3	.....	3	6	.....	2	4	1
Diatoma	32	10	.....	16	9	17	29	.....	2	6	6
Himantidium	.....	.....	6	.....	.....	10	8	.....	.....	.....	2
Meridion	6	.....	.....	7	.....	.....	.....	.....	.....	.....	.....
Navicula	.....	6	.....	.....	14	5	5	12	.....	.....	19
Nitzschia	6	28	4	.....	12	40	12	34	20	49	60
Syncdra	30	40	88	300	220	153	196	200	90	290	240
Tabellaria	10	14	.....	6	4	6	42	12	.....	14	4
Cyanophyceæ:											
Chroococcus	6	.....	.....	.....	2	.....	.....	.....	.....	.....	.....
Cœlosphærium	4	2	.....	.....	.....	.....	.....	.....	.....	.....	.....
Endoriana	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Lyngbya	2	.....	2	.....	2	3	3	.....	.....	.....	1
Oscillaria	10	6	.....	.....	6	58	60	10	19	61	75
Chlorophyceæ:											
Arthrodesmus	.....	2	.....	1	.....	.....	.....	.....	.....	.....	.....
Closterium	.....	.....	.....	.....	.....	.....	2	.....	1	.....	.....
Desmidium	.....	.....	.....	.....	.....	.....	1	2	.....	4	.....
Dictyosphærium	1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....
Eudorina	1	.....	.....	.....	1	.....	.....	.....	1	2	.....
Hydrodictyon	.....	.....	4	.....	.....	.....	.....	.....	1	.....	.....
Pandorina	.....	.....	.....	.....	.....	.....	.....	.....	.....	1	.....
Pediastrum	.....	6	.....	.....	.....	.....	2	5	.....	7	1
Protococcus	1	.....	.....	.....	.....	.....	.....	4	.....	5	.....
Raphidium	2	.....	.....	2	.....	.....	.....	2	1	.....	.....
Scenedesmus	.....	.....	.....	.....	.....	.....	2	6	.....	16	.....
Spirogyra	.....	.....	.....	.....	.....	4	.....	.....	.....	2	.....
Ulothrix	8	2	.....	.....	.....	.....	.....	.....	20	10	6
Schizomycetes:											
Beggiatoa	10	8	3	.....	.....	.....	.....	.....	.....	.....	.....
Crenothrix	.....	12	.....	.....	.....	3	.....	.....	1	.....	.....
Protozoa:											
Chloromonas	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Monas	6	2	.....	4	6	2	27	10	.....	12	2
Paramæcium	10	.....	.....	31	4	.....	3	1	.....	4	2
Protomonas	8	.....	.....	6	.....	7	2	.....	6	.....	2
Synura	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	3
Vorticella	2	.....	.....	1	2	4	3	.....	.....	.....	1
Rotifera:											
Rotifer	3	.....	2	.....	2	3	1	.....	.....	2	1
Crustacea:											
Daphnia	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	1
Miscellaneous	6	2	12	7	.....	6	22	14	40	15	33
Total organisms	182	147	284	514	323	358	508	408	242	644	542
Total genera	26	16	16	13	14	18	21	15	15	22	21

TABLE 9.—*Number of micro-organisms found in water at designated points*—Continued.

Family and genus.	Illinois River above Peoria.						Illinois River above Grafton.					
	May 27.	June.				July 11.	May 28.	June.				July 11.
		3.	10.	18.	25.			3.	10.	18.	25.	
Diatomaceæ:												
Asterionella	41	61	186	21	94	120	18	43	7	8	30	
Cyclotella		8			16	4	1			3	2	
Diatoma	12	38	6	31		4	7	4	2			2
Himantidium							1					
Melasira								2				
Navicula		9			12		2					2
Nitzschia	23	6	27	31	40	14	4	14	12	3	6	6
Pleurosigma								1				1
Stephanodiscus							1					
Synedra	71	100	22	98	209	153	46	280	140	22	90	170
Tabellaria		12				12						
Cyanophyceæ:												
Lyngbya							1					
Oscillaria	5			16	64	50	1	28	20	4		
Chlorophyceæ:												
Arthrodesmus			1		1					3		6
Closterium	1	2	1	2						1		1
Conferva			6									
Eudorina								2				
Hydrodictyon							1					
Pandorina			1			1						
Pediastrum	19	29	12	6			4	8		4		
Protococcus	4	6		5	10	6		4	19		6	7
Scenedesmus	14	9	18	6	5	5	4	24			8	10
Spirogyra	5	12	12	12			2				3	3
Ulothrix			6		30	40		11			6	9
Zygnema				2								
Schizomycetes:												
Crenothrix							1					
Protozoa:												
Cryptomonas							2				1	
Monas	22	12	4			3	8	12	6		1	2
Paramæcium			2	2		1		1	1			1
Peridinium					1							
Protomonas	9	6		2								
Synura	3		2				3	2		4		4
Vorticella		3		2	5		1			2		
Rotifera:												
Anuræa	4	1	2									
Polyarthra	4											
Rotifer			1			1				2		
Crustacea:												
Cyclops	2	2			2	2						
Daphnia	4	1			1	2						
Miscellaneous	8	12	6	2	43	4	5					4
Total organisms	251	329	315	238	533	422	113	436	207	56	153	228
Total genera	19	19	18	16	17	17	20	15	8	11	10	15

TABLE 9.—*Number of micro-organisms found in water at designated points*—Continued.

Family and genus.	Mississippi River above Grafton.			Mississippi River above Alton.			Mississippi River at Hartford.			Mississippi River at intake tower.		
	May 28.	June 3.	July 11.	May 28.	June 3.	July 11.	May 29.	June 3.	July 11.	May 28.	June 3.	July 11.
Diatomaceæ:												
Asterionella	4	39.	12	12	4	60	9	14	4	21	4	16
Cyclotella	......	4	......	4	......	......	4	1	......	......	2	2
Cymbella	......	......	2	2	......	......	3	......	2	......	1	......
Diatoma	3	12	......	8	4	4	6	......	5	......	......	2
Himantidium	......	......	......	......	......	......	3	......	2	......	......	2
Meridion	4	......	......	6	......	......	2	......	......	6	......	8
Navicula	6	......	......	8	2	2	5	......	6	......	14	11
Nitzschia	9	60	12	10	5	15	19	30	12	32	24	16
Synedra	30	49	239	41	220	96	50	60	22	40	12	39
Tabellaria	7	2	6	9	......	6	12	4	4	8	6	12
Cyanophyceæ:												
Cœlosphærium	......	......	......	......	......	......	4	4	5	......	......	2
Lyngbya	......	......	......	2	......	......	6	......	......	......	......	......
Oscillaria	2	14	2	2	19	......	4	10	10	20	16	22
Chlorophyceæ:												
Arthrodesmus	......	......	......	4	......	1	......	......	2	1	......	1
Closterium	......	......	1	2	......	......	1	......	1	3	......	2
Desmidium	1	......	......	......	......	2	2	2	3	3	3	......
Dictyosphærium	......	......	......	......	......	......	6	2	......	......	......	......
Hydrodictyon	17	......	......	4	......	......	1	......	......	......	......	4
Pediastrum	......	17	......	9	38	11	12	6	4	16	9	3
Protococcus	......	......	5	3	4	......	2	......	5	5	......	......
Scenedesmus	8	16	......	4	16	12	6	12	19	26	8	14
Spirogyra	......	......	......	1	5	......	4	......	8	......	......	1
Ulothrix	12	22	......	4	29	......	......	......	10	4	......	8
Protozoa:												
Cryptomonas	1	......	......	3	......	......	3	4	......	......	2	......
Glenodinium	......	......	1	......	......	......	......	......	......	......	......	......
Monas	3	10	5	12	8	3	10	12	8	6	12	9
Paramæcium	......	1	......	1	......	1	......	......	2	1	......	1
Synura	5	2	2	......	3	3	9	3	3	3	......	......
Vorticella	......	......	......	1	......	......	......	......	2	......	......	......
Rotifera:												
Anuræa	1	......	......	......	......	1	......	......	......	......	......	......
Rotifer	......	......	......	......	1	......	......	......	1	2	......	......
Miscellaneous	6	12	2	5	6	2	7	11	2	3	1	2
Total organisms	119	260	289	152	364	219	190	175	142	200	114	177
Total genera	17	14	12	24	14	15	25	15	24	18	14	22

Witness then took up a part of the bacteriological data afforded by the investigations of the year 1900 and assembled it in weekly averages of the daily determinations made. (353–376.) A chart (Complainant's Exhibit No. 1) was presented, showing such data for:

Illinois river above Grafton.
Mississippi River above Grafton.
Mississippi River above Alton.
Mississippi River opposite Hartford.
Missouri River at Fort Bellefontaine.
Chain of Rocks near Missouri shore.
Chain of Rocks near Illinois shore.
Chain of Rocks at intake tower.

The information in this chart is all included in Table 4.

The witness then endeavored to show that the bacteriological data give positive evidence of the commingling of the waters of Illinois and Mississippi rivers at the St. Louis water intake at Chain of Rocks. His observations were based on the fact, shown by a comparison of numbers of bacteria and river gage heights, observations being taken coincidently, that whenever there is a rise in either of the three streams—Illinois, Mississippi, and Missouri rivers—there is a coincident rise in the number of bacteria, and it appears that the greater the rise in water level the greater the proportionate number of bacteria. This was explained by stating that a rise in either of these streams is caused by melting snows or ice or by great precipitation, both of which result in the washing into the rivers of large amounts of filth and earth, which teem with bacteria. The witness then cited a case which appeared in the examination series beginning January 23 and ending October 9, 1900, as follows:

Illinois River was high from February 12 to 20, 1900 (dates approximate). At that time the Mississippi was low and covered with ice, as was also the Missouri. A thaw occurred in the whole Illinois River Valley, with resulting flood. The bacteriological examination shows that the waters of Illinois River contain enormous numbers of bacteria, while those of the Mississippi above the mouth of the Illinois and of the Missouri above its mouth contain a comparatively small amount. During the two weeks beginning February 13 and 20, respectively, the average number of bacteria per cubic centimeter in Illinois River at Grafton was 257,600 and 221,800, while in the Mississippi above Grafton during the same period the number was 161,000 and 105,500, and at Fort Bellefontaine, on Missouri River, the number was 52,500 and 69,500. As a result of the intermingling of these waters, the number of bacteria in the water at the Chain of Rocks intake was 133,500 and 112,000. This, in the opinion of the witness, clearly proved that Illinois River water enters the intake. Chart marked Complainant's Exhibit No. 2 was presented to support this contention. The witness called attention to the fact that during the week of January 23 the bacteria in Illinois River numbered 240,000, in Missouri River 155,000, and at the intake 150,000, the intake water corresponding very closely with the Missouri water. During the week of January 30 the number of bacteria in Mississippi River on the Illinois shore was 150,000, on the Missouri shore 75,000, and at the intake 130,000, these figures being taken within the cross section defined by the Chain of Rocks intake; and the contention was made that the figures indicate that the water at the intake was during that week comprised more largely of Mississippi River water than of Missouri River water. (376–381.)

Several charts were then introduced, and were designated Complainant's Exhibits Nos. 3 to 9, inclusive (382–404), showing weekly averages of the daily quantitative determinations of the number of bacteria per cubic centimeter in water taken from Illinois River during 1900, together with the stages of the river during the same periods, at the following points:

Mississippi River above Grafton.
Mississippi River at Alton.
Mississippi River at Hartford.
Missouri River at Fort Bellefontaine.
Mississippi River at Chain of Rocks near Missouri shore.
Mississippi River at Chain of Rocks near Illinois shore.
Mississippi River at Chain of Rocks, intake tower.

These charts were apparently introduced for the purpose of showing the relationship between the rise and fall of the stream and the number of bacteria per cubic centimeter found in the water, and from the evidence presented by them the opinion of the witness was that coincident with a rise in the river there is always an increase in the number of bacteria, while, on the other hand, a decrease in the number of bacteria coincides with a fall in the river gage height. It was further observed that during steady periods in the stream there is a constant and steady decrease in the number of bacteria.

Two charts were then introduced, ultimately marked Complainant's Exhibits Nos. 11 and 12, for the purpose of showing the effect of the Chicago drainage canal on the water in the river at Peoria. These charts, which are not reproduced, contain the results of the bacteriological determinations made during the period from September to November, 1901, assembled in diagrammatic form for the following sampling points:

Chicago drainage canal at Bear Trap dam, Lockport.
Desplaines River at Ruby street, Joliet.
Desplaines River at Brandon's bridge, Joliet.
Illinois River 3 miles above Peoria.

From an examination of these diagrams the witness noted an enormous fluctuation in the bacterial content at the Bear Trap dam, the number varying from 25,000 to 7,200,000 per cubic centimeter. The variations are relatively as great and are practically synchronous at the three lower sampling points. The record of river stages at Peoria indicates that the river was steady during this period to an extraordinary degree; in fact, the greatest change in the river levels during any one period of twenty-four hours was 0.2 foot, and the entire variation from beginning to end of the period was 0.6 foot. It was claimed by Doctor Ravold that this is unimpeachable testimony concerning the effect of the Chicago drainage canal on the river at Peoria. The great diversity in the number of bacteria in the water, along with the extraordinary steadiness in the river stage, taken in conjunction with the observed fact that in Desplaines River above Bear Trap dam comparatively small numbers of bacteria were found, could, in the opinion of the witness, be accounted for in no other way than by the entrance of sewage from the Chicago drainage canal. (449–460.)

The witness then introduced another chart, showing the results of daily quantitative determinations of bacteria and the daily stages in Illinois River from October 1 to November 27, 1901, at Grafton, 163 miles below Peoria by river. He stated that the greatest number of bacteria per cubic centimeter occurred November 17; that while there was a slight rise in the river on that date it was not as high as it had been from October 21 to 30, when the number of bacteria had been comparatively low. No further attempt was made by the witness to discuss these results, although it is clear from a reading of his statements that he inferred that such results lead to the belief that the great mass of bacteria were due to artificial contamination rather than to any natural causes, and therefore were presumably contributed by the drainage canal.

The witness then outlined the results of a series of experiments made to determine the longevity of *Bacillus typhosus* in sterilized distilled water and in sterilized water from chosen points in Mississippi and Illinois rivers. These results are set forth in condensed form in Table 10. (468–470.)

Table 10.—*Longevity, in days, of Bacillus typhosus in sterilized water under various conditions.*

Source of water.	Cultures in darkness at 10° C.			Cultures in darkness at 20° C.			Cultures in open window facing east, in summer.		
	A.	B.	C.	A.	B.	C.	A.	B.	C.
Distilled	51	25	22	22	54	30	22	25	45
Mississippi River above Grafton	59	......	40	......	37	......	......	45	60
Drainage canal at Lockport	45	......	22	54	54	......	40	31	22
Missouri River at Fort Bellefontaine	59	57	57	......	......	57	......	......	......
Mississippi River at Chain of Rocks	59	59	34	54	55	54	......	46	45

A second series of tests on the longevity of *Bacillus typhosus*, made to determine the length of time in which the bacillus persists in live water, was then described. Samples of water were collected at various times from Chicago River, the drainage canal at Lockport, Illinois River at Peoria, and Mississippi River at the Chain of Rocks intake. Then 200 c. c. of each of these samples were poured into sterilized Erlemeyer flasks and carefully stoppered. Some flasks were exposed to sunlight by placing them upon a shelf in a window facing the south, where the direct rays of the sun impinged on them from 10.45 a. m. to 2.15 p. m., the total average time of exposure daily being about three hours. Others were kept in cold storage. The results were as shown in Table 11. (470–477.)

TABLE 11.—*Longevity, in days, of Bacillus typhosus in water from various sources.*

Sampling point.	Length of life in—	
	Sunlight.	Refrigerator.
Chicago River at Adams street	4	5.5
Drainage canal at Western avenue, Chicago	6	7.5
Drainage canal at Lockport	4.75	10.66
Drainage canal above controlling works, Lockport	....	9
Drainage canal at Jackson street, Joliet	9	13
Illinois River above Peoria	7.66	11.5
Illinois River at Pekin	7	15
Laboratory tap, St. Louis	7	12
Chicago River at Adams street (sterilized water)	16	....
Drainage canal at Lockport (sterilized water)	....	23

The witness then discussed the results of other tests during June, July, and August, 1900. Sterilized distilled water at 10° C., culture A thirty-three days, B thirty-five days, C thirty-one days; sterilized Mississippi water, Grafton, culture A fifty-five days, B fifty-two days, C fifty-seven days; sterilized Missouri water, Fort Bellefontaine, culture A fifty-five days, B sixty-two days, C sixty-five days; sterilized Illinois River water, Lockport, culture A forty-four days, B fifty-eight days, C thirty-one days; sterilized Mississippi water, intake, culture A fifty-one days, B fifty-four days, C fifty-two days. (477–478.)

Testifying further, the witness stated that it was impossible to obtain in laboratory experiments the conditions which prevail in a running stream; but inasmuch as the laboratory conditions are more unfavorable to the longevity of typhoid bacilli than the stream conditions the results of laboratory experiments are conservative. He said that it had never been determined how long bacteria survive in a running stream. (478–480.)

In reply to questions concerning the population tributary to the Illinois River system, and the Chicago drainage canal, the amount of sewage derived from the population and the effect thereof on the streams involved, Doctor Ravold testified as follows:

The sewage of upward of 2,000,000 people enters the Chicago drainage canal above the controlling works at Lockport. Determinations made by the witness and confirmed by the work of other investigators reveal the fact that from 3 to 6 ounces, dry weight, of fecal matter and 40 ounces of urine are voided each day by the normal human being. A calculation based on 3 ounces of solid matter and 40 ounces of liquid per capita, and 2,000,000 as the population tributary to the Chicago drainage canal, would give a total excretion of 187½ tons of fecal matter and 670,000 gallons of urine per day. It is commonly assumed that the amount of sewage in a city is fairly represented by the amount of water consumed. The water consumption in Chicago being placed at 150 gallons per capita per day, the total daily sewage discharge would be 360,000,000 [300,000,000?] gallons. (767-769.)

Doctor Ravold then calculated the percentage of sewage to water in the Chicago drainage canal at the controlling works. The maximum discharge over the controlling dam being 300,000 cubic feet per minute, the proportion of sewage to pure lake water would be 1 to 9. The effect of all this contamination was to render the water at the controlling works extremely foul, and the results of the bacteriological examinations which he had presented were sufficient to substantiate this statement. One of the observers employed by the city of St. Louis had seen 500 dead fish pass over the controlling dam in a period of ten minutes. (769-770.)

With reference to the city of Peoria, the witness stated that a calculation based on a population of 56,100, as given by the census of 1900, the minimum flow of Illinois River past Peoria of 1,200 cubic feet per second, and a sewage outfall at Peoria proportional to that of Chicago, namely, 150 gallons per capita per day, would give the proportion of sewage to water 1 to 92 at the low-river stage. The witness stated that if the 300,000 cubic feet per second added by the Chicago drainage canal were unpolluted lake water the dilution of sewage at Peoria would be 1 to 413, which, in his opinion, would reduce to a minimum the danger from Peoria pollution to the places below, such as Grafton. (772-773.)

Doctor Ravold then gave facts concerning the population in the drainage basin of Illinois River and the sanitary district of Chicago, giving credit for the data to Lyman E. Cooley and Jacob A. Harman. The information is summarized in Table 12. (774-776.)

TABLE 12.—*Population of Illinois River drainage basin.*

River basin.	Flow.	Population.		
		Urban.	Rural.	Total.
	Second-feet.			
Desplaines River	13.21	20,354	45,247	75,601
Dupage River	32.77	5,344	10,890	16,234
Kankakee River	509.24	26,697	140,441	170,138
Fox River	329.95	72,763	89,889	162,652
Vermilion River	4.00	17,543	43,257	60,800
Mackinaw River	....	5,247	30,106	35,353
Spoon River	87.76	19,619	56,428	76,074
Sangamon River	372.30	103,720	177,638	281,358
Crooked Creek	....	12,739	44,289	57,028
Macoupin Creek	....	9,155	32,296	41,453
McKees Creek	....	....	8,823	8,823
Illinois River [a]	....	135,139	184,877	320,016
Sanitary district of Chicago	....	1,800,000	....	1,800,000

[a] Not including drainage canal.

Taking up the sources of pollution along Mississippi River below Illinois River, the witness stated that Alton had a population of 15,000. The sewage from this city is discharged into the Mississippi by five main outlets, three of which empty into the river behind dikes, which effectually check that portion of the sewage from becoming mixed at once with the waters of the river. (776.)

He then summarized the bacteriological evidence with reference to sampling stations maintained above Alton and at Hartford, a few miles below Alton, the results of which are given in Table 13. (778-778.)

TABLE 13.—*Monthly averages of quantitative bacteriological determinations of Mississippi River water 1 mile above Alton and opposite Hartford, and percentage of samples in which Bacillus coli communis was found.*

Month.	Alton.		Hartford.	
	Bacteria per cubic centimeter.	Per cent of B. coli communis.	Bacteria per cubic centimeter.	Per cent of B. coli communis.
1900.				
January	118,800	14	90,600	17
February	192,500	17	190,600	50
March	192,300	51	208,300	52
April	29,400	39	29,700	41
May	10,300	54	12,800	86
June	8,200	60	5,800	61
July	7,700	52	61,000	55
August	2,400	88	2,100	89
September	2,600	90	2,800	93
October	2,100	100	2,400	100
1901.				
October	1,137	100	2,141	86.4
November	1,566	77	3,000	56

Taking up the consideration of this evidence, the witness stated that if it is assumed that the whole sewage of Alton becomes mixed with the water of the Mississippi at once and is carried directly toward Hartford with a minimum flow of 25,000 cubic feet per second in the river, it will be seen that the Alton sewage, representing 15,000 people, is diluted over 70,000 times; in fact, the results in Table 13 above indicate that the sewage is so largely disposed of by dilution that the bacteriological results at Alton and Hartford show no difference. From the evidence thus presented, the witness asserted that it was his expert opinion that "the sewage of the city of Alton has no effect on the sanitary condition of the Mississippi River water at Hartford." (778–779.)

Doctor Ravold then proceeded to a discussion of the work performed by him with reference to *Bacillus prodigiosus* and its longevity when placed in the waters of Mississippi and Illinois rivers. Inasmuch as the testimony created considerable comment at the time and was brought out by the witness as a strategic move of great importance to the plaintiff's case, it will be given nearly in full. (779–787.)

The *Bacillus prodigiosus* is a micro-organism discovered by Ehrenberg. It is a trifle larger than the typhoid bacillus and is nonspore forming and nonpathogenic. The name was derived from the fact that in European countries the host in the chalice of Catholic churches has a red growth upon it which in early times was declared to be the blood of Christ. This red growth was investigated and found to be in one case a micro-organism which produces within its cell a red pigment. This is the legend connected with the name, and it was called therefore *B. prodigiosus.* It has been very rarely found in the waters of America and apparently is not a germ which is domestic to this country, although it is said that in Europe and in Egypt it is found abundantly in surface waters. It grows very freely on the ordinary culture media, and its behavior and appearance are so characteristic that it is easily identified.

In the investigation made by the witness, beginning in August, 1899, and extending to August, 1900, every sample of water that was received was examined for distinctive bacilli, but *B. prodigiosus* was never found. Throughout the examinations it never appeared in over 10,000 samples of water from Lake Michigan, the drainage canal, Mississippi and Illinois rivers, except when it was placed there by the St. Louis investigators. It was therefore concluded that *B. prodigiosus* was not a normal inhabitant of the streams under investigation and that it was rarely, if ever, present.

In August, 1900, the witness prepared a 40-gallon barrel full of a broth culture of *B. prodigiosus.* The barrel was first sterilized with steam heat and was then filled with boiling hot water and allowed to stand until cool, but while the water was boiling hot 1 pound of sterilized Liebig's beef extract was mixed into it. After two or three days when the water was sufficiently cool, a large number of *B. prodigiosus* in a broth culture were placed in it. This particular culture of *B. prodigiosus* came from Europe and was given to the witness by Dr. Ludwig Bremer several years previous. The barrel culture was allowed to develop until it was found that each cubic centimeter of the broth contained over 1,000,000,000 bacilli. August 31, 1900, this barrel of *prodigiosus* broth was emptied into the Mississippi just below the mouth of Illinois River. September 3, four days later, the organism was found in a sample collected in the channel of the river above Alton, but at no other place. September 20 the experiment was repeated. A barrel containing 40 gallons of the same culture was emptied at the same point, and September 23 the organism was found in a sample collected near the Illinois shore of the Mississippi at Chain of Rocks. October 18 the bacterium was again found in a sample collected from the laboratory tap at the old city hall, St. Louis, and October 24 in a sample collected near the Illinois shore of the Mississippi at Chain of Rocks.

Preparations were then made for an extensive experiment which it was believed would be conclusive. The object was to empty into the Chicago drainage canal a large quantity of *Bacillus prodigiosus* and to identify it, if possible, along Illinois River and even to the St. Louis intake. The witness made the following preliminary statement: "I must say that in the first place I needed a courageous man to do this thing—a very powerful man—and I didn't know where to look for him except in a brother of mine whom I brought up from Arizona; he knows a thing or two about taking care of himself and is physically a powerful man." November 6, 1901, "in spite of the active vigilance of the police," E. J. Ravold successfully emptied into the drainage canal at Lemont, 8 miles above the Bear Trap dam, 107 barrels of *prodigiosus* broth, which contained 40 gallons each. There were over 1,000,000,000 bacilli per cubic centimeter in each of these barrels.

All the laboratories along the river were notified and samples were collected every hour of the day and night at the Bear Trap dam, in the drainage canal; at Joliet, Peoria, and Grafton on Illinois River; and at the intake of the St. Louis waterworks at Chain of Rocks. The bacillus was not found by Dr. W. C. G. Kirchner, stationed at Joliet. It was found at the St. Louis laboratory in a sample collected by Mr. Werner at the intake tower, Chain of Rocks, at 8.45 a. m., December 4, and again on the 5th, in the sample collected at 9 a. m. It was found December 6 in a sample collected by Mr. Homer from Illinois River above Grafton at 8 a. m., and again in a sample taken from the same point at midnight, December 7. (779–784.)

Doctor Ravold then described experiments made to determine the longevity of *Bacillus prodigiosus*, the results of which are set forth in Table 4. (785.)

TABLE 14.—*Longevity of Bacillus prodigiosus in water under different conditions.*

Source of water.	Sterilized.	Place kept.	Duration of sunlight.	Temperature.	Longevity.
			Hours.	° *C.*	*Days.*
Laboratory tap [a]	Yes	Open air	9.5		2
Drainage canal above Lockport	No	Window	3		10
Desplaines River at Joliet	No	do	3		7
Chicago River at Adams street	Yes	do	3		11
Drainage canal at Lockport	No	Refrigerator	Dark.	16	32
Desplaines River at Joliet	No	do	Dark.	16	†41
Drainage canal at Western avenue, Chicago	No	do	Dark.	16	31
Illinois River at Pekin bridge	No	do	Dark.	16	†53

[a] Suspended on cord, 8 feet from south wall of laboratory building.

Comparing the above results with similar tests made on the bacillus of typhoid, which are outlined in previous pages, Doctor Ravold concluded as follows:

With these micro-organisms side by side, comparative estimates were made of the longevity of *Bacillus typhosus* and *B. prodigiosus* in separate samples of water, collected at the same time and place, and kept under the same conditions as to temperature, sunlight, and darkness. *B. prodigiosus* in sunlight, in living waters, that is, non-sterilized waters, lived from two to ten days; *B. typhosus* in sunlight and in living waters lived from twenty-four hours to ten days. *B. prodigiosus* lived in the dark, in living waters, from thirty to fifty days and was still alive when the experiments ceased; *B. typhosus* under like conditions lived from twenty-four hours to twenty-one days, showing that *B. prodigiosus* is an organism which closely resembles *B. typhosus* in its power to resist unfavorable surroundings.

As a result of these experiments the witness declared it to be highly probable that a typhoid bacillus can be carried in its virulent condition from the Chicago sewers, by way of the drainage canal and Illinois River, into the St. Louis water intake, especially during high-water conditions. (788)

Continuing, the witness testified that it was impossible to determine the absolute longevity of the typhoid bacillus in running water, because the conditions which prevail in a running stream can not be reproduced in laboratory experiments. In stagnant waters, such as are kept under observation in laboratory experiments, the water bacilli destroy the life of the typhoid bacilli. If typhoid bacilli are placed in foul water, such as that taken from the Chicago drainage canal, the water bacilli increase enormously, but the typhoid bacilli do not increase. The destructive action of the water bacillus on organic matter, both solid and liquid, in water results in the production of poisons which act deleteriously on both the water bacillus itself and the pathogenic organisms in the water, so that in laboratory experiments bacilli die much more quickly in living water than they do in water which has been sterilized. In streams, however, the typhoid bacilli, which are motile, can move out of the influence of these poisons and thus prolong their life. (790–791)

In response to a series of questions concerning the probability of destruction of bacteria by sunlight in streams, the witness stated that the assumption that bacteria were destroyed in a few hours by this cause is unfounded, although there is no doubt that the effect of sunlight is detrimental. Practically, this effect depends on the character of the stream and especially the turbidity of the water and the depth to which it will admit the sun's rays. A turbid water will protect bacteria from the sun; in the Illinois, for example, the effect of the sun would be dissipated in a depth of less than 1 foot. It was then brought out, by leading questions of counsel, that in the opinion of the witness the bacteria are endowed with instincts of self-preservation and, being motile, can escape from adverse conditions in the water. In case the sun's rays are detrimental, they can go deeper into the water, and if they enter strata of water having a greater velocity than at the surface or at the bottom of the stream, they will be carried downstream at a faster rate, to the increased detriment of municipalities along the lower reaches of the stream which take their supply from it. (797–799)

The witness then asserted that in his opinion the bacteriological experiments indicate that bacteria discharged by the drainage canal, especially in high-river stages, are carried into Mississippi River by way of Illinois River and enter the intake of the St. Louis waterworks. Bacteriologically, the water of the Mississippi at the St. Louis intake is impure and unfit for human consumption. (799–803)

The witness then sought to justify his conclusions taken from his experimental work on longevity of the typhoid bacillus as follows:

Bacillus typhosus will survive in sterilized distilled water, or water containing no food supply, "a great number of days." In sterilized river water containing no water bacteria, but retaining the food supply and many of the toxins produced by bacterial life, they will live "a great number of days," experiments having shown that at the end of sixty-five days they were still alive. In unsterilized river waters, or "living waters," in flasks sown with typhoid the water bacteria increase enormously either in the sunshine or in the dark refrigerator at 16° C., up to a point at which they have apparently exceeded the food supply and—what is more important—have produced toxins which injure or actually destroy the other bacteria. Nevertheless, in the experiments of the witness the typhoid bacillus lived under these identical conditions a maximum period of twenty-one days. Several theories which have been promulgated to account for the disappearance of bacteria in living waters were then explained. First, the plankton, or the lower forms of animal and vegetable life which inhabit waters, are said to feed on bacteria. This, according to the witness, is not substantiated by any scientific proof. The second theory assumes the absorption of food supply by the associated bacteria. The witness believes this to be unimportant, because of the fact that, as experiments show, the typhoid bacillus lives for "a great number of days" in distilled water. Third, the toxins produced by the associated bacteria have a destructive action on the typhoid bacilli. Now, in streams where water is in constant motion, carrying away the toxins produced, and where the food supply is abundant and the bacteria per cubic centimeter less numerous, the typhoid bacillus can swim away from "uncomfortable surroundings." It would therefore seem that the conditions which prolong the life of the typhoid bacillus would act more favorably in a running stream than in the stagnant water of a laboratory flask. Therefore, in the opinion of the witness, conclusions based on laboratory experiments err, if at all, on the side of safety. (804–807.)

The laboratory experiments indicate that bacteria would live from four to twenty-one days in the various streams connecting the Chicago drainage canal with the Mississippi at St. Louis. If, however, the more favorable conditions in the running streams were taken into consideration, a conservative estimate of the longevity would be from fifteen to thirty days. Assuming, then, that the time consumed in traveling from Chicago to the St. Louis intake would be seventeen days, and allowing three days more for storage at St. Louis and final distribution, the witness regarded it as highly probable that typhoid organisms would be delivered to the consumer in a condition sufficiently virulent to cause disease in a susceptible individual. (807–808.)

After discussing the various factors which cause the disappearance of bacteria in running water—namely, aeration, dilution, sunlight, sedimentation, disappearance of food supply, and production of toxins—the witness stated that sedimentation and dilution are the prime factors, and that in case a large number of pathogenic bacteria are deposited on the bottom of a stream by sedimentation they would not necessarily be killed by this process, but would be washed up again by any disturbance, such as a freshet or dredging, and would be carried downstream and probably cause disease. Under such an assumption the witness admitted that the longevity of the organism would be a factor and that some of them would be destroyed by infusorial life. (809–813.)

The witness then considered the series of samples collected between February 8 and 20, 1900. These samples came from Illinois River at Peoria and Grafton, from Mississippi River above Grafton and at Alton and Hartford, from Missouri River at Fort Bellefontaine, and from Mississippi River at Chain of Rocks along the cross section defined by the intake tower and the Illinois and Missouri shores. The samples from Illinois River at Peoria and Grafton were almost black, the Mississippi water above Grafton was remarkably clear, while Mississippi River flowing by Alton and Hartford showed a mixture of the two waters. That from Missouri River was exceedingly clear, as was that taken from Mississippi River near the Missouri shore at Chain of Rocks, but the Mississippi water near the Illinois shore was black. At the intake tower there was a distinct mixture of the clear and the black water which represented a mean between the two streams on either side of the river. The bacteriological results confirmed unmistakably the conditions indicated by physical examination. The number of bacteria in the Illinois samples was very high; a lower number appeared in the Mississippi samples above Grafton, and the lowest in Missouri River at Fort Bellefontaine, while the samples taken from the intake tower showed a distinct mixture. The rivers were covered with ice during this period. Subsequent to this, but within the incubation period of typhoid fever, there was an enormous increase in the occurrence of the disease in St. Louis, 117 cases and 16 deaths occurring in March. In connection with this the witness recalled the fact that the Chicago drainage canal had been opened January 17, and that the samples just discussed were collected from February 8 to 20 following. There was a heavy thaw in the Illinois River basin about February 10, which did not extend to the basins of the upper Mississippi and Missouri until some time later, and therefore the Illinois River water largely predominated in the Mississippi at St. Louis. From this the witness deduced the following conclusions: A great mass of filth had accumulated in the Chicago drainage canal previous to its opening. When the Bear Trap dam was lowered this material rushed down the valley and could be readily traced by the naked eye. At that time Illinois River was low, and the greater part of the foul mud was finally deposited on the bottom of the stream. As during the winter months the anaerobic bacteria were ineffective, the foul material remained unchanged, and when it was carried down into the Mississippi by the flood it must have been in a highly virulent condition. (835–840.)

Pages 406–449, inclusive, of the record give the testimony of the witness in regard to typhoid at St. Louis. He stated that prior to 1895 the St. Louis water intake was located at Bissells Point, about 3 miles above Market street and just above the present Merchants Bridge across Mississippi River. About 1,000 feet above this intake Harlem Creek discharges into the Mississippi. At that time probably about 10,000 people lived in its drainage area, the sewage from whom, as well as offal from a number of dairy stables, discharged into this creek. All this material during freshets was washed into the Mississippi and at times flowed directly into the Bissells Point intake. The result was an extended epidemic of typhoid fever in St. Louis, beginning in August, 1892, and continuing until February, 1893. The water commissioner placed a dam across Harlem Creek 500 yards back from Mississippi River and diverted the water downstream to a point below the intake, with the result that the epidemic was ended. Typhoid fever, however, continued to be excessive in St. Louis until 1895, when the intake was removed to its present location at Chain of Rocks, after which there appeared to be a great improvement.

The witness gave the number of cases of typhoid fever and deaths therefrom in St. Louis during each week of the period 1890 to 1900, inclusive, with the exception of 1892, 1893, and 1894. The figures appear on pages 419 to 432, inclusive, of the record. The monthly statement computed from these and other figures is reproduced in Table 1.

The evidence given in Table 1, together with a statement of Mississippi River gage heights at St. Louis during coincident periods, was introduced in diagrammatic form and designated Complainant's Exhibit No. 10. The diagram showed simply that as a whole low gage heights were accompanied by high typhoid morbidity in St. Louis.

A special chart, designated Exhibit No. 10a, was then introduced into evidence and is herewith produced as Pl. I. It contains curves indicating the number of cases and deaths from typhoid fever in St. Louis during the year 1900, gage heights of Mississippi River at St. Louis and of Missouri River at Hermann, Mo., during the period, and the proportion of Mississippi River water entering the St. Louis waterworks intake at Chain of Rocks, determined according to the relative amounts of total solids found in daily samples of the water taken from Missouri River at Fort Bellefontaine and from Mississippi River at Hartford and at the intake. This method of determination will be discussed in connection with the testimony of Professors Keiser and Teichmann.

In discussing Exhibit 10a (Pl. I) the witness called attention to the fact that in the early part of the year 1900 the proportion of Mississippi River water entering the intake increased, reaching 100 per cent February 8, but falling rapidly to 12 per cent February 15. The period of incubation of typhoid fever varies from five or six days to three or four weeks. March 3, or twenty-three days after February 8, the date at which 100 per cent of Mississippi River water entered the intake, there was an increase in the number of typhoid cases, which reached a maximum March 17. The witness further called attention to the fact that from January 27 to February 10 both Mississippi and Missouri rivers were falling, but that according to the gage height records at Peoria, Illinois River was high. These records show that there was a steady rise from January 17 to 29, and the inference drawn from this was that a large percentage of Illinois River water was directed into the intake at Chain of Rocks and produced the typhoid above noted. March 24, 25, 26, 27, and 28, 100 per cent of Mississippi River water was going into the intake. There was a fall to 62 per cent on March 29 and a rise on March 31 to 100 per cent. April 1 the proportion was 87 per cent; April 2, 50 per cent; April 3, 62 per cent; April 5, 56 per cent; April 6, 32 per cent; and April 7, 1 per cent, after which it rose rapidly. The proportion of Mississippi River water in the intake fell during the summer, fluctuating until August 7, when it reached 6 per cent. By August 31 it had risen to 50 per cent. During all this time the number of typhoid cases in St. Louis increased with the increase in the proportion of Mississippi River water at the intake tower. This proportion fluctuated between 10 per cent September 15 and 46 per cent September 22. After this there was a steady rise, until a percentage of 64 was reached October 4. It fell again October 6 to 27 per cent, rose on the 7th to 42, fell on the 9th to 24, and rose on the 10th to 26. From all this Doctor Ravold concluded that when the volume of the river is very great the percentage of typhoid is very low, and that the typhoid increases with the increased percentage of Mississippi River water going into the intake. (432–447.)

Doctor Ravold described in some detail the great typhoid epi-

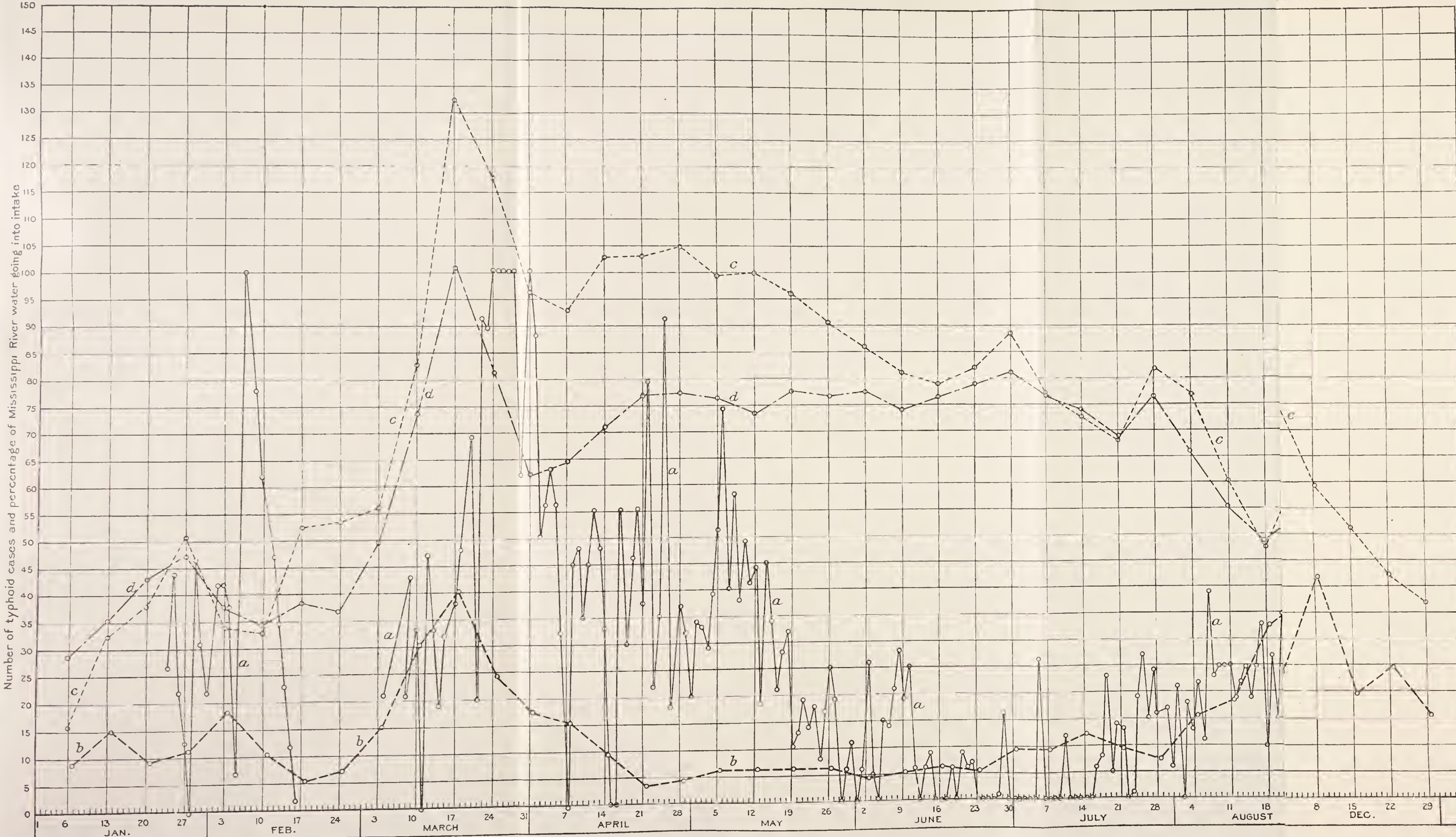


DIAGRAM SHOWING STAGE OF MISSISSIPPI AND MISSOURI RIVERS AT ST. LOUIS, PERCENTAGE OF MISSISSIPPI WATER FLOWING INTO INTAK

a, Percentage of Mississippi River water flowing into intake. *b*, Number of cases of typhoid fever. *c*, Weekly average of stage of Mississippi River at St

demics at Plymouth, Pa., and at Lowell and Lawrence, Mass., as well as several which had taken place in Europe. (463–467, 739–752.)

He then gave a record of the deaths from typhoid fever in representative foreign and American cities, the substance of which is included in Table 15. (753–755.)

TABLE 15.—*Deaths from typhoid fever per 100,000 population in different cities, 1890–1896.*

Year.	Filtered or upland water supplies.				Polluted water supplies.			
	Rotterdam.	Munich.	Berlin.	Vienna.	Chicago.	Pittsburg.	Louisville.	St. Louis.
1890	6	8	9	9	92	....	88	94
1891	4	7	10	6	154	100	81	30
1892	6	3	8	8	106	100	72	37
1893	5	15	9	7	45	111	84	103
1894	5	2	4	5	31	56	72	31
1895	2	3	5	6	32	77	77	19
1896	12	3	5	5	46	61	45	19

Continuing, Doctor Ravold discussed a chart which was presented in evidence, showing the incidence of typhoid fever and its results in St. Louis during the decade 1890–1900. The chart emphasizes especially the fact that from January, 1890, to September 28, 1894, during which time the water supply was taken from Bissells Point, where it was constantly contaminated by the waters of Harlem Creek, the cases of typhoid fever numbered 6,222 and the deaths 1,268. During the period from September 28, 1894, to December, 1900, when the supply was taken from the new intake at Chain of Rocks, the cases of typhoid fever numbered 2,490 and the deaths 562, indicating plainly a decrease in typhoid-fever rate of 125 per cent. This chart further showed that during the three years intervening since the opening of the Chicago drainage canal and the end of the year 1902 there had occurred 3,246 cases of typhoid fever and 588 deaths, an increase since the opening of the canal of 68 per cent.

The record for the three years previous to and the three years subsequent to the opening of the Chicago drainage canal is as follows:

TABLE 16.—*Typhoid-fever cases and deaths at St. Louis, 1897–1902.*

Year.	Cases.	Deaths.	Year.	Cases.	Deaths.
1897	433	125	1900	1,213	168
1898	426	95	1901	1,101	198
1899	948	130	1902	1,112	222

The witness endeavored to explain the increase in the number of cases occurring in 1899, previous to the opening of the Chicago drainage canal, as due to the fact that in that year the water in Mississippi River was so low that it was feared that the lowest gates in the intake tower would not admit enough water to supply the city, so that a cofferdam was built about the intake and workmen were engaged to put a lower gate in the tower, the contention being that the unavoidable stirring up of mud which accompanied this work was responsible for the increase in the typhoid-fever rate during that year. The witness stated that in addition to this, extensive dredging was going on in Illinois River at Kampsville. (763–765.)

With reference to the comparative reliability of morbidity and mortality statistics in determining the prevalence of typhoid fever, the witness expressed a preference for the mortality data and justified his conclusions as follows:

> When we go back over the statistics—that is, of the typhoid-fever cases and deaths—take the case of Plymouth, for instance; there were 1,104 cases and 114 deaths, 10.3 per cent; in other words, 10 out of every 100 died; and my personal experience in this city, in hospitals, would make the per cent anywhere from 7 to 15, depending upon the stage of the disease in which the typhoid cases reached the hospital, while in my experience for twenty years as a practicing physician in this city, in the treatment of typhoid fever, the relation of deaths to cases would not be 1 to 15—that is, practising in the homes of the individuals sick. The reason for this is that we see the cases early and can do more for them at home, while in the hospitals the patient reaches there after he is seriously sick and the chances for treatment and recovery are not so good, so these figures on the chart, showing the relation of cases to deaths, are not comparable at all.
>
> Take any one of these years—any one you may please. We find that for 1892, for instance, we have 488 deaths and 3,624 cases recorded. There ought to be at least 5,000 cases recorded by physicians—or take the lowest there, 1898, 95 deaths, which would mean 950 cases in the town.

The witness concluded from this that physicians had not reported every case, but reported necessarily every death. (765–766.)

CROSS-EXAMINATION.

The most of the cross-examination (837–949) consisted of a review of the statements already made by the witness, and only a few of the important facts not brought out during the direct examination will be mentioned here.

The witness stated that the results of the examination of the water of Illinois River carried on during 1899 were not, in his opinion, a fair test of the conditions.

A series of questions was then put to the witness, the purpose of which was apparently to show that, sedimentation and dilution being important factors in the disappearance of bacteria from water, the conditions along Illinois River were favorable for such disappearance. The witness conceded that there must be considerable sedimentation at numerous points along the river where the channel assumed the form of a basin, or where dams were built across the channel. He denied that there was any significant amount of sedimentation in the basin at or near Joliet, but conceded that at such places as La Salle, Peoria, Henry, Copperas Creek, Lagrange, Beardstown, and Kampsville considerable sedimentation occurred. The witness confessed ignorance concerning the amount of water normally contributed by each of the tributary streams of the Illinois basin, but admitted that there must be considerable dilution. It was then admitted that there are on Mississippi River and its tributaries entering above St. Louis many other cities which discharge raw sewage into the streams, and that it would be impossible to determine whether typhoid bacilli occurring in the water at the St. Louis intake came from the Chicago drainage canal or from the sewers of the cities mentioned. He further admitted that the drainage area of Illinois River was very small compared with that of the Missouri and upper Mississippi and stated that his conclusion as to the dangerous quality of water from Illinois River was based on the discovery not of organisms which actually produce disease, but rather of kindred species which are known to accompany them.

Doctor Ravold admitted that there had not been in this country any authentic report of a water-borne typhoid epidemic in which the proved source of contamination was at a greater distance than about 50 miles, but explained this by stating that when greater distances were involved the difficulty of such proof became insurmountable, inasmuch as there were always other towns in the drainage area which complicated the field of research.

The witness expressed his opinion that no running stream on which towns or villages are situated is fit as a source of water for domestic use without purification, and in this connection many instances of typhoid epidemics were cited to support his statement.

WILLIAM C. TEICHMANN.

DIRECT EXAMINATION.

Dr. William C. Teichmann, a witness called in behalf of the complainant, testified that since April, 1893, he had been city chemist of St. Louis. He was graduated from the academic department of Washington University in 1875; in the fall of the same year entered the Polytechnic College of Brunswick, Germany, and there studied chemistry until the summer of 1879; in the fall of 1879 he entered the University of Berlin and continued the study of chemistry and other courses. During this period he made a specialty of water analysis under Prof. Ferdinand Tiemann. In 1881 he entered the University of Leipzig, and in 1882 the University of Munich, remaining there until 1885, when he graduated as a doctor of philosophy in chemistry and history. On returning to this country in 1885 he engaged in literary pursuits until 1890, when he again took up chemistry and served as private assistant to Charles O. Curtman, professor of chemistry in the Missouri Medical College of St. Louis. In 1891 he became assistant instructor of chemistry in this college, retaining this position until 1896. As city chemist his duties had been the analysis of waters, disinfectants, medicines, and articles of food under the department of health and for the city institutions, together with toxicological work for the police department. (1148–1150.)

Doctor Teichmann stated that he had charge of the chemical part of the entire investigation carried on by the complainant; that he had organized the system of collection of chemical samples and had directed as well as taken part in the chemical procedure. The chemical work was divided into several periods, which will be taken up in chronological order. (1151–1155.)

The first period commenced August 23, 1899, and closed January 22, 1900. The samples were not taken at regular intervals, but only at such times as the city harbor boat and the funds at the disposal of the witness permitted. The total number of samples collected during this period was 142, taken from the following points (641–643):

Samples of water collected from August 23, 1899, to January 22, 1900.

	Number of samples.
Mississippi River at Chain of Rocks, near intake tower of St. Louis water supply.	26
Mississippi River at Chain of Rocks, near Missouri shore	3
Mississippi River at Chain of Rocks, near Illinois shore	3
St. Louis waterworks distributing well	28
Mississippi River at Madison Landing, between Chain of Rocks and mouth of Missouri River, near Missouri shore	3
Mississippi River at Madison Landing, near Illinois shore	7
Mouth of Missouri River	10
Mississippi River at points between Alton and mouth of Missouri River	13
Mississippi River at Clifton Terrace	6
Mississippi River at Elsah	5
Illinois River at points 1, 2, 3, and 5 miles above Grafton	19
Mississippi River at points 1, 2, 3, and 5 miles above mouth of Illinois River..	19

For about two months from the beginning of the work the samples were collected in demijohns held in the hand under the surface of the water. After this period collecting machines were devised and the water was taken at a point from 3 to 4 feet beneath the surface. The capacity of the bottles was one-half gallon. After the sample was taken a cloth was tied over the stopper and the neck of the bottle or demijohn, and a tag was attached to the bottle with sealing wax, the seal of the city chemist's office being used. (644–645.)

The second period extended from January 23 to October 11, 1900, the number of samples collected and analyzed during that period being 3,492. The samples were taken from the following points (1182–1183):

Samples of water collected from January 23 to October 11, 1900.

	Number of samples.
Lake Michigan	11
Chicago drainage canal above Bear Trap dam at Lockport	219
Desplaines River at Joliet	219
Illinois River 3 miles above Peoria	260

	Number of samples.
Illinois River 3 miles below Pekin	1
Illinois River at Pekin Bridge	1
Illinois River at Wesley	1
Illinois River 3 miles above Grafton	265
Mississippi River 2 miles above Grafton	264
Mississippi River 1 mile above Alton	260
Mississippi River opposite Hartford	260
Missouri River opposite Fort Bellefontaine	261
Mississippi River at Chain of Rocks, near Missouri shore	253
Mississippi River at Chain of Rocks, near Illinois shore	246
Mississippi River at Chain of Rocks, at intake tower	250
St. Louis waterworks uptake	260
St. Louis waterworks outlet reservoir	261
Tap at city chemist's office	156
Harbor boat and special samples	47

After the close of this period weekly samples were taken until November 30, 1900, at the following points (1183–1184):

Samples of water collected from October 12 to November 30, 1900.

	Number of samples.
Lake Michigan	5
Desplaines River at Lockport	7
Illinois and Michigan Canal at Lockport	7
Desplaines River above entrance of Chicago drainage canal	7
Desplaines River at Ninth Street Bridge, Lockport	7
Bear Trap dam, Chicago drainage canal	7
Desplaines River at Joliet	7
Illinois River 3 miles above Peoria	7
Illinois River 3 miles above Pekin	7
Illinois River 3 miles above Grafton	9
Mississippi River 2 miles above Grafton	9
Mississippi River 1 mile above Alton	7
Mississippi River at Hartford	8
Missouri River at Fort Bellefontaine	7

Beginning with January 23 the samples were taken in duplicate and registered at the city chemist's office, one of the duplicate samples being analyzed there, while the other was analyzed in the laboratory of Washington University under the supervision of Prof. Edward H. Keiser. The chemical samples were sent to St. Louis by common carrier and were packed in ice.

From October 12, 1900, to September 30, 1901, daily samples were collected from Mississippi River at Chain of Rocks along the cross section previously defined. Daily samples were also taken from the outlet chamber of the St. Louis waterworks and from the tap at the city chemist's office. (661–662.)

The next period included the most thorough investigation and extended from October 1 to November 30, 1901. The work consisted principally of a daily collection of samples at the following points (1247–1249):

Illinois and Michigan Canal at Bridgeport.
Drainage canal at Bridgeport.
Drainage canal at Bear Trap dam, Lockport.
Illinois and Michigan canal at Lockport.
Desplaines River above Bear Trap dam, Lockport.
Desplaines River at Ninth Street Bridge, Lockport.
Desplaines River at Ruby Street Bridge, Joliet.
Desplaines River at Brandon's bridge, Joliet.
Illinois River at La Salle.
Illinois River at Peoria, 3 miles above railroad bridge.
Illinois River at Pekin.
Illinois River at Kingston, 8 miles below Pekin.
Illinois River at Beardstown.
Illinois River at Grafton.
Mississippi River at Grafton.
Mississippi River at Alton.
Mississippi River at Hartford.
Mississippi River at Chain of Rocks, Illinois shore.
Mississippi River at Chain of Rocks, midstream.
Mississippi River at Chain of Rocks, waterworks intake.
Mississippi River at Chain of Rocks, Missouri shore.
Missouri River at Fort Bellefontaine.
St. Louis waterworks at outlet chamber.
Tap in city chemist's office, St. Louis.

Triweekly samples were collected from Lake Michigan at Chicago during this period and semiweekly samples from South Branch of Chicago River, near the Chicago and Alton Railroad bridge; also from Illinois River at Wesley, 3 miles below Peoria. Four sets of samples were taken above and below each of the following points along Missouri River: Omaha, Nebr.; Kansas City, Jefferson City, Hermann, and St. Charles, Mo. Two samples were collected from Missouri River at Wathena, Kans., and two samples from Kaw River, near Argentine, Kans. (1249–1250.)

During this period occasional cross-section samples were taken at such places as Pekin Bridge, Kingston, and Peoria, Illinois River; Joliet, Desplaines River; Alton, Chain of Rocks, and Hartford, Mississippi River; and Fort Bellefontaine, Missouri River. (1250.)

The last period of examination extended from December 1, 1901, to July 1, 1902, and represents the daily collection and analysis of samples from Mississippi River at the intake tower, Illinois shore, and Missouri shore at Chain of Rocks, from the outlet chamber of the St. Louis waterworks, and from the tap in the city chemist's office. Duplicate samples were sent to Professor Keiser for examination. (1289–1290.)

The witness prefaced his discussion of his analytical results by a review of some figures by Lyman E. Cooley on the flow of Illinois

River and its tributaries, in order that there might be a proper understanding of the effect of dilution.

Mr. Cooley gives the low-water flows in various parts of the Illinois River basin as follows: Desplaines River above Lockport in 1887, 256 cubic feet per minute; in 1879, 339 cubic feet per minute; Kankakee River, at Wilmington, during the twelve years from 1871 to 1883, 25,200 cubic feet per minute; Kankakee River at mouth, September 9, 1867, 27,377 cubic feet per minute; Fox River, at Ottawa, September 17, 1867, 31,539 cubic feet per minute. On this date the Mazon was practically dry. In Illinois River, at Morris, from May 13 to 28, 1887, the water was within 2 or 3 inches of the lowest stage since 1856, and it is doubtful if the amount exceeded 15,000 to 20,000 cubic feet per minute, or 250 to 350 cubic feet per second. At least 60 per cent of the water passing Morris in 1887 came from Lake Michigan by the Illinois and Michigan Canal, and probably one-half of the volume in ordinary low-water years comes from this source. A measurement made at La Salle by the canal authorities before the canal was deepened showed 37,900 cubic feet per minute, and doubtless Lake Michigan water has represented one-half of the volume passing in some recent low-water periods.

In 1888 Illinois River at the Henry dam ran less than 500 cubic feet per second for nine days, and at Copperas Creek the same amount for twenty days. The water at Copperas Creek was at or below the same level in 1887 for one hundred and seventeen days, in 1886 for eighteen days, and in 1879 for forty-four days; at Henry in 1877 for thirty days, in 1875 for forty-seven days, and in 1871 apparently for a longer period. The volume in 1888 was less than that discharged through the canal at Chicago for the same period. How much leakage there might have been through the dams at this time is unknown. In 1867 or earlier a measurement was made at La Salle of 633 cubic feet per second; in 1879, 1,566 cubic feet; and in 1887, 1,685 cubic feet. Part of the water in the last two measurements is chargeable to Lake Michigan.

It is probable that since the Bridgeport pumps were erected in 1883 over half of the minimum discharge above Havana and one-third of the minimum below the Sangamon has come from Lake Michigan. For the purposes of calculation the normal low-water volume is taken at 600 cubic feet per second for the upper section of the river. In 1887 60 per cent of the flow at Morris came from the Illinois and Michigan Canal, or, in other words, the natural flow of the Illinois above that point was only 8,000 cubic feet per minute, or 134 cubic feet per second. Let it be assumed for the purposes of calculation that, independent of Chicago sewage, the natural low-water volume for the section of the river above Havana is 300 [a] cubic feet

[a] Probably a misprint in the record for 200.

per second, and for the section below this point 800 cubic feet per second. This is the condition prior to the opening of the Chicago drainage canal. These figures show that the ratio of dilution of Chicago sewage in upper Illinois River prior to the opening of the drainage canal was 1:0.5, and in the lower division 1:2. (1163–1166.)

The witness stated that he had no personal data for Illinois River previous to the opening of the drainage canal in 1900. He referred, however, to the following reports which contain such data (1174):

Long, John H., Chemical investigations of the water supplies of Illinois: Rept. Illinois State Board of Health, pt. 1.

Palmer, A. W., Chemical survey of the water supplies of Illinois.

Long, John H., Advance notes of the sanitary investigation of Illinois River and its tributaries: Rept. Illinois State Board of Health, 1900.

Jordan, E. O., Some observations upon the bacterial self-purification of streams: Jour. Experimental Medicine, vol. 5, December 15, 1900.

Selected tables in these reports show, in the opinion of the witness—

1. That prior to the opening of the Chicago drainage canal Illinois River was polluted by the effluent of the Illinois and Michigan Canal to such an extent as to make the entire river a conduit for dilute sewage. The dilution of sewage between Utica and the mouth of the river was 1 to 2 in times of drought.

2. That while dilution, sedimentation, and oxidation are effective in reducing the quantity of characteristic sewage ingredients, they are not, in the case of Illinois River, sufficient to complete the process previous to the discharge of the river into the Mississippi.

3. That the tributaries of Illinois River are much purer than the main stream.

4. That during the interval between 1888 and 1899 there was a continual increase in the pollution of Illinois River while there was no corresponding increase in the pollution of its tributaries.

5. That it is only necessary to consider the increase in the amount of water pumped into the Illinois and Michigan Canal from Chicago River and discharged therefrom into Desplaines and Illinois rivers, and to recall the enormous growth of population and industries in Chicago, to obtain the explanation of the gradual conversion of Illinois River into an open sewer. (1174–1176.)

The witness then presented the results of his determinations of certain constituents in the water of Illinois and Mississippi rivers a short distance above Grafton, from September 6, 1899, to January 17, 1900. (1177–1178.)

TABLE 17.—*Maximum, minimum, and average results of analyses of water from Mississippi and Illinois rivers 3 miles above Grafton, September 6, 1899, to January 17, 1900.*

[Parts per million.]

	Illinois River.			Mississippi River.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Residue on evaporation:						
Total	510	330	413	450	195	285
Dissolved	460	240	340	280	130	205
Albuminoid ammonia	.763	.317	.553	.614	.394	.503
Free ammonia	.440	.091	.215	.134	.030	.069
Nitrites	.020	.003	.012	.008	.000	.002
Nitrates	1.1	.4	.8	.6	.2	.3
Oxygen consumed:						
Total	6	3.1	4.1	11.4	4.6	6.9
Dissolved	4.9	2.3	3.4	8.9	2.9	5.6
Chlorine	36	15	25	9	4	6

The witness called attention to the excess in nitrites, free ammonia, and chlorine of Illinois River over those of the Mississippi.

He then took up the discussion of analytical data procured from September 6 to December 4, 1899, concerning the character of water in Mississippi River between Grafton and Chain of Rocks, samples being taken from points specified on page 48. (1179–1180.)

The results of the analyses of semiweekly samples taken at the intake from October 16, 1899, to January 22, 1900, were then presented as shown in Table 18. (1180–1181.)

TABLE 18.—*Maximum, minimum, and average results of analyses of semiweekly samples from Mississippi River at St. Louis waterworks intake, October 16, 1899, to January 22, 1900.*

[Parts per million.]

	Maximum.	Minimum.	Average.
Free ammonia	0.138	0.008	0.0063(?)
Nitrates	.010	.000	.002
Nitrates	.8	.2	.4
Chlorine	27	9	17

The witness noted the wide variability of the water reported in the above table and assigned as a reason the "great fluctuations in the daily varying mixtures of Mississippi and Missouri river waters at the intake." The following conclusions were then given from the results of the work in 1899 (1181–1182):

1. The Illinois at its mouth was badly polluted.

2. The Mississippi above the mouth of Illinois River was of better quality.

3. The Mississippi between Grafton and St. Louis showed the effects of pollution from the Illinois, and on occasions when this water affected the intake at Chain of Rocks the St. Louis water supply became polluted.

4. Missouri River was generally purer than the Illinois above Grafton and than the Mississippi below the confluence with the Illinois.

The witness then proceeded to a discussion of the amount of Chicago sewage entering Illinois River from the Chicago drainage canal and the Illinois and Michigan canal. (1191–1196.)

He then presented ten charts, which were admitted in evidence and marked for identification "Complainant's Exhibits 52 to 61," inclusive. These charts contain in diagrammatic form the results of the determinations of nitrogen as free ammonia, nitrites, and nitrates, and of chlorine. The various records were grouped in different ways to illustrate the various points brought out by the witness, but as many of them constitute a duplication the charts will not be reproduced in this review. The results of the tests are set forth in Table 19.

TABLE 19.—*Results of sanitary analyses of water from designated points, January to October, 1900.*

NITROGEN AS FREE AMMONIA.

[Parts per million.]

Week beginning—	Bear Trap dam, Lockport.	Desplaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River above Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine, Mo.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
Jan. 23	....	....	2.80	1.40	0.105	0.682	0.740	0.140	....	0.120	....
Jan. 30	....	....	2.43	1.68	.175	1.052	.865	.112	....	.230	....
Feb. 6	....	....	1.24	1.15	.130	.830	.695	.290	....	.280	....
Feb. 13	....	....	.95	.81	.181	.507	.475	.137	....	.175	....
Feb. 20	....	....	1.27	.69	.280	.610	.575	.137	....	.280	....
Feb. 27	1.45	3.02	.92	.53	.260	.456	.426	.101	....	.136	....
Mar. 6	2.77	3.48	1.06	.24	.175	.190	.258	.190	....	.201	....
Mar. 13	....	1.91	.55	.33	.393	.366	.383	.305	....	.312	....
Mar. 20	1.80	1.88	.41	.32	.428	.323	.331	.230	....	.360	....
Mar. 27	1.50	1.71	.50	.28	.362	.352	.312	.175	....	.276	....
Apr. 3	1.58	2.30	.50	.31	.378	.315	.298	.098	....	.288	....
Apr. 10	1.17	2.07	.44	.26	.280	.281	.297	.110	....	.200	....
Apr. 17	1.45	2.48	.54	.23	.160	.206	.200	.150	....	.118	....
Apr. 24	1.10	1.93	.35	.14	.160	.137	.130	.146	....	.125	....
May 1	1.48	2.41	.14	.12	.085	.115	.105	.200	....	.107	....
May 8	1.80	2.65	.28	.13	.086	.120	.100	.130	....	.086	....
May 15	1.18	2.40	.33	.14	.090	.106	.098	.143	....	.113	....
May 22	1.55	2.27	.28	.14	.080	.088	.072	.095	....	.095	....
May 29	1.23	2.68	.27	.07	.045	.075	.061	.110	....	.067	....
June 5	1.24	2.95	.27	.09	.055	.070	.060	.078	....	.070	....
June 12	1.60	2.60	.24	.07	.041	.042	.050	.084	....	.065	....
June 19	1.30	2.72	.25	.06	.059	.045	.053	.090	....	.058	....
June 26	1.53	3.12	.43	.08	.060	.068	.076	.115	....	.090	....
July 3	1.97	3.40	.23	.06	.047	.070	.067	.140	....	.085	....
July 10	1.53	2.75	.28	.08	.058	.062	.077	.125	....	.082	....
July 17	1.47	2.70	.44	.09	.072	.120	.100	.190	....	.135	....
July 24	1.67	2.62	.18	.10	.110	.135	.120	.208	....	.220	....
July 31	1.30	2.05	.17	.10	.111	.110	.110	.150	....	.140	....
Aug. 7	1.42	2.16	.16	.10	.106	.091	.093	.110	....	.100	....
Aug. 14	1.25	2.36	.18	.10	.096	.081	.087	.070	....	[illegible]	....
Aug. 21	1.61	3.70	.22	.08	.090	.100	.121	.138	....	.105	....
Aug. 28	1.42	2.05	.19	.08	.079	.082	.068	.140	....	.115	....
Sept. 4	1.47	3.05	.15	.07	.072	.078	.068	.180	....	.125	....
Sept. 11	2.48	5.03	.17	.05	.068	.078	.088	.095	....	.080	....
Sept. 18	2.05	6.21	.21	.12	.090	.062	.097	.120	....	.082	....
Sept. 25	1.85	3.27	.70	.10	.086	.099	.093	.130	....	.085	....
Oct. 2	1.20	2.11	1.35	.10	.107	.120	.120	.170	....	.120	....

TABLE 19.—*Results of sanitary analyses of water from designated points, January to October, 1900*—Continued.

NITROGEN AS NITRITES.

Week beginning—	Bear Trap dam, Lockport.	Desplaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River above Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine, Mo.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
Jan. 23	....	....	0.029	0.031	0.005	0.021	0.014	0.007	0.007	0.006	0.017
Jan. 30	....	....	.042	.039	.002	.028	.026	.005	.005	.008	.021
Feb. 6	....	....	.035	.021	.007	.020	.019	.008	.008	.012	.025
Feb. 13	....	....	.032	.019	.006	.015	.014	.008	.008	.013	.012
Feb. 20	....	....	.038	.023	.012	.021	.019	.010	.010	.014	.018
Feb. 27	....	0.033	.027	.030	.011	.029	.023	.016	.016	.014	.018
Mar. 6	0.048	.050	.033	.021	.010	.022	.019	.015	.015	.016	.015
Mar. 13	.065	.061	.019	.018	.010	.019	.014	.017	.017	.017	.017
Mar. 20	.043	.048	.020	.019	.008	.020	.019	.015	.015	.014	.017
Mar. 27	.085	.079	.016	.015	.007	.017	.018	.015	.015	.014	.019
Apr. 3	.098	.066	.020	.023	.017	.024	.026	.011	.011	.020	.027
Apr. 10	.060	.056	.034	.035	.024	.037	.034	.008	.008	.022	.031
Apr. 17	.074	.060	.061	.046	.016	.042	.049	.012	.012	.019	.031
Apr. 24	.043	.027	.077	.050	.025	.042	.040	.011	.011	.019	.028
May 1	.019	.026	.072	.040	.004	.022	.022	.011	.011	.010	.017
May 8	.042	.031	.122	.039	.008	.027	.028	.010	.010	.013	.015
May 15	.038	.035	.084	.057	.013	.038	.036	.011	.011	.011	.017
May 22	.009	.017	.082	.061	.008	.031	.027	.005	.006	.010	.019
May 29	.015	.032	.122	.056	.004	.014	.013	.004	.005	.008	.009
June 5	.027	.027	.133	.016	.004	.006	.005	.003	.004	.005	.005
June 12	.004	.033	.147	.015	.005	.007	.005	.004	.005	.005	.005
June 19	.006	.034	.139	.018	.007	.009	.009	.003	.004	.003	.004
June 26	.006	.036	.137	.046	.007	.030	.026	.002	.003	.002	.002
July 3	.006	.057	.159	.022	.006	.016	.013	.002	.003	.003	.004
July 10	.012	....	.158	.025	.006	.016	.012	.002	.003	.002	.005
July 17	.005	.032	.213	.033	.008	.022	.017	.003	.003	.003	.008
July 24	.007	.042	.119	.047	.008	.021	.018	.008	.008	.006	.015
July 31	.004	.033	.149	.032	.006	.012	.010	.005	.004	.004	.008
Aug. 7	.009	.049	.159	.030	.004	.014	.012	.006	.006	.004	.001
Aug. 14	.023	.061	.206	.043	.006	.021	.017	.006	.006	.004	.015
Aug. 21	.009	.046	.178	.020	.011	.015	.014	.005	.004	.004	.009
Aug. 28	.007	.031	.142	.016	.003	.009	.008	.004	.004	.003	.007
Sept. 4	.009	.107	.155	.018	.006	.011	.009	.006	.003	.003	.007
Sept. 11	.002	.027	.094	.023	.005	.012	.011	.002	.002	.003	.009
Sept. 18	.008	.035	.084	.033	.006	.012	.011	.003	.003	.004	.009
Sept. 25	.011	.026	.106	.043	.006	.014	.014	.004	.003	.004	.011
Oct. 2	.011	.051	.145	.042	.008	.019	.017	.008	.006	.006	.013

Table 19.—*Results of sanitary analyses of water from designated points, January to October, 1900*—Continued.

NITROGEN AS NITRATES.

Week beginning—	Bear Trap dam, Lockport.	Desplaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River above Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
Jan. 23	....	....	2.95	2.55	0.50	1.35	1.50	0.35	....	0.60	....
Jan. 30	....	....	1.85	1.85	.60	1.20	1.40	.35	....	.50	....
Feb. 6	....	....	1.55	2.05	.70	1.35	1.15	.55	....	.65	....
Feb. 13	....	....	1.25	1.15	.50	.85	.95	.45	....	.80	....
Feb. 20	....	....	1.20	1.05	.50	1.00	.95	.35	....	.55	....
Feb. 27	0.25	0.25	1.35	1.45	.70	.95	1.10	.60	....	.70	....
Mar. 6	.25	.30	1.00	.80	.60	.70	.75	.80	....	.80	....
Mar. 13	.50	.50	.82	1.05	.70	1.05	1.00	1.35	....	1.10	....
Mar. 20	.30	.60	.95	1.15	.60	1.10	1.15	1.10	....	.90	....
Mar. 27	.20	.25	1.00	1.00	.20	.75	.95	.95	....	.60	....
Apr. 3	.30	.35	1.15	1.10	.60	1.05	.90	.35	....	.55	....
Apr. 10	.35	.30	1.30	1.05	.80	1.15	1.10	.50	....	.70	....
Apr. 17	.35	.40	1.30	....	.60	1.05	1.10	.55	....	.55	....
Apr. 24	.40	.30	.80	.85	.50	.90	.80	.65	....	.60	....
May 1	.20	.20	.60	.65	.20	.65	.50	.60	....	.45	....
May 8	.25	.25	.67	.45	.20	.35	.40	.50	....	.45	....
May 15	.20	.10	.80	.55	.33	.50	.44	.50	....	.55	....
May 22	.10	.10	.55	.45	.20	.40	.35	.35	....	.45	....
May 29	.17	.15	.55	.65	.20	.40	.35	.35	....	.35	....
June 5	.50	.05	.75	.55	.05	.40	.35	.30	....	.30	....
June 12	0	.05	.70	.60	.10	.40	.30	.20	....	.30	....
June 19	0	0	.75	.65	0	.45	.40	.20	....	.20	....
June 26	0	0	.40	.45	.15	.40	.35	.25	....	.25	....
July 3	0	0	.30	.40	.05	.30	.20	.20	....	.20	....
July 10	0	0	.40	.40	.10	.25	.25	.25	....	.25	....
July 17	0	0	.50	.40	.15	.30	.30	.20	....	.25	....
July 24	0	0	.55	.46	.25	.30	.30	.40	....	.40	....
July 31	.15	.05	.56	.35	.20	.33	.25	.30	....	.35	....
Aug. 7	.12	.08	1.25	.95	.15	.45	.35	.40	....	.45	....
Aug. 14	.12	.12	1.30	.80	.10	.30	.30	.30	....	.40	....
Aug. 21	.15	.13	1.05	.95	.45	.75	.65	.75	....	.45	....
Aug. 28	.10	.19	1.35	1.15	.45	.80	.75	.90	....	.75	....
Sept. 4	.15	.24	1.60	1.00	.55	.80	.75	.95	....	.75	....
Sept. 11	.12	.13	1.35	1.25	.45	.70	.65	.70	....	.55	....
Sept. 18	.11	.27	1.75	1.00	.20	.50	.45	.65	....	.55	....
Sept. 25	.15	.15	1.50	1.20	.30	.60	.55	.85	....	.75	....
Oct. 2	0	.04	1.70	1.20	.40	.65	.50	.85	....	.70	....

TABLE 19.—*Results of sanitary analyses of water from designated points, January to October, 1900*—Continued.

CHLORINE.

Week beginning—	Bear Trap dam, Lockport.	Desplaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River at Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine, Mo.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
Jan. 23	....	....	23	18	8	12	12	28	26	23	10
Jan. 30	....	....	21	21	9	15	14	29	25	25	12
Feb. 6	....	....	17	14	8	12	11	22	23	16	12
Feb. 13	....	....	12	11	6	9	8	33	27	16	8
Feb. 20	....	....	15	10	6	9	9	23	22	14	10
Feb. 27	15	26	12	10	6	9	8	21	21	18	8
Mar. 6	15	32	14	7	6	7	7	12	22	10	8
Mar. 13	19	19	8	7	5	6	6	11	11	9	6
Mar. 20	15	19	6	6	4	7	7	12	13	8	6
Mar. 27	18	18	8	6	5	7	7	16	15	8	7
Apr. 3	18	23	8	7	5	7	7	18	18	10	7
Apr. 10	14	22	9	7	5	7	7	11	14	9	7
Apr. 17	16	27	11	8	5	7	7	12	12	9	7
Apr. 24	13	19	11	8	4	7	7	13	12	10	7
May 1	13	19	12	9	4	8	8	14	14	10	7
May 8	13	22	15	10	4	8	7	12	13	9	7
May 15	11	19	17	9	4	10	9	14	12	10	9
May 22	12	18	14	7	4	9	9	13	12	11	8
May 29	11	20	11	12	4	9	7	13	12	11	8
June 5	13	23	16	12	4	9	8	14	12	12	9
June 12	15	23	16	14	5	9	8	11	11	10	10
June 19	13	21	20	12	5	9	9	11	11	11	9
June 26	12	22	19	15	5	11	10	9	12	9	9
July 3	17	29	20	16	6	13	11	10	10	10	9
July 10	15	26	22	15	7	12	11	10	10	10	9
July 17	13	23	29	14	5	10	9	12	12	11	9
July 24	15	24	23	19	3	9	9	10	10	9	8
July 31	14	21	23	21	5	10	10	14	11	10	9
Aug. 7	14	20	19	19	4	12	10	18	13	12	9
Aug. 14	14	22	20	19	6	12	11	20	15	13	10
Aug. 21	17	27	20	13	3	8	8	14	13	10	7
Aug. 28	14	20	19	15	4	10	8	23	18	17	9
Sept. 4	12	28	19	15	4	10	10	22	22	17	10
Sept. 11	20	42	18	16	4	10	9	17	15	13	9
Sept. 18	17	55	22	15	3	8	9	19	14	13	8
Sept. 25	15	27	25	16	3	8	6	21	18	15	6
Oct. 2	11	20	27	16	2	6	6	13	12	9	5

In discussing the results set forth in Table 19 the witness stated that the determinations in samples taken from the Chicago drainage canal at Lockport, from Desplaines River at Joliet, and from Illinois River 3 miles above Peoria show that the water undergoes little change and practically no improvement in passing from the first to the third point and that the high free ammonia and nitrites which are found to persist in the Peoria water present unmistakable evidence that it has not yet reached its final process of purification. The witness called attention to the alleged coincident fluctuations which take place at all three points. Whenever there is an increase in the proportion of any or all of the ingredients determined at Lockport there follows in due time a corresponding increase in the same ingredients at Joliet and Peoria. This was mentioned by the witness as proving absolutely that the character of the water at Peoria is governed by that of the drainage canal. (1204–1207.)

Comparing the results of samples taken from Illinois River above Peoria and above Grafton, the witness stated that after the opening of the canal there was an increase in chlorine from an average of 21 to 28 parts per million at Peoria and from 15 to 23 parts at Grafton, while the fluctuations in nitrites and free ammonia correspond. During the summer months the increased anaerobic action below Peoria causes divergence in the figures. (1207–1209.)

The witness then testified with reference to the effect of Peoria sewage on Illinois River. The total daily discharge from Peoria sewers, based on a poulation of 56,100 and 150 gallons of sewage per capita per day, would be 8,415,000 gallons, or 1,122,000 cubic feet. As at the time of testimony the sewerage system at this city had been extended to serve only 47 per cent of the population, the actual discharge based on the above factors would be 527,000 cubic feet per day. The minimum flow of Illinois River at Peoria, according to the measurements of Lyman E. Cooley, was, before the opening of the drainage canal, 72,000 cubic feet per minute; the discharge of the drainage canal is 250,000 cubic feet per minute, so that the minimum flow of Illinois River at Peoria after the opening of the canal was 322,000 cubic feet per minute. The witness then used the value 1,122,000 cubic feet per day, or 779 cubic feet per minute, to represent the flow of sewage from Peoria, notwithstanding the fact that he had testified that the real flow of sewage was only 47 per cent of this amount. Comparing this calculated sewage flow with the minimum flow of the river, he deduced a ratio of dilution 1 : 413. He then expressed his opinion that were the water of Illinois River as it came down to Peoria comparatively pure instead of being highly polluted, the effect of this dilution of Peoria sewage would be such that the river would purify itself after running 25 to 50 miles. Therefore the effect of Peoria sewage on Illinois River, so far as the St. Louis water supply is concerned, is negligible. (1211–1215.)

The witness claimed that the figures show Illinois River above Grafton to be particularly unstable in comparison with the Mississippi above the mouth of the Illinois by reason of fermentative changes which were taking place. Along with these figures were given the relative gage heights in both streams, which supported the witness's contention that the variations taking place in the waters of the two rivers are not due to any flood effects, because there were no significant relative differences in the stages of the rivers during the period of examination. During the latter part of February and the month of March there was a rise in both rivers, resulting in an increase in the free ammonia; but after the rivers had receded to ordinary stage the difference in the free ammonia practically disappeared. Throughout the year the nitrites, nitrates, and chlorine were much higher in the Illinois than in the Mississippi. (1209–1211.)

Concerning the results of examination of water from Illinois River 3 miles above Grafton and from Mississippi River above Grafton, above Alton, and at Hartford, the witness claimed that the evidence shows that the fluctuations in amounts of different ingredients in Illinois River samples are accompanied by similar fluctuations in samples from Mississippi River above Alton and at Hartford, while the samples of Mississippi River above Grafton show no such relation, demonstrating, in his opinion, that Illinois River pollution markedly affects Mississippi River at Alton and Hartford and excluding the possibility that such an effect might have arisen in the Mississippi above the mouth of the Illinois. (1215–1217.)

Continuing, the witness discussed the resemblance appearing between the water from Missouri River at Fort Bellefontaine and that from Mississippi River at Chain of Rocks, near the Missouri shore.

He then took up the results of the examinations made at three points along the cross section of Mississippi River at Chain of Rocks, and from a consideration of the total solids, chlorine, and nitrites advanced the idea that the water entering the intake tower in the middle of the river partakes of the character of that from either shore and is generally a definite mixture of both. It was pointed out that Missouri River water contains a higher proportion of total solids and chlorine than that from Mississippi or Illinois rivers, while the nitrites in the two latter streams are generally higher than in the former. When the Missouri is high and the Mississippi low the water from the former predominates in the intake tower, and when the Mississippi is higher than the Missouri the reverse condition is maintained. The witness further explained that the occurrence of a higher proportion of chlorine in the Missouri water is due to the influx of water from Kaw River, which drains extensive salt countries in Kansas, while the high proportion of total solids in the Missouri water is due to the character of the soil drained and the erosion caused therein, and he asserted without qualification that although Missouri River water contains a higher proportion of albuminoid ammonia it is not accompanied by high free ammonia and nitrites, proving that the organic matter is derived from vegetable rather than from animal sources. (1217–1225.)

The witness then presented a series of tables designed to show the percentage of Missouri River and Mississippi River water entering the intake tower during the period from January 24 to October 10, 1900, based on the determinations of total solids in samples taken from Mississippi River at Hartford, the lowest sampling point above the mouth of Missouri River; from the Missouri at Fort Bellefontaine; and from the intake tower at the waterworks. These values being given, the percentages of water from each river at the intake are, according to the witness, accurately and easily calculated, as shown in Table 20. (1226–1240.)

It will be observed that when the value for total solids at the intake is intermediate between those at the other two points the percentages are calculated on the basis of an equal mixture of the two waters. When this value is greater or less than the other two, however, it is assumed that all the water comes from the river, showing respectively the greater or less content of total solids.

TABLE 20.—*Total solids in samples collected at Fort Bellefontaine, Hartford, and St. Louis waterworks intake, and percentages of Missouri River and Mississippi River water entering intake, January 24 to October 10, 1900.*

Date.	Total solids (parts per million).					Percentage of water entering intake from—	
				Difference between—			
	Fort Bellefontaine.	Intake.	Hartford.	Fort Bellefontaine and Hartford.	Intake and Hartford.	Missouri River.	Mississippi River.
Jan. 24	800	720	500	300	220	73	27
25	740	670	580	160	90	56	44
26	710	685	380	390	305	78	22
27	710	670	390	320	280	87	13
28	690	690	460	0	230	100	0
29	720	570	400	320	170	53	47
30	700	590	340	360	250	69	31
31	640	580	370	270	210	78	22
Feb. 2	535	450	330	205	120	58	42
3	500	450	380	120	70	58	42
4	540	490	410	130	80	62	38
5	470	460	320	150	140	93	7
7	1,540	400	400	1,140	0	0	100
9	1,500	1,290	1,230	270	60	22	78
10	1,160	1,430	1,680	520	200	38	62
12	1,050	1,120	1,200	150	80	53	47
13	1,020	1,220	1,590	570	370	65	35
14	770	920	1,430	660	510	77	23
15	500	600	1,300	800	700	88	12
16	500	540	2,325	1,825	1,785	98	2
Mar. 4	690	640	450	240	190	79	21
8	3,430	2,940	1,130	2,300	1,810	79	21
9	2,435	1,900	1,180	1,255	720	57	43
10	2,520	2,040	1,060	1,460	980	67	33
12	3,410	2,340	1,115	2,295	1,225	53	47
13	3,940	3,100	1,420	2,520	1,680	67	33
14	4,050	3,180	1,485	2,325	1,895	81	19
15	4,050	3,180	1,310	2,740	1,870	68	32
17	3,590	2,680	1,210	2,290	1,410	62	38
18	3,430	2,380	1,240	2,190	1,140	52	48
20	2,370	1,600	1,250	1,120	350	31	69
21	2,010	1,890	1,420	590	470	80	20
22	2,375	1,205	1,091	1,284	114	9	91
23	1,575	891	806	769	85	11	89
24	1,470	678	830	....	....	0	100
25	1,233	728	765	....	....	0	100
26	1,142	640	831	....	....	0	100
27	1,363	528	670	....	....	0	100
28	1,142	554	647	....	....	0	100
29	928	627	439	489	188	38	62
31	1,010	590	600	....	....	0	100
Apr. 1	1,180	590	510	670	80	12	88
2	1,280	870	460	840	410	50	50
3	1,400	880	480	920	400	44	56
4	1,510	860	480	1,030	380	37	63
5	1,540	935	455	1,085	480	44	56
6	1,530	1,200	480	1,050	720	68	32
7	1,570	1,595	630	....	....	100	0
8	1,785	1,220	545	1,240	675	55	45
9	1,875	1,235	545	1,330	690	52	48
10	1,735	1,300	480	1,255	820	65	35
11	1,675	1,150	500	1,175	650	55	45
12	1,860	1,085	455	1,405	630	45	55
13	1,965	1,240	450	1,515	790	52	48
14	2,955	2,110	415	2,540	1,695	67	33

TABLE 20.—*Total solids in samples collected at Fort Bellefontaine, Hartford, and St. Louis waterworks intake, and percentages of Missouri River and Mississippi River water entering intake, January 24 to October 10, 1900*—Continued.

Date.	Total solids (parts per million).					Percentage of water entering intake from—	
	Fort Bellefontaine.	Intake.	Hartford.	Difference between— Fort Bellefontaine and Hartford.	Difference between— Intake and Hartford.	Missouri River.	Mississippi River.
Apr. 15	3,402	3,542	376	....	....	100	0
16	1,861	2,048	....	....	....	100	0
17	3,604	1,842	401	3,203	1,441	45	55
18	2,395	1,807	424	1,871	1,383	70	30
19	2,410	1,488	410	2,000	1,078	54	46
20	2,384	1,309	425	1,959	884	45	55
21	2,300	1,611	458	1,848	1,153	63	37
22	4,374	1,342	520	3,854	822	21	79
23	1,987	1,657	493	1,494	1,154	78	22
24	1,755	1,354	615	1,140	739	65	35
25	1,938	1,488	1,444	494	44	9	91
26	1,574	1,375	469	1,105	906	82	18
28	2,000	1,455	521	1,479	934	63	37
29	1,730	1,310	440	1,290	870	68	32
30	1,438	1,240	458	980	782	80	20
May 1	1,655	1,245	455	1,200	790	66	34
2	1,665	1,260	420	1,245	840	67	33
3	1,845	1,435	445	1,400	990	71	29
4	2,287	1,535	380	1,887	1,155	61	39
5	2,600	1;485	415	2,185	1,070	49	51
6	2,880	1,685	1,235	1,645	430	26	74
7	2,110	1,485	510	1,600	955	60	40
8	1,951	1,449	1,091	860	358	42	56
9	1,913	1,390	545	1,368	845	62	38
10	2,013	1,300	555	1,458	745	51	49
11	1,696	1,202	491	1,205	717	59	41
12	1,885	1,258	448	1,437	810	56	44
13	2,198	1,884	453	1,745	1,431	82	18
14	3,563	2,147	410	3,163	1,737	55	45
15	3,010	2,120	420	2,590	1,700	66	34
16	2,380	1,960	415	1,965	1,545	79	21
17	2,495	1,930	450	2,045	1,480	72	28
18	2,335	2,050	405	2,430	1,645	68	32
19	2,615	2,396	545	2,070	1,851	90	10
20	2,160	1,945	505	1,655	1,440	87	13
21	2,340	1,985	490	1,850	1,495	81	19
22	2,280	2,033	546	1,734	1,487	86	14
23	2,358	2,032	565	1,793	1,467	82	18
24	2,136	2,007	526	1,610	1,481	83	17
25	2,204	1,917	575	1,689	1,402	83	17
26	2,283	1,834	457	1,826	1,377	75	25
27	2,120	1,805	502	1,618	1,303	81	19
28	1,743	1,918	440	1,303	1,478	100	0
29	2,280	2,122	420	1,805	1,702	94	6
30	3,480	2,255	380	2,090	1,865	89	11
31	2,290	2,290	435	....	....	100	0
June 1	2,200	2,099	410	1,790	1,680	94	6
2	2,580	2,005	390	2,190	1,615	74	26
3	2,280	2,180	335	1,945	1,845	95	5
4	2,170	2,285	430	1,740	....	100	0
5	2,455	2,155	460	1,995	1,695	85	15
6	2,360	2,105	435	1,925	1,660	86	14
7	2,355	1,950	410	1,945	1,540	79	21
8	2,375	1,825	390	1,985	1,433	72	28
9	2,405	2,010	380	2,025	1,630	81	19
10	2,475	1,935	330	2,145	1,605	75	25
11	1,950	1,858	340	1,610	1,515	94	6
12	2,015	2,030	425	....	....	100	0
13	2,315	2,215	595	1,720	1,620	94	6
14	4,315	3,955	320	3,995	3,635	91	9
15	3,538	3,730	375	....	....	100	0
16	2,562	2,935	335	....	....	100	0
17	2,326	2,657	324	....	....	100	0
18	2,545	2,412	340	2,205	2,072	94	6
19	2,189	2,280	345	....	....	100	0
20	2,179	2,080	335	1,844	1,670	91	9
21	2,210	2,100	305	1,905	1,795	94	6

TABLE 20.—*Total solids in samples collected at Fort Bellefontaine, Hartford, and St. Louis waterworks intake, and percentages of Missouri River and Mississippi River water entering intake, January 24 to October 10, 1900*—Continued.

Date.	Total solids (parts per million).					Percentage of water entering intake from—	
	Fort Bellefontaine.	Intake.	Hartford.	Difference between—		Missouri River.	Mississippi River.
				Fort Bellefontaine and Hartford.	Intake and Hartford.		
June 22	3,258	3,055	315	2,943	2,740	93	7
23	3,683	3,910	363	...	...	100	0
24	3,205	4,184	471	...	...	100	0
25	3,506	3,892	471	...	...	100	0
26	3,330	3,503	...	...	...	100	0
27	3,170	3,156	470	2,700	2,685	99	1
28	3,325	2,870	455	2,870	2,415	84	16
29	2,760	2,805	405	...	...	100	0
30	2,686	2,805	405	...	...	100	0
July 1	2,440	2,770	380	...	...	100	0
2	2,515	2,867	345	...	...	100	0
3	2,115	2,800	325	...	...	100	0
4	2,782	2,873	335	...	...	100	0
5	3,945	3,000	330	3,615	2,660	74	26
6	3,400	4,175	331	...	...	100	0
7	3,125	3,193	364	...	...	100	0
8	3,060	3,234	864	...	...	100	0
9	3,435	3,490	343	...	...	100	0
10	3,822	3,400	330	3,492	3,070	88	12
11	2,690	2,855	320	...	...	100	0
12	2,430	2,655	540	...	...	100	0
13	2,175	2,415	310	...	...	100	0
14	1,970	2,210	290	...	...	100	0
15	1,450	2,100	270	...	...	100	0
16	2,433	2,315	280	2,155	2,135	94	6
17	2,575	2,405	415	2,160	1,990	92	8
18	2,360	1,880	310	2,050	1,570	77	23
19	2,415	2,300	327	2,088	1,973	95	5
20	2,293	2,050	610	1,683	1,440	86	14
21	2,020	1,800	370	1,650	1,430	87	13
22	1,895	2,132	380	...	...	100	0
23	2,780	2,760	344	2,436	2,416	99	1
24	3,885	3,210	310	3,575	2,900	81	19
25	4,580	3,420	335	4,245	3,090	73	27
26	3,791	3,277	408	3,383	2,869	85	15
27	3,157	2,500	480	2,677	2,020	76	24
28	2,730	2,371	450	2,280	1,921	84	16
30	2,310	1,995	408	1,902	1,587	83	17
31	2,061	1,972	512	1,549	1,460	94	6
Aug. 1	2,127	1,795	522	1,605	1,273	79	21
2	1,725	1,807	495	1,230	1,312	100	0
3	1,975	1,693	455	1,520	1,238	82	18
4	1,812	1,630	382	1,430	1,248	87	13
5	1,622	1,339	340	1,282	999	78	22
6	1,530	1,393	315	1,215	1,078	89	11
7	1,530	1,045	302	1,228	743	61	39
8	1,294	1,069	305	989	764	77	23
9	1,243	1,008	305	937	703	75	25
10	1,226	990	289	937	701	75	25
11	1,220	970	240	980	730	75	25
12	1,082	935	280	802	655	81	19
13	1,060	890	292	768	589	78	22
14	1,110	904	300	810	604	75	25
15	1,000	860	270	730	590	81	19
16	1,053	860	234	730	576	75	25
17	1,053	860	284	769	575	67	33
18	960	890	260	700	630	90	10
19	1,343	1,061	283	1,060	778	73	27
20	1,482	1,305	318	1,164	988	85	15
21	1,785	1,305	405	1,380	900	65	35
22	1,845	1,525	665	1,180	860	73	27
23	1,760	1,445	685	1,075	760	71	29
24	1,610	1,470	688	922	782	85	15
25	1,556	1,320	584	972	736	76	24
26	1,556	1,320	584	972	736	76	24
27	1,410	1,358	538	872	820	94	6
28	1,595	1,422	445	1,150	977	85	15
29	1,565	1,379	420	1,145	951	83	17

TABLE 20.—*Total solids in samples collected at Fort Bellefontaine, Hartford, and St. Louis waterworks intake, and percentages of Missouri river and Mississippi River water entering intake, January 24 to October 10, 1900*—Continued.

Date.	Total solids (parts per million).					Percentage of water entering intake—	
				Difference between—			
	Fort Bellefontaine.	Intake.	Hartford.	Fort Bellefontaine and Hartford.	Intake and Hartford.	Missouri River.	Mississippi River.
Aug. 30	1,881	1,125	375	1,508	750	50	50
31	1,881	1,125	375	1,506	750	50	50
Sept. 1	1,376	1,315	430	946	885	94	6
2	1,460	1,450	420	1,040	1,030	99	1
3	1,610	1,414	445	1,165	969	82	18
5	1,930	1,489	365	1,565	1,124	72	28
6	1,600	1,545	370	1,230	1,175	96	4
8	1,635	1,436	354	1,281	1,082	84	16
9	1,570	1,308	352	1,218	1,056	87	13
10	1,430	1,240	340	1,090	900	83	17
12	1,492	1,033	359	1,143	674	60	40
13	1,305	1,048	340	965	708	73	27
14	1,213	931	348	865	583	67	33
15	1,110	896	298	812	598	74	26
16	1,270	900	345	945	555	60	40
17	1,186	900	330	856	570	67	33
18	1,230	853	300	930	553	60	40
19	1,210	864	340	870	524	60	40
20	1,428	970	311	1,117	659	56	44
21	2,200	1,380	311	1,889	1,069	57	43
22	3,230	1,900	313	2,917	1,597	54	46
23	2,985	1,920	327	2,658	1,593	60	40
24	3,116	1,980	330	2,786	1,650	59	41
25	2,558	1,836	360	2,198	1,476	67	33
26	2,365	1,640	320	3,045	1,320	65	35
27	1,970	1,500	580	1,390	920	66	34
28	1,870	1,325	350	1,520	975	64	36
29	1,785	1,330	605	1,180	925	68	32
30	1,840	1,373	400	1,440	973	68	32
Oct. 1	1,847	1,357	444	1,403	913	65	35
2	1,990	1,320	365	1,625	965	59	41
3	2,960	1,990	448	2,512	1,542	61	39
4	2,920	1,332	455	2,465	877	36	64
5	2,677	2,036	394	2,283	1,642	72	28
6	2,480	1,895	376	2,104	1,519	72	28
7	3,095	1,937	370	2,725	1,567	58	42
8	2,578	1,878	357	2,221	1,521	68	32
9	2,605	2,095	355	2,250	1,740	77	23
10	2,807	2,165	370	2,437	1,791	74	26

A chart designated as Complainant's Exhibit No. 60, showing diagrammatically the records of typhoid fever in St. Louis for 1895 to 1899, inclusive, and for 1900 in connection with the percentage of Mississippi River water entering the intake from January 24 to October 10, 1900, calculated from the total solids as described, was then discussed by the witness. He claimed that a great increase in the percentage of Mississippi River water entering the intake in 1900 was followed in due time, a proper period of incubation being allowed, by an increase in the typhoid rate of the city. He further remarked that such increase was very much higher than the average for the five years previous. He called attention to the variations in the typhoid rate of 1900. (1240–1242.)

According to these calculations it appears that on or about February 6 100 per cent of Mississippi River water entered the intake tower, followed by 90 per cent February 21. During the week beginning February 20 there was an increase in the number of cases reported, and it reached a maximum of 40 during the week ending March 13. There was a sharp decline after this and the rate remained comparatively low until the week ending September 4, when there was a considerable increase, continuing until a maximum of 102 cases was reached during the week ending October 2, after which there was another sharp decline. This latter increase was preceded by an increase in the proportion of Mississippi River water entering the intake, but the percentage was not at any time previous to the apex of the outbreak greater than 50, and this occurred only on two days—August 30 and 31. Inasmuch as the chart is not presented in this review, it is fair to state that immediately after the outbreak which reached its height March 13 and declined sharply thereafter, the rate remaining low for the remainder of the summer, a larger proportion of Mississippi River water entered the intake than at any other time during the investigation. March 15 the proportion of Mississippi water began to increase, reaching 100 per cent March 24 and remaining practically at that point for a week. This was not, however, followed by any increase in typhoid, but, on the contrary, the rate declined and remained low during the subsequent heavy influx of Mississippi water between April 17 and 26.

The witness then discussed the chart representing diagrammatically the comparison of samples of water from the intake tower with those taken from the reservoir after two days' sedimentation and with those from the tap in the city chemist's office. It was noted that, although the water had passed through the sedimentation reservoir and 85 per cent of its suspended matter had been removed, its condition as it left the reservoir and was drawn from the tap was not greatly improved over its condition at the intake tower. A marked increase in the free ammonia and nitrites in the intake water was followed by similar increase in these ingredients at the two other points. Therefore, in the opinion of the witness, from the standpoint of actual purification the reservoir can not be said to be highly effective.

Doctor Teichmann then called attention to an unusual rise in the proportion of free ammonia and nitrites in the early part of 1900, and stated that none of the analytical results on record, representing analyses made during twenty years previous, had shown so remarkable a quantity of free ammonia and nitrites at the intake tower, the reservoir, or the tap. Such an increase was marked all along Illinois River to its mouth and at the various sampling points along Mississippi River down to the intake tower. No corresponding increase occurred in the water of Mississippi River above the mouth of the Illinois nor in the Missouri, and all of it occurred directly after the opening of the drainage canal in January, 1900. The analyses of samples taken at the various points in 1899 previous to the opening of the canal and in 1900 after such opening being compared, the general result was shown to be that there were evidences of increased pollution all along the course, from Desplaines River at Lockport even down to the intake tower and the tap in the laboratory of the city chemist. (1242–1246.)

The testimony of the witness was then directed to investigations subsequent to that of 1900. He stated that a number of samples were collected between October 12 and November 30, 1901, from points in Illinois River, but inasmuch as they were not collected regularly, the results were not included in the evidence. Samples were collected daily during these two months from Mississippi River along a cross section at Chain of Rocks, near the Missouri shore, at the intake tower, and near the Illinois shore. The results show that the water along the Illinois shore was at all times more polluted than that along the Missouri shore, while that at the intake was a mixture of the two, partaking of the nature of one side or the other according to the relative heights of Mississippi and Missouri rivers. (1246–1247.)

The witness presented a series of charts which were admitted in evidence and marked for identification as Complainant's Exhibits Nos. 62 to 70, inclusive. The charts contain statements in diagrammatic form of weekly average results of analyses of water during this period from the various sampling points mentioned, these averages being combined in a series intended to bring out more clearly the points which the witness considered important in establishing the case of the complainant. The results are included in Table 21.

TABLE 21.—*Weekly average results of analyses of water at various points, October and November, 1901.*

Sampling point.	Week ending—							
	Oct. 4.	Oct. 11.	Oct. 18.	Oct. 25.	Nov. 1.	Nov. 8.	Nov. 15.	Nov. 22.
FREE AMMONIA.								
Illinois and Michigan Canal at Bridgeport	9.70	14.25	11.72	12.80	10.60	14.35	16.55	21.80
Illinois and Michigan Canal at Lockport	20.82	17.54	17.02	15.25	17.75	22.12	18.70	22.48
Chicago drainage canal at Bridgeport	.95	.97	.79	1.06	1.18	2.37	.55	.09
Chicago drainage canal at Bear Trap dam	1.32	1.33	1.17	1.34	1.28	1.24	.95	1.11
Desplaines River above Lockport	.08	.09	.11	.04	.03	.04	.04	.04
Desplaines River at Ruby street, Joliet	3.275	2.925	2.487	2.275	2.475	2.895	2.895	2.600
Desplaines River at Brandon's bridge, Joliet	3.38	2.93	2.48	2.27	2.45	2.90	2.93	2.600
Illinois River at La Salle	....	.475	.462	.437	.625	.750	1.125	1.575
Illinois River at Averyville	.018	.232	.280	.283	.225	.350	.510	.940
Illinois River at Pekin	.228	.185	.240	.270	.210	260	.510	.780
Illinois River at Kingston	295	.390	.385	.615	.350	.430	.720	.880
Illinois River at Beardstown	.355	.435	.364	.410	.390	.270	.550	.660
Illinois River at Grafton	.125	.125	.140	.095	.085	.70	.065	.170
Mississippi River at Grafton	.070	.070	.065	.072	.055	.045	.045	.035
Mississippi River at Alton	.070	.073	.077	.075	.055	.045	.045	.045
Mississippi River at Hartford	.063	.070	.080	.080	.055	.054	.040	.052
Missouri River at Fort Bellefontaine	.068	.070	.090	.065	.050	.063	.078	.073
Mississippi River at intake tower, Chain of Rocks	.077	.067	.085	....	.042	.060	.068	.064
Outlet, St. Louis reservoir	.060	.055	.062	.045	.035	.035	.044	.059
Tap in city chemist's office, St. Louis	.057	.050	.063	.048	.030	.030	.045	.053
NITROGEN AS NITRITES.								
Illinois and Michigan Canal at Bridgeport	0.0090	0.0200	0.0120	0.0170	0.0110	0.0140	0.0120	0.0060
Illinois and Michigan Canal at Lockport	.0000	.0000	.0000	.0012	.0013	.0030	.0020	.0017
Chicago drainage canal at Bridgeport	.0095	.0130	.0080	.0120	.0030	.0030	.0050	.0030
Chicago drainage canal at Bear Trap dam	.0102	.0102	.0110	.0070	.0130	.0120	.0090	.0100
Desplaines River above Lockport	.000	.000	.0005	.000	.0005	.0015	.0010	.0000
Desplaines River at Ruby street, Joliet	.070	.069	.071	.075	.063	.056	.031	.022
Desplaines River at Brandon's bridge, Joliet	.0700	.0691	.0710	.0750	.0630	.0561	.0312	.0221
Illinois River at La Salle	....	.172	.156	.154	.116	.119	.064	.048
Illinois River at Averyville	.106	.154	.111	.090	.079	.076	.076	.051
Illinois River at Pekin	.105	.117	.099	.089	.091	.073	.066	.054
Illinois River at Kingston	.120	.174	.114	.114	.086	.094	.076	.058
Illinois River at Beardstown	.130	.131	.098	.102	.089	.074	.069	.063
Illinois River at Grafton	.059	.045	.053	.033	.034	.039	.036	.031
Mississippi River at Grafton	.0005	.0003	.0002	.0002	.0007	.0005	.0015	.0005
Mississippi River at Alton	.012	.006	.005	.002	.0025	.0025	.0035	.0010
Mississippi River at Hartford	.015	.010	.011	.008	.008	.012	.010	.011
Missouri River at Fort Bellefontaine	.0010	.0015	.0015	.0010	.0035	.0065	.0065	.0040
Mississippi River at intake tower, Chain of Rocks	.0020	.0010	.0015	.0020	.0035	.0050	.0060	.0035
Outlet, St. Louis reservoir	.0020	.0010	.0015	.0010	.0030	.0040	.0060	.0040
Tap in city chemist's office St. Louis	.0020	.0015	.0015	.0010	.0020	.0020	.0040	.0030

TABLE 21.—*Weekly average results of analyses of water at various points, October and November, 1901*—Continued.

NITROGEN AS NITRATES.

Sampling point.	Week ending—							
	Oct. 4.	Oct. 11.	Oct. 18.	Oct. 25.	Nov. 1.	Nov. 8.	Nov. 15.	Nov. 22.
Illinois and Michigan Canal at Bridgeport	0.09	0.15	0.08	0.07	0.07	0.20	0.09	0.15
Illinois and Michigan Canal at Lockport	.04	.11	.06	.06	.06	.15	.11	.11
Chicago drainage canal at Bridgeport	.14	.11	.07	.05	.14	10	.10	.11
Chicago drainage canal at Bear Trap dam	.06	.09	.03	.04	.07	.14	.07	.09
Desplaines River above Lockport	.06	.12	.06	.05	.05	.08	.05	.06
Desplaines River at Ruby street, Joliet	.29	.24	.25	.21	.20	.21	.15	.15
Desplaines River at Brandon's bridge, Joliet	.29	.24	.25	.22	.20	.22	.15	.16
Illinois River at La Salle	....	2.00	1.97	1.97	1.90	1.85	1.35	1.05
Illinois River at Averyville	1.82	1.97	2.15	1.97	1.95	1.97	1.80	1.55
Illinois River at Pekin	1.71	1.93	2 03	1.93	1.80	1.89	1.70	1.59
Illinois River at Kingston	1.64	1.89	1.91	1.85	1.71	1.84	1.74	1.59
Illinois River at Beardstown	1.54	1.56	1.85	1.73	1.52	1.78	1.70	1.57
Illinois River at Grafton	1.76	1.64	1.70	1.66	1.80	1.42	1.34	1.58
Mississippi River at Grafton	.08	.12	.10	.10	.10	.12	.10	.12
Mississippi River at Alton	.40	.30	.20	.16	.13	.20	.10	.12
Mississippi River at Hartford	.56	.59	.52	.55	.58	.61	.45	.48
Missouri River at Fort Bellefontaine	.56	.50	.65	.65	.54	.61	.56	.38
Mississippi River at intake tower, Chain of Rocks	.43	.48	.47	.50	.53	.60	.53	.34
Outlet, St. Louis reservoir	.42	.43	.40	.49	.47	.45	.40	.36
Tap in city chemist's office, St. Louis	.48	.45	.37	.47	.50	.45	.43	.35

CHLORINE.

Sampling point.	Oct. 4.	Oct. 11.	Oct. 18.	Oct. 25.	Nov. 1.	Nov. 8.	Nov. 15.	Nov. 22.
Illinois and Michigan Canal at Bridgeport	80	88	104	100	85	156	115	150
Illinois and Michigan Canal at Lockport	106	158	129	126	135	170	128	147
Chicago drainage canal at Bridgeport	12	11	10	14	10	21	18	21
Chicago drainage canal at Bear Trap dam	11	12	10	13	12	11	10	10
Desplaines River above Lockport	27	23	20	16	17	19	16	15
Desplaines River at Ruby street, Joliet	28	27	25	22	22	23	23	21
Desplaines River at Brandon's bridge, Joliet	28	28	25	21	21	22	22	21
Illinois River at La Salle	....	22	23	20	20	20	22	20
Illinois River at Averyville	22	24	23	22	21	20	21	21
Illinois River at Pekin	22	24	24	23	22	21	22	21
Illinois River at Kingston	23	24	24	23	21	21	21	21
Illinois River at Beardstown	22	22	23	22	21	20	21	20
Illinois River at Grafton	25	23	22	22	22	21	20	20
Mississippi River at Grafton	5	6	4	4	4	4	4	4
Mississippi River at Alton	9	7	6	5	5	5	5	5
Mississippi River at Hartford	10	10	9	9	9	10	10	9
Missouri River at Fort Bellefontaine	13	16	17	20	17	24	20	18
Mississippi River at intake tower, Chain of Rocks	11	14	17	17	16	19	....	17
Outlet, St. Louis reservoir	11	14	17	16	16	18	17	16
Tap in city chemist's office, St. Louis	13	12	15	15	17	16	20	17

In discussing the above results the witness repeated much of his testimony given in connection with the presentation of the results of analyses for the previous year. His remarks consisted of a general indictment of the drainage canal and appear in the record, pages 1255–1276. Only a few facts in addition to those already mentioned were brought out. Among them were the following:

That the sewage emptied into the old Illinois and Michigan Canal undergoes anaerobic action and when it is discharged into Desplaines

River is in an advanced state of purification, so that the aerobic action which rapidly takes place after the effluent is discharged into the river is sufficient to complete the purification after a few miles of flow in the river bed. The sewage turned into the new drainage canal, on the other hand, reaches the discharge point at Desplaines River much more quickly and the fermentative changes have hardly commenced. Therefore it was argued by the witness that the discharge from the drainage canal is carried much farther down the river before its final purification takes place than that from the Illinois and Michigan Canal; and he pointed to the alleged fact that inasmuch as the great volumes of water discharged into Desplaines River from the drainage canal markedly increase the rate of flow the danger from the sewage is much accentuated thereby.

That the water of Desplaines River above the point of entrance of Chicago drainage canal is potable.

That the nitrites at Joliet are lower than at La Salle and Peoria, demonstrating, in the opinion of the witness, that the purification is by no means complete at Peoria.

That the determinations, especially those of the nitrites, vary in samples taken from the stations along the lower reaches of the stream coincidently with variations in the upper-station samples, irrespective of the flow of the stream, demonstrating, in the opinion of the witness, the effect of Chicago sewage on the river water.

That the variations in Illinois River water at Grafton are similar to and coincident with variations at Joliet. These variations do not, however, occur in the water from Mississippi River above Grafton, and the analyses show that the water from the latter point is far superior to that from the former.

That the excessive quantities of organic matter turned into Desplaines River from the Chicago drainage canal make self-purification of the stream impossible.

That the figures, in addition to showing increased pollution caused by the opening of the drainage canal in January, demonstrate also the effect of closing the canal during the following September. The effect produced on the sanitary quality of the water at Peoria and Grafton by the opening of the canal after this closing was exactly similar to but not as pronounced as the effect caused by the original opening of the canal in January.

That the figures show that the enormous pollution caused by the flushing out of Chicago River and the drainage canal during the period from January 17 to March 16, 1900, had a marked effect on the chemical character of the water of Mississippi River at Alton and Hartford.

That the water in Mississippi River at Chain of Rocks near the Missouri shore is practically Missouri River water and is not influenced to any great extent by mixing with Mississippi River water.

That the sanitary quality of Mississippi River water as shown by the cross-section samples at Chain of Rocks is distinctly inferior to that of the Missouri.

That, although the sedimentation reservoirs connected with the St. Louis waterworks system effect a removal of 85 per cent of suspended matter and 44 per cent of bacteria, the specific ingredients denoting pollution are by no means sufficiently removed when the water reaches the consumer.

The witness then presented the results of two series of analyses of water collected from the points along Missouri and Kaw [Kansas] rivers designated on page 50. These results are contained in Table 22. The first series extended from November 13 to November 22, and the second series from November 24 to December 3. (1276–1286.)

TABLE 22.—*Results of analyses of water from Missouri and Kaw rivers at stated points, 1901.*

[Parts per million.]

Sampling point.	Total residue.		Free ammonia.		Nitrites.		Nitrates.		Chlorine.		Oxygen consumed.	
	1.	2.	1.	2.	1.	2.	1.	2.	1.	2.	1.	2.
Missouri River—												
Above Omaha	1,325	1,290	0.062	0.056	0.004	0.001	0.18	0.18	10.0	11.0	7.1	0.6
Below Omaha	1,074	1,050	.136	.126	.006	.003	.16	.14	11.5	11.5	......	6.2
Above St. Joseph	1,225	1,135	.076	.080	......	.006	.22	.20	12.5	16.0	9.0	7.1
Below St. Joseph	1,150	......	......	......	.007	......	.26	......	7.0	......	8.7	......
Above Kansas City	1,152	1,070	.070	.116	.005	.004	.026	.24	24.2	16.0	8.1	6.2
Below Kansas City	1,290	1,100	.112	.130	.005	.004	......	.24	18.0	23.0	8.5	6.7
Kaw River at Argentine	687	650	.062	.036	.004	.000	.100	.04	89.8	109.0	7.8	5.9
Missouri River—												
Above Jefferson City	1,295	1,055	.094	.136	.005	.008	.360	.28	20.0	23.0	9.6	6.7
Below Jefferson City	1,315	1,005	.090	.136	.006	.007	.300	.26	21.0	24.0	7.4	6.6
Above Hermann	1,740	950	.090	.106	.005	.005	.360	.28	9.0	19.0	9.0	6.5
Below Hermann	1,155	170	.090	.126	.005	.004	.360	.26	18.5	......	5.5	6.4
Above St. Charles	1,101	950	.083	.246	.004	.005	.560	.26	18.5	23.0	9.1	6.5
Below St. Charles	1,072	940	.046	.112	.004	.006	.620	.24	19.0	23.0	9.5	6.6

The only interpretation which the witness could make of the data contained in the above table was as follows: The chemical analyses show that the Missouri River water as analyzed from Omaha down to St. Louis has a character of considerable stability. The results are fairly uniform along the route, with the exception that the high chlorines coming from Kaw River increase somewhat the amount of chlorine in the Missouri between Kansas City and St. Louis. (1287.)

The witness then discussed the fifth period of investigation, beginning December 1, 1901, and continuing to July 1, 1902. Daily samples were collected from Illinois River above Grafton until December 18, 1901, and from Mississippi River a few miles above Grafton until December 14. With the exception of these samples taken above Grafton from the two rivers no samples were collected during this period above Chain of Rocks in Mississippi River. Three cross section samples were taken at this point, as in previous periods of examination; a fourth was taken from the outlet of the sedimentation reservoir; and a fifth from the tap in the city chemist's office. The general results of these investigations were that free ammonia and nitrites frequently rose to very high proportions in the samples from the Illinois shore. Such increases were always found to be the result of similar increases in the water of Illinois River above Grafton. A notable instance was during the second and third weeks of December, 1901, when an enormous rise in free ammonia occurred at Grafton, followed by a similar rise at Chain of Rocks, near the Illinois shore, and at the intake tower. This persisted during the early part of 1902. While the figures for Missouri River during this period were higher than usual for this stream, the samples collected at the intake showed considerably more pollution, and the only inference to be drawn is that the excess of organic matter came from the Illinois side of the river. A similar instance occurred during the latter part of March, 1902. Throughout this whole investigation, ending July 1, 1902, and also the sixth period, beginning October 1, 1902, and ending January 1, 1903, the same relations were apparent. An increase in free ammonia and nitrites, which the witness accepted as indicative of sewage pollution along the Illinois shore, was always reflected in samples taken at the intake tower, at the outlet of the sedimentation basins, and finally in the water taken from the tap at the city chemist's office in St. Louis. It was the contention of the witness, in summing up the evidence presented by the chemical data gathered in the various periods, that the discharge of sewage into Desplaines River from the Chicago drainage canal is felt throughout Illinois River and down the Mississippi. The variations in the character of the water in the canal at Lockport are followed by similar variations at Peoria and these by similar ones at Grafton, the wave progressing onward even to the water taps of consumers in St. Louis. (1289–1307.)

CROSS-EXAMINATION.

The cross-examiner sought to show that the witness was not justified in selecting records of the lowest flow of Illinois River as a basis for his determination of the degree of dilution of Chicago sewage, contending that the mean stages of water would serve as a fair basis. To this the witness replied that he did so to calculate the lowest possible amount of dilution, although he admitted that such a condition was uncommon and nonrepresentative and that the mean stage of water could readily be calculated. He stated that he had sought for the lowest stages in the report of Lyman E. Cooley for 1890 and in those of Jacob A. Harman in various State board of health publications up to 1899, the avowed purpose being to show the worst possible pollution recorded on the charts presented in evidence. (1380–1382.)

The cross-examiner then sought to show that the figures given by the witness concerning the minimum flow of the upper section of the

Illinois drainage basin (1163–1166) at 600 cubic feet per second were too low, inasmuch as by his own statement the lowest recorded flow of Desplaines River was 256 cubic feet per minute, of Kankakee River 25,200 feet per minute, of Fox River 31,339 feet per minute, and of the Illinois and Michigan Canal at La Salle 37,900 feet per minute, the combined flow of which would represent a far greater amount of water than that accepted by the witness as a basis for his calculations of sewage dilution. The witness was unable to reply to this presentation, but fell back on the reports of Messrs. Cooley and Harman, which he quoted in his testimony. (1382–1386.)

The cross-examiner sought to show that the calculation made by the witness with reference to the proportion of sewage per capita at Peoria discharged in Illinois River (1212–1213) was unfair, inasmuch as Peoria is a great manufacturing center, containing distilleries, glucose works, etc., from which a disproportionate amount of organic matter is discharged into the stream, and therefore the assumption of a sewage discharge equivalent to the consumption of water was unwarranted and the basis of calculation should be raised. This was denied by the witness, who contended that the sewage conditions were representative of the majority of other cities. (1402–1405.)

The cross-examiner then took up the statement made by the witness (1213) that if the water of Illinois River came down to Peoria in a potable condition the polluting effect of Peoria sewage on the stream would be removed after running a distance of 25 to 50 miles below the city, and, presenting a supposititious case based on the specified premises, asked the witness to confirm or deny his former statement. Doctor Teichmann refused to make a direct reply, but qualified his statement made in direct testimony by asserting that chemical evidences of the pollution would be removed in that distance. His final reply to the question was as follows: "I said chemically; yes. I didn't say that at the time, but it was understood, and if I had been asked the question I would have said so at that time, that a chemical examination of the samples of water taken at a point below Peoria, and taking into consideration the general conditions of the river, I would say that that sewage disappears from the channel—that is, the chemical result would not show its presence." (1405–1410.)

The cross-examiner drew from the witness the following information: The number of wells in St. Louis in 1899 was from 3,500 to 4,000 and the number of drain-water cisterns used was about 3,000, making in all about 7,000 private water supplies to be used in the city. In 1900 there were 1,160 cases of typhoid reported. Three-fourths of the patients had used water from the city supply only, while the remainder admitted that they drank well water, but frequently would use the city supply in addition. (1436–1437.)

The cross-examiner endeavored to establish the allegation that the apparent increase in the number of typhoid cases in St. Louis was not due to greater incidence of the disease, but to more faithful reporting to the health department on the part of the practicing physicians in the city. He procured an admission from the witness that in 1900 a special letter was sent out to all physicians in the city calling attention to the fact that the law required them, under penalty, to report all cases of typhoid fever occurring in their practice and that for the seven years previous no special effort had been made to obtain compliance with this law. The witness stated that there had, nevertheless, always been general discussion in connection with the potability of the water supply, and warnings had frequently been issued by the health department against the use of the city water. (1439–1442.)

The witness then admitted that during the five years previous to 1900 the St. Louis water was not potable and required boiling or filtration to make it safe. He asserted, however, that it had become worse after the opening of the canal, and stated his belief that the pollution of the St. Louis supply previous to the opening of the canal was derived from Illinois River and that from a chemical standpoint the water from Missouri River had been, and was at the time of the testimony, in a potable condition. (1446–1448.)

On being questioned with reference to the distance which a stream must flow in order to purify itself, the witness stated that it could not be given offhand, but would require careful consideration of the local conditions, the volume of water, its character, the character of the sewage discharged, etc. He admitted that he did not know whether the sewage of St. Paul and Minneapolis was purified by flowing in Mississippi River from these two cities to St. Louis, and confessed the same lack of information concerning the sewage from McGregor, Prairie du Chien, Dubuque, Clinton, Quincy, Burlington, Keokuk, Rock Island, Moline, and Davenport. (1460–1464.)

The witness then modified his former statement concerning the potability of the Mississippi River water above the mouth of Illinois River, and stated that the water is not potable except during the summer months, when the purification processes are greatly accelerated. (1465–1467.)

The cross-examiner continued along this line for the apparent purpose of determining how the witness reconciled his statement concerning the potability of the Mississippi River water above Grafton, which receives the sewage of the above-named cities, with his opinion concerning the unpotability of the Illinois River water above Grafton. The contention of the cross-examiner was that if the witness had determined that the Mississippi water above Grafton was potable then the irresistible conclusion would be that sewage from the above-named cities must have been purified by the time it reached Grafton, and such being the case the theory that polluted water becomes purified by running a certain distance must be correct.

The witness refused to make a direct reply, basing his refusal on his ignorance of the conditions on the drainage area without a knowledge of which he could not be expected to give an opinion. For the same reason he refused to give a direct reply to the question whether or not there were any conceivable conditions on the Mississippi drainage area above Grafton which would change his opinion of the potability of the water, it being assumed that his chemical data remained unchanged. Whatever the conditions above might be, he would draw only one conclusion from his data—namely, that the water was potable during the summer months. In short, he based his conclusion solely on chemical data. Shortly afterwards, in response to similar questions, he gave an opinion diametrically opposite to that expressed in the preceding paragraph, viz: "Practically throughout the year it is permissible as a good drinking water." He added that if he were placed in charge of the water supply of Grafton he would advise the use of raw water from Mississippi River above the city. Being further pressed, he admitted that there were some authorities who would disagree with him on the matter, and then asserted that he supported the views of this very class of authorities. The witness then stated that he would render an opinion concerning the potability of the water from chemical evidence, but would supplement it in a measure by bacteriological evidence. He then professed ignorance of any instances in which a water appeared to be unpolluted from chemical evidence but polluted from bacteriological evidence. He stated that if it should exist the water must be considered unpotable. (1467–1479.)

The witness then testified as follows:

I am testifying to the facts as I found them at the mouth of the Illinois River. What the conditions are hundreds of miles above the mouth of the Illinois on the Mississippi I am not considering. I only ascertained the character of the Mississippi River water 3 and 5 miles above the mouth of the Illinois. "Is it good or bad?" And I find it potable, and I have so expressed it. What it might have been miles and miles above the mouth of the Illinois is immaterial, to my mind, in considering the questions involved in the investigation that I conducted these years. (1482.)

The attention of the witness was called to the fact that Doctor Ravold had declared the water of the Mississippi above Grafton unfit for domestic purposes, and after much circumlocution he stated that he differed with Doctor Ravold and held to his opinion. (1485–1490.)

The cross-examination is continued in the record to page 1697. Although many different points were taken up, no important new facts were enunciated. The greater part of the cross-examination consisted of questions apparently designed to test the qualifications of the witness as an expert on the interpretation of water analyses and the general subject of stream pollution, and it would seem to the impartial reader that the credibility of the witness suffered.

EDWARD H. KEISER.

DIRECT EXAMINATION.

Edward H. Keiser, a witness called in behalf of the complainant, in qualifying as an expert, made the following statements: Since 1899 he had been professor of chemistry in Washington University, St. Louis; for fourteen years previous he had occupied the same position in Bryn Mawr College, Pennsylvania; for eighteen months previous to that was instructor in chemistry in Johns Hopkins University, Baltimore. He was graduated from Swarthmore College, Pennsylvania, in 1880, with the degree of bachelor of science, and in 1881 took the degree of master of science; in 1884 received the degree of doctor of philosophy at Johns Hopkins University. In the summer of 1884 he studied at Freiburg, Saxony; in 1887 at Göttingen, Germany; and in 1894 at Heidelberg. He had given his entire professional life to chemistry and had been called on during his career to analyze many samples of water. (968–971.)

The witness stated that he had commenced his work for the city of St. Louis January 24, 1900, and continued the analysis of samples collected daily until October 11, following. A second series of analyses was conducted extending from October 1 to November 30, 1901. The following determinations were made in the analyses carried on by Professor Keiser: Total solids, free ammonia, albuminoid ammonia, total ammonia, oxygen consumed, nitrites, nitrates, and chlorine. For the first five determinations mentioned the water was used in an unfiltered state; the other three were made with filtered water. The methods used in making these determinations were described and the witness stated that they were, in general, those recommended by the American Association for the Advancement of Science. (974–980.)

Samples from the following points were analyzed in the series of 1900: Reservoir of St. Louis water-supply system at Chain of Rocks; along the cross section defined by Mississippi River intake tower; Illinois shore, and Missouri shore; Missouri River at Fort Bellefontaine; Mississippi River at Hartford, above Alton, and above the mouth of Illinois River; Illinois River 3 miles above Grafton and 2 miles above Peoria; and Desplaines River at Joliet and Lockport. (981.)

The witness stated that of the determinations made he regarded the nitrites and free ammonia as of chief importance, for the reason that—

> The presence of measurable quantities of nitrites in drinking water is often regarded as a sure sign of contamination, and a chemist finding a measurable quantity of nitrites in water would condemn that water as unsafe for drinking purposes; and so free ammonia likewise is of great importance for the reason that the first product produced by bacteria in decomposing sewage is ammonia. We always find a quantity of free ammonia in sewage; so the chemist lays special stress on these two constituents, namely, nitrites and free ammonia. (982.)

The witness then introduced data concerning the character of the water in the reservoir at Chain of Rocks, reciting in his testimony the weekly and monthly averages of the daily determinations made. He mentioned only the determinations of albuminoid ammonia, free ammonia, nitrites, and nitrates, and it does not appear from the record that he presented tables or gave any other data. The results given are recorded in Table 23. (985–1007.)

TABLE 23.—*Weekly and monthly averages of daily analyses of water from reservoir St. Louis waterworks.*

[Parts per million.]

Date.	Albuminoid ammonia.		Free ammonia.		Nitrites.		Nitrates.	
	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.
1900.								
January 24–31	0.214	0.214	0.1112	0.1112	0.0044	0.0044	0.50	0.50
February 1–7	.199	.271	.2265	.2098	.0074	.0133	.52	.59
February 8–14	.285		.2345		.0080		.49	
February 15–21	.259		.1689		.0140		.57	
February 22–28	.344		.2094		.0240		.78	
March 1–7	.233	.410	.1357	.1890	.0100	.0107	.61	.77
March 8–14	.325		.1643		.0080		.91	
March 15–21	.582		.1980		.0120		.89	
March 22–31	.501		.2848		.0130		.67	
April 1–7	.264	.313	.2690	.1664	.0140	.0180	.51	.56
April 8–14	.387		.2234		.0170		.67	
April 15–21	.248		.1030		.0260		.53	
April 22–30	.352		.0703		.0140		.54	
May 1–7	.279	.261	.0417	.0377	.0097	.0055	.51	.39
May 8–14	.285		.0254		.0046		.38	
May 15–21	.224		.0345		.0049		.32	
May 22–31	.257		.0491		.0031		.35	
June 1–7	.155	.182	.0234	.0130	.0040	.0032	.39	.41
June 8–14	.172		.0066		.0039		.37	
June 15–21	.161		.0100		.0027		.43	
June 22–30	.240		.0120		.0020		.43	
July 1–7	.219	.234	.0117	.0199	.0017	.0017	.51	.46
July 8–14	.192		.0228		.0013		.49	
July 15–21	.249		.0265		.0021		.34	
July 22–31	.275		.0186		.0017		.51	
August 1–7	.304	.257	.0320	.0276	.0004	.0021	.48	.35
August 8–14	.233		.0220		.0018		.27	
August 15–21	.202		.0223		.0035		.22	
August 22–31	.289		.0343		.0025		.42	
September 1–7	.276	.237	.0208	.0250	.0015	.0013	.39	.37
September 8–14	.238		.0348		.0011		.36	
September 15–21	.225		.0263		.0016		.36	
September 22–30	.210		.0283		.0010		.38	
October 1–10	.335	.335	.0316	.0316	.0021	.0021	.53	.53
1901.								
October 1–7	.885	.673	.1290	.074	.0037	.0059	.60	.38
October 8–14	.677		.0510		.0029		.29	
October 15–21	.523		.046		.0050		.21	
October 22–28	.727		....		.0048		.43	
October 28–November 4	.553		.071		.0131		.38	
November 5–11	.493	.559	.070	.074	.0131	.0130	.27	.23
November 12–18	.794		.086		.0143		.25	
November 19–25	.536		.072		.0130		.12	
November 25–30	.420		.071		.0116		.12	

In discussing the results set forth in the above table, Professor Keiser stated that early in February, 1900, the quantity of nitrites and free ammonia in the reservoir water began to increase very materially, and the water became highly polluted. This was also noted in the case of the other determinations. Beginning with the first part of the month of May, there was a gradual decrease in these constituents, and during the summer months—indeed, up to the end of the period of investigation—the proportion thereof remained low. The results for October and November, 1901, showed considerable increase over those of the previous year. These results, in the opinion of the witness, indicated that an enormous amount of polluting matter was coming down Mississippi River and that the water could not be classed as potable, owing to the large amount of decomposing organic matter in it. (1008–1009.)

The witness then presented data on the free ammonia, nitrites, and nitrates in daily samples of Mississippi water at Chain of Rocks, taken from points near the Missouri and Illinois shores. The results are set forth in Table 24. (1013–1031.)

Table 24.—*Weekly and monthly averages of analyses of daily samples of water from Mississippi River at Chain of Rocks.*

[Parts per million.]

Date.	Free ammonia.				Nitrites.				Nitrates.			
	Missouri shore.		Illinois shore.		Missouri shore.		Illinois shore.		Missouri shore.		Illinois shore.	
	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.
1900.												
January 24–31	0.1208	0.1208	0.4920	0.4920	0.0070	0.0070	0.0130	0.0130	0.565	0.565	1.040	1.040
February 1–7	.2200	.1673	.4670	.4180	.0065	.0144	.0214	.0187	.457	.485	.765	.790
February 8–14	.1800		.....		.0183		.0000		.457		.....	
February 15–21	.1431		.4820		.0123		.0211		.542		.882	
February 22–28	.1260		.3050		.0206		.0136		.....		.....	
March 1–7	.1048	.1457	.3000	.2981	.0140	.0168	.0123	.0164	.688	.935	1.205	1.004
March 8–14	.1582		.2851		.0128		.0080		1.343		.822	
March 15–21	.1731		.3020		.0183		.0254		.954		1.011	
March 22–31	.1468		.3060		.0223		.0200		.754		.980	
April 1–7	.0828	.0609	.2930	.1770	.0325	.0168	.0365	.0308	.577	.478	.977	.936
April 8–14	.0525		.2152		.0118		.0305		.462		1.022	
April 15–21	.0582		.1241		.0080		.0288		.434		.897	
April 22–31	.0503		.0790		.0148		.0274		.497		.851	
May 1–7	.0445	.0614	.0571	.0566	.0057	.0035	.0175	.0154	.594	.455	.600	.435
May 8–14	.0474		.0503		.0028		.0134		.451		.331	
May 15–21	.0668		.0506		.0028		.0148		.371		.394	
May 22–31	.0871		.0685		.0023		.0178		.405		.497	
June 1–7	.0365	.0416	.0351	.0267	.0028	.0026	.0050	.0050	.325	.364	.422	.435
June 8–14	.0277		.0162		.0026		.0032		.285		.388	
June 15–21	.0374		.0214		.0028		.0035		.371		.434	
June 22–30	.0648		.0342		.0024		.0084		.474		.494	
July 1–7	.0560	.0504	.0240	.0291	.0015	.0014	.0041	.0041	.423	.483	.508	.581
July 8–14	.0231		.0237		.0017		.0043		.423		.514	
July 15–21	.0517		.0300		.0010		.0043		.434		.514	
July 22–31	.0708		.0388		.0014		.0037		.651		.788	
August 1–7	.0388	.0322	.0428	.0304	.0001	.0012	.0037	.0063	.491	.345	.514	.419
August 8–14	.0174		.0260		.0015		.0077		.251		.234	
August 15–21	.0202		.0157		.0014		.0102		.314		.304	
August 22–31	.0525		.0371		.0017		.0038		.325		.622	
September 1–7	.0368	.0454	.0271	.0448	.0016	.0008	.0070	.0068	.268	.358	.485	.433
September 8–14	.0265		.0394		.0003		.0071		.320		.505	
September 15–21	.0628		.0506		.0004		.0067		.365		.428	
September 22–30	.0557		.0768		.0011		.0067		.480		.313	
October 1–10	.0508	.0508	.0448	.0448	.0011	.0011	.0064	.0064	.617	.617	.388	.388
1901.												
October 1–7	.0805	.0584	.0869	.0732	.0024	.0048	.0110	.0132	.428	.375	.485	.327
October 8–14	.0502		.0571		.0027		.0124		.428		.291	
October 15–21	.0449		.0706		.0058		.0144		.240		.269	
October 22–28	.0449		.0557		.0048		.0160		.377		.331	
October 29–November 4	.0717		.0957		.0082		.0123		.400		.360	
November 5–11	.0634	.0780	.0714	.0706	.0124	.0014	.0167	.0162	.234	.246	.497	.326
November 12–18	.0894		.0720		.0141		.0177		.257		.257	
November 19–25	.0810		.0489		.0096		.0171		.260		.291	
November 26–30	.0844		.0648		.0128		.0170		.184		.223	

The witness stated in discussing the above table that the investigation was made in this way for the purpose of determining whether the water at the intake was of "homogeneous character" and whether the water on both sides of the river was of the same chemical constitution. A marked difference was found at times, as shown in the table. The witness pointed out that soon after the beginning of the investigation nitrites were found to be twice as great in proportion on the Illinois side as on the Missouri side, and attributed this to the fact that in February there was a rise in Illinois River coincident with the opening of the Chicago drainage canal; during the same time, however, Mississippi River was at low stage. The witness found that in general, during the analytical period, the water on the Illinois side of the river was from four to five times more polluted than that on the Missouri side. He concluded further, from the fact that the amount of nitrites in the reservoir was greater than that in Mississippi River along the Missouri shore and less than that along the Illinois shore, that there must have been a mixture of the two waters at the intake. He added that all the determinations made confirmed this interpretation. He then compared the character of the water from Missouri River opposite Fort Bellefontaine with that from Mississippi River at Chain of Rocks near the Missouri shore and declared them to be the same. He further stated that the water at Chain of Rocks near the Illinois shore was at all times Mississippi water and that the waters from the two rivers became mixed at the intake. This conclusion was reached from a consideration of the amounts of chlorine, total solids, and free and albuminoid ammonia taken at the three points at Chain of Rocks. In every case the samples from the intake represent a mean between those from the two shores. (1013–1032.)

The witness then discussed a formula by which the proportion of Mississippi and Missouri rivers waters entering the intake at Chain of Rocks might be determined. (1032–1034.) This formula may be expressed in simple equations, as follows:

$$x + y = 1$$
$$ax + by = c$$

in which

x = Proportion of Missouri River water entering intake.

y = Proportion of Mississippi River water entering intake.

a = Amount of chosen constituents in water at Missouri shore, Chain of Rocks.

b = Amount of chosen constituents in water at Illinois shore, Chain of Rocks.

c = Same in mixed water entering intake.

Taking as an example the week ending August 21, 1900, with the nitrite determination as a basis, the witness gave a practical demonstration of the use of this formula. The values of a, b, and c for the week mentioned are 0.0014, 0.0102, and 0.0035. Substituting these values in the above equation, we have—

$$0.0014x + 0.0102y = 0.0035.$$

Since in the first equation

$$x + y = 1,$$

the values may be reduced to

$$0.0014x + 0.0102\ (1 - x) = 0.0035,$$

whence

$$x = \tfrac{3}{4}\ \text{(nearly)}$$
$$y = \tfrac{1}{4}\ \text{(nearly)}.$$

The above computation showed, in the opinion of the witness, that during the week mentioned three-fourths of the water delivered to St. Louis was from Missouri River and one-fourth from Mississippi River.

It should be especially noted at this point that Professor Keiser based the greater part of his interpretations on the nitrite determinations, occasionally considering the ammonia. Continuing with his testimony, he stated that there was always more or less Mississippi River water in the reservoir at Chain of Rocks. Although there might be one or, perhaps, two days at a time during which the water would be largely from the Missouri, yet the mixture in the reservoir would always contain a certain amount of Mississippi water. In the opinion of the witness Mississippi River is a badly polluted stream below a point a short distance above the mouth of Illinois River. Above this point the water is in much better condition. He also characterized Missouri River as a fairly good stream from a sanitary standpoint. (1034–1035.)

The witness then entered on a comparison of the nitrites in the water of Mississippi River at Chain of Rocks, Illinois shore, at Hartford, and at Alton, and stated that the determinations showed in general that nitrites were higher at Hartford than at Chain of Rocks, and again higher at Alton than at Hartford, though they were very much lower in Mississippi River above the confluence of Illinois River. The results of these determinations are set forth in Table 25. (1035–1037.)

TABLE 25.—*Weekly and monthly averages of nitrite determinations in daily samples of water from Mississippi River at Chain of Rocks (Illinois shore), Hartford, and Alton.*

[Parts per million.]

Date.	Chain of Rocks.		Hartford.		Alton.	
	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.
1900.						
January 24-31	0.0130	0.0130	0.0183	0.0183	0.0225	0.0225
February 1-7	.0214	.0187	.0220	.0199	.0263	.0253
February 8-14			.0151		.0190	
February 15-21	.0211		.0180		.0225	
February 22-28	.0136		.0248		.0334	
March 1-7	.0123	.0164	.0234	.0173	.0365	.0248
March 8-14	.0080		.0128		.0225	
March 15-21	.0254		.0140		.0211	
March 22-31	.0200		.0191		.0191	
April 1-7	.0365	.0308	.0240	.0358	.0205	.0378
April 8-14	.0305		.0345		.0394	
April 15-21	.0288		.0417		.0428	
April 22-30	.0274		.0431		.0485	
May 1-7	.0157	.0154	.0213	.0269	.0223	.0289
May 8-14	.0134		.0285		.0268	
May 15-21	.0148		.0340		.0388	
May 22-31	.0178		.0240		.0277	
June 1-7	.0050	.0050	.0080	.0099	.0075	.0104
June 8-14	.0032		.0047		.0048	
June 15-21	.0035		.0047		.0053	
June 22-30	.0084		.0225		.0243	
July 1-7	.0041	.0041	.0114	.0121	.0153	.0159
July 8-14	.0043		.0105		.0163	
July 15-21	.0043		.0123		.0177	
July 22-31	.0037		.0143		.0144	
August 1-7	.0037	.0063	.0053	.0095	.0071	.0104
August 8-14	.0077		.0080		.0100	
August 15-21	.0102		.0173		.0180	
August 22-31	.0038		.0074		.0064	
September 1-7	.0070	.0068	.0100	.0097	.0111	.0115
September 8-14	.0071		.0084		.0103	
September 15-21	.0067		.0084		.0114	
September 22-30	.0067		.0120		.0134	
October 1-10	.0064	.0064	.0101	.0101	.0124	.0124
1901.						
October 1-7	.0110	.0132	.0235	.0173	.0160	.0151
October 8-14	.0124		.0184		.0121	
October 15-21	.0144		.0150		.0180	
October 22-28	.0160		.0163		.0190	
October 29-November 4	.0123		.0137		.0102	
November 5-11	.0167	.0171	.0191	.0183	.0103	.0096
November 12-18	.0177		.0190		.0124	
November 19-25	.0171		.0167		.0072	
November 26-30	.0170		.0186		.0088	

In reply to a question concerning the effect of the sewage of Alton the witness stated that the chemical data proved that it has no apparent effect on the river, because the dilution is so great that the amount of sewage entering there does not perceptibly increase the amount of organic matter. Continuing, the witness stated that in Illinois River the nitrites are considerably higher than in the Mississippi, but far lower in the Mississippi above Grafton than they are in the same stream at Alton, Hartford, or Chain of Rocks, indicating that Mississippi River above Grafton is in a purer condition than it is below. He further stated that chemical analyses show that the pollution of the Mississippi comes from Illinois River, and that if it were not for that pollution the water of the river at Chain of Rocks along the Illinois shore would be very similar in character to that along the Missouri shore with respect to free ammonia and nitrites. Missouri

River water, however, contains more chlorine than that of the Mississippi because of the fact that large amounts of salt are emptied into the river from Kansas. He finally stated, without qualification, that were it not for the flow of the polluted waters of Illinois River the Mississippi at Chain of Rocks would afford a good drinking water on both sides of the channel. (1041–1043.)

A chart was then introduced (Complainant's Exhibit No. 22) showing graphically the variation in the quantities of nitrites found in Illinois River above Grafton and above Peoria. It was the contention of Professor Keiser that this chart showed that the water in Illinois River above Grafton was inferior to that in Mississippi River at Alton, and that as Illinois River was ascended the conditions became worse, and his conclusions from these facts were as follows: Although before the opening of the drainage canal Illinois River contained sewage matter, there was greater oxidation in the region above and immediately below Peoria and in fact all along the river, the movement of the water was slower in the river, and while the water was impure above Peoria a smaller quantity of nitrites was found, showing that oxidation had proceeded further than it did subsequent to the opening of the canal; in other words, by the turning in of so great a quantity of water into the Illinois system the "region of bacterial action and the conversion of the nitrogenous organic matter into nitrites was moved much farther down Illinois River and into Mississippi River below the mouth of the Illinois." The witness further stated that inasmuch as the analyses made during October and November, 1901, showed a more highly polluted condition than those made during 1900 the conditions were growing worse rather than improving. (1043–1046.)

Data concerning the nitrites and free ammonia in Illinois River at various points were presented and are included in Table 26. (1042–1060.)

The witness then stated that the analyses indicate a decided increase in the amount of impurities since the opening of the canal. In his judgment this pollution continues down to Chain of Rocks, a portion of it finding its way to the intake tower of the waterworks and thence to the reservoir at St. Louis. As the volume of water going down Illinois River is greater now than previous to the opening of the canal there is less opportunity for sedimentation to take place. (1048–1049.)

The maximum allowable amount of free ammonia is 0.05 part per million, and when this is exceeded the water is to be regarded with suspicion. If there are measurable quantities of nitrites the water should be condemned, inasmuch as good drinking water should have no nitrites in it. (1052.)

TABLE 26.—*Monthly averages of daily determinations of nitrites and free ammonia in water from Illinois River at specified points.*

[Parts per million.]

Date.	3 miles above Grafton.		Above Peoria.				At Joliet.				At Lockport.			
	Nitrites.	Free ammonia.	Nitrites.		Free ammonia.		Nitrites.		Free ammonia.		Nitrites.		Free ammonia.	
			Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.
1900.														
January 24-31	0.0300	1.498		0.0248		2.485								
February	.0245	.946	0.0414	.0358	2.169	1.416								
March	.0170	.322	.0268	.0209	1.201	.685	0.067	0.0558	3.491	2.689	0.0945	0.0643	3.095	2.437
April	.0370	.113	.0771	.0467	.455	.392	.1014	.0663	3.140	2.732	.1011	.0730	2.591	1.806
May	.0459	.1079	.1023	.0752	.361	.266	.0340	.0256	3.604	2.995	.0405	.0234	2.236	1.598
June	.0193	.0321	.1448	.1317	.319	.228	.0345	.0326	3.600	3.270	.0295	.0114	1.677	1.411
July	.0352	.0443	.2171	.1657	.401	.230	.0728	.0551	4.647	3.710	.0114	.0081	1.834	1.631
August	.0239	.0406	.1743	.1597	.172	.142	.0597	.0465	3.999	2.933	.0140	.0083	1.974	1.589
September	.0257	.0517	.2171	.1382	.672	.255	.0754	.0524	5.473	4.498	.0108	.0071	2.685	2.195
October	.0428	.0677		.1857		1.404	.0562	.0562		3.306		.0130		1.555
1901.														
October	.0720	.1502					.0830	.0780	5.519	3.801	.0172	.0167	1.663	1.446
November							.0781	.0510	3.494	3.152	.0210	.0189	1.368	1.239

The witness gave the data presented in Table 27, with reference to the amount of chlorine in the water of Illinois and Mississippi rivers above Grafton. (1053.)

TABLE 27.—*Monthly averages of daily determinations of chlorine in water from Illinois and Mississippi rivers above Grafton, 1900.*

[Parts per million.]

Month.	Illinois River.	Mississippi River.	Month.	Illinois River.	Mississippi River.
January	14.1	5.7	June	12.6	5.1
February	13.1	6.1	July	18.0	7.7
March	7.0	4.5	August	16.5	5.2
April	6.1	4.8	September	14.8	3.3
May	10.9	4.2	October	16.9	3.9

He then gave the comparisons shown in Table 28 with reference to Illinois River above Grafton and above Peoria. (1047–1048.)

TABLE 28.—*Monthly averages of daily determinations of nitrites and free ammonia in water from Illinois River above Grafton and above Peoria.*

[Parts per million.]

	Grafton.		Peoria.	
	Nitrites.	Free ammonia.	Nitrites.	Free ammonia.
October, 1900	0.0428	0.0677	0.1857	1.404
October, 1901	.720	.1502	.1240	.305

The witness then gave the following data concerning the water from the drainage canal off Pauline street, Chicago (1060–1064):

TABLE 29.—*Determinations of free ammonia, nitrites, and chlorine in daily samples of water from the Chicago drainage canal off Pauline street.*

[Parts per million.]

Date.	Free ammonia.	Nitrites.	Chlorine.	Date.	Free ammonia.	Nitrites.	Chlorine.
1901.				1901.			
October 9	0.328	0.016	22.8	November 6	0.568	0.015	10.0
October 10	2.860	.040	23.0	November 7	.652	.018	16.0
October 11	.676	.018	18.0	November 8	.436	.028	12.0
October 12	.812	.017	12.1	November 9	.452	.015	10.8
October 13	1.66	.036	20.8	November 10	.849	.015	14.2
October 14	....	.015	21.0	November 11	.560	.013	14.8
October 15	1.072	.017	19.0	November 12	5.192	.025	106.0
October 16	1.500	.018	23.2	November 13	.568	.015	12.2
October 17	.884	.018	19.5	November 14	.640	.015	9.0
October 21	.672	.019	22.3	November 15	.468	.027	8.0
October 22	.334	.027	22.5	November 16	.428	.016	11.0
October 23	.884	.013	17.5	November 17	.588	.023	11.0
October 24	.796	.016	18.2	November 18	.452	.015	9.0
October 26	.732	.015	22.0	November 19	.560	.016	11.2
October 27	1.020	.014	21.3	November 21	.716	.007	8.0
October 28	1.288	.025	21.7	November 22	.564	.013	11.9
October 29	.744	.016	23.8	November 23	.504	.018	11.3
October 30	.700	.019	29.0	November 24	.628	.017	12.3
October 31	.744	.018	24.2	November 26	.404	.017	9.0
November 1	.968	.028	21.5	November 27	.968	.017	11.6
November 2	.628	.016	23.0	November 28	256	.016	16.1
November 3	.648	.017	13.8	November 29	1.892	.017	16.2
November 4	.988	.013	13.2	November 30	2.140	.015	29.0
November 5	1.068	.017	11.3				

The results were then discussed by Professor Keiser substantially as follows:

From these analytical results it is apparent that the water of Illinois River was more highly contaminated with nitrogenous organic matter at Joliet and Lockport than at Peoria. Higher values are shown for free ammonia and nitrites at Joliet than at Lockport. This is accounted for by the fact that the samples at Joliet were taken immediately under the Illinois and Michigan Canal, which passes over the river at that point. The analyses are typical of sewage; it can not be called water. Several months after the analyses began, the quantities of nitrites and free ammonia diminished both at Lockport and at Joliet. This is accounted for by the outflow of the water of the drainage canal. In other words, after the opening of the drainage canal this concentrated sewage at Lockport and Joliet was diluted. That, in part, is the result shown by the analyses. The results obtained at Peoria and points below show that this sewage from Lockport and Joliet had been washed farther down the river. There were at Grafton much higher nitrites and free ammonia after the opening of the canal than before, and that is evidence of the flushing down of the sewage matter which had accumulated at Lockport and Joliet and in the upper regions of the river. (1064-1065.)

Professor Keiser was recalled to the witness stand for the purpose of making comprehensive interpretations of the chemical data which had been offered in evidence by the witnesses on behalf of the plaintiff. He submitted the data given in Table 30 concerning the analytical results. The first and second entries in the table are the averages of 17 analyses made from May 2, 1893, to January 24, 1894, by the water department of St. Louis, and originally appeared in the message of the mayor for 1894. The third entry is the average of 21 analyses made at intervals from December 15, 1892, to April 20, 1894, in the chemical laboratory of Washington University. The fourth entry is an average of 26 analyses made by the city chemist at intervals from September 9, 1899, to January 22, 1900. The remainder of the table consists of data given in the testimony of Dr. William C. Teichmann.

TABLE 30.—*Average results of sanitary analyses of Mississippi River water at St. Louis.*

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Sampling point.
May 2, 1893, to January 24, 1894.	17	1.033	0.046	0.003	0.38	....	Distributing well.
April 14, 1893, to January 24, 1894.	17	.411	.019	.002	.44	....	Settling basin.
December 15, 1892, to April 20, 1894.	21	.310	.048	.005	.38	....	Not designated.
September 9, 1899, to January 22, 1900.	26	.522	.063	.002	.39	....	Intake tower.

TABLE 30.—*Average results of sanitary analyses of Mississippi River water at St. Louis*—Continued.

AFTER OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Sampling point.
February, 1900	28	0.676	0.217	0.013	0.60	....	Intake tower.
March, 1900	31	1.202	.348	.014	.80	....	Do.
April, 1900	30	1.036	.186	.020	.60	9	Do.
May, 1900	31	1.190	.094	.011	.50	10	Do.
June, 1900	30	1.148	.070	.004	.30	11	Do.
July, 1900	31	1.350	.127	.004	.30	10	Do.
August, 1900	31	.810	.101	.005	.40	12	Do.
September, 1900	30	.818	.093	.004	.70	15	Do.
October, 1900	31	.898	.118	.006	.60	9	Do.
November, 1900	30	.705	.098	.007	.60	10	Do.
December, 1900	31	.289	.105	.011	.40	17	Do.
January, 1901	31	.396	.144	.009	.80	19	Do.
February, 1901	28	.296	.121	.007	.70	19	Do.
March, 1901	31	1.455	.310	.013	1.3	11	Do.
April, 1901	30	1.034	.191	.016	1.1	6	Do.
May, 1901	31	.506	.088	.002	.4	9	Do.
June, 1901	30	1.161	.105	.002	.5	10	Do.

AVERAGES.

Before opening	[a] 81	0.569	0.044	0.003	0.40	....	
After opening	[a] 515	.880	.150	.009	.6	12	

[a] Total.

In interpreting the above data the witness stated that the analyses recorded prior to the opening of the canal show that the water was comparatively stable and not unwholesome compared with its subsequent condition. January 17, 1900, the drainage canal was opened. The water must have reached St. Louis about the beginning of February and the results are clearly shown in the analytical statement made for that month. A portion of the great increase noted in free ammonia and nitrites in February and March might have been due to the fact that in the winter months impurities are usually found to run higher than in spring and summer, but the increase during these two months was very much greater than had been observed in any previous year. From the subsequent results it is apparent, according to the witness, that the character of the water has permanently changed. (1697-1702.)

In reply to questions concerning the Missouri River data, the witness presented the average results recorded in Table 31. Contrasting the condition of the water before and after the opening of the canal, he stated that the differences were slight—that no change resulted in the general character of the water—showing conclusively that the changes noted in the Mississippi River water at the Chain of Rocks intake tower, could not have been due to any increase of impurities in Missouri River. (1702-1704.)

TABLE 31.—*Average results of sanitary analyses of Missouri River water near Fort Bellefontaine.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.
Prior to February 1, 1900	19	0.499	0.107	0.0045	0.39

AFTER OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.
February 1 to October 10, 1900	268	1.203	0.142	0.007	0.50
October 1 to November 30, 1901	61	.631	.069	.003	.55

The witness then testified concerning the results in evidence, with reference to the character of the water of Mississippi River at Hartford, 1 mile above the mouth of the Missouri, 17 analyses of the water having been made at intervals between August 3 and December 4, 1899. The average of these analyses, together with those obtained after the opening of the canal during the periods January 23 to October 10, 1900, and October 1 to November 30, 1901, will be found in Table 32. (1705.)

TABLE 32.—*Average results of sanitary analyses of Mississippi River water opposite Hartford.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.
August 3 to December 4, 1899	17	0.622	0.107	0.004	0.5

AFTER OPENING OF DRAINAGE CANAL.

Date.	Number of samples	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.
January 23 to October 10, 1900	260	0.613	0.275	0.018	0.7
October 1 to November 30, 1901	61	.368	.062	.011	.54

In interpreting these results, the witness pointed out the fact that at Hartford, as at the intake, there had been a permanent increase in the amount of pollution in the water after the opening of the canal. (1704–1706.)

The witness then took up the analyses of samples from Mississippi River above the mouth of the Illinois and presented the average results, as shown in Table 33. (1706-1707.)

TABLE 33.—*Average results of sanitary analyses of water from Mississippi River above mouth of Illinois River.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.
September 6, 1899, to January 17, 1900.	18	0.503	0.069	0.002	0.30	6.0
AFTER OPENING OF DRAINAGE CANAL.						
January 23 to October 10, 1900	264	0.587	0.138	0.008	0.46	5.0
October 1 to November 30, 1901	61	.348	.057	.001	.10	4.3

The witness stated that these data plainly showed that the water from Mississippi River above the mouth of the Illinois is in stable condition, and that practically no change has taken place in its composition since the opening of the canal—a fact which excludes the possibility that the change in the character of the St. Louis water is due to increased impurities in the upper Mississippi. (1706–1707.)

He then gave the results of analyses of samples of water from Illinois River 3 miles above Grafton, collected before and after the opening of the Chicago drainage canal. These results are included in Table 34. (1707–1708.)

TABLE 34.—*Average results of sanitary analyses of Illinois River water 3 miles above Grafton.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.
September 6, 1899, to January 17, 1900.	19	0.553	0.215	0.012	0.8	25.0
AFTER OPENING OF DRAINAGE CANAL.						
January 23 to October 10, 1900	265	0.509	0.272	0.032	0.96	13.0
October 1 to November 30, 1901	61	.373	.110	.043	1.71	21.6

The witness stated that prior to the opening of the canal the Illinois water above Grafton was badly polluted and unpotable. Nevertheless, for ten months after the opening of the canal there was an increase in free ammonia of nearly 27 per cent and in nitrites of 167 per cent. The only conclusion to be drawn from these figures is, according to the witness, that after the canal was opened there was a much larger quantity of sewage undergoing putrefactive change than before, and he argued that it was this sewage from Illinois River which had caused a permanent change in the character of the water entering the St. Louis intake at Chain of Rocks. (1707–1708.)

The witness then presented the average results of analyses of water from Illinois River above Grafton and above Peoria; from Desplaines River at Joliet; from the Illinois and Michigan Canal and the drainage canal at Lockport, and from Lake Michigan. These results are shown in Table 35. (1708–1710.)

TABLE 35.—*Average results of analyses of water from stated points, January 23 to October 10, 1900.*

[Parts per million.]

Sampling point.	Number of analyses.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.
Illinois River 3 miles above Grafton	265	0.482	0.239	0.034	1.11	14.7
Illinois River 3 miles above Peoria	260	.284	.468	.095	1.48	19.4
Desplaines River at Joliet	219	.452	2.732	.057	.22	23.9
Illinois and Michigan Canal at Lockport	....	....	13.250	.009	0	150.0
Drainage canal at Lockport	219	....	1.585	.026	.15	15.0
Lake Michigan	219	....	.043	.005	.15	6.0

The witness pointed out that the figures in the above table show that the water becomes steadily more and more impure as Illinois River is ascended, and that the entire river is in a highly polluted condition. The water of Lake Michigan, from which the supply of the two canals is derived, is in good condition from a sanitary standpoint, and the fact that it contains so large an amount of organic matter by the time it reaches the canals is sufficient proof that this matter must be derived from the sewage of Chicago, the results of which are traceable all along the valley and down to the St. Louis intake. (1708–1710.)

The witness made and discussed a series of statements concerning the pollution or amount of organic matter in water from various points before and after the opening of the Chicago drainage canal, based on averages of analyses made at specified periods. He considered that the determinations of albuminoid and free ammonia and nitrites would constitute a sufficient index of pollution. The results are set forth in Table 36. (1073–1078.)

TABLE 36.—*Averages of analyses of water at chosen points before and after the opening of the Chicago drainage canal.*

[Parts per million.]

Sampling point.	Albuminoid ammonia.		Free ammonia.		Nitrites.	
	Before.	After.	Before.	After.	Before.	After.
Reservoir, St. Louis	0.214	0.271	0.111	0.210	0.004	0.013
Mississippi River at Alton	.200	.728	.288	.460	.212	.104
Missouri River at Fort Bellefontaine	.063	.395	.135	.148	.008	.014
Mississippi River above Grafton	.478	.565	.113	.176	.005	.005
Illinois River above Grafton	.478	.913	.113	.946	.005	.025
Illinois River above Peoria	a .572	a 2.210; b .627	c .895	a 3.060; b 1.950	a .141	a .060; b .030

a According to J. H. Long. b According to E. H. Keiser.

The periods of analyses included in the above table are as follows:

For the reservoir at St. Louis: Before opening of canal, January, 1900.
After opening of canal, February, 1900.

For Missouri River at Fort Bellefontaine: Before opening of canal, January, 1900.
After opening of canal, February, 1900.

For Mississippi River at Alton: Before opening of canal, January, 1900.
After opening of canal, February, 1900.

For Mississippi River above Grafton: Before opening of canal, January, 1900.
After opening of canal, February, 1900.

For Illinois River above Grafton: Before opening of canal, January 23–31, 1900.
After opening of canal, February 21–28, 1900.

For Illinois River above Peoria: Before opening of canal, J. H. Long's results for 1899.
After opening of canal, Long's results, February to April, inclusive, 1900, and those of the witness, February to March, inclusive, 1900.

According to the witness the figures in Table 36 show unmistakably that there was a great increase in the pollution of Illinois River after the opening of the canal, but no corresponding increase in that of the Mississippi above Grafton or of Missouri River at Fort Bellefontaine.

CROSS-EXAMINATION.

The cross-examination brought out the admission from Professor Keiser that he had made no personal investigation of the Illinois River drainage area and that the physical conditions, except as they might be learned from maps, were unknown to him. He declared, however, that such knowledge is not necessary to an intelligent interpretation of his results. (1080–1081.)

The cross-examiner then endeavored to show that the method used by the witness to determine the proportion of Mississippi and Missouri river waters entering the intake at St. Louis is faulty, because the algebraic formula does not take account of the relative amounts of water furnished by these streams, to which the witness responded that no such fallacy is involved, because the values are true irrespective of the volumes of water making the mixture. If in a mixture of Missouri and Mississippi river waters the amount of Missouri water was one-third greater than the Mississippi, but the Mississippi polluted twice as much as the Missouri, the degree of pollution in the mixture chargeable to each stream would not correspond with the relative volumes of the two streams, but with the relative proportions of impurity. (1100–1103.)

In response to questions, the witness then gave the monthly average results of his analyses of water from Missouri River at Fort Bellefontaine. (1104–1106.)

TABLE 37.—*Monthly averages of daily analyses of water from Missouri River at Fort Bellefontaine, 1900.*

[Parts per million.]

Month.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.
January	0.363	0.135	0.008	0.415	23.5
February	.395	.232	.014	.592	18.6
March	1.182	.144	.023	.965	12.1
April	.775	.069	.018	.485	12.5
May	1.484	.083	.013	.484	11.5
June	1.181	.067	.003	.418	11.4
July	1.556	.055	.001	.462	11.2
August	.842	.038	.001	.435	12.8
September	1.133	.068	.002	.381	16.3
October	1.382	.055	.002	.560	11.4

The witness stated that he had made no determinations of the volume of water contributed to Illinois River by its tributaries nor had he taken this into consideration. He had regarded all the impurity found in Illinois River as coming from the drainage canal, because these impurities increased steadily as the river was ascended. If the impurities were derived from the tributaries, the amounts of albuminoid and free ammonia and nitrites would be fairly constant throughout the length of the main stream, but inasmuch as there was a constant increase all the way upstream and as at Joliet the river water was found to be merely dilute sewage, the chief cause of pollution must lie in the drainage canal. (1108–1110.)

The cross-examiner then directed the attention of Professor Keiser to that part of his testimony in which he referred to a report of Prof. J. H. Long in presenting figures to show the comparative condition of the water of Illinois River at Peoria before and after the opening of the canal. He pointed out that the witness had given for free ammonia the values 0.895 (Long) before the opening and 3.060 (Long) and 1.950 (Keiser) after the opening. (See p. 87.) The cross-examiner showed that the witness had selected Long's free ammonia determinations from samples taken at "The Narrows," above Peoria, to show the condition before the opening of the canal, and the determinations from samples taken at Wesley, below Peoria, and in the field of high contamination from Peoria sewers, to show the condition after the opening of the canal. It appears from an examination of the testimony and Long's report that three series of examinations were conducted by him at Peoria. The first extended from July 5 to November 29, 1899, the samples being taken at Peoria Narrows (above Peoria) and at Wesley (below Peoria); the second extended from March 7 to April 25, 1900, all the samples being taken at Wesley; the third extended from June 7 to October 10, 1900, the samples being taken at both points mentioned.

The witness finally admitted that he had compared the figures for Peoria Narrows for 1899 (before canal opening) with those for Wesley for March and April, 1900 (after canal opening). In attempting to justify this comparison the witness made the following statements: First, as no analytical results appeared in Long's report with reference to the water above Peoria in the examination of March and April, 1900, and as the witness desired to procure data for a period as close as possible to the opening of the canal he had selected the Wesley figures for the stated period, believing that the effect of the Peoria sewage was negligible. Second, the analyses made by Long of water taken from Peoria Narrows, July 5 to November 29, 1899, and June 7 to October 10, 1900, would not admit of comparison by average statements, as the comparisons were stated in the witness's testimony, because the average of the determinations for 1899 included analyses made during November, while those of 1900 ended October 10. Free ammonia and nitrites increase greatly in November, and to include these determinations in the average for 1899 would result in an unfair comparison in favor of the defendants. Why, if such were the case, he did not make the comparison by eliminating the results of Long's analyses for November, 1899, and leaving only the determinations extending to October 10, the date of the closing of Long's investigation of 1900, he did not venture to explain. It is evident from the testimony that he believed it equitable to take for comparison the results of an entirely different part of the year, viz, March and April, 1900. Third, while he had quoted figures from Long's report, as above stated, he also included the results of his own analyses for 1900, and his interpretations were not affected by Long's results. Why, if such were the case, he included them in his testimony was not explained.

The cross-examiner pointed out that had he taken Long's results for Peoria Narrows in 1900 there would have appeared in the comparison a great decrease in ammonia and nitrites instead of the increase reported. The witness thereupon denied that such a comparison would be warranted for reasons above stated.

After further questions concerning the figures of the comparison made by the witness, he made the following statements:

> I wasn't aware that there was any certain degree of difference. In making this comparison I found the table on page 44 [Long's report] was the nearest one that Professor Long has published of results made after the opening of the drainage canal, and I took Peoria here as being the nearest point to that point where I had taken samples for analysis. I didn't know where it was exactly, and I didn't know whether the sewage of Peoria got into the river at Wesley. I thought it was considerably below, if anything. I did not think it was right in the town of Peoria. (1128–1129.)

The cross-examiner then called the attention of the witness to page 36 of Long's report, in which values for free ammonia, albuminoid ammonia, nitrites, and nitrates are given for samples of water taken at the Narrows, above Peoria, from July 5 to November 23, 1899, and again to page 64 of the same book, where values are given for the same determinations from samples taken at the same point during the period from June 7 to October 9, 1900. It will be noted that these two periods are before and after the opening of the canal, respectively. The witness was then asked if in the showing for free ammonia, albuminoid ammonia, nitrites, and nitrates there was a considerable reduction in the latter period as compared with the former period. To this he replied "Yes," and in explanation of this reply made the following statement:

> I wish to state that we are now comparing analyses of waters made at different seasons of the year. We are comparing analyses made in the fall of the year, from July down to the end of November, when the rivers are apt to be low, with the analyses made in the early summer, * * * when the rivers are apt to be swollen with rainfall, and therefore it is not altogether a good comparison. In my work I was not endeavoring to establish the yearly value. I was endeavoring to determine what the effect of the opening of the canal was, and for that purpose I compared [analyses made before the opening of the canal[a]] with the analyses made immediately after the opening of the canal * * * and I found my own analyses showed an increase immediately after the opening, taking analyses as near as we have them to the opening. (1131–1132.)

The cross-examiner then called the attention of the witness to that part of his testimony in which he affirmed that the waters of Missouri River at Fort Bellefontaine and of Mississippi River above the mouth of the Illinois were fairly good from a sanitary standpoint. He then recalled the statement of the witness that water containing a measurable quantity of nitrites should be regarded with suspicion. Finally, he reviewed the testimony of the witness concerning the character of the water of Missouri River at Fort Bellefontaine, in which he stated that there was an average of 0.008 and 0.014 part per million of nitrites before and after the opening of the canal, respectively, and asked him to reconcile these statements. In reply, the witness stated that only during the summer months were the nitrites low and the water potable, but during the winter the nitrites were high and the water was unfit for use in its raw state. (1132–1134.)

Other features of this cross-examination are of interest as showing the basis on which the witness interpreted sanitary analyses. In reply to various questions he made the significant statements that he did not include in the evidence presented the determinations of total solids, because they would throw very little light on the sanitary condition of the water; that he would be able to give an opinion as to the sanitary condition of the St. Louis water without a knowledge of the chlorine content, although in general to determine the potability of water this factor should be taken into consideration; that the determination of oxygen consumed is not always of importance, although at times it assists in forming an opinion about the water, especially when very little is known about the natural history; that he did not think it necessary to determine dissolved oxygen, because

[a] Phrase in brackets missing in record; inserted here to complete sentence.

it did not add information of value; that he considered the determination of albuminoid ammonia of very little value in determining the character of the waters under discussion. (1711–1717.)

It was apparent from the statement of the witness (1716) that he accepted an absolute standard of potability defined by the analysis as follows: Free ammonia should not be greater than 0.1 part per million and the nitrites should be hardly measurable. Several analyses were recited to him and he at once designated the waters good or bad according as the ingredients were below or above the standard just mentioned.

GEORGE CHANDLER WHIPPLE.

DIRECT EXAMINATION.

George Chandler Whipple, called as a witness on behalf of the complainant, in qualifying as an expert, stated that he was biologist and director of the Mount Prospect laboratory of the department of water supply, gas, and electricity of the city of New York, and that he had held that position since 1897, except that before the consolidation of New York and Brooklyn he was employed by the city of Brooklyn. He had graduated from the Massachusetts Institute of Technology in 1889 in the course of civil engineering, and immediately after graduation was employed on some water-filtration experiments under Desmond Fitzgerald, superintendent of the Boston waterworks. In the fall of the same year he was placed in charge of the newly established biological laboratory of the Boston water department, with the title of biologist, and was given supervision of all the water supplies of the city. In connection with this work he made tests of sewage and water purification plants and trips of inspection to other water supplies in the State and to the Lawrence experiment station. He made many studies on the growth of organisms in water, on the temperature of large bodies of water, and on stagnation phenomena, and assisted in designing the thermaphone, an instrument for obtaining the temperature of water at the bottom of reservoirs. In 1896 he spent four months with Prof. Albert R. Leeds in the study of the Brooklyn water, which at that time was infected with organisms, causing a bad odor. In 1897 he established the Mount Prospect laboratory for the city of Brooklyn, the scope of which was later extended to cover all the water supplies of Greater New York. In 1903 all the sanitary work of the extensive investigation on an additional water supply for the city of New York was placed in his hands. He had had considerable private practice and had carried out in that capacity a number of important investigations connected with water-supply questions. He is the author of a book entitled "The Microscopy of Drinking Water" and is engaged in a work on hygienic analysis and another on water supply. He devised the scheme for numerically recording odors in water and also the silica standard for turbidity. He is a member of the American Society of Civil Engineers, the American Chemical Society, the American Microscopical Society, the Society of American Bacteriologists, the American Public Health Association, the Society of Chemical Industry, and the American Limnological Commission and a fellow of the Royal Microscopical Society of London. He was at the time of the testimony secretary of the laboratory section of the American Public Health Association, and secretary of the committee on standard methods of water analyses of that section. (1903–1908.)

The witness testified that during the months of October and November, 1901, he had made microscopical examinations of 136 samples of water collected from various stations on Lake Michigan, the drainage canal, Illinois River and its tributaries, and Mississippi and Missouri rivers, with the object of determining the number and character of the microscopic organisms present. In certain of these samples he also made determinations of the turbidity and the color. Mr. Whipple described microscopic organisms as "those minute forms of life which are too small to be readily identified without the use of a microscope, but which are large enough so that they do not need to be studied by artificial cultures as we study bacteria." The witness stated it as his opinion that in the transit from the point of collection to the laboratory at Brooklyn certain of the forms present might die out, others might increase somewhat, and still others would remain practically unchanged in numbers. (1909–1911.)

The witness then put in evidence fifteen sheets showing the results of his examinations. (See Table 9, p. 29.) After describing in some detail the organisms found in the various waters he directed special attention to the diatoms. He stated that owing to the character of the diatom skeleton, which is of silica and practically indestructible, this organism was more likely than other microscopic organisms to be identified after the trip from Lake Michigan through the drainage canal and Desplaines and Illinois rivers to the St. Louis intake. (1911–1922.)

The following testimony is especially important:

Q. Are you able or not to say from your examinations and your knowledge upon this subject whether any particular species of these diatoms or micro-organisms came from Lake Michigan or not?

A. There were certain diatoms found during my examinations which appeared to be characteristic of Lake Michigan and Lake Michigan alone—I would like to change that—Lake Michigan and nowhere else excepting the streams below to which the water from Lake Michigan has access.

Q. Can you say whether or not any of the micro-organisms which were peculiar to Lake Michigan were found in the Mississippi River at the intake? And, if so, state which ones they were and how they got there.

A. There was an organism which I will describe as *Synedra pulchella* variety *subprolongata* which was found at the intake of the waterworks at the Chain of Rocks, and which was found also in the water of Lake Michigan, but which was not found in the water of the Missouri River or the water of the upper Mississippi River, or in any of the tributaries of the Illinois River unless we consider the Chicago drainage canal as being a tributary. (1924.)

The summary of the counts of this class of organisms appears in Table 38. (1925.)

TABLE 38.—*Average results of examinations for microscopic organisms in samples taken at designated points.*

[Number per cubic centimeters.]

Source of samples.	Synedra.	Tabellaria.	Melosira.	Cyclotella.	Asterionella.	Stephanodiscus.
Lake Michigan	577	236	13	38	25	8
Drainage canal at Lockport	270	236	13	30	22	2
Desplaines River at Lockport	2	2	1	264	113	9
All other tributaries of Illinois River	17	3	2	709	13	1
Illinois River above Peoria	126	62	8	48	10	3
Illinois River at Beardstown	95	19	0	784	31	0
Illinois River at Grafton	90	46	8	4,468	41	3
Mississippi River at Grafton	1	0	2,400	1,372	569	307
Mississippi River at Alton	19	16	1,741	2,534	124	174
Missouri River at Fort Bellefontaine	5	0	22	16	0	6
Mississippi River at Chain of Rocks, Illinois shore	51	21	1,380	1,957	396	192
Intake tower, Chain of Rocks	16	0	403	443	40	93
Settling basin, St. Louis	0	12	0	256	68	10

Referring to this table, witness stated his belief that the 16 *Synedra* found at the St. Louis intake came not from the Mississippi nor the Missouri, but from Illinois River, and that since there were 577 *Synedra* in Lake Michigan and all the tributaries of the Illinois together except Desplaines River gave only 17 *Synedra*, the *Synedra* at the intake came from Lake Michigan by the drainage canal and Desplaines River. Similarly he concluded that the *Tabellaria* found in the settling basin came mainly from the lake rather than from any other source; that the *Melosira* found at the intake came not from Illinois River nor from Lake Michigan, but from Mississippi River above Grafton; that the *Cyclotella* came chiefly from Mississippi and Illinois rivers and only to a slight extent from the lake; that the *Asterionella* came in the main from the Mississippi; and that the *Stephanodiscus* came mainly from the Mississippi above Grafton. (1926–1929.)

Mr. Whipple then introduced five charts (complainant's Exhibit No. 47, pls. 1–5) showing diagrammatically the figures given in Table 38, and discussed the variations noted. (1930–1934.)

Two diagrams were then introduced, one showing the results of an examination of samples from twelve points in a cross section of Mississippi River above Alton and the other the results of a similar examination of eleven samples on a cross section of the Mississippi about 1 mile above Chain of Rocks. Besides the numbers of the microscopic organisms in these samples the witness determined also the color and the turbidity. He made a calculation from the relative numbers of *Melosira*, *Cyclotella*, *Asterionella*, and *Stephanodiscus* present in the Missouri River water at Fort Bellefontaine, the Mississippi River water at Alton, and the water at the intake of the St. Louis water-works to determine the relative amounts of Missouri River water and Mississippi River water (including Illinois River water) entering the intake, estimating the proportions as 68 per cent of Missouri water and 32 per cent of Mississippi water. (1934–1941.)

Mr. Whipple described Mississippi River in respect to the direction of its banks and the curves of the river between the mouth of the Missouri and Chain of Rocks. He stated that the curves were of such a nature that they would tend to allow or increase or would be favorable to the mixture of the waters which came down Mississippi and Missouri rivers. In his opinion, if the figures introduced in evidence concerning the total solids in Missouri and Mississippi river waters (Table 20, p. 63) are reliable, then the calculations based on them to show the percentages of the waters of the two rivers entering the intake are also reliable. He stated that the total solids were the most accurate analytical determinations to use in such a calculation, because the two streams in question differ most widely in that respect. Chlorine, alkalinity, and color may also be used for the same purpose. (1978–1989.)

If only the cities on the drainage area of Mississippi River above St. Louis having 25,000 population or more are considered, the addition of Chicago doubles the population contributing sewage to the river, while if all communities having a population of 4,000 or more are considered the addition of Chicago increases the total contributing population by 63 per cent. The limit of 4,000 is the one commonly used by sanitarians in considering the population contributing pollution to a given drainage area, and it is assumed that the small amount of pollution from towns not included in the estimate is balanced by an equal amount from inhabitants of the communities included who are not connected with sewerage systems. (1989–1991.)

From complainant's Exhibit No. 1, already in evidence, the witness had calculated certain average analytical figures, as follows: Daily samples from October 30 to November 29, 1901, collected at five points in a cross section of Mississippi River at Alton, gave the average figures shown in Table 39 for nitrites and chlorine. Station A was at the Missouri shore, station E at the Illinois shore, and the other stations were intermediate. (1992.)

TABLE 39.—*Averages of nitrites and chlorine in Mississippi River at Alton, October 30 to November 29, 1901.*

[Parts per million.]

Station.	Nitrites.	Chlorine.	Station.	Nitrites.	Chlorine.
A	0.002	5.2	D	0.0105	9.7
B	.005	6.8	E	.0115	10.0
C	.009	8.7			

Similar samples for the same period from five points in a cross section of Mississippi River at Hartford gave the average results shown in Table 40. (1993.)

TABLE 40.—*Averages of nitrites and chlorine in Mississippi River at Hartford, October 30 to November 29, 9101.*

[Parts per million.]

Station.	Nitrites.	Chlorine.	Station.	Nitrites.	Chlorine.
A	0.006	6.8	D	0.009	8.8
B	.006	7.1	E	.010	9.1
C	.008	8.0			

From these figures, together with similar averages from Mississippi River at Grafton and Illinois River at Grafton (the latter two series of averages not being offered in evidence), the witness calculated the percentage of Illinois River water at the five points in each cross section, as shown in Table 41. (1993–1994.)

TABLE 41.—*Percentage of Illinois River water in Mississippi River at Alton and at Hartford, October 30 to November 29, 1901.*

Station.	Alton.	Hartford.	Station.	Alton.	Hartford.
A	7.8	17.17	D	35.4	29.8
B	7.7	19.5	E	37.2	31.7
C	29.3	25.0			

The longevity of the typhoid bacillus in natural waters was stated by the witness to be several months, though the numbers would gradually decrease. On the assumption that the Chicago sewage reached the St. Louis intake in ten and one-half days, he stated as his opinion that if typhoid organisms were present in the Chicago sewage a part of them would survive the passage to the intake, and that in times of flood, when the journey from the lake to St. Louis is made in eight days, a greater proportion of such germs would survive. He cited epidemics at Detroit and Lawrence, in both of which the organisms had persisted in the water for a period of over ten and one-half days. On the assumption of an increased typhoid death rate in St. Louis since the opening of the drainage canal and of a normal amount of the disease on the drainage basin of Mississippi River above the city, and the further assumption that the source of the St. Louis water supply had remained unchanged during the time considered, the witness stated that, in his opinion, the increase in the typhoid death rate in St. Louis was most probably due to the discharge of the Chicago sewage into Mississippi River. (1996–2002.)

On the assumption that large numbers of *Bacillus prodigiosus* were placed in the waters of the drainage canal at Lemont and that the same organism was found in the city water of St. Louis after the lapse of a proper time, the witness believed that the organisms at St. Louis originated in those placed in the canal. He stated that the longevity of *B. typhosus* and *B. prodigiosus* was, so far as his experience enabled him to judge, about the same. He further believed that if, since the opening of the drainage canal, a larger amount of the Chicago sewage has reached Mississippi River than formerly, the water of the river has become less valuable as a source of domestic supply. (2002–2009.)

CROSS-EXAMINATION.

On cross-examination Mr. Whipple stated that the best way to determine the presence of sewage in water is to actually find out whether or not sewage enters the water. In the absence of this information analytical results will supply the information in some cases only. If the water is grossly polluted, analyses will show the presence of the contaminating matter, but if it is only slightly polluted the presence of such matter can not be determined in this way. There are no qualities of water which, taken alone, would enable the witness to determine possible pollution, but among the qualities which he would naturally consider in forming an opinion would be the amount of organic matter as shown by the determination of nitrogen as albuminoid ammonia, free ammonia, nitrites, and nitrates, together with the amount of chlorine, the hardness, the total and suspended solids, and the color; also the number of bacteria in the water and the presence of particular species of bacteria, such as *Bacillus coli communis*. The witness stated that he would further take into consideration the possible presence of certain microscopic organisms commonly associated with sewage. It is not always necessary to make all the determinations above noted. With respect to certain of the determinations, the witness stated that there is no such substance as "albuminoid ammonia," this being merely a form of expression used in describing the amount of organic matter present. "Free ammonia" is used in a similar manner, and it is taken to mean that the water contains ammonium compounds that on boiling are broken up so that the ammonia is driven off. Neither of the two terms is the name of a substance actually existing in the water, but they stand for substances. (2051–2061.)

With reference to the significance of the presence of *Bacillus coli communis*, the witness said that he could not state definitely that it indicates sewage origin. It is believed by many scientists that this organism may be found in waters where pollution is remote. It is a common inhabitant of the human intestine and is present in large numbers in ordinary sewage. As it is abundant in waters known to be polluted and occurs only in small numbers or is entirely absent in waters presumably not polluted, most bacteriologists agree that the test for the presence of this organism is highly important in determining the presence of pollution. If the organism is constantly or very often present in a water it is probably an indication of sewage contamination. In the opinion of the witness, however, it is not an absolute test, but a valuable one, to be interpreted in connection with the remainder of the analysis. Even though this bacillus might be found in the intestines of fish, it would not, in his judgment, materially influence the interpretation to be made from the results of the *coli* test, because it had been his observation that fishes' intestines do not ordinarily contain this bacillus, and if it is present there it is probably derived from the water in which the fish is living. (2075–2077.)

Referring to micro-organisms, the witness stated that he did not know of any that absolutely demonstrate the presence of sewage, but there are certain organisms which are so often associated with sewage that in a very general way they do serve as an index of its presence. However, it could not be asserted that a stream was sewage polluted merely because these organisms were found there. (2078.)

The witness could not state definitely the number of typhoid germs discharged by one patient, but as a general statement it was true that the number is enormous. Under certain conditions this number would be sufficient to create an epidemic if they were turned into water used for a city supply, but many factors would be involved, among which are the original vitality of the organisms, the rate at which they might die out in water, the relation of the number of organisms to the amount of water that they enter, the amount of sedimentation that might occur between the time at which they infected the water, and the time at which they entered the city intake, the influence of certain microscopic organisms, and the possible influence of sunlight. He knew of no scientist who had actually demonstrated how long the bacillus of typhoid will live in the sewage-contaminated water of a stream, but some men have arrived at certain conclusions by way of laboratory experiments. According to the results of such experiments, the time may be stated as varying from some weeks to some months. (2080–2082.)

The witness stated that he knew of some investigators who had claimed to have discovered the typhoid germ in river water, but was unable to state whether the claim was substantiated. In the earlier days of bacteriology, when species were not so carefully studied as they are to-day, certain results were obtained and published by bacteriologists that would hardly be credited in the present state of the science. (2082.)

The effect of dilution was then discussed by the witness, who stated that if a certain number of typhoid bacilli were put into different amounts of water and thoroughly mixed, the larger quantity of water would contain the fewer bacteria per unit volume. This statement, however, assumed a uniform distribution of the bacilli throughout the water, which he did not regard as a condition that would be likely to exist. Usually when bacilli are discharged into water, many of them are clustered together and held in that condition by some force or substance, while on the other hand some of them are widely distributed throughout the water; but the conditions are not such as would allow the dangerous qualities of typhoid-polluted water with different degrees of dilution to be fairly compared. (2083–2084.)

Referring to the speed of current necessary to permit sedimentation, the witness stated that if the velocity is reduced to about half a foot per second, sedimentation of suspended matter of a certain character might occur. If the suspended matter were coarser it would settle in a current of greater velocity, but he could imagine such matter so fine that it would not settle even if the velocity were only a quarter of a foot per second. The knowledge of the subject had not reached a point where any strict rule could be given. The whole matter of sedimentation depends on the character of the suspended matter, the temperature, and other conditions, as well as the velocity of flow. Experiments have been made on the subject, but not in sufficient number to warrant the formulation of a precise statement. (2088–2089.)

It was the opinion of the witness, from what he knew of the existing conditions on the drainage area of Missouri River and from the fact that there are salt deposits in the drainage area of Kaw River, that the amount of chlorine found in Missouri River at Fort Bellefontaine can not be used as an index of pollution, although part of it may have been derived from sewage pollution, because the effect of the chlorine from the salt deposits would interfere with interpretations relating to sewage pollution alone. (2090–2091.)

With reference to the rôle played by microscopic organisms in the purification of waters, the witness stated that there was practically no knowledge on the subject. These organisms might perhaps exert some influence on bacteria, but the information was not very definite. (2101.)

The cross-examiner then referred to the testimony of the witness in which he expressed the opinion that the *Synedra pulchella* variety *subprolongata* found in the water of Illinois and Mississippi rivers was probably derived from Lake Michigan, and endeavored to draw from him a statement as to his reasons for this opinion. The witness admitted that this organism could exist in the ponds and lakes along the lower reaches of Illinois River. The following question and answer are given substantially as they appear in the record:

Q. Assume that the relative amount of water now discharged from the drainage canal into Illinois River is greater than that naturally flowing in that river, and further assume that the number of *Synedra* and *Tabellaria* per cubic centimeter in the waters of Lake Michigan and in the waters of the Illinois River lakes and tributary streams are exactly equal; that in all physical respects the organisms from both sources have equal vitality when they start from their habitat on a journey to the St. Louis intake; that the ones from Lake Michigan have to pass through the drainage canal; and finally, that these microscopic organisms are found in the water at the St. Louis intake. Eliminating all other considerations than those above mentioned, to which source would you prefer to attribute them?

A. If we have a certain volume of water contributed by the tributaries of Illinois River and the assumed lakes which contain a certain number of these organisms, and if we have a greater volume of water through the Chicago drainage canal which contains per cubic centimeter an equal number of these organisms, and assuming a thorough mixing of the waters from both sources, it would be my judgment that these organisms would come from both sources, but that more of them would come from the water which was greatest in volume, provided the two waters contain an equal number per cubic centimeter. The fact that the organisms from Lake Michigan had traveled through 24 miles of sewage would be of no practical significance. (2104–2106.)

The witness stated that if bacilli naturally inhabiting running water should be removed, developed by special culture, put in bottles of sterilized water, and hung out in the sun, the determination of their longevity under such conditions would not enable us to tell how long they would live in natural water or give any definite information on that point, although it might guide in an opinion as to how long they might live. (2111–2112.)

With reference to the longevity of *Bacillus prodigiosus*, it was the opinion of the witness that if a stream were infected with a large culture the numbers of the bacteria would probably decrease, but just how rapidly he was not prepared to say. If a 40-gallon barrel full of *Bacillus prodigiosus* culture were dumped into Illinois River at or near its mouth in August, 1900, and if in November of the following year 107 barrels full of the same culture were discharged into the drainage canal near Lockport, and after this latter discharge a colony of these bacilli were found at the intake of the St. Louis waterworks and another at some point in the distribution system of the city, the witness would naturally assume it to be more reasonable to consider that these colonies were derived from the second discharge, if they came from either, because during the interval between August, 1900, and November, 1901, all of the water in Illinois and Mississippi rivers between the point where the first dose was added and the intake of the St. Louis waterworks would have passed downstream, and many, if not all, of the bacilli would have died in that time. Therefore it was not likely that the *B. prodigiosus* found in St. Louis in 1901 were derived from the culture discharged into Illinois River in August, 1900. (2112–2114.)

The importance to be attached to the numerical results of a single bacteriological examination of water was discussed by the witness, who stated that if the number of bacteria was extremely low it might indicate a comparatively good sanitary condition; if extremely high it might indicate the reverse, but if the number was intermediate no conclusions could be drawn from that alone. In order to obtain the most accurate result the bacteriological examination of a sample should be begun immediately after its collection, though the character of the water would to a considerable extent determine this point. A water containing comparatively little food for bacteria might be allowed to stand longer before the bacteriological examination than a water rich in organic matter, and the result of the examination would not be seriously affected. (2120–2122.)

The witness expressed the opinion that investigators had not ascertained by any experiments the probable duration of pathogenic germs, such as the typhoid-fever bacillus, in running water. In general, experiments such as had been made under laboratory conditions would be less favorable to such bacteria than natural conditions. Of course, it must be considered that circumstances alter cases, but in very general terms he believed this statement to be true. He was referred by the cross-examiner to page 294 of a work entitled "Micro-organisms in water," by Percy and G. C. Frankland, in which the results of experiments made by Krans with unsterilized waters were cited. On this page the statement was made that the typhoid bacilli had disappeared or were no longer demonstrable when the water bacteria became active. The witness stated that he was of the opinion that no such assertion could be warranted, because the identification of the typhoid bacillus in the presence of common water bacteria is extremely difficult and in most instances impossible. The details of the report were then enumerated, namely, that the water, taken from the Munich supply, contained on the first day 57,960 typhoid bacilli; on the second day, 50,400; on the third day, 15,680; on the fifth day, 9,000, and on the seventh day none, while there were no ordinary water bacteria on the first, second, and third days, 80 on the fifth day, 288,000 on the seventh day, 400,000 on the ninth day, and 970,000 on the twentieth day. In regard to these results, the witness stated that it was no wonder that the investigator did not find the typhoid bacilli in the samples at the end of the seventh, ninth, or tenth days, because he believed it a bacteriological impossibility to demonstrate the presence of typhoid germs under such circumstances, and he would question whether the results obtained would actually stand the test of present-day methods. The subject has been very carefully considered, and the poverty of the results shows the difficulties encountered. (2131–2133.)

The cross-examiner then cited two series of results given in the work above mentioned. The first referred to the river Spree. The water of this river passes through Berlin and receives the city sewage. A few miles below Berlin the river widens into a fairly quiescent body of water known as Havre Lake. The results show that the water leaving Havre Lake had become purified from the effects of Berlin sewage to such an extent that its condition, as shown by the analytical results, was practically the same as above Berlin. The second case was that of the river Limmat, flowing out of Lake Zurich. The number of micro-organisms in the water as it leaves the lake varies from 100 to 200 per cubic centimeter. This number is increased enormously by the inflow of sewage from the city of Zurich; but at a point about 6 miles below, the bacterial condition approaches that of the water as it leaves the lake. The cross-examiner then asked whether, in view of these two instances, on the assumption that the conditions are truly stated, it was not highly probable that the water of Illinois River above Peoria, a distance of over 100 miles from Chicago, would have attained a bacteriological condition similar to that which it had before it received the Chicago sewage. The witness stated that the results cited would not be of any material value in estimating what the bacteriological conditions would be at Peoria, but that the experiments made seemed to be in line with what is generally known in regard to the decrease in the total number of bacteria in streams below points at which pollution is introduced. It is quite conceivable that the conditions in Illinois River between the Chicago drainage canal and Peoria are such that the total number of bacteria at the latter point might be as low or even lower than in the water of Lake Michigan; but in taking this into consideration the character of the bacteria at Peoria must be considered. The probability is that pathogenic germs would decrease in transit, as well as the water bacteria; but whether they would decrease in exactly the same proportion the witness was not able to state. It is conceivable that there might be a greater decrease in the pathogenic germs than in the ordinary water bacteria, but that would depend on the character of the water bacteria and the conditions of the water. It should be remembered that even the water bacteria are not at all times multiplying. They are sometimes dying, and certain forms of the water bacteria might die at even a greater rate than the typhoid bacilli under such conditions. If we neglect all other considerations, such as sedimentation, etc., and consider only the fact that typhoid bacilli do not multiply in water, while water bacteria will multiply under the conditions presumed, it is not probable that the typhoid bacilli would remain alive in water as long as the water bacilli; but in practice, it would not do to neglect all other considerations in studying a problem of this character. (2133–2138.)

The witness then stated that the reason why cities having a population of 4,000 or over were often considered in estimates as having a polluting influence on the water of a river, while those of a smaller population were not so considered, was that this limit furnishes, on the whole, a better means of comparing the effect of human life on different drainage areas than to take the total population. The reason for this was that throughout the country, communities of 4,000 population or over are more commonly provided with a public water supply than those having less than 4,000. The witness admitted that this is an arbitrary distinction, but claimed that, taken broadly all over the country, it is a fair one. It is true that rural pollution may be washed from barnyards and feeding pens by rains into a river, but such added pollution has no real effect, because there is at the same time an enormous dilution, so that the result may not be different from that which would occur under normal conditions with a constant pollution of the stream by a sewer, for example. (2145–2147.)

ALLEN HAZEN.

DIRECT EXAMINATION.

Allen Hazen was called as a witness in behalf of the complainant. In qualifying as an expert on water supplies, Mr. Hazen stated that he was educated at the public schools of Hartford, Vt., at the New Hampshire State College, the Thayer School of Civil Engineering, Hanover, N. H., and at the Massachusetts Institute of Technology, and later, for one term, at the technical school in Dresden, Germany. He further testified that he had made a special study of the chemistry of water supplies; that for a number of years he was in direct charge of the experiment station of the Massachusetts State board of health at Lawrence, with the title of chemist; that he had twice visited Europe and studied the water supplies and sewerage systems of most of the large cities there; that he was in charge of the sewage-disposal plants and the inspection of drinking waters at the world's fair at Chicago at 1893; and that he was at one time a member of the firm of Noyes & Hazen, of Boston, who gave special attention to water supply and sewerage problems. He advised the city of Albany, N. Y., on the subject of its water supply and later superintended the construction of sand filters there; was then building a filter for the city of Ithaca, N. Y., and had been engaged in similar work for Harrisburg, Pittsburg, Chester, and Lancaster, Pa.; West Superior, Wis.; Watertown and Yonkers, N. Y.; Providence, R. I.; Washington, D. C.;

Trenton, N. J.; Toledo, Ohio; Grand Rapids, Mich., and Millbury, Mass.; and for a few years acted as consulting engineer for the Ohio State board of health. In 1891 the witness visited Chicago and examined its waterworks and sewerage systems, becoming generally familiar with the conditions existing at the time. In 1892 he published jointly with Professor Sedgwick a paper on the water supply and typhoid fever in Chicago. In 1893, with Doctor Reynolds, health commissioner of Chicago, he wrote a joint paper on the water supply of Chicago, which was read before the American Public Health Association. The following year he wrote a report on the drinking water used at Jackson Park during the world's fair. He was a member of the commission appointed in 1901, consisting besides himself of Messrs. Williams and Wisner, to report on an improved water supply for St. Louis. He then examined thoroughly the water system of the city and the whole drainage area. (2789–2798.)

The witness stated that he believed that the quality of the water at the St. Louis intake was seriously damaged by the sewage of Chicago, and based this view on the facts that the amount of sewage entering the watercourses above the intake has been nearly doubled by this discharge; that the distance between Chicago and St. Louis is very considerably less than the average distance of the other points of pollution from the St. Louis intake; that the mixing of the waters in the channel of the Mississippi is such that the amount of sewage received at the intake is a large percentage of what it would be if the mixing were complete; and that the time of passage from the point of pollution to the intake is not sufficient to allow the complete destruction of the injurious and polluting matters discharged. In view of these facts the witness believed that the discharge of the sewage of Chicago into Mississippi River by way of the drainage canal, Desplaines River, and Illinois River "seriously injures the quality of the water." (2799–2802.)

CROSS-EXAMINATION.

The witness gave evidence of thorough familiarity with the water-supply system of the city of St. Louis and the conditions of the Illinois, Mississippi, and Missouri river basins above the intake, with reference to their population, the pollution of the rivers, and the degree of mixing which takes place, such familiarity arising from his work as commissioner in 1901. In connection with this work he had examined the waterworks plants at Kansas City, St. Joseph, and Omaha, on Missouri River, and taken into consideration the discharge of sewage into the stream from these cities. He finally stated that he did not consider Mississippi River at Chain of Rocks a fit source of supply nor would the water be safe for drinking even though the pollution brought in by the Illinois were eliminated. The cities lying along Missouri and Mississippi rivers above St. Louis discharge sufficient polluting material to render the use of the water without previous purification dangerous. (2809–2813).

In explanation of the comparative statements concerning the safety of water which he had made, the witness said that some waters are so polluted that they cause the death of more than one person per thousand per annum from typhoid fever; in fact, sometimes as many as four or five persons; such water is extremely bad, and probably as bad as is used anywhere in the United States. Waters that are less polluted than this produce smaller amounts of sickness and death. It is difficult to draw the line absolutely and it may be a question whether even the best waters are absolutely free from suspicion of causing typhoid. But when a water causes so little sickness that it can not be traced and measured, it is classed as a good water, so that the various degrees of acceptability are merely relative, depending on the effect of the water on the persons using it habitually as a beverage; no sharp line of demarkation can be drawn. (2814.)

The witness stated that the diversion of Chicago sewage from the lake and into the drainage canal would undoubtedly greatly improve the Chicago water supply, but that he was of the opinion that it would not render it absolutely safe, because the shipping is a source of considerable pollution. The matter discharged from vessels entering and leaving Chicago is undoubtedly a menace to the purity of the water supply, but just how important a menace the witness was not prepared to say. (2817–2819.)

The dilution of Chicago sewage by the large influx of Lake Michigan water, according to the witness, would not mitigate the danger to St. Louis. Such dilution would have some effect on the sewage, but its effect on the specific germs of disease would be doubtful, and these germs, after all, are the real sources of danger. In discussing the various factors in the self-purification of streams, the witness stated that sedimentation is a mere transference of some of the polluting matters from the moving water to the bottom of the stream. He would not call that purification, because such sewage matter is liable to be taken up again and transported. If the water alone is considered it is purification, but in a broad view of the whole subject it is not. (2824–2825.)

The witness stated that no definite length of time could be set during which it would be necessary for such sewage to lie upon the bottom of a stream in order to become noninjurious, but that in the Millbury case he was confronted by the proposition, backed up by eminent experts, that the trouble was due to sewage mud which had been deposited several years previously. (2827.)

With reference to the function of analytical work in showing the potability of water, the witness stated that chemical analyses never show infection; they can only show pollution, from which infection can sometimes be inferred. The bacteriological examination may possibly show the presence of infectious matter, but the difficulty of finding it, even when it is known to be present, is so great that it is very seldom found. (2837.)

The witness was then questioned concerning the relative importance of cases and of deaths as an index of the amount of typhoid fever present, replying that if, as stated, the number of deaths from typhoid fever at St. Louis were 168 in 1900, 198 in 1901, and 222 in 1902, and the total number of cases reported were for the same years 1,213, 1,101, and 1,112, respectively, he would give greater weight to the deaths than to the cases in considering the amount of typhoid in the city. He believed that under the conditions prevailing in American cities the number of deaths from typhoid is a more accurate measure of the typhoid than the number of cases, because the deaths are more accurately and carefully reported. The above record, if true, would indicate that the disease was occurring with greater severity, and this might reasonably be called an increase in the typhoid condition. (2838–2841.)

In answer to questions as to the amount of mixing which occurs at the junction of the Missouri and the Mississippi, Mr. Hazen stated that from analyses which he had seen it was his belief that the water received at the St. Louis intake contained 30 per cent of Mississippi River water. He could not state how much of this water came from the Illinois, but was of the opinion that the mixing of the Illinois and the Mississippi waters was, owing to the nature of the channel, fairly complete. (2844–2847.)

WILLIAM THOMPSON SEDGWICK.

DIRECT EXAMINATION.

William Thompson Sedgwick, called as a witness on behalf of the complainant, qualified as an expert by stating that he graduated at Sheffield Scientific School, Yale University, in 1877; studied for the greater part of two years at Yale Medical School; taught physiological chemistry at Yale for one year, and then became fellow, assistant, and associate at Johns Hopkins University; since 1883 had been assistant professor, associate professor, and professor in the Massachusetts Institute of Technology; received the degree of doctor of philosophy at Johns Hopkins in 1881; served as biologist to the State board of health of Massachusetts from 1888 to 1896; is a member of the American Academy of Arts and Sciences, Massachusetts Association of Boards of Health, New England Waterworks Association, Society of American Bacteriologists, American Society of Naturalists, American Public Health Association, and of the advisory board of the hygienic laboratory of the United States Public Health and Marine-Hospital Service; past president of the American Society of Naturalists and of the Society of American Bacteriologists; has been employed by various cities and towns as an expert in water supply and sewage disposal, especially by Burlington, Vt., Pittsburg, Pa., and Lowell, Mass.; is the author of a text-book on general biology and of a treatise on the principles of sanitary science and the public health; has made numerous reports and investigations of epidemics of typhoid fever for the State board of health of Massachusetts and a report on typhoid fever in Pittsburg in 1898; has published numerous papers on water supply, water purification, and sewage purification; and in 1892, in collaboration with Allen Hazen, published a paper on typhoid fever in Chicago. (2184–2185.)

The witness then made certain general statements concerning the Chicago water supply and methods of sewage disposal, and stated that he was familiar with conditions prevailing in the Illinois River basin along the Mississippi above St. Louis and in general throughout the drainage basin of Missouri River. He defined ordinary pollution as a condition in which the water contains organic matter, or even filth, from whatever source and in whatever degree of putrefaction, without the presence of the specific germs of any disease; the term infectious pollution refers to water containing germs of disease, without reference to the amount of putrescible organic matter or any physical condition whatever. A water polluted with organic wastes, however bad it may appear, is not, in general, dangerous to public health if it does not contain the specific germs of a water-borne disease; on the other hand, a water that is perfectly clear and acceptable from a physical standpoint may be dangerous to public health by reason of the presence of disease germs. (2187–2190.)

Mere dilution does not destroy or eliminate infectious pollution. Under dilution alone, the sewage turned into Illinois River from the sanitary district of Chicago would not be rendered safe and pure by the time it reached Peoria. In this whole matter of self-purification of streams the ideas of to-day are very different from those of twenty or thirty years ago. Running water under some conditions might purify itself from infectious germs, but those conditions would be so unusual as to be virtually theoretical. Experts have abandoned the old belief that running water readily purifies itself. Acting on that belief, which was the result of the best knowledge available twenty or thirty years ago, numerous cities and towns of the United States installed waterworks with intakes in streams into which sewage had been poured at points above. That was the best art of the time, and engineers, chemists, and sanitarians agreed about it. The city of Pittsburg, for example, introduced a water supply from Allegheny River with the confident belief that such sewage as might find its way into that river at points above would be effectually removed before the water came to the citizens. That belief has been found to be erroneous. Pittsburg suffers to-day with typhoid fever perhaps more than any other city of the United States. The cities on the lakes—Niagara Falls, Buffalo, Cleveland, Detroit, Chicago, Milwaukee, Duluth—take water supplies exposed to contamination by sewage, and are to-day, one after another, considering at any rate the possibility of abandoning such supplies, because of the failure of the self-purification of sewage. Nevertheless, there is a large measure of self-purification of streams. The subject is complex and difficult, and the tendency of opinion has been to increase distrust in the efficiency of self-purification of water or sewage. (2191–2192.)

In reply to specific questions concerning the effect of the discharge of Chicago sewage from the drainage canal, the witness stated that such discharge at once throws suspicion on the character of the water in Illinois River and undoubtedly affects the entire water-supply value of the stream and that of the Mississippi at the St. Louis waterworks, rendering the water dangerous for drinking purposes and more liable to carry germs of typhoid fever. (2193–2195.)

The addition to the flow of Illinois River of the water from the Chicago drainage canal, equivalent to about five-sixths of the minimum flow of said river, will quicken the flow in the channel and thereby hinder effective sedimentation by shortening the time required for infectious germs to pass through the river, and, by interfering with their detention, will aggravate the danger of their arrival at the mouth of the river. The witness laid especial stress on the statement that any factor which results in quickening the flow of the stream is of grave importance. The time, more than the distance, is the basis of self-purification in streams. Other things being equal, the rate of sedimentation is quicker in a turbid water than in a clear water. An addition of clear water, like that from Lake Michigan, to the water of Illinois River will serve to retard sedimentation. Therefore these two factors—namely, the quickening of stream flow by the addition of a large quantity of water and the partial clarification of the river due to the fact that this water added from Lake Michigan is clear—undoubtedly have the effect of increasing typhoid fever in St. Louis. (2195–2196.)

The witness stated that the matter deposited in the bed of a running stream may lie there for some time or may be swept out by an increase in the velocity of the stream. In case it is allowed to remain for some time, it may be more or less modified by chemical and bacterial action. If it is swept from the bottom of the stream by an increase in the velocity, it may be redeposited at lower points or pass into some other body of water. In regard to the longevity of typhoid as a general proposition in connection with sewage-polluted water, to speak broadly, recent observations have indicated a greater longevity than was formerly supposed. Practical experience has shown that in a sewage-polluted stream typhoid germs may live in gradually diminishing numbers for weeks or months, or even years. Continuing, the witness stated that even if the number of colon bacilli, as shown by actual tests, was no higher subsequent to the opening of the canal than previously, it does not indicate that the water is not more dangerous for drinking purposes. The mere fact that a vast additional population is contributing sewage to Illinois River must always constitute an added menace to the health of the persons using the waters of the river at its mouth or below. Bacteriological examinations are, in the opinion of the witness, not absolute guides as to the sanitary condition of water, because they obviously can not be made at every moment or at all times or at all seasons or hours of the day, and therefore there might be intervals between times of sampling when infectious materials would flow by and thus escape analysis, but nevertheless would pass on and do harm to the people using the water below. (2197–2198.)

If typhoid-fever germs coming from Chicago sewage are deposited in large numbers in the lakes and slack-water portions of Illinois River above Peoria, in event of flood conditions the water leaving these lakes might contain more infectious and dangerous pollution than the sewage entering Desplaines River at the Bear Trap dam, because a large amount of typhoid fever in Chicago might result in the storage of vast numbers of these germs in the slack-water basins, and a sudden flood would sweep out this accumulation, so that sometimes more typhoid-fever germs would be flowing in Illinois River than in the drainage canal itself. The witness then mentioned the case of the city of Detroit, where the removal of deposits of sewage matter had resulted in a typhoid-fever epidemic. The dredging of Black River at Port Huron caused the carriage of detached sediment down St. Clair River, through St. Clair Lake, and into the intake of the Detroit waterworks. (2198–2199.)

Continuing, the witness expressed the opinion that the water of Illinois River as it enters the Mississippi can not be used with safety for drinking purposes. Assuming that the only pollution of the Illinois is contributed to it by the Chicago sanitary district, he was emphatically of the opinion that the effects of time interval, dilution, and sedimentation between Chicago and Grafton would not be sufficient to render the water as it enters the Mississippi at all times free from disease-producing elements. In support of this contention he cited the Lowell epidemic, in which the large body of water in Merrimac River was contaminated by a small amount of water in Stony Brook, and compared the conditions as to volume and size of the rivers under consideration. (2199-2201.)

The witness stated that for fifteen years prior to 1900 the typhoid death rate of St. Louis was not in general greater than that of many cities provided with purer water supplies. During the period following the removal of the water intake from Bissells Point to Chain of Rocks, the typhoid death rate in the city had been remarkably good—lower in fact, than the rate for the same period in Boston, which has a good water supply and a reasonably normal incidence of the disease. Since January 1, 1900, there has been a marked annual increase in the typhoid rate of St. Louis, which has been higher than at any time in its own history since 1885, and very much higher than the Boston rate, with which it previously compared favorably. The increase in the number of deaths from typhoid fever in St. Louis between January 1, 1900, and the date of the testimony, over the number of deaths from the same disease in the previous fifteen years, excluding one year (1892) in which there was a great epidemic due to the causes specified in the testimony of Doctor Ravold, has been about 26 per cent, while the increase since January 1, 1900, in annual mortality from typhoid over that for the preceding five years, was 73 per cent. Before 1900 the typhoid death rates of St. Louis and of Boston were below those of most cities having polluted water supplies. New York has the lowest death rate from typhoid fever; Boston and St. Louis ran very closely together until January 1, 1900, since which time Boston has gone lower and St. Louis increased; Philadelphia shows a much higher death rate than Boston and St. Louis, while Chicago has the worst record of all. (2202-2203.)

Professor Sedgwick referred to the experiment made with 107 barrels of *Bacillus prodigiosus* culture, which were emptied into the Chicago drainage canal at Lemont, the germs, as reported, having been identified in the water entering the St. Louis intake at Chain of Rocks, and stated that this interesting and valuable experiment seems to show that typhoid fever or Asiatic cholera germs might pass from the drainage canal and finally enter the water supply of St. Louis by way of Illinois and Mississippi rivers. (2204-2205.)

On being questioned with reference to instances in which typhoid-fever epidemics have been conveyed by surface waters, the witness gave a brief summary of several prominent cases.

A celebrated and important epidemic occurred at Plymouth, Pa., in 1885. On the drainage area supplying the town four storage reservoirs had been built, and on the bank of the stream which supplied the uppermost of these reservoirs a case of typhoid fever appeared in the early spring of 1885. The reservoirs had all been drawn very low to supply the demands of a continued season of cold weather, and on the arrival of the spring thaw 1,200 cases of typhoid fever broke out in this little town of 8,000 inhabitants. These were traced—correctly, it is believed by sanitarians—to the occurrence of one case of typhoid fever on the bank of the uppermost reservoir, followed during the thaw by the washing in of the dejecta of that patient and, in the low state of the reservoirs, the rapid transmission of the germs to the people of the town. (2205-2206.)

In 1890 there was an epidemic at Lowell, Mass., followed very soon after by a worse one at Lawrence, 9 miles below on the Merrimac. These were traced to infection which began on Stony Brook, and of course the Lawrence sickness was caused largely by the typhoid-fever germs in the sewage of Lowell, the larger city above it. (2206.)

Two years after, in 1892, the witness investigated a very interesting epidemic at the mouth of the same river, in Newburyport. The people of the city supposed that they were drinking spring water, but the superintendent of the waterworks had surreptitiously connected the mains with the Merrimac, and for two or three months the people were getting, as he himself admitted, Merrimac River water. This was particularly instructive because for the first two months, say, of this time there was no typhoid in Newburyport. On going up the river the witness found the reason to be that although they had been drinking simple filth—good straight sewage—it was apparently uninfected. Unluckily, however, a little epidemic broke out in Lowell, the result of which was perfectly obvious in Lawrence, although the water had to travel 9 miles and pass through a storage reservoir where it had been detained for at least a week. This infected water reached Newburyport, at a distance of 20 or 30 miles, and it was one of the saddest cases ever investigated, because the people supposed that they were drinking spring water, while they were in fact drinking infected sewage. (2206-2207.)

The rivers pollution commission of Great Britain, in a report published in 1874, states that there is no river in the United Kingdom long enough to purify itself from any sewage admitted to it even at its source. That stands as one of the axioms of sanitary science to-day. (2207.)

In 1898 the witness made a special study of typhoid fever in Pittsburg. Acting on the advice of one of the most eminent engineers of the time, the city had introduced a water supply drawn mainly from Allegheny River and partly from the Monongahela. The important points of pollution lie at considerable distances above Pittsburg, but as the Allegheny is a swift stream the infectious material is borne down in a comparatively fresh state. As a result of the study, a filtration plant was recommended for the Pittsburg water supply, for the reason that infectious materials might be brought to the intake from points as far distant as Oil City 113 miles or more. (2208.)

Another very serious epidemic due to pollution on the drainage area of a public water supply occurred at New Haven, Conn., in 1900. The city gets a part of its water supply from a sparsely inhabited drainage basin. The large storage reservoirs had been drawn low during severe winter weather, and when the spring thaw and heavy rains came some feces from a house on the basin where there had been a very few cases of typhoid fever were washed down into one of these reservoirs. The result was that the infected water passed quickly to the city and there were 470 cases of typhoid fever in the spring—not in the fall, when typhoid in communities generally occurs. (2209.)

The recent epidemic at Ithaca, N. Y., arose from conditions very similar to those at Plymouth and New Haven. It was a serious epidemic of about 1,000 cases, with a high death rate. (2209–2210.)

The witness then referred to typhoid fever in Chicago and to the conditions at Detroit, Cleveland, Buffalo, and Niagara Falls. He had found in Buffalo a prevailing feeling among medical men that the time was at hand when the city must purify her water because of the pollution discharged into the lake at Cleveland and higher points. Niagara Falls was suffering severely from typhoid fever, which the local physicians believed to be derived from sewage that had run down Niagara River from Buffalo and higher points. It is a question whether the people who are using the Great Lakes as a water supply must not give them up after a while. The growth of opinion is more and more toward the idea that it will not do to trust to self-purification. It used to be thought that running water when it became thoroughly aerated was pure, especially if it came from long distances. That was the theory on which Pittsburg put in its waterworks and on which Lowell took the obviously sewage-polluted water of the Merrimac and used it for water-supply purposes; but these cities and all others that have trusted to that theory have been typhoid ridden. It is not to-day so much a question of distance as of time during which the germs may settle out or die; in other words, it is a matter of quiescence. "You have got to eliminate all idea of distance from these things and bring in the question of time largely, and that is what I have stated in my treatise on sanitary science and public health, written two or three years ago. It is nothing that I have got up for this case; * * * it is a fact that is borne in upon me by long experience, and I believe that in that respect I stand entirely square with the sanitarians of the world. At any rate, I hold that opinion myself." (2210–2212.)

An increased amount of infectious pollution has no effect on the time needed for purification, but the degree of danger is increased. One microbe coming down from Chicago and resting in the slack water of the Illinois would certainly die if it lay there long enough; but if a million came down, the chances are that some might be carried on by a freshet before they died and the danger would be greatly enhanced. Other things being equal, the greater the amount of infection the more serious the danger. (2212.)

The aeration received by the water flowing over Niagara Falls does not change the amount of pollution which the river contains. The late Prof. Albert R. Leeds repeatedly analyzed the water both above and below the falls and found it to be in exactly the same condition in each place. (2212–2213.)

The witness stated that after a careful consideration of the whole subject, including the typhoid-fever conditions in the sanitary district of Chicago, the sewer outfalls, the amount of sewage, and existing conditions in Desplaines, Illinois, Mississippi, and Missouri rivers, he believed that beyond a reasonable doubt the principal portion of the increase of typhoid fever in St. Louis since January 1, 1900, had been due to the pollution of the water of St. Louis by the Chicago sewage. The typhoid rate of St. Louis from 1895 to 1899, inclusive, compared very favorably with the rate in Lowell and Lawrence, Mass., after the introduction of pure-water supplies at these two places. (2213–2215.)

In reply to the question whether or not the Illinois River water containing mixed sewage and canal water from the Chicago sanitary district had been rendered less safe since the opening of the drainage canal than before, the witness testified substantially as follows:

In the first place we must consider the matter of dilution. The addition of an amount of lake water equal to 5,000 cubic feet per second at Lockport unquestionably dilutes the Chicago sewage and Chicago River is clearer and better than it was before. At the same time it must be borne in mind that the water thus used for purposes of dilution is not the unpolluted water of Lake Michigan. It is drawn chiefly from the mouth of Chicago River and vicinity and has long been known to be polluted more or less. The problem then in part resolves itself into this question: "Does the dilution of a presumably infected sewage by a presumably often infected water contribute to the purity of Illinois River?" The infectious materials that were formerly put into Chicago River are now carried with comparative swiftness down the drainage canal and into Desplaines and Illinois rivers. We have then to consider whether sewage as described, carried quickly and in considerable volume into Illinois River, does or does not render that river safer than before. The belief of the witness, based on the effect of time as a purifying factor, was that it is at least very doubtful whether the pouring of the Chicago sewage into Illinois River does at any time improve that river. This opinion was strengthened by considering the larger amount of sewage now delivered, the opportunities for sedimentation, the susceptibility of Illinois River to freshets, and the changed conditions brought about by the introduction of this fresher sewage with a larger volume of water. Undoubtedly at times the dilute sewage may have improved the appearance of the river water and may seem to have improved its quality; but if the condition throughout the year, at all times and seasons is considered, it is doubtful whether such improvement has taken place. (2216–2217.)

The witness believes that the danger to St. Louis is practically constant, inasmuch as it can never be known at what moment infectious material may arrive from the sewers of Chicago. It is not supposed that such material is arriving every minute or every hour, but no one can ever know when it may come. The danger is believed to be immediate in the sense that it is urgent and serious, and it is impending by reason of the fact that it is hanging over the citizens of Missouri on the shore of Mississippi River all the time. It is as if ever since the opening of the drainage canal there had been located on the drainage area of the Mississippi a big additional city, notorious for its typhoid epidemics and its high typhoid death rate, and as if the placing of that city virtually on the Mississippi basin had introduced a new element into the life and welfare of the people on the river below. It is no trifling matter to take on a city of that size and add its sewage to a stream already sewage polluted. The danger line must by that addition be reached sooner by those who use the water, and it is for that reason that the danger is regarded as impending, immediate, aggravated, and continuous. (2217–2218.)

Dams undoubtedly favor purification so far as they produce slack water or quiescence, but if the sediment or sludge is allowed to remain on the stream bed, the chances are good that in freshets it may be returned to the current, travel with it, and produce trouble below. The witness cited as an example the Merrimac, which is often in dry seasons a series of mill ponds in which sedimentation goes on, but in the event of a thunder shower or any sudden precipitation sufficient to upset the stream it begins to rise, scouring takes place, and trouble may ensue, as was the case at Newburyport. Epidemics at Lowell and Lawrence have generally followed freshets in the river. It is a general principle that dams are useful, but not sufficient to bring about complete purification. (2218–2220.)

The witness stated that the rate of growth in population of the Chicago sanitary district exceeds that of any other area in the Mississippi basin. The growth in rural population in this basin during the years 1890–1901 was less than 1 per cent, that in the urban population outside the sanitary district of Chicago was 28.2 per cent, and that of the city of Chicago was 54.4 per cent. Such a growth in the city population, accompanied by a corresponding dilution of its sewage through the drainage canal, must obviously quicken the flow of Illinois River and bring the infectious materials more rapidly to the people of Missouri. It is as if Chicago should be gradually moved toward St. Louis. The larger Chicago gets, the nearer it practically comes. It is of interest not only to St. Louis and to Missouri, but to Illinois and to cities and towns that are bound to grow up in the Illinois valley, that if Asiatic cholera or any other disease capable of being water borne should appear in a Chicago five times as big as the present city, it would be a menace to the welfare of the inhabitants of these places lower in the valley very much greater in proportion than the existing danger. Even if Chicago should purify her water supply and reduce her typhoid-fever death rates, the mere existence of this large number of beings pouring their sewage down the Mississippi Valley, no matter how good their general sanitary conditions might be, would be a very serious item in the welfare of these places, because epidemics sometimes appear even in communities having good water supply and good sanitary conditions. (2220–2223.)

In reply to specific questions, the witness stated that the construction of the Chicago drainage canal had added to the sewage-producing population tributary to Mississippi River above the St. Louis water intake a number equal to about 63 per cent. Only municipalities having 4,000 inhabitants or more being considered, the population tributary to Mississippi, Missouri, and Illinois rivers, exclusive of the sanitary district of Chicago, was 2,695,782, distributed as follows: Missouri River, 1,090,832; Mississippi River above the mouth of the Illinois, 1,219,645; Illinois River, 385,305. (2235–2236.)

The witness then stated that there were well-known cases where settling basins holding suspected water for long periods had failed to protect the people from typhoid fever. At Covington, Ky., the water of Ohio River, more or less polluted, is kept at times as long as thirty-two days, and yet Covington suffers severely from typhoid fever, due apparently to infected water. At New Albany, Ind., the storage is about a month in the sedimentation basin, and here also typhoid fever is prevalent. (2238.)

Counsel for the complainant then propounded a long hypothetical question to the witness with reference to the relative effect of the discharge of sewage from Chicago through the drainage canal and from all the other large cities on the drainage areas of the Missouri, upper Mississippi, and Illinois, exclusive of the Chicago sanitary district. The cities, population, distance from St. Louis, the rivers into which the respective sewages were discharged, and the number of deaths from typhoid in each city were included in the question and are given in Table 42. (2239–2249.)

TABLE 42.—*Population, deaths from typhoid, etc., in cities in Missouri, upper Mississippi, and Illinois drainage basins.*

MISSOURI DRAINAGE BASIN.

City.	Population.	River receiving sewage.	Distance from St. Louis.	Deaths from typhoid. 1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.
St. Charles, Mo	7,982	Missouri	47	....	....	....	....	....	....	22	5	6	14
Kansas City, Mo	163,752	....do	403	59	37	34	29	38	49	52	49	58	58
St. Joseph, Mo	102,000	....do	501	20	22	31	19	13	19	37	20	12	13
Omaha, Nebr	102,552	....do	676	22	40	29	18	22	32	26	24	23	22
Council Bluffs, Iowa	25,802	....do	676	5	7	6	8	8	6	11	6	6	8
Lincoln, Nebr	40,169	Platte	745	33	21	23	15	14	12	13	4	13	10

UPPER MISSISSIPPI DRAINAGE BASIN.

City.	Population.	River receiving sewage.	Distance from St. Louis.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.
Quincy, Ill	36,000	Mississippi	148	21	28	25	13	13	7	6	10	14	17
Keokuk, Iowa	14,041	....do	185	8	13	2	3	7	9	9	10	4	8
Burlington, Iowa	23,201	....do	225	8	10	8	13	3	4	8	13	12	11
Rock Island, Ill	35,300	....do	310	15	13	3	13	....	....	10	14	28	5
Davenport, Iowa	35,254	....do	310	5	6	4	3	5	2	12	14	11	11
Moline, Ill	7,987	....do	313	7	9	8	11	3	5	20	22	16	7
Des Moines, Iowa	62,139	Des Moines	387	22	29	30	14	20	17	13	7	22	21
Minneapolis, Minn	102,718	Mississippi	707	134	107	88	60	148	86	71	13	121	66
St. Paul, Minn	163,055	....do	694	51	32	38	37	22	43	30	30	24	18

ILLINOIS DRAINAGE BASIN.

City.	Population.	River receiving sewage.	Distance from St. Louis.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.
Peoria, Ill	56,000	Illinois	198	....	....	....	13	18	18	12	23	15	18
Springfield, Ill	34,159	Sangamon	191	....	....	....	....	....	....	....	20	10	8
Bloomington, Ill	23,286	....do	238	12	14	15	9	10	10	9	15	9	15
Decatur, Ill	20,754	....do	246	5	7	2	....	2	5	7	11	5	4
Ottawa, Ill	10,588	Illinois	282	2	5	2	2	4	4	3	3	5	2
Joliet, Ill	29,000	Desplaines	322	12	14	....	12	12	15	13	13	13	21
Pekin, Ill	6,420	Illinois	188	....	....	....	....	....	....	....	2	1	2
Elgin, Ill	22,433	Fox	348	5	3	5	14	....	4	5	15	15	8
Aurora, Ill	24,147	....do	328	6	12	19	10	5	10	4	17	11	2
Havana, Ill	3,268	Illinois	......	3	7	2	5	....	....	....	....	1	2
				....	....	....	....	369	357	385	338	442	365
Chicago, Ill	[a] 1,500,000	Drainage canal	408	....	....	518	751	437	636	442	336	509	801

[a] Estimated.

The question continued as follows:

Assuming that the total number of deaths from typhoid fever on said watersheds in all other towns and cities of 4,000 population and over have not increased for said years in any greater or different proportion than in the cities above mentioned;

Assuming that the three rivers mentioned run through alluvial soil principally, and the Illinois River enters the Mississippi at Grafton, 29 miles above the Chain of Rocks intake tower of the St. Louis waterworks, that the Missouri River enters the Mississippi 23 miles below Grafton and 6 miles above the intake tower * * * located on the Missouri side of and in the channel of the Mississippi River about 1,500 feet from the Missouri shore;

Assuming that the city of St. Louis obtains its water from the Mississippi at the intake tower, * * * by which it supplies its citizens, about 600,000 in number, with water for drinking and domestic purposes, and that no substantial change in the method of taking said water or treatment thereof has occurred since January 17, 1900;

Assuming that the sewage of 1,500,000 inhabitants of Chicago has, since January 17, 1900, been discharged into the Chicago drainage canal at Lockport, 291 miles above Grafton, and that the sewage-polluted water from said city and canal has continually since said day proceeded into the Desplaines River at Lockport, and that the Desplaines enters * * * Illinois River, forming a continuous water course from Chicago to the Missouri shore of the Mississippi River and to St. Louis;

Assuming that in the years 1895 to 1902, inclusive, the number of deaths in Chicago from typhoid fever was [as indicated in above table]; and

Assuming that in St. Louis for the years 1900, 1901, and 1902, and to this day, the percentage of annual typhoid-fever mortality to total mortality has increased about 73 per cent over and above that of the years 1895, 1896, 1897, 1898, and 1899, and that the typhoid deaths in all towns and cities over 4,000 inhabitants were about the same per [unit] population as those given above on the watersheds of said three rivers during said time, and that on the ordinary basis of computing sanitary population by taking the aggregate population of all towns and cities of 4,000 inhabitants or over on the watersheds named, there was a population as follows: On the Missouri watershed, 10,901,832; on the Mississippi above Grafton, 1,219,645; on the Illinois River, exclusive of the sanitary district of Chicago, 385,305;

State what, in your opinion, the sewage from 1,500,000 people of Chicago discharged into the drainage canal had to do with the increased death rate from typhoid fever in St. Louis, as above stated.

The reply of the witness to this hypothetical question was as follows:

After having carefully considered the question and the assumptions which it contains, and in view of my studies of the typhoid-fever statistics of the city of St. Louis to which I referred in my testimony of yesterday. * * * I believe that beyond all resonable doubt the principal factor of the annual increase of typhoid-fever mortality of the city of St. Louis since January 1, 1900, has been due to the pollution of the water supply of the city of St. Louis by the unpurified sewage of the sanitary district of Chicago. (2250)

In closing the direct testimony the witness asserted that, in his opinion, no competent expert either can or will say that any means exist at present by which the unpurified sewage of the sanitary district of Chicago can be warded off from the people on the Missouri shore and the citizens of St. Louis in the event of a period of low water in Missouri River synchronously with a flood on the Illinois basin. (2253)

CROSS-EXAMINATION.

An important point brought out in the cross-examination was the opinion of the witness that even if all the sewage from the sanitary district of Chicago were eliminated from the Illinois River basin, leaving only the pollution otherwise entering the Illinois and that in upper Mississippi and Missouri rivers, the water entering the intake of the St. Louis waterworks would still certainly be polluted and dangerous to the people of St. Louis and the towns below; and that so far as purification of this water by filtration or other means is concerned the cost thereof would not be materially affected by the addition of the sewage from the Chicago sanitary district. (2254–2258.)

During the cross-examination the statement was made by the witness that the chemical examination of water for the purpose of determining its potability is useful under some but not all circumstances. If the water be grossly polluted, no great skill is required; if only slightly polluted no evidence of value would be produced by the analysis. The same is true of bacteriological evidence. Both kinds of evidence would be preferable to either alone, but the combined testimony is subject to the same conclusion, namely, that pollution would be sometimes indicated and sometimes not. (2258–2260.)

The witness stated that the addition of 1 gallon of typhoid-infected sewage to Mississippi River at Alton might make the water of St. Louis dangerous to drink. He was then asked if the same would be true of St. Charles, Kansas City, and Omaha, stating in reply that he would consider that the water into which such sewage was emptied would be unfit for drinking purposes when it reached St. Louis. In explaining his answer the witness stated that it is hard to draw the line in cases of this kind, as it always is in sanitary matters, and that if the sewage pollution were to take place only once he would not ordinarily consider the water unfit for drinking. There is a point in questions of this kind where it is a very difficult matter to decide; chemical and bacteriological evidence and the conditions of purification en route should be taken into consideration. (2263–2266.)

The longest well-established distance which typhoid germs are known to have traveled to cause infection in water supplies was stated by the witness to be 57 miles, in the case of the Detroit epidemic. The greatest assumed distance for such a journey was 113 miles, from Oil City to Pittsburg. In fact, no limit may be placed on the distance that a typhoid bacillus may travel in water and retain its virulence, if the rate of travel is fast enough. In the present state of knowledge the witness was unwilling to set any limit of distance, but the real problem was, according to him, based not so much on the distance as on the time. (2270–2271.)

The witness then discussed the process of calculation by which he reached his results of typhoid-fever mortality at St. Louis. The ratio of the total number of deaths from typhoid fever to the total number of deaths from all causes gives the percentage of mortality for that specific disease. In the case of St. Louis the statement of 73 per cent increase in mortality from typhoid does not mean that the number of deaths from this disease since 1900 was increased by 73 per cent over the number of deaths from the same disease during the five years previous, but that such increase had taken place in the percentage of typhoid deaths to total deaths in the two periods. In other words, the typhoid death rate is based on the total number of deaths, a definite factor, rather than on the population, an extremely indefinite and fluctuating factor. In the present case a percentage of mortality was computed for each of the years specified. The deaths for the five years 1895 to 1899, inclusive, were added together and divided by five, and those for the years 1900, 1901, and 1902 were added and divided by three, and the results were compared, showing that the increase subsequent to January 1, 1900, was 73 per cent. There are, according to the witness, various ways of getting at the relative efficiency of any particular disease as a death agent. The quickest way is to compare the total number of deaths from that disease with the ascertained or estimated population. This is what is known as the death rate from that disease, always a more or less uncertain factor. On the other hand, it is generally held that the total number of deaths is ascertained in most cities with considerable precision. (2293–2295.)

In response to the question, "Suppose that a certain identified quantity of water should require in its transmission from the outlet of the sanitary district canal into the Illinois River to Grafton five weeks, would you say that the typhoid bacillus might live in that given body of water?" the witness answered in the affirmative. The same answer was given with the time specified as five months. With reference to a time interval of one year the witness stated that he could conceive of conditions which might prolong its life to that extent. For example, the pouring of a large quantity of acid from manufacturing wastes down the canal during that year might conceivably destroy the typhoid germs in the water and in the sediment. On the other hand, the discharge of an unusual amount of organic matter from the stock yards might so enrich the water as to sustain the life of the germ perhaps even longer than one year. The fact is that the conditions which must be considered in a case of this kind are so many that it is impossible to make categorical deductions which will have any real value. The chances are good that the greater part of the germs would die, but the possibility remains that some might still be alive if they came from sewage under the conditions existing on Illinois River. In reply to the same hypothetical question with the time fixed at fifteen months, the witness replied: "I should say that in regard to a period beyond a few weeks or months that in general the mortality among the typhoid bacteria would be heavy, but that I should never feel certain, even after one or two years, or possibly longer, that some of those were not still living there. (2315–2316.)

In reply to a direct question, the witness stated that he attributed the typhoid fever in St. Louis during 1895 to 1899, inclusive, to a variety of circumstances, each of which probably played its proportionate part in making up the total. The water may have contributed to the net result; also milk, oysters, and secondary infection. Other infected foods, such as water cress, celery, and unwashed fruits, had an important bearing; also flies and all similar factors, each of which tends to keep up in all cities of the world a small but rather constant amount of typhoid fever. The witness asserted that the increase of typhoid fever subsequent to January 1, 1900, was not due to an overindulgence in oysters on the part of the inhabitants, while there was no doubt that some typhoid-infected oysters may have been eaten in St. Louis during those years and may have caused some cases of typhoid fever. The amount of increase of the disease subsequent to January 1, 1900, in view of the size of the city, would mean, if attributed to oysters, so vast a change in the habits of the people or in the condition of the oyster supply of the United States, that such a theory would be unreasonable, particularly as oyster-caused epidemics are not frequent and are local, while the rise in typhoid fever in St. Louis has been persistent. (2328–2331.)

The agency of wells in St. Louis as a factor in the distribution of typhoid fever was then discussed by the witness, who stated that his investigations showed that there were about 2,000 wells in use, and that the chances are that many of them were infected; but a consideration of all the circumstances, so far as they could be learned by making careful inquiries as to changes in the customs of the people after January 1, 1900, would put the investigator in a position to say positively whether the increase in typhoid was due to any such cause. The witness had considered the subject of the number of wells and whether such number was materially changed after the date mentioned, and had come to the conclusion that there was no reason to believe that any material change in the habits of the people in regard to the use of such wells had occurred since that date, and that, therefore, this agency may be entirely excluded as a factor in causing any portion of the increase. The witness affirmed that he was justified in making this statement, even though he had made no personal inspections of any wells or outhouses and did not know how many people drinking well water had contracted the disease.

Continuing, the witness stated that the theory of well water as a factor in the production of typhoid fever had, in his opinion, been overworked, and that the danger of well waters had been greatly exaggerated in public belief. In his extensive bacteriological experience he but very seldom had had occasion to attribute to infected wells epidemics of typhoid fever, and had never seen an epidemic of any considerable size from such sources. From his experiments made for the State board of health of Massachusetts on the purifying power of earthy materials he had found that as a rule the passage of infectious materials through open soils removes all traces of infection. If the soil is not open, obviously infection can not pass. The only case, in the judgment of the witness, in which privies and cesspools are dangerous to wells are those in which the soil is either very open or cracked or fissured in some way. In view of all these facts, and in view of the further fact that no material or essential change had taken place in the habits of the people of St. Louis since January 1, 1900, the witness excluded altogether the wells as an element in the typhoid-fever increase. While they may have contributed to keep up the usual small amount of this disease in St. Louis, they formed no factor in the large, steady, and continuous increase since January 1, 1900. The witness stated that his investigations showed that the characteristics of this disease in St. Louis are such as might be expected, and have in fact been present, in epidemics due to infected water supply. In the rare instances in which epidemics have been traced to wells, the deaths are numerous within a short period—bunched together, so to speak, both as to time and place. Even on the assumption that the wells in St. Louis might be contaminated with typhoid, it would be a comparatively easy matter to ascertain and demonstrate the fact that the disease was derived mainly from the general water supply, for if it were caused by infected wells, inasmuch as it is absolutely inconceivable from a sanitary standpoint that any very large number of wells should be infected, the vital statistics must then show a much larger number of deaths in restricted localities than ever before, but so concentrated in time as to pass like a wave over these localities, whereas no such waves could be recognized in the present case. (2341–2353.)

In response to the question whether or not the witness would, as a sanitarian, have recommended to the citizens of St. Louis the Mississippi water in its unpurified state as a water supply at any time previous to 1900, he stated that he probably would not have recommended it at any time for drinking purposes without treatment or purification, inasmuch as one could never know with any precision or certainty that the specific disease germs derived from the sewage emptied into the river at different places above on the drainage area had been effectually removed, and inasmuch as the stirring of sediments by steamers or by fishermen might at any moment convert what would otherwise be a well-purified stream into one of danger. (2362–2363.)

REDIRECT EXAMINATION.

The witness referred to his use of the term "normal" as referred to the rate of typhoid fever in a city, and classed it as objectionable, substituting the word "residual" in its stead. He explained that in using the word "normal" he was simply trying to arrive at a good scientific expression for subsequent use. If it should appear that the typhoid fever remaining in a city conformed comparatively with the amounts remaining in other cities having good water supplies, such a remnant or remainder might well be called the residual typhoid and represents the typhoid which will occur in any community sporadically and without reference to any particular source. (2379–2380.)

He then pointed out, in response to questions, that during 1897, 1898, and 1899, the number of deaths from urban typhoid on the drainage area of Mississippi River above St. Louis, excluding the sanitary district of Chicago, was about 1,100, and that the fatality in typhoid being assumed as 10 per cent, this represents at least 11,000 cases for the three years under consideration. In the sanitary district of Chicago during the same years there were 1,515 deaths from typhoid, which would mean, when calculated on the same basis, 15,150 cases, or 4,000 more than occurred in all the remainder of the Mississippi drainage area above St. Louis. The witness further pointed out that the number of deaths from typhoid on the Mississippi drainage area, exclusive of the sanitary district of Chicago, during 1900, 1901, and 1902, was 1,144, representing an estimate of 11,440 cases, while the number in the sanitary district of Chicago was 1,647, representing 16,470 cases—an excess in Chicago of about 5,000. The witness expressed himself as greatly impressed with this comparison, as it showed that by the diversion of the Chicago sewage into Illinois River the morbidity from typhoid fever in the Mississippi drainage area above St. Louis had been increased by considerably more than 100 per cent.

On being asked to reconsider his assertion made in cross-examination that the cost of filtering the St. Louis water supply would not be materially increased by the addition of the pollution derived from the drainage canal, the witness stated that on reflection he realized that he did not sufficiently consider the fact that, aside from the masses of filth that might be washed down in certain cases and that would add somewhat to the cost of cleaning and care of the filter, there would be the necessity for a much keener watch of the filters and for more intelligent management, so that it might make a difference between the employment of a low-salaried and a high-salaried man as resident manager of the works. Then there was the further contingency that with the unexampled increase of population in Chicago the Illinois and the Mississippi above Chain of Rocks might be reduced to an open sewer, and that under such conditions a single filtration of the water might not suffice. The witness admitted that this condition could not take place for a long period of years and until a vast population was added to that already living in Chicago; but, summing up the analogous cases in the United States in which pure streams had been reduced to a condition of hopeless pollution, stated that it was precisely these long looks into the future which should be taken in cases of this kind. Furthermore, in view of the facts that the low-water flow of Mississippi River at St. Louis is something like 40,000 cubic feet per second, and that Chicago is already pouring down 5,000 cubic feet per second in dilute sewage, while the drainage canal is built to discharge, eventually, 10,000 cubic feet per second, it is well to inquire what will be the effect of discharging that amount of water and sewage into Mississippi River, which is at times flowing only 40,000 cubic feet per second. At such times the danger line will be approached, and it is not at all inconceivable that when 10,000 cubic feet per second are poured down, the presence of this material in the Mississippi, itself growing more polluted meanwhile, may bring about or help to bring about at certain seasons of the year a condition approaching that of a septic tank, when the dissolved oxygen will begin to decrease and the water will begin to degenerate into a condition of dilute sewage. All these things would add to the cost to-day and would involve a greatly increased cost in the near future; within fifty or one hundred years they might even amount to such a pollution of Mississippi River in low-water times as to make it an impossible source for any modern civilized city. (2381–2385.)

Professor Sedgwick was recalled to the stand to testify concerning the epidemic at Cumberland, Md., which was generally believed to have been the cause of an increase in the typhoid-fever rate at Washington, D. C., through the infection of Potomac River, from which Washington takes its water supply, and on which Cumberland is situated, about 175 miles above.

From the testimony of the witness it appears that there were, in 1890, at Cumberland, 98 deaths from typhoid fever, distributed as follows: January, 18; February, 27; March, 39; April, 8, and May, 5. The number of cases reported in this epidemic was 485, which was believed by the witness to be entirely too small, as the number of deaths indicates that, with the usual fatality of 10 per cent, the total number of cases should have been about 980. The sewers of Cumberland, so far as sewerage was provided, emptied into North Branch of Potomac River and into Wills Creek, a tributary of North Branch at that point. In addition to the sewers, there were an unusually large number of privy vaults set directly over the river or its tributaries. The result of this epidemic was a large increase of the disease in Washington, and this was pronounced by the witness to be one of the most important examples on record of the transmission of typhoid-fever germs over long distances. Beginning in March, 1890, the number of deaths was as follows: March, 19; April, 11; May, 13; June, 33; July, 36; August, 28; a total of 140, exceeding the normal rate in Washington by about 100 per cent and indicating an incidence of the disease amounting to about 1,400 cases. (2759–2761.)

This instance, according to the witness, is particularly interesting by reason of the fact that Cumberland is about 175 miles from Washington, and because the river is of such a character as to offer a good example of a stream neither very swift nor very slow, but having occasional areas of what might be called slack water. The epidemic at Cumberland must have afforded a heavy infection of the stream, although it is a fact that at that time the city was not thoroughly sewered. It is, however, peculiarly arranged with reference to the water courses flowing past or through it. It is at the junction of that portion of the river which comes down from the Allegheny Mountains and another portion which comes from the West Virginia hills. One other fact of great importance should be mentioned. Between October 4, 1899, and March, 1890, the sedimentation basin and the distributing reservoir in Washington were out of service, so that during that period the water of the Potomac was delivered to the citizens of Washington without purification of any kind. As a result of the pollution of Potomac River, Congress authorized and provided for the construction of a filtration system for the city of Washington. (2761–2763.)

GEORGE W. FULLER.

DIRECT EXAMINATION.

George W. Fuller was called as a witness in behalf of the complainant, and in qualifying stated that he was a sanitary expert, professionally educated at the Massachusetts Institute of Technology and at the University of Berlin. In connection with his work in Germany, he studied bacteriology at the Hygienic Institute and in the private laboratory of the engineer in charge of the filtration plant of the Berlin waterworks. After returning from his European studies he was for five years in the service of the State board of health of Massachusetts, the greater portion of that time being spent at Lawrence, where there is an experimental plant, conducted with a view to finding the best ways of purifying sewage and water. During most of his stay at this experimental plant he was in immediate charge. For four years after leaving Lawrence he worked in the valley of Ohio River at Louisville and Cincinnati, being engaged in studying the best means of purifying the polluted Ohio River water at those cities. Since finishing the Ohio River work he had been in private consulting practice and had made investigations at upward of twenty-five or thirty cities, among which are a number of the most important cities in this country, such as Washington, D. C.; Springfield, Mass.; New Haven, Conn.; Oswego, N. Y.; Meadville, York, and Columbia, Pa.; and the group of cities lying directly west of New York, furnished by affiliated water companies, including Paterson, Passaic, Jersey City, and Hoboken. The witness further stated that he was a member of the American Society of Civil Engineers, the American Chemical Society, the Society of American Bacteriologists, the American Public Health Association, the American Waterworks Association, and the American Society of Naturalists, and that in connection with his membership in the American Public Health Association he had been chairman of the committee on the pollution of public water supplies and of the committee on standard methods of water analysis. (2602–2605.)

The witness gave the following facts in regard to the water supply of St. Louis: The Mississippi for many years has been the source of the

St. Louis water supply. Thirty years or more ago the municipal water department established an intake at Bissells Point, near the present Merchants Bridge. At that place four settling basins, each having a capacity of about 15,000,000 gallons were provided. The water from the river was pumped to these basins, in which it was settled—that is, partially clarified—and partially purified, and then it was pumped into the distributing mains that conveyed it to the citizens of St. Louis. These works continued in service until the autumn of 1894. For about ten years preceding that time attention had been given to the subject of locating a new point of intake, and as soon as the enabling acts were passed construction was commenced of the works as they now exist at Chain of Rocks. The object of moving the intake from Bissells Point to Chain of Rocks, 8 miles or so upstream and about 6 miles below the mouth of the Missouri, was to avoid all possibility of sewage pollution such as had been caused at Bissells Point by the inhabitants of the northern district of St. Louis where the population had increased rapidly since the time that the Bissells Point plant was constructed. (2606.)

At Chain of Rocks a tunnel is constructed through the solid rock, extending out from the Missouri shore about 1,500 feet and terminating in an intake tower located on the Missouri side of the main channel of the river; the water entering this intake tower flows by gravity through the tunnel, which connects with a suction well 100 yards or so distant from the shore. From this suction well the water is pumped by the low lift pumps situated in the adjoining station to a series of six settling basins, each of which is about 660 feet long and 400 feet wide and has an average depth of water of about 15 feet to flow line and a capacity of about 29,000,000 gallons. The river water in passing through these settling basins is clarified to a considerable degree, a large amount of the mud found in the raw river water being left in the form of a deposit. A considerable portion of the bacteria are also removed, including those of infectious diseases, if such are present in the raw water.

From these settling basins at Chain of Rocks the water flows by gravity through a masonry conduit leading to the old waterworks plant at Bissells Point, where a portion of it is taken by the pumps in the original station and delivered to the consumers. Since 1897, a part of the water, however, has been taken from this conduit about halfway between Chain of Rocks and Bissells Point, at Baden, where the high-service pumping station is located. At this station a considerable part of the water going to the hilly portions of St. Louis is pumped. (2606–2607.)

The witness stated that no change in the method of treatment of the raw water from Mississippi River had taken place since the late autumn of 1894.

It was his opinion that the best index of the sanitary character of a public water supply is the record of mortality from water-borne diseases in the community using it, and especially the mortality statistics of typhoid fever. It had been his experience that the typhoid statistics are preferable to those of other water-borne diseases, because of the widespread nature and distribution of typhoid, its abundance in those communities supplied with sewage-polluted waters, its well-defined character, and the substantially large percentage of deaths to cases. The witness believed, however, that if Asiatic cholera should become established in this country, it might serve equally well as an index to the character of water. He further stated that the number of typhoid-fever deaths in the United States, based on a conservative estimate, is from 25,000 to 30,000 per year, and that the number of cases will reach more than 250,000 annually. (2608)

The witness then stated that the water supplied to the citizens of St. Louis during the years 1895 to 1899 was what might be called good sanitary water, basing his judgment on the typhoid-mortality statistics. The water entering the intake tower of the waterworks during the same period was what might be called a suspicious water, by which he meant not distinctly a good water, and was in a much less safe condition from a sanitary standpoint than after it had been stored in the settling basins. (2608–2610.)

The witness then reviewed the number of deaths from typhoid fever in St. Louis from 1895 to 1902, inclusive,[a] and went on to state that averaging the number of deaths during the first five years, 1895 to 1899, gives 112 deaths per annum from typhoid fever, while a similar average during the three years beginning January, 1900, is 196, showing an increase in round numbers of about 80 per cent in the number of deaths. The increase of population during that period being taken into consideration and the typhoid-fever deaths being expressed with reference to the number per 100,000 population, there had been an increase since January, 1900, of about 60 per cent. The number of deaths from typhoid fever during the eight years being compared with the number of deaths from all causes, the increase since January, 1900, in the average percentage of typhoid mortality was 73 per cent. The witness then stated that, to speak broadly, there had been an increase during the period from January 1, 1900, to the date of the testimony of about 60 to 70 per cent above the average of the earlier period. Comparing the number of deaths from typhoid fever during the first five months of each year in the two periods, the witness stated that the earlier periods showed numbers very much less than the later. This was particularly true of the year of the testimony, 1903, when there were in January 15 deaths, in

[a] Date given in testimony of W. T. Sedgwick.

February 15, in March 20, in April 17, and in May, up to the date of testimony, 18, indicating an unusual prevalence of typhoid fever. (2610–2612.)

The witness then stated that he ascribed the increased amount of infection to the public water supply and predicated this opinion on the practically uniform distribution throughout the city of the residences in which typhoid deaths had occurred, and the further fact that a careful examination of several other possible sources of typhoid fever showed that no substantial portion of tnis increase can be explained in that way. Since January, 1900, the sanitary character of the public water supply delivered to the consumers in St. Louis has been less safe than formerly and it could not be classed as good water. As the treatment of the raw water after it left the intake tower had been essentially the same since January, 1900, as before, the witness declared that the change must have come about in the water before entering the tower and at some place above the waterworks. Continuing, he stated that he was generally familiar with typhoid statistics in the large centers of population on the Mississippi watershed above Chain of Rocks. During the periods under discussion there had been at a number of points some variation in the amount of typhoid fever prevailing in different years. To take the typhoid-fever statistics on this watershed, as a whole, excluding the sanitary district of Chicago, it was his judgment, based on the average number of deaths from typhoid per year, that there had not occurred on the natural drainage area of the Mississippi watershed above St. Louis any increase in the number of deaths sufficient to explain to any material degree the less safe condition of the Mississippi water at the intake tower. He considered that the cause of this condition was the discharge of sewage from the drainage canal, containing filth and infection from the city of Chicago. (2612–2615.)

The approximate number of persons sewering into Mississippi River and its tributaries above the waterworks intake at Chain of Rocks, exclusive of the sanitary district of Chicago, was in round numbers, according to the witness, 2,700,000. This figure was based on a separation of the sewerage-contributing population from the rural population by taking the towns of 4,000 and over as representing those which had sewerage systems and contributed sewage directly to the watercourses. Some towns of more than 4,000 population are undoubtedly not provided fully with sewerage facilities, and on the other hand there are a number of towns of less than 4,000 population which have in a limited measure some sewerage. As a practical proposition the amount of sewage contributed by the population in towns of less than 4,000 inhabitants no more than offsets in the aggregate the amount of pollution in the cities larger than 4,000 inhabitants which do not have sewerage and whose sewage therefore reaches the river indirectly. In making his statement as to the number of people in the aggregate sewering into Mississippi River above Chain of Rocks, the witness intended to include Missouri and Illinois rivers, exclusive of the sanitary district of Chicago. Based on these data, the witness calculated that the increase in population sewering into the Mississippi above St. Louis due to the construction of the Chicago drainage canal was about 60 per cent. (2616–2617.)

The witness estimated that it would require from ten to twenty-five days for the Chicago sewage to flow from Lockport to Grafton, the average time being from fifteen to eighteen days. He considered that typhoid germs may and do live in sewage and polluted water, such as is found in the Illinois River valley, for weeks and even months. The dilution of the Chicago sewage as it flows from Lockport to Grafton by the waters of Illinois River and its tributaries is extremely variable. At times the dilution is considerable; at other times the flow of the canal may exceed that of Illinois River, particularly that of its upper reaches. Consequently there results at times a dilution of the sewage by the river and at other times a dilution of the river by the sewage. Dilution at best does not destroy the disease germs or infectious matter. Its effect is simply to minimize the danger to those who drink the water so diluted. One effect of the dilution existing in Illinois River at low stages is to bring to Grafton more quickly than would otherwise be the case injurious matter entering the river at points along its route. (2617–2618.)

With reference to the significance of the ponds, dams, and slack-water stretches found in Illinois River, the witness stated that there are a good many days in the course of a year when the velocities at these points are so low that deposition takes place to a considerable degree. But deposition does not mean permanent elimination from the flowing water. The dangerous substances may be disturbed from time to time by changes in velocity of the stream flow due to small or great floods, or by the passage of boats or the action of the wind. These disturbances cause the bacteria to leave the bed of the river and be carried on to greater or shorter distances, and in this way the germs of disease may pass from the Chicago drainage canal at Lockport to the mouth of Illinois River at Grafton. In fact, the witness stated that it was probable that the water of Illinois River, passing into Mississippi River at Grafton, was sometimes richer in typhoid-fever germs derived from the sanitary district of Chicago than the water running over the Bear Trap dam. Such a condition of affairs might arise at times through disturbances of the sediment lying upon the bed of the stream in places. As the typhoid germs are returned to the flowing stream from their position on the bed an accumulated result is effected, whereby, at times at least, the waters of Illinois River flowing to Grafton may discharge the concentrated essence of the infection by taking, in the manner above described, portions of the infection coming from many days' flow through the drainage canal into the river. (2619–2620.)

Continuing, the witness stated that he did not believe it possible for Illinois River water ordinarily to flow by the intake at Chain of Rocks without some of it entering the intake tower. In his judgment, the sewage of the sanitary district of Chicago pollutes and infects the water of Mississippi River along the Missouri shore to such an extent that it makes this water less safe for drinking and domestic purposes than it was before the opening of the drainage canal. This conclusion he believed to be borne out by an examination of the records of typhoid-fever mortality. There were on the drainage area of Mississippi River above Chain of Rocks, exclusive of the sanitary district of Chicago, about the same number of typhoid deaths from year to year between 1895 and the date of the testimony, 1903; but since the opening of the drainage canal there had been added to the drainage area an amount of pollution shown by 1,647 typhoid deaths for 1900, 1901, and 1902, and there was no doubt in the mind of the witness that these added cases had been the cause of the increase in St. Louis. (2621–2622.)

Considering the probable future growth of Chicago and the constantly increasing amount of sewage discharged through the drainage canal, the witness believed that the water in Mississippi River along the Missouri shore would be rendered less safe than at the present time by reason of the increased amount of infection discharged into the canal and the shorter interval of time required for its passage from the canal to Chain of Rocks as a result of the constantly increasing amount of water used to dilute the sewage, which would quicken the flow of Illinois River. At low stages of Illinois and Mississippi rivers it is quite possible, in the opinion of the witness, that the amount of pollution may become sufficient to exceed the amount of oxygen available in the water and to make the two rivers resemble open sewers rather than streams carrying live, natural water. (2622–2623.)

In reply to the question whether or not the Chicago sewage would increase the difficulties of the problem of filtering or otherwise purifying the water supply of St. Louis, the witness stated that, in his judgment, the increased amount of infection adds to the responsibility of treating the water so as to make it perfectly safe and wholesome for the citizens of St. Louis, and that financially there would be the greater expense of the construction of a filtration plant and the added cost of supplies used in connection with its operation, especially in times of low water. It would also mean that filtration works, if adopted, must at times be operated at lower rates of filtration than if this infection were absent, and this reduction of the rate of filtration would necessitate a larger and hence a more expensive plant to purify the same quantity of water. Looking some distance into the future, and considering the various centers of population tributary to Mississippi River above St. Louis, but excluding the sanitary district, the witness was certain that there will ultimately come a time when single filtration can hardly be expected to produce a satisfactory quality of water at Chain of Rocks. This condition and the time at which it arrives will depend on the rate of increase of population in the communities on the drainage area; but whatever the rate of growth in those communities may be, it is certain that the added infection due to Chicago sewage will hasten the day when single filtration will prove unsatisfactory and when it will be necessary to resort to other methods involving increased expense and responsibility. (2623–2624.)

CROSS-EXAMINATION.

In reply to questions the witness stated, among other things, that if a stream of water flowing 300,000 cubic feet per minute, into which was poured the sewage of Chicago, were started in a tortuous course at the Bear Trap dam, receiving no dilution on the way, it would not, in his opinion, be absolutely freed from infection by the time it reached New Orleans. While there would be a very great reduction in the number of typhoid germs present, there was no certainty of absolute elimination. The witness further emphasized the fact that the self-purification of a stream is controlled by the time and not by the distance which it runs. Speaking absolutely, he believed it to be very doubtful whether there was any such thing as the purification of a stream of running water into which infected sewage is poured. The construction and maintenance of filtration systems for the purification of the St. Louis water were then discussed by the witness, who stated, with reference to the filtration of the Missouri River water as contrasted with that of the Mississippi, that there would not be any material difference in the construction of any unit portion of the filters, but that as the pollution and infection increased a larger area would be required in order to satisfactorily purify the infected water. If he were providing a filter to treat Missouri and Mississippi water without the admixture of that from Illinois River, there would be no necessity for making it larger or more expensive because of the union of these waters. But in the case of the admixture of Illinois River water, although there would probably be no marked difference in the size of the first installation, the reserve portion of that installation would serve for a shorter period of years than would be the case if that water were excluded. With the Illinois water included, it would also require more skill and judgment on the part of the engineer in charge of filter maintenance. (2624–2633.)

The witness further stated that there were a good many days when the proportion of Illinois River water entering the St. Louis intake is exceedingly small, but to guard against danger arising on those occasions when a considerable proportion of Illinois River water enters the intake, there would be required a constant exercise of care and skill equivalent to that which would be necessary if it were absolutely certain that a considerable proportion of Illinois River water came in constantly.

The cross-examiner then sought to establish the assertion that if it were necessary to provide more expensive filters and maintain a more expensive superintendence because of the discharge of Chicago sewage, the same necessity would arise in case there were a great epidemic of typhoid fever at Kansas City, the infection from which, as admitted by the witness, would reach Chain of Rocks under ordinary conditions in about one week. The apparent purpose was to show that for the safety of St. Louis at all times it would be necessary to provide as expensively for the elimination of sewage naturally running into the Mississippi drainage area as it would for that of sewage artificially diverted through the drainage canal. The witness replied that there would be an added danger from Illinois River, in that it is intermittently flushing out large accumulations of infected sediments, making the water constantly dangerous, whereas in the case of the supposed Kansas City epidemic the danger would not be constant but confined to a single limited period. As a general proposition, the growth of Kansas City is an impending menace to the water supply of St. Louis, but the contingency is remote, while the addition of the sewage from the Chicago drainage canal makes much less distant the day when serious trouble will result from the use of the water at the Chain of Rocks intake. (2639–2641.)

With reference to the sewage pumped from Chicago River into the Illinois and Michigan Canal, thence entering Desplaines River, the witness stated that, in his opinion, prior to 1899 this canal contained infection in a considerable proportion, though a large part of the infection from Chicago sewage remained in Chicago River. When the sewage was pumped into the Illinois and Michigan Canal the organic matter was in so advanced a state of decomposition that the proportion of typhoid-fever germs present compared with that originally present in Chicago River was exceedingly small, particularly as the much diluted contents of the canal flowed into Desplaines River. While this water was not absolutely free from infectious germs dangerous to the people of St. Louis, it was absolutely certain that it was not sufficiently infected to cause any trouble in that city, as evidenced by the low typhoid-fever rate. The Illinois and Michigan Canal was in effect a septic tank. It encouraged the growth of certain kinds of bacteria which are known to have a destructive influence on the germs of typhoid fever. This septic action, such as occurs in a tank or has occurred in the Illinois and Michigan Canal, does not ordinarily, if ever, take place in the bed of a stream to such an extent that it would affect very materially the life of typhoid germs. (2644–2645, 2652.)

In the course of over a year's investigation of water in Ohio River at Cincinnati, involving practically daily examinations, the witness found *Bacillus prodigiosus* on one occasion. While there is a possibility that others existed in the same water, it is a fact that the bacterium is rarely found in American waters, although it is a very easy germ to discover. (2665–2666.)

REDIRECT EXAMINATION.

With reference to specific instances of typhoid bacilli being traced through the outfalls of the sewers of a city into running streams and conveying typhoid to persons using that water, the witness said that there were many in the sewage-polluted Ohio basin, especially at Louisville. The sewage coming down to Louisville originates almost entirely at Cincinnati, a distance of about 150 miles, and points above. At times of very low flow in the river the velocity is so slight that the period of time required for those germs to pass from Cincinnati to Louisville is more than a month. Nevertheless there was typhoid in Louisville due to the consumption of river water, even though the water had passed through settling basins holding five or six days' supply, in which sedimentation takes place. This, in the opinion of the witness, was a very reliable demonstration that typhoid-fever germs are not absolutely removed from sewage-polluted waters in a period of one month. He cited, further, the instance of Covington, Ky., mentioned in the testimony of Professor Sedgwick, and stated that he considered that there was no room for doubt that a portion of the pollution existing in Ohio River at Cincinnati is due to the sewage from cities located in Allegheny County, Pa., such as Pittsburg and Allegheny, which are 450 to 500 miles by river above Cincinnati. (2666–2667.)

In reply to a question concerning the deposits of sediment in the slack-water places in Illinois River, such as Lake Peoria, the witness stated that there is documentary evidence and practical observation as to the amount of scouring which takes place. He quoted from reports of the Chief of Engineers of the United States Army as follows:

Channels dredged twenty years ago are but little deteriorated, and it is surprising to find that there has been no deterioration in depth in the pools created by the Henry and Copperas Creek dams after from fifteen to twenty-eight years' use.[a]

The dams [in Illinois River] have no appreciable effect above mid-stage of the river

[a] Rept. Chief of Engineers, U. S. Army, 1895, p. 2716.

when currents are the strongest, so that all lighter sediment is swept away as well now as before the construction of the dams. That there has been no appreciable change felt in the pools of Illinois River is a fact that has been often remarked upon by steamboat men and persons interested in the use of the river since the construction of the first dam at Henry, thirty years ago.[a]

The witness concluded his redirect examination by stating that in his judgment no great amount of sediment remains upon the bed of the stream of Illinois River for any great length of time. (2667–2668.)

GARDNER S. WILLIAMS.

DIRECT EXAMINATION.

Gardner S. Williams, a witness called in behalf of the complainant, stated that he was a consulting water supply and hydraulic engineer of Ithaca, N. Y., consulting engineer of the Ithaca Waterworks Company, and professor of experimental hydraulics in Cornell University, having occupied the latter position since the fall of 1898; that he had been educated in the common and high schools of Michigan and in the engineering department of the University of Michigan, where he took the degree of bachelor of science in civil engineering in 1889 and the advanced degree of civil engineer in 1899, the latter being conferred on him by reason of his extensive studies in connection with water supplies, especially from a sanitary standpoint, water-borne diseases, and investigations of the flow of water, on which he had later been awarded the Normal medal by the American Society of Civil Engineers. He had been connected with the construction of waterworks at Bismarck, N. Dak., and Greenville and Owasso, Mich.; from 1893 to 1898 he was civil engineer to the board of water commissioners of Detroit, where he was in charge of the engineering work connected with the construction of the extensive supply system of the city and made investigations on the flow of Detroit River in the American channel. He was also engaged as consulting engineer in the construction of other systems and planned and constructed additions to the waterworks plant at Ithaca, N. Y. The witness stated that since assuming charge of the hydraulic laboratory at Cornell University, which he claimed to be the most extensive hydraulic experiment station in the world, he had had abundant opportunity to study the flow of waters and their effects on the beds of streams, having conducted extensive experiments on the flow of water in open channels and over dams for the United States Board of Engineers on Deep Waterways, for the city of New York in connection with its investigations of the Croton water supply, and for the New York State canal survey, together with a number of less important investigations instituted by the laboratory itself. At the time of testimony the laboratory was

[a] Rept. Chief of Engineers, U. S. Army, 1898, p. 2436.

engaged on an extensive series of experiments for the hydrographic branch of the United States Geological Survey. During this time he investigated the flow of water at Holyoke, Mass., and Sault Ste. Marie, Mich.

The witness stated that he had made investigations of typhoid fever epidemics at Detroit, Saginaw, and Charlevoix, Mich., and Ithaca, N. Y., and had studied the information published in regard to epidemics of water-borne diseases in this country and abroad. (2418–2421.)

The sewerage system of Chicago was described as a combined system, receiving both household sewage and washings and filth from the streets of the entire city. The sewers receive the discharges of about 1,750,000 people, amounting to about 4,400 cubic feet, or 150 tons, of solid human fecal matter every twenty-four hours, which, according to the witness, was more than 50 per cent of the suspended solid matter at Lockport. The greater portion of this sewage is delivered into Chicago River and its branches and carried by way of the drainage canal into Desplaines, Illinois, and Mississippi rivers; the remainder of the sewage is emptied into Lake Michigan. That going through the drainage canal is diluted with Lake Michigan water, taken from a point directly over the beds of sewage deposit, which are from 1 to 4 feet deep. This water is so poor that in the opinion of the witness if it were delivered, unmixed with sewage, to a conduit sufficient to carry it to the Mississippi at Grafton in the same period it takes for the present mixture to pass downstream to the same point it would be very likely to carry disease infection and would thereby constitute a menace to the health of the people using the Mississippi water below Grafton for drinking purposes. (2422–2424.)

Referring to the physical characteristics of Desplaines and Illinois rivers, the witness stated that below Lockport the Desplaines has a rapid fall to Joliet, where the slope becomes materially less and lower velocities follow. The stream then passes on into the Illinois, which has a moderate slope in its upper portion, but as it comes down toward La Salle reaches a very flat country, where it partakes essentially at times of the nature of an estuary rather than of a river. It leaves its banks at a stage a little over 10 feet above ordinary low water and overflows large areas, forming basins which temporarily store the flood waters and then return them to the stream. For the purpose of improving navigation numerous dams have been constructed across the stream; these, being intended solely to store water in times of drought, are not of the nature of dams built for power purposes. The difference in height of the water surfaces, measured from the crests of the dam, in what would be the upper and the lower pools is frequently less than half a foot, so that in the case of markedly higher water the dams become submerged weirs. In times of low water they cause considerable quiescence and an extensive sedimentation of suspended matter results. As depositions occur in flowing water, the heavier materials naturally are deposited first. It is a notable fact that in such a stream the pressures existing in the thin layers of water vary inversely as the velocity; that is, the higher the velocity the less the pressure which the flowing water is able to exert on the water adjacent to it. The velocity in streams is ordinarily rather uniform for some distance below the surface, so that it is easily possible for suspended matter to disappear from the surface of the stream and get into the lower layers. As it approaches the bottom, however, the decrease in velocity becomes more rapid, and hence the increase of pressure from point to point becomes more marked and the sinking particles meet a higher resistance, so that there accumulates at the bottom a layer of water that is highly charged with suspended matter. The lighter particles in the water will be the last to be deposited, and we may say, generally speaking, that the bacteria, which are of very nearly the same specific gravity as that of the water itself, will only be borne to the bottom when entangled with the heavier suspended matter. Therefore such bacteria would be less liable to be deposited than the inert mineral matter. (2425–2427.)

Although it is true that large amounts of sedimented material have been deposited in Illinois River, there are also times when the river scours, or, in other words, takes up such deposited matter and carries it downstream. Observations of the United States engineers who have had charge of the improvement of that river show that there has been no extensive silting up or filling of the channels of the stream, either natural or artificial. It is not necessary to have flood conditions in order that this suspended matter shall be taken up and carried along. Very small changes in the stages of the river make very decided differences in the transportation of this material. The passage of boats also has very decided effects in stirring up these deposits. The witness stated that during his investigations of the flow of St. Marys River he had opportunity to observe the extent to which these variations in the velocity of the stream were felt. There was at that time a channel about 2,600 to 2,800 feet wide and through the major part of its extent the depth was 50 to 56 feet. When a steamer drawing from 14 to 17 feet passed through the channel, the velocities in the stream were disarranged and disturbed for a distance of as much as 100 feet each way from the steamer and extending to the bottom, and this disturbance continued sometimes for as much as half an hour after the passage of the steamer before the water was able to resume its normal regimen. Such effects can not fail to be an important factor in the disturbance of the sedimentary deposits that may be formed along the bottom of a river, and they will lead to the picking up of particles from the highly loaded layer of water next to the bottom. The lighter particles will of course be disturbed first, and therefore the bacteria will be much more likely to be resuspended and carried farther downstream than the mineral matter. They might be redeposited in some places in the course of flow, but some of them would undoubtedly be carried for very long distances, and in the case of Illinois River would be eventually discharged into Mississippi River. Whether or not their virulence would be diminished would depend on the length of time during which the bacteria might have remained deposited in the bed of the stream, but under such conditions as exist in Desplaines and Illinois rivers, receiving sewage from the city of Chicago, the witness saw no reason to believe that germs so deposited would be destroyed. It seemed to him entirely possible that as a result of the scouring action set up at the bottom of the slack-water portions of Illinois River, the water in times of flood might be more heavily charged with polluted and infectious matter than is the dilute sewage delivered into Desplaines River over the Bear Trap dam. (2427–2433.)

The witness stated that, according to his estimates, during over three hundred days in the year 1900 the water would have flowed from the Bear Trap dam to the mouth of Illinois River in less than fifteen days. The discharge of Illinois River, containing the mixture of Chicago sewage and water, would increase the pollution and infection of the water of Mississippi River at Grafton and render it less safe for drinking and general household purposes. Water so discharged would become mixed with Mississippi River water so as to affect its quality on the Missouri shore. When Illinois River enters the Mississippi at a lower velocity than that of the latter stream, the Illinois water would be drawn or forced to mingle with the Mississippi water in the same way that it is possible to pump water by means of the jet pump, which delivers a jet of water through a channel at a high velocity, entraining with it the slower-moving water at its side. Expressed in more popular language, the principle as stated by the witness, was that the more swiftly moving stream exerts a suction on the water of the slower stream which leads to the dissemination and mixing of the latter throughout the volume of the former. When the velocity of Illinois River is greater than that of the Mississippi, the momentum of the particles delivered to the Mississippi would be such as to carry them well out into the stream. The backing up of Mississippi River water into Illinois River would also have the effect of producing a fairly thorough mixture of the waters of the Illinois and so much of the waters of the Mississippi as backed up into the stream, and as the flow of this water which had been stored in the Illinois came out of the mouth of the river, it would have the same effect as a flood rising in the Illinois itself, producing an additional scouring on the bottom of the river. The witness then stated that he was prepared to assert positively that at times the waters of Illinois River reach the intake of the St. Louis waterworks at Chain of Rocks. (2434–2436.)

The witness stated that if all the disease organisms discharged into Illinois River through the Chicago drainage canal should become innocuous at Lockport, the discharge would still be a menace to the health of the people of Missouri who used the Mississippi water for drinking purposes, for the reason that this quantity of water added to the stream tends to decrease materially the time required for the flow from various points of pollution along Illinois River, thereby making the infection reach St. Louis in a much shorter time than was required previous to the opening of the canal. Concerning the probable average and probable range of dilution of the suspended matter in the water of Mississippi River flowing past Chain of Rocks, caused by the discharge of Illinois River, the witness stated that his computations showed that during seven months in the year the ratio of the amount of suspended matter delivered into Desplaines River from the Chicago drainage canal and the amount of water flowing in Mississippi River at Chain of Rocks is from five-tenths to 1 part of the suspended matter per million parts of water in the Mississippi, and at a time of low water $1\frac{3}{4}$ parts per million. This computation is based on the solids which are in suspension in the sewage at the Bear Trap dam and has no bearing on any substances which may be in solution, and therefore do not appear as solids in suspension. (2436–2439.)

The witness then described a case where a similarly polluted mixture of suspended solids from sewage matter had produced typhoid fever, as follows:

The water supply of the city of Detroit is drawn from the American channel of the Detroit River, at the head of the river or at the foot of Lake St. Clair. Detroit River, as you know, is one of the links in the connecting waters between the upper lakes, Huron, Michigan, and Superior, and the lower lakes, Erie and Ontario, and is the natural outlet of the upper Great Lakes to the sea. The water from Lake Huron enters the St. Clair River and flows through it a distance of about 35 miles, to the delta of the St. Clair River, when it discharges into Lake St. Clair. Lake St. Clair is nearly circular in form, being 24 miles wide and, including its delta, about 24 miles in length, measured in the direction of flow. The water supply of Detroit is taken practically from the lake or from the river a few hundred feet below the point where it takes its origin in Lake St. Clair.

In the year 1890 the number of deaths in the city of Detroit from typhoid fever were 39; in the year 1892 the number of deaths from typhoid fever in the city of Detroit were 209. This remarkable increase was such as to cause Detroit for that year to take rank among those cities which have had the highest death rates from typhoid fever in America—there are but one or two of our large cities that have had death rates notably higher than this, one of them being Chicago. An examination of the record showed that this epidemic began in June, during which month there were 38 deaths by typhoid fever. As the civil engineer to the board of water commissioners of Detroit, it was very natural that my attention should be called to this condition of affairs, as many people attributed the cause of the epidemic to the water supply, and I started to ascertain, if it were possible, where such a remarkable infection could have come from so suddenly and so unexpectedly. After an extended investigation I found that the epidemic was undoubtedly caused as a result of improvements to the channel of Black River, which flows into St. Clair River near its head, at Port Huron, a distance of about 57 miles from the intake of the Detroit waterworks. I found that Black River, which was a sluggish stream, having ordinarily no current whatever and only in times of heavy rains a perceptible current, had been for years receiving the sewage from the city of Port Huron, through the center of which it flows. In order to improve the harbor of Port Huron, which was virtually the lower portion of Black River, the United States Government had caused the river to be dredged during the early months of 1892, and in the process of that dredging had removed deposits from near the mouths of the sewers which ranged in depth from a foot to 7 or 8 feet, and, according to the testimony of some of those who lived along the banks, to as much as 10 feet in depth. This material was loaded upon scows and transported out into the St. Clair River, where it was discharged or dumped into the stream, at a point, as I have already stated, about 57 miles above the intake of the Detroit waterworks. I found upon further investigation that this work had been begun during 1891 and that conditions were such that this particularly highly infectious deposit of material was reached right at the beginning of the operations in 1892, so that this fully explained the sudden outbreak of typhoid fever in Detroit, it having been carried through the water of the St. Clair River and through Lake St. Clair to the intakes of the Detroit waterworks, and thence distributed to the consumers throughout the city, with the result above mentioned. (2439–2441.)

The time elapsing between the deposit of infectious matter at Port Huron and the arrival of the water into which it was so discharged and the delivery of the same to the consumers in Detroit, as stated by the witness, would be the time required for the water to flow from the point in St. Clair River where the material was discharged to the intakes of the Detroit waterworks, which he estimated could not have been less than eight days and was probably about ten days. (2443.)

The witness then stated that the incubation period of typhoid fever in about 75 per cent of the cases is from ten to fifteen days, and pointed out the fact that the sum of the time required for the appearance of infection in Detroit after the dumping of the pollution at Port Huron, the average incubation period, and the ordinary time elapsing between the onset of the disease and the occurrence of death agreed within twenty-four hours with the time which had elapsed from the deposit of the dredged material to the time when there were in a single day in Detroit four deaths from typhoid fever, there having been only one death from this disease during the preceding twenty-four days. (2444–2445.)

The discharge of St. Clair River, according to the witness, varies from 180,000 to 200,000 cubic feet per second. At the time of the epidemic the discharge was about the former amount, which is equivalent to the discharge of Mississippi River at St. Louis during ordinary stages. Assuming the degree of dilution from such discharge, the witness found that during the month of April, 1892, the ratio of volume of dredged material discharged per day into St. Clair River at Port Huron to the volume flowing in said river for twenty-four hours ranged from 0.55 to 1.1 parts of dredged material per million parts of water. The range of dilution of the sewage matter of Chicago in the waters of Mississippi River flowing past Chain of Rocks was stated to be at ordinary stages from 0.5 to 1 part of suspended matter per million parts of water. The witness said that the proportion of suspended matter in the sewage and water at Lockport was something over twenty times as great as that in St. Clair River, while that in the Mississippi at Chain of Rocks, coming from the Chicago drainage canal, was substantially the same as that in St. Clair River at the time of the Detroit epidemic. (2445–2449.)

The witness then described the epidemic at Grand Forks, N. Dak., substantially as follows:

The main sewer of the city of Crookston, Minn., became damaged so that it failed to discharge the material delivered into it. This led to the accumulation of deposits of sewage matter in the sewer, and to afford a temporary relief a small connection was made around the break, which carried off a portion of the liquid matter of the sewage and discharged it into Red Lake River, the regular outlet for Crookston sewage. In the fall of 1893 this sewer was repaired, and November 17 the sewerage system of Crookston was flushed of the accumulations which had gathered during the several months preceding. Typhoid fever to the extent of about 60 cases had existed in Crookston in October and November. At the time of the flushing of these sewers and the consequent delivery of sedimentary accumulations to Red Lake River the surface of the river was frozen over. The town of Grand Forks is located on this river about 60 miles below Crookston. In November 2 cases of typhoid fever and no deaths were recorded in Grand Forks, and for months preceding there had been a very small amount of this disease. In December, following the flushing of the Crookston sewers on November 17, 230 cases of typhoid fever and 4 deaths were reported in Grand Forks, in January 712 cases and 52 deaths, in February 231 cases and 27 deaths, in March 46 cases and 10 deaths, in April 26 cases and 2 deaths, and in May 1 case and no deaths—a total of about 1,200 cases of typhoid fever and 100 deaths at Grand Forks as a result of the flushing of the sewers at Crookston. Grand Forks was at that time taking its water supply from the river. This evidence was introduced to show that the infectious material accumulated in the Crookston sewers had retained its virulence and after such a term of storage and a transmission of 60 miles by water had resulted in this great epidemic. (2455–2456.)

In response to a direct question the witness said that it was his opinion, based on his knowledge of the transmission of typhoid fever through water, the conditions found on investigation to exist along the drainage canal and the streams which unite the sewers of Chicago with the intake of the St. Louis waterworks, and the conditions which have existed in Chicago and St. Louis prior to and since the opening of the canal, that typhoid infection has at times been transmitted from Chicago to the St. Louis intake, and that such conditions might be expected to persist in the future. The best criterion of the sanitary quality of a water supply that is used by a community for domestic purposes is the presence or absence among the people who use it of water-borne diseases, of which typhoid is the most important. The evidence afforded by the typhoid-fever statistics of St. Louis for the period 1895 to 1899 would indicate that the water supply was not ideal. Nevertheless, it would compare favorably with the supplies of a very large number of American cities and would rank with about the second class of American water supplies, as experts usually consider them. The evidence presented by the typhoid-fever statistics in St. Louis subsequent to January 17, 1900, however, showed that the probable infection of the supply had become nearly twice as great and that its rank had materially dropped, judged by the conventional standards of purity. (2460–2463.)

The significance of the sanitary analysis as an aid in determining the presence of infectious pollution was then explained by the witness, who said that if it fails to show anything of a deleterious character, it is nevertheless not to be accepted as an evidence of purity, but if it does show the presence of substances which are recognized as connected with infectious material, then it is to be regarded as a valuable indication of the possibility of contamination. Whenever chemical, microscopical, or bacterial analyses of water indicate the presence of substances that are known to be related to infectious matter, it is proper to give to such evidence great weight in estimating the quality of the water. On the other hand, it is not necessary for the expert to depend on or to require either of these analyses in order to determine the degree of pollution of a water if it is possible for him to see the polluting material flowing into it. (2464–2467.)

The witness then stated that if, with a knowledge of the existence of the conditions at Chicago and along the drainage canal and Desplaines and Mississippi rivers, as they were known to the witness, an "expert" should state that it is impossible for infectious matter discharged by the sewers of Chicago to reach the Missouri shore of Mississippi River and the intake of the St. Louis waterworks and be a source of danger to the citizens of Missouri residing on that shore and using the water from the Mississippi below the mouth of Illinois River for drinking purposes and to the citizens of St. Louis using the water supply drawn through the intake at Chain of Rocks, he (the witness) would say that the person making this statement had thereby shown such a lack of knowledge of the history of water-borne diseases and the life and phenomena connected with their transmission and infection as well as of the laws of flow of water in open channels as to totally disqualify him as an expert on the sanitary value or quality of a public water supply. The problem before future generations in St. Louis by reason of the discharge of Chicago sewage into Illinois River is far more difficult than that which is to be faced at present. A careful study of the relations existing between the flow of rivers contributing to the water flowing past the St. Louis intake and the prevalence of water-borne diseases in the city of St. Louis among those of her citizens who are using the public supply has led to the conclusion that at the present time the remarkable immunity from serious typhoid infection which the citizens of St. Louis have thus far experienced is due very largely to the character and amount of water contributed by Missouri River. As the Missouri enters the Mississippi the amount of silt in suspension in its water often amounts to over 1,200 parts per million. A large part of this silt is of such a nature as to be readily deposited when the water approaches a state of approximate quiescence; and so vast a quantity of depositing matter can not fail to remove a very considerable percentage of the bacteria that are daily brought into the settling basins. As time goes on, the history of the Missouri will become the same as the history of every other stream on whose shores the hand of man has rested, and while the total quantity of water which that stream will deliver from year to year will remain about the same as now, the amount during periods of drought will be decidedly less and larger portions of the discharge will be gathered in a few floods. The result of this on the water mingling to form the supply of St. Louis will be that in the future Missouri River will show a diminution in the percentage which it represents of the total flow of Mississippi River past the city. It will therefore follow that the amount of silt furnished by Missouri River will be less and less sufficient to remove from the mixed water the number of disease germs, even aside from the certainty that the number of these germs will vastly increase as time goes on. It therefore seems clear that the pollution of the waters of Illinois and Mississippi rivers will have from year to year a continuously greater effect on the healthfulness and quality of the water delivered to the citizens of St. Louis by their waterworks system. In view of this fact, together with the wonderful growth of the city of Chicago, there can be no question that in the future the menace to the health of St. Louis arising from the discharge of Chicago sewage into Illinois River will be much more tremendous and impending than it is at the present time, grave though the present condition may be. (2473–2477.)

CROSS-EXAMINATION.

The witness stated, in response to a hypothetical question, that, assuming the existence of an equal number of cases of typhoid fever at St. Charles, Mo., and at Omaha, Nebr., and a subsequent occurrence of the disease at St. Louis, he would attribute the St. Louis typhoid to infection from both points. The life of the typhoid bacillus in streams is a matter of time rather than of distance, as a general proposition, but it was the opinion of the witness that no stream of water on the surface of the earth flowing in natural channels is long enough to warrant the absolute assurance that the typhoid germ might not live from one end of it to the other. If typhoid-fever germs were discharged into Mississippi River at St. Paul and no other possible source of infection of the waters appeared, they might arrive at New Orleans and infect the water supply of that city. (2547–2549.)

Pages 2551–2583 of the record contain the report of cross-examination directed to the witness for the purpose of ascertaining his reasons for declaring that the increase in the number of deaths from typhoid fever in St. Louis subsequent to the opening of the Chicago drainage canal was due to the discharge from that canal rather than to the discharge of sewage from the numerous cities located on Missouri, Mississippi, and Illinois rivers above the St. Louis waterworks intake. The witness confessed that it was impossible to determine by technical methods whether the virulent typhoid bacilli entering the intake were derived from the sewage of one city or another, but held that such demonstration was unnecessary to substantiate his claim of the culpability of Chicago sewers. Previous to the opening of the canal the water of St. Louis could not be considered safe at all times, by reason of infected discharges from city sewers lying in either one of the streams that converge above the intake, but the records show that the conditions that prevailed during the years previous to the opening of the canal had not been changed except that Chicago sewage had been discharged into Illinois River through the drainage canal. If this canal had not been opened these conditions would not lead one to expect any material increase in typhoid mortality in St. Louis, but the fact that the canal had been opened and Chicago sewage had been discharged into Illinois River, and that within a short time the typhoid in St. Louis had increased and such increase had been persistent, demonstrated that the discharge from the canal is responsible. In other words, the increase of typhoid fever in St. Louis must be due to some change of conditions with reference to the pollution of the St. Louis water supply, and the records of typhoid mortality throughout the contributing drainage area above the St. Louis intake reveal only one important change—namely, that of the added contribution of Chicago sewage. Therefore the observed effect in St. Louis must be due to that single cause.

In closing his testimony, the witness stated that in considering the increase in the typhoid rate in St. Louis since the opening of the drainage canal he had used the records of deaths only. If the number of deaths in St. Louis should show an increase and the number of cases reported show a decrease he would still give attention to the death record because it is the more reliable. He would never base conclusions in a typhoid epidemic on the number of cases reported, because a man never dies but once, and in the case of death, under the laws of the United States, generally a record is made somewhere, whereas a man may be sick of typhoid and no record of it appear. As a matter of fact, it is a rare occurrence for more than 60 per cent of the actual typhoid cases to be reported. Therefore the case record is of no value. (2588–2589.)

TESTIMONY FOR DEFENDANTS.

The testimony for the defense was commenced on board the Illinois fish commission boat *Illinois* July 13, 1903, the boat proceeding up Mississippi and Illinois rivers and stopping at various points at which local testimony was taken. At each point where samples had been taken for examination by the experts to be produced in behalf of the defendants, the local collectors testified as to the manner of taking the samples, identified tags, and in all respects established the identity of the samples to be reported in subsequent testimony. In addition to this the testimony of many local persons living beside or working on the river was introduced at each point for the purpose of procuring their views with reference to the condition of the water in the stream before and after the opening of the drainage canal. As was stated by the counsel for the defendants, these witnesses were not offered as experts on the subject, but merely as laymen who had lived and worked on the river for considerable periods and had had ample opportunity to observe the waters before and since the opening of the drainage canal. The general testimony of these laymen throughout the course of the river was that in physical appearance the water had been greatly improved since the opening of the canal, that previously there had been, in times of low water, a large abundance of aquatic vegetation which frequently gave off foul odors, but that since the opening no such growth had occurred. The testimony of steamboat men and manufacturers with reference to the allged improvement of the water for boiler purposes was also presented, together with certain important testimony concerning the discharge of industrial wastes into the river, which will be reviewed at length in subsequent pages. The report of this testimony covers pages 2890–3498 of the record, representing the period from July 13 to July 24, during which time the commission convened at all important points along the river from St. Louis to Henry, Ill.

C. G. HERGET.

C. G. Herget was called as a witness in behalf of the defendants and testified that he was manager of the Globe distillery, located at Pekin, about one-half mile from Illinois River. At this distillery whisky was manufactured, 90 per cent of the raw material being corn and 10 per cent rye and malt. The slop, amounting to 40,000 gallons for each thousand bushels of grain used, was stored in tubs and fed to cattle. At this distillery 4,400 head of cattle were kept in barns located about one-half mile from the river. The slop was fed three times per day to the cattle, about 3 pecks per head at each feeding, together with hay or straw or cotton-seed hulls. The refuse from the stables, consisting of uneaten slop and hay and the excreted discharges of the cattle, the latter amounting to about 4 or 5 gallons per animal per day, was washed from the stable into drains and deposited in the river, where in low and medium stages of the stream it formed a sort of island, composed principally of manure, hay, straw, and refuse. During high water this island was cast loose and went floating down the river. (3325–3331.)

PETER CASEY.

Peter Casey testified that from 1895 to 1901 he was manager of four distilleries in Peoria, belonging to what is known as the whisky trust, and from June, 1901, to the date of the testimony, had been manager of the Corning Distilling Company. Between 1895 and 1900 from 12,000 to 20,000 cattle were fed in Peoria in a manner similar to that described in the testimony of C. G. Herget. By 1901 and 1902 the number of cattle fed had dropped to about 8,000. All the waste slop and excrementitious matter from the cattle was discharged into the river. The matter would accumulate along the banks for indefinite periods until high water washed it away, when it would flow down the stream in large islands, one of which was too large to pass between the piers of the Pekin bridge and it was necessary to break it up in order that it might continue on its course.

The witness stated that during recent years there had been a large diminution in the number of cattle fed at Peoria, because of the fact that under the contract it was necessary to feed the cattle for a period of nine months. This made it necessary for them to continue the manufacture of liquor whether there was a demand for the goods or not, and they found that there was a loss in storing high-proof spirits not in demand, which more than compensated for the small amount of profit afforded by the keeping of cattle. This diminution would probably continue because of the growth of the custom of drying the slop by evaporation and selling it for export. (3509–3517, 3540–3544.)

ADOLPH WOOLNER, JR.

Adolph Woolner, jr., for nine years manager of the Atlas distillery, which has a capacity of 7,500 bushels in twenty-four hours, testified that there had been as many as 40,000 head of cattle fed in Peoria at one time, but at the date of testimony about 10,000 were being fed at Peoria and from 5,000 to 8,000 at Pekin. It was the aim to feed about a bushel of distillery waste per animal per day, equivalent, according to the witness, to about 400 pounds. Based on this weight, an animal would consume 98,400 pounds of slop in two hundred and forty days. A steer will gain in eight months an average of 400 pounds in weight. The witness figured that the excretions would amount to 98,000 pounds, or for the entire year 120,000 pounds; therefore the discharge from 40,000 head of cattle would be 2,400,000 tons per year, and that from 10,000 cattle, the number fed at the date of testimony, would be 600,000 tons, so that the amount of pollution from the Peoria cattle sheds will vary between these two limits. (3689–3692.)

ISHAM RANDOLPH.

DIRECT EXAMINATION.

Isham Randolph, chief engineer of the sanitary district of Chicago, was called as a witness on behalf of the defendants, and stated that his engineering experience began in 1868, when he entered the service of the Baltimore and Ohio Railroad as axman. From that time until 1880 he performed engineering services for various railroads, and then became chief engineer of the Chicago and Western Indiana Railroad and the Belt Railway of Chicago, remaining in that position four years. During the next two years he maintained an office for general engineering work in Chicago, and in 1886 entered the service of the Illinois Central Railroad and built the Chicago, Madison and Northern and the Freeport and Dodgeville railroads. In 1888 he returned to private practice and was consulting engineer for various roads until 1893, when he was elected chief engineer of the sanitary district of Chicago, holding this position at the date of the testimony. The duties of this office involve responsibility for all work coming under the term engineering, the preparation of plans and forms of contract, and the enforcement of contracts in connection with construction. (6607–6609.)

The witness then described the condition of Chicago River from 1880 until the opening of the drainage canal, and gave an outline of the sewerage system of Chicago and the effect of its discharge on Chicago River and Lake Michigan. (6609–6613.)

The Illinois and Michigan Canal was then described, the witness stating that it was commenced in 1836 and completed in 1848. It extends from the south fork of South Branch of Chicago River in a southwesterly direction across the divide between the drainage areas of Lake Michigan and Illinois River to Peru, Ill., a distance of about 96 miles. The original canal had a navigable depth of about 5 feet and a width of about 6 feet. The locks were 110 feet long and 18 feet wide. Since 1884 the "summit level," or the 29-mile stretch of the canal extending from Chicago River to Lockport, had been supplied with water from Chicago River by pumps located at Bridgeport, in the city of Chicago. These pumps were supposed to have a capacity of 60,000 cubic feet per minute, but they did not accomplish this, and in practice the capacity ranged between 45,000 and 50,000 cubic feet. At some seasons of the year the supply of water from Desplaines River was very small, and the canal was almost wholly dependent on the Bridgeport pumps. This water came partly from the stock yards branch and partly through South Branch of Chicago River from Lake Michigan. It flowed through the "summit level" at a velocity of about 1 mile per hour, and was a black liquid of very foul odor. The water in the two pools at Joliet was as bad as that in the canal proper at some seasons of the year, when Desplaines River was low, because of the small amount of dilution. (6613–6616.)

The following statements with reference to the drainage canal were then made by the witness: This canal was the outcome of Chicago's necessities. The conditions affecting her water supply, owing to sewage pollution in Chicago River and the lake, had become steadily worse from the days when the city began to grow. Finally a crisis was reached, and the city council authorized the appointment of an expert commission to determine on a solution of the difficulties. In January, 1886, the commission was appointed, consisting of Rudolph Hering, Benezette Williams, and Samuel J. Artingstall, and as a result of its labors the State legislature in 1889 passed the sanitary-district law, under which a board of nine trustees was elected. This board adopted the project for a waterway from Chicago to Lockport, which finally resulted in the construction of the drainage canal. It follows the general location of the old Illinois and Michigan Canal, connecting with the west fork of South Branch of Chicago River at Robey street, Chicago, and discharging into Desplaines River at Lockport. (6616–6617.)

The first 7 or 8 miles of the canal is through a clay formation which is easily dredged, and the cross section here is less at present than it will be ultimately. It is 110 feet wide on the bottom, the side slopes being 1 foot vertical to 2 feet horizontal, giving a surface width of 198 feet with a minimum depth of water of 22 feet. Beyond this clay stretch a glacial drift was encountered which could not be dredged. In this material the canal was made full size, namely, 202 feet wide on the bottom, with side slopes of 2 feet horizontal to 1 foot vertical, a surface width of water of 290 feet, and a maximum depth of 22 feet. The canal continues of this size for 5.3 miles to Willow Springs, where rock was encountered. From this point to the outlet at Lockport the channel is either wholly in rock or underlain by rock. The width of the canal contracts at this point to 160 feet and the grade is increased from 1 foot in 40,000 feet to 1 foot in 20,000 feet. The length of canal having this cross section is 14.95 miles. Through 7 miles of this distance the sides are cut practically vertical, and wherever rock was not found at the surface walls were built upon rock foundation to a height of 5 feet above Chicago datum. (6617–6618.)

The controlling works at Lockport consist of seven gates of the Stoney type and the Bear Trap dam. The gates have an opening of 32 feet and operate under a maximum pressure of 62,000 pounds. The Bear Trap dam is a structure which can be raised or lowered and is in active use for regulating the flow from the canal, the gates being seldom required. The dam is the largest structure of the kind ever attempted, having a clear waterway of 160 feet with a possible oscillation of 17 feet. The essential parts of the dam were then described by the witness, who stated that it was lowered and the water first turned into Desplaines River January 17, 1900, at 11.05 o'clock a. m. (6618–6621.)

The witness then described the bridges erected across the canal and the improvement of Chicago River and the Desplaines River channel below the foot of the canal at Lockport. The cost of the construction up to the date of the testimony was stated by the witness to be $42,503,168. (6619–6624.)

The original sanitary district included all of Chicago north of Eighty-seventh street and 42 square miles of country lying directly west of that portion of the city, embracing in all 185 square miles. In 1903 the legislature of Illinois passed an act extending the boundaries of the sanitary district by adding 78.6 square miles of territory on the north, known as the north-shore district, and 94.5 square miles on the south, known as the Calumet district. The district now includes all of the city of Chicago, and ultimately the sewage from this entire area will be discharged into the drainage canal, which at that time will be widened so that it will have a discharge capacity of 825,000 cubic feet per minute. (6624–6625.)

The witness then stated that the total population of the sanitary district was 1,942,000. In connection with the sewerage of the southern district it was proposed to reverse the flow of Calumet River by constructing a channel from Little Calumet River near Blue Island southwestward through what is known as Sag Valley to the drainage canal at or near Sag Bridge station on the Chicago and Alton Railroad. This channel will prevent the discharge of Calumet River into Lake Michigan at all times except in excessive floods. On the north it is proposed to extend North Branch of Chicago River as far as Evanston and make a connection with Lake Michigan at that point. It will be impossible to secure a gravity flow through this channel; therefore pumping works will be erected designed to lift 60,000 cubic feet per minute. (6627–6628.)

The witness then gave the maximum and minimum discharge of the drainage canal during the years 1900–1902, inclusive, together with computations of dilution of sewage and weight and proportion of sewage matter therein. This information is included in Table 43. (6629–6633.)

TABLE 43.—*Discharge and pollution of Chicago drainage canal.*

Year.	Population of Chicago.		Daily water consumption of city (gallons).	
	Total.	Discharging sewage into canal.	Total.	Per capita.
1900	[a] 1,698,575	1,443,789	322,599,630	190
1901	[b] 1,758,000	1,494,300	342,813,449	195
1902	[b] 1,818,000	1,545,300	358,101,710	197

Year.	Discharge of channel at Dam No. 1, from weekly averages (cubic feet per minute).			Quantity of sewage discharged (gallons per day).[c]	Proportion of sewage to mean discharge of canal.	Weight of urine and fecal matter (pounds per day).	Proportion of urine and fecal matter to mean discharge of canal.
	Maximum.	Minimum.	Mean.				
1900	351,088	40,481	233,976	274,209,685	1: 9.2	3,880,183	1:5,429
1901	615,392	197,124	277,153	291,391,432	1:10.2	4,015,931	1:6,211
1902	450,328	244,428	295,527	304,386,454	1:10.4	4,215,494	1:6,310

[a] Census. [b] Estimated. [c] Same as water consumption.

The quantity of sewage stated in above table is determined by taking the amount of water consumed per capita in the city of Chicago, as shown by the reports of the water commissioner for the years mentioned. This sewage is compared with the mean discharge of water from the Illinois and Michigan Canal, the drainage canal, and Desplaines River where they come together at Dam No. 1 in Joliet. The absolute weight of the urine (40 ounces per capita) and fecal matter (3 ounces per capita) given in the table is based on the testimony of Dr. Ravold and statistics gathered from other sources, and is compared with the total weight of water discharged in twenty-four hours from the three sources mentioned. (6634.)

The witness then presented another table differing from the preceding only in the method of determining the amount of sewage per day, which in this table is based on a clause in the report of the commission of hydraulic engineers of St. Louis, dated 1902, reading as follows:

From observations made upon water systems of cities where the quantity of water used is measured, it appears that in large cities the average volumes needed for domestic, public, and manufacturing purposes are, respectively, 30 gallons, 5 gallons, and 25 gallons per day for each inhabitant, and that any supply in excess of 60 gallons per day per capita goes to underground leakage and unnecessary waste.

In Table 44 some of the data given in Table 43 are repeated for convenience of reference, and the quantity of sewage is based on a water consumption of 60 gallons per capita per day. (6636–6637.)

TABLE 44.—*Pollution of Chicago drainage canal.*

Year.	Population discharging sewage into the canal.	Discharge of channel at Dam No. 1, from weekly averages (cubic feet per minute).			Quantity of sewage discharged (gallons per day).	Proportion of sewage to mean discharge of canal.	Weight of urine and fecal matter (pounds per day).	Proportion of urine and fecal matter to mean discharge of canal.
		Maximum.	Minimum.	Mean.				
1900	1,443,789	351,088	40,481	233,976	86,627,340	1:29.1	3,880,183	1:5,429
1901	1,494,300	615,392	197,124	277,153	89,658,000	1:33.3	4,015,931	1:6,211
1902	1,545,300	450,328	244,426	295,527	92,718,000	1:34.3	4,215,494	1:6,310

The witness then presented Table 45, containing statistics of the population of Chicago. (6641.)

TABLE 45.—*Population of Chicago, 1840–1903.*

1840	4,470	1890	1,099,850
1850	29,963	1900	1,698,575
1860	112,172	1901	1,758,000
1870	298,977	1902	1,818,000
1880	503,185	1903	1,878,000

The figures for 1840 to 1900, inclusive, are from the census reports; those for 1901 to 1903, inclusive, are estimated. The proportion of the population discharging into the drainage canal was stated to be 87 per cent by the Federal census of 1890; 84 per cent by the school census of 1898, and 85 per cent by the present estimates, as shown in Table 43.

The amount of sewage discharged per day was reduced to terms of gallons and cubic feet per minute, as follows:

TABLE 46.—*Sewage discharged into drainage canal.*

Year.	Gallons per day.	Gallons per minute.	Cubic feet per minute.
1900	274,209,685	190,423	25,458
1901	291,391,432	202,355	27,053
1902	304,386,454	211,379	28,259

The witness presented another table showing the amount of excreta of 100,000 persons per year, and subsequently discussed the same with reference to the drainage canal and the dilution therein. (6644–6645.)

He then presented Table 47, showing the number of inhabitants and estimated pollution of Illinois River basin. (6646.)

TABLE 47.—*Pollution of Illinois River.*

Drainage basin.	Area (square miles).	Population (census of 1900).	Urban population (towns of 1,000 and over), 1900.	Estimated water supply.		
				Gallons per day.		Cubic feet per second.
				Per capita.	Total.	
Desplaines River	1,758	124,855	70,748	99.3	7,025,000	10.86
Dupage River		21,704	6,851	23.1	158,000	.24
Kankakee River	5,302	192,226	44,681	53.2	2,377,000	3.66
Fox River	2,697	175,353	81,743	47.3	3,866,000	5.96
Vermilion River	1,413	68,601	27,631	70.1	1,937,000	2.99
Mackinaw River	1,182	47,296	10,924	37.1	405,000	.62
Spoon River	1,905	81,782	28,519	40	1,141,000	1.76
Sangamon River	5,592	303,096	133,632	91.4	11,215,000	17.28
Crooked Creek	1,286	54,574	14,344	13.9	199,000	.30
McKees Creek		16,461	5,624	32	180,000	.28
Macoupin Creek	1,000	46,362	15,778	32	505,000	.77
Illinois River (directly)		379,077	177,189	65.5	11,606,000	17.89
Peoria industries					15,000,000	23.11
Total		1,511,387	617,664	65.7	55,614,000	85.72

The discharge of the Illinois is estimated as follows:

Discharge of Illinois River.

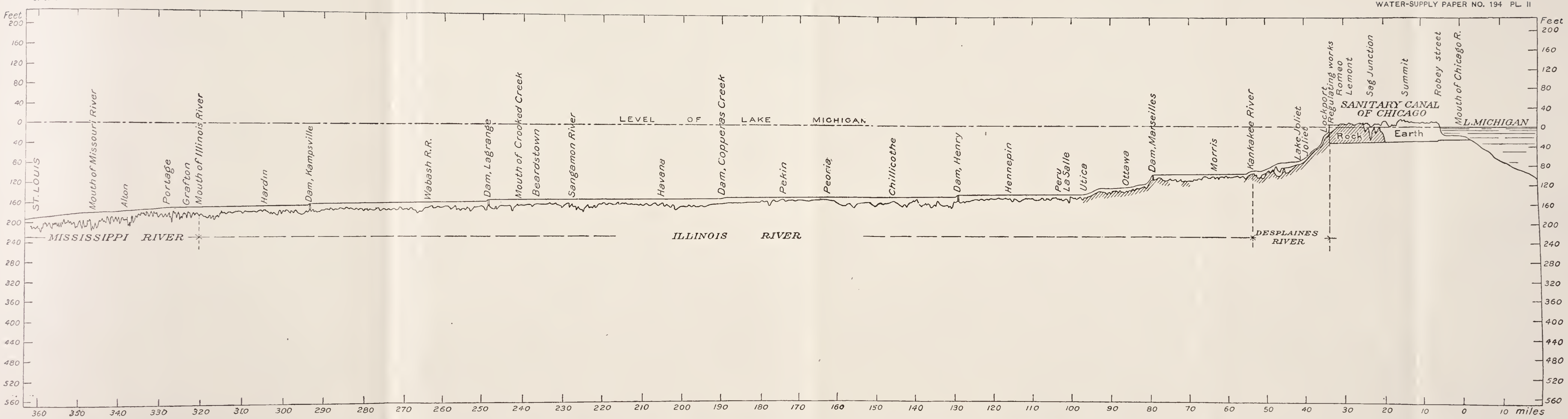
	Cubic feet per second.
Discharge of Illinois River at Kampsville October 20, 1891 (according to United States engineers)	1,452.7
Less discharge of Illinois and Michigan Canal	600
Natural discharge of river at Kampsville	852.7
Add for basin of Macoupin Creek	147.3
Natural discharge of Illinois River	1,000

The sewage produced by the urban population, based on water supply as shown in table, is 85.72 cubic feet per second, or, when reduced to a basis of 60 gallons per capita per day, 57.19 cubic feet per second. Dividing 1,000, the natural discharge of the river, by 57.19, the amount of sewage, gives a ratio of pollution of 1 to 17.48, as against the drainage-canal pollution of 1 to 34.3.

After discussing the items in the above table the witness stated that his conclusion was that the ratio of pollution in Illinois River due to the urban and rural population naturally draining into its basin, exclusive of all sewage coming from Chicago, was greater than the present ratio, resulting from the combination of this natural pollution with the discharge from the drainage canal. The discharge from the canal being omitted, the proportion of pollution to diluting water is 1 to 17.48, whereas the proportion in the canal (see Table 44) is 1 to 34.3. (6647–6648.)

The witness then described and discussed the physical characteristics of Desplaines and Illinois rivers throughout the length of their channels. (6650–6651.)

He then presented a map showing the population of the drainage areas of Illinois, Mississippi, and Missouri rivers above St. Louis and stated that the population of the Illinois basin, exclusive of Chicago, was 599,751, and with Chicago included, 2,298,326; of the Mississippi



PROFILE OF WATERWAY ALONG THE CHICAGO DRAINAGE CANAL, DESPLAINES RIVER, ILLINOIS RIVER, AND MISSISSIPPI RIVER, FROM LAKE MICHIGAN TO ST. LOUIS, MO.

basin above Grafton, 1,839,586, and of the Missouri basin above the mouth of the river, 1,650,594, giving a total population above St. Louis of 5,788,506. (6653–6655.)

The witness then entered into a detailed discussion of river flow and gaging, covering all the streams above mentioned. (6655–6667.) He introduced into evidence a profile of the entire waterway from Lake Michigan to Cairo, Ill., which is reproduced herewith as Pl. II.

The witness then described some float measurements made for determining the velocity of the river from Chicago to St. Louis. Wooden balls were put in the river at Lake street and allowed to float down to Robey street, a man following in a boat to ascertain the time required in transit. From Robey street to Lockport the velocity was computed from the known volume and cross section. From Lockport to St. Louis floats were used of the same general character as those described in the testimony of Mr. Van Ornum. These floats were followed throughout the distance, part of the time on shore, because a boat could not be taken through the rapids. They were kept going night and day except when accidents of any kind stopped the work; on such occasions they were taken out and the time noted. Through the rapids wooden balls were substituted for the floats. The river at the time of this measurement was at a fairly full stage, somewhat above that which might be called the mean stage, but not anything like a maximum flood flow. The results are contained in Table 48. (6667–6670.)

TABLE 48.—*Results of float measurements from Lake Michigan to St. Louis.*

	Interval.			Corrected interval.			Total time.			
	Days.	*h.*	*m.*	*Days.*	*h.*	*m.*	*Days.*	*h.*	*m.*	*Days.*
Lake street to Robey street	0	5	30	0	6	52	0	6	52	0.3
Summit		5	42		5	42		12	32	.5
Willow Springs		7	22		7	22		19	54	.8
Controlling works		18	54		18	54	1	14	48	1.6
Joliet		1	58		2	28	1	17	16	1.7
Lake Joliet		1	24		1	45	1	19	1	1.8
Through Lake Joliet		2	15		2	49	1	21	50	1.9
Kankakee cut-off		3	40		4	35	2	2	25	2.1
Morris		8	11		10	14	2	12	39	2.5
Seneca		7	45		9	41	2	22	20	2.95
Marseilles		6	45		8	26	3	6	46	3.3
Ottawa		3	25		4	16	3	11	2	3.45
Utica		5	55		7	24	3	18	26	3.75
Peru		5	30		6	52	4	1	18	4.05
Henry dam	1	0	31	1	6	39	5	7	57	5.35
Lacon		8	48		11	0	5	18	57	5.8
Peoria	2	21	15	3	14	34	9	9	31	9.4
Pekin		10	2		12	32	9	22	3	9.9
Copperas Creek dam		13	43		17	9	10	15	12	10.65
Havana		14	31		18	9	11	9	21	11.4
Louderbach		15	36		18	43	12	4	4	12.15
Frederick		10	0		12	30	12	16	34	12.7
Beardstown		1	58		2	22	12	18	56	12.8
Lagrange dam		10	24		13	0	13	7	56	13.35
Griggsville		12	53		16	6	14	0	2	14
Pearl		16	52		21	5	14	21	7	14.9
Kampsville dam		12	52		16	5	14	13	12	15.55
Hardin		12	44		15	55	16	5	7	16.2
Hadleys		10	24		13	0	16	18	7	16.75
Grafton		17	47		22	14	17	16	21	17.7
Alton		7	40		9	35	18	1	56	18.1
Merchants' Bridge		6	51		8	34	18	10	30	18.45
Eads Bridge			58		1	10	18	11	40	18.5

Counsel for the defense then directed the attention of the witness to various reports made by the health commissioner of the city of St. Louis, together with the resolutions adopted by the city council and a draft of a bill introduced in Congress, all relating to the matter of pollution of St. Louis water supply by the effluent from Illinois River. (6672–6688.)

CROSS-EXAMINATION.

The cross-examination of this witness brought out no new facts or opinions.

RUDOLPH HERING.

DIRECT EXAMINATION.

Rudolph Hering, a witness called in behalf of the defendants, qualified as an expert by making the following statements: He was a member of the firm of hydraulic and sanitary engineers composed of Rudolph Hering and George W. Fuller. He took the course in civil engineering at Dresden, Germany, in 1867, and after returning to America began his engineering work at Brooklyn, on Prospect Park, and then went to Philadelphia, on Fairmont Park. From 1873 to 1880 he was first assistant engineer in charge of bridges and sewers in Philadelphia, and in the latter year was commissioned by the national board of health to examine and report on European sewerage systems. Since that time he had been consulting engineer for the waterworks and sewerage systems of many cities, including Philadelphia, Cleveland, Chicago, New York, Baltimore, New Orleans, and Washington. (6975–6978.)

The witness stated that in March, 1886, he was engaged as chief engineer of the drainage and water-supply commission of the city of Chicago, and in that capacity made investigations with reference to obtaining pure water and scientific drainage for the city. A preliminary report was made in January, 1887, giving the general conclusions which had been reached up to that time. The witness then read a part of this report, which appears in the record of testimony, pages 6980 to 6990. Commenting on the facts and conditions on which the conclusions were based, the witness stated that the proposition was somewhat novel, and that in order to reach a safe conclusion in regard to the size and other conditions for the proposed drainage canal it was necessary for him to study all the facts bearing on the subject which could be ascertained both in Europe and America. He found at the outset that the problem of water pollution was distinct from that of setting up a standard of purity based on the minimum allowable proportion of sewage. If the water is to be used for drinking, it should evidently be considered in a different light than if mere inoffensiveness were required. The question was very different at that time from what it is at the present day, and the best information available was afforded by the observations of Dr. John Rauch, secretary of the State board of health of Illinois, who, in making investigations on the gradual change of the water of the old Illinois and Michigan canal after it entered Illinois River, had fixed a unit of flow of water equal to 180 cubic feet per minute for every thousand persons draining into the river at Chicago as sufficient to obviate any substantial injury to the water. From the results of other investigations made by the witness, he concluded that the Chicago drainage canal should have a sufficient capacity to carry water at the rate of 240 cubic feet per minute for each thousand persons. With reference to the subject of dilution in the above connection, the witness stated that if the foul water of a community is to enter a stream used for drinking purposes, it is imperative to purify either the water or the sewage, but if such stream is not used for water supply so complete a purification may not be required, as it is then necessary merely to prevent a nuisance. It is impossible to prevent all disease germs from going into a watercourse. The rain falling on the streets, fields, and forests and discharging into the streams must carry along the dust of the air and of the ground and myriads of bacteria, including disease germs. Parts of the intestinal discharges of animals, birds, and insects must also be washed in, and altogether much injurious matter is carried into watercourses by the rain; therefore, inasmuch as it is impossible to prevent river pollution, all surface-water supplies must be purified. (6990–6993.)

After the report of the drainage and water-supply commission was published, the Massachusetts State board of health made some investigations, and from this information the witness had compiled Table 49, which he then presented. (6995.)

TABLE 49.—*Calculated composition of sewage of different degrees of dilution in a running stream.*

Amount of flowing water.		Composition of sewage (parts per 100,000).				Remarks.
Cubic feet per second per 1,000 persons.	Gallons per capita per day.	Ammonia. Free.	Ammonia. Albuminoid.	Dissolved solids.	Chlorine.	
0.062	40	4.50	0.90	65.4	12.6	Dilution is offensive.
.077	50	3.60	.72	52.3	10.1	
.093	60	3.00	.60	45.3	8.4	
.108	70	2.57	.52	37.4	7.2	
.124	80	2.25	.45	32.7	6.3	
.140	90	2.00	.40	29.1	5.6	
.155	100	1.80	.36	26.2	5.0	
.186	120	1.50	.30	21.8	4.2	
.232	150	1.20	.24	17.4	3.4	
.310	200	.90	.18	13.1	2.5	
.388	250	.72	.14	10.5	2.0	
.465	300	.60	.12	8.7	1.7	
.5	323	.5580	.114	8.10	1.56	
1	646	.2790	.0557	4.05	.78	
1.5	969	.1860	.0371	2.70	.52	
2	1,292	.1395	.0278	2.02	.39	
2.5	1,615	.1116	.0223	1.62	.31	
3	1,938	.0930	.0186	1.35	.26	
4	2,584	.0697	.0139	1.01	.19	
5	3,230	.0558	.0111	.81	.16	
6	3,876	.0465	.0093	.67	.13	
7	5,522	.0399	.0080	.58	.11	
8	5,168	.0349	.0070	.51	.10	Dilution is not offensive.
9	5,814	.0310	.0062	.45	.09	
10	9,463	.0279	.0056	.40	.08	
15	9,694	.0186	.0037	.27	.05	
20	12,926	.0139	.0028	.20	.04	
30	19,389	.0093	.0019	.13	.03	
40	25,852	.0070	.0014	.10	.02	
50	32,315	.0056	.0011	.08	.02	
100	64,630	.0028	.0006	.04	.01	

In discussing the above table, the witness stated that in applying the factors it is necessary to take into consideration each specific case, because no single rule applies to the great differences found in streams. He called attention to the two lines drawn across the table. Above the upper line conditions are indicated where the dilution is in all cases offensive; below the lower line the dilutions expressed have never been found to give offense; between the two lines the conditions are debatable, and it is the duty of the engineer to select between these limits that dilution that conforms to local conditions. In connection with the drainage canal he had adopted the standard of 4 cubic feet per second per thousand persons, because in the state of knowledge at that time he did not feel justified in recommending a less dilution. Subsequently, the amount was reduced to 3.33 feet per thousand persons, and on that basis the canal was constructed. (6996.)

The witness then presented Table 50, based on population and flow of the drainage canal, showing approximate dilutions. (6997.)

TABLE 50.—*Flow of drainage canal.*

Year.	Population discharging sewage into the canal.	Maximum.		Minimum.		Mean.	
		Cubic feet, per minute, weekly average.	Cubic feet per second per 1,000 inhabitants.	Cubic feet per minute, weekly average.	Cubic feet per second per 1,000 inhabitants.	Cubic feet per minute, weekly average.	Cubic feet per second per 1,000 inhabitants.
1900	1,443,789	351,088	4.05	40,481	0.46	233,976	2.70
1901	1,494,300	615,392	6.86	197,124	2.19	277,153	3.09
1902	1,545,300	450,328	4.85	244,426	2.63	295,527	3.18

The witness then stated that in figuring out the matter of dilution he had considered first the habitations and cities which lie along the drainage canal and Desplaines and Illinois rivers, in front of which the water was to pass. As the dilution would become greater by the inpourings of the tributaries of these rivers, it was to be presumed that what would be a satisfactory dilution in the canal would be still more satisfactory with the greater dilution below. The advances made in the subject of sewage disposal since his recommendations had not changed his views concerning the Chicago problem, and were he to make another recommendation it would be practically the same as that which had been carried out. (6998–7000.)

The witness then introduced a chart, entitled "Schematic representation of the self-purification of the waters of Missouri, Mississippi, and Illinois rivers, between points indicated, based on the length of life of the typhoid bacillus as fixed by experiments made under the direction of Hiram F. Mills." This chart contained profiles of Missouri, Mississippi, and Illinois rivers above St. Louis, and the witness pointed out that the Missouri is the steepest of the three, falling from Omaha, at an elevation of 960 feet, to St. Louis, at an elevation of 380 feet above sea level; the Mississippi falls from Minneapolis, at an elevation of 794 feet, to 380 feet at St. Louis; the Illinois and the drainage canal fall from an elevation of 578 feet at Lake Michigan to 400 feet at Grafton and finally to 380 feet at St. Louis. The distance from Omaha or Minneapolis to St. Louis by water is about 680 miles and that from Lake Michigan to St. Louis by water is about 400 miles. Therefore it will be seen that the velocity of Missouri River is the greatest of the three and that the Illinois is the flattest and has the lowest velocity. The chart also presented certain deductions made on the basis indicated in the title, namely, the longevity of the typhoid bacillus as determined by Hiram F. Mills. In Mills's report it is attempted to prove whether typhoid germs would survive in Merrimac River water at the low temperature of the month of November long enough to pass from the Lowell sewers to the service pipes in Lawrence. A series of experiments were made by the Massachusetts State board of health by inoculating water from the service pipe with typhoid-fever germs, keeping the water in a bottle surrounded by ice, and each day taking out 1 c. c. and determining the number of typhoid organisms. The number continually decreased, but some survived about twenty-four days, as follows:

Number of typhoid-fever germs surviving in water at about freezing point.

First day	6,120	Fifteenth day	100
Fifth day	3,100	Twentieth day	17
Tenth day	490	Twenty-fifth day	0

The ordinates of the curves presented on the chart represented the relative number of typhoid bacilli still living at the various points indicated, it being assumed in the absence of other information that the number of germs is directly proportional to the population. So far as the average flow of water is concerned, Chicago is about eighteen and one-half days distant from St. Louis, Kansas City six and three-fourths days, Omaha eleven and six-tenths days, and Minneapolis and St. Paul are about fifteen days. The conclusions to be drawn from the chart are that the relative proportions of typhoid bacilli arriving at St. Louis from populations on Illinois, Missouri, and Mississippi rivers, below Chicago, Omaha, and Minneapolis, are about as 13 to 96 to 107, respectively. These figures are merely the proportions. They indicate the relative frequency of the still virulent typhoid bacilli arriving at St. Louis from various cities on the three rivers, based on the population of the cities and the determinations made by Mills as above outlined. (7002–7003.)

The witness expressed the opinion that the waters of Illinois River above Grafton, of Mississippi River at the same point, and of Missouri River above its mouth were not fit for domestic consumption in the raw state either before or after the opening of the Chicago drainage canal, and that the discharge of the drainage canal into Illinois River makes practically no difference in the method of construction or cost of operation of a suitable filtration system for St. Louis. Under the assumption that the water was to be taken from the present intake at Chain of Rocks, he added that in providing for such a filtration system he would first procure some satisfactory evidence as to the turbidity of the water, because that affects the manner of treatment more than anything else, and after that he would consider the pollution of the river and the number and kind of bacteria contained in the water, because the treatment that would remove the suspended matter from the water of Mississippi River at St. Louis would also remove the greater part of the dangerous bacteria. He stated that he would give no consideration to the sewage from Chicago, because it would be too small a factor in the problem to materially affect any recommendation; moreover, the operation of such a filter would not require a higher degree of skill or more expensive attendance under the present conditions than it would before the opening of the canal. (7000–7007.)

CROSS-EXAMINATION.

The witness reviewed the suggested measures presented in his report to the city in 1886, by which purification of the Chicago water supply could be brought about. Besides the construction of the canal, there was a proposition to remove the sewage to lands adjacent to the city and dispose of it by broad irrigation, and another to continue the discharge into Lake Michigan under much improved conditions, namely, that the intake for the water supply should be located as far as practicable from the point of sewage discharge and that the sewage should be treated by screening so as to deprive it of the grosser pollution and in that way make it more unobjectionable and more rapidly dispersed. He was of the opinion, however, that this was not a satisfactory method. He stated that discharge directly into the lake rather than by way of Chicago River was preferable because the river was loaded with an accumulation of organic matter, collected during those times when the flow was very slight, and whenever there was heavy rainfall all this accumulated matter would be carried out to one of the water intakes, whereas in the method of lake dilution there would be a continuous discharge and no sudden rush of an accumulation of filthy matter, so that its effects would cover smaller areas. He noted on one occasion, for example, the effect of such a sudden discharge. Shortly after a freshet he followed the river water out into the lake until dark and computed that within an hour's time, approximately, the water would reach the intake crib and then go to the pumping station and be delivered to the residents. He therefore returned to his home, which was located close to the pumping station, and observed the condition of the water in the bathroom during the entire night. Early in the morning the water running into the bath tub, which had been comparatively clear and pure, became foul smelling. (7021–7023.)

The possible pollution of the Chicago water supply from the sewers of Milwaukee was discussed by the witness, who stated that the distance was about 90 miles and that, according to observations, the velocity of the currents in the lake sometimes reached 2 or 3 feet per second, though usually less. In response to requests of the cross-examiner he estimated that, with a current from the north having a velocity of 2 feet per second, it would require seventy hours, or about three days, for the Milwaukee sewage to reach the Chicago intake, and he then stated that the assumption was false and that no Milwaukee sewage could reach the intakes, because the water near the lake shore does not move in a parallel direction to the shore, but there are cycloidal motions and the water passing the Milwaukee sewage outlet would be so dispersed, even though the winds were favorable, that that particular water would not reach Chicago for weeks and possibly months. (7025–7026.)

JACOB A. HARMAN.

Jacob A. Harman, called as a witness in behalf of the defendants, outlined an extensive engineering experience and stated that for the five years previous he had been consulting engineer to the State board of health of Illinois. The purport of the testimony was to show the flow of Illinois River and its various tributaries and to discuss the same. The full testimony occupies pages 6847 to 6868, and the most comprehensive results are contained in Table 51.

The witness then stated that he had made an investigation of the sewerage system of St. Charles, Mo., March 10 and 11, 1903. This city is located on the left bank of Missouri River at a distance overland from the business district of St. Louis of about 16 miles. All the sewers of the city drain into the river. The land rises abruptly from the river bank, and, at a distance of three or four blocks back therefrom, the elevation is 100 feet or more above the stream. The drainage of all the business district and nearly all of the residence district therefore flows directly into the river. A part of the residence district drains into the Mississippi. St. Charles is not provided with a complete sewer system. There are four public sewers, ranging from three or four blocks to eight blocks in length, and many private sewers from hotels and business houses leading direct to the river.

It was brought out on cross-examination that although less than one-third of the area of St. Charles is sewered a somewhat larger percentage of the population is connected with sewers. (6863–6864, 6867.)

JOHN H. LONG.

DIRECT EXAMINATION.

John H. Long, called as a witness in behalf of the defendants, qualified by stating that he was a teacher of chemistry at Northwestern University, Chicago, and had held such position for twenty-two years. Prior to that he had taught in Wesleyan University, at Middletown, Conn., and for seven years previous had been engaged in the study of chemistry. He graduated from the University of Kansas in 1887, and for three years thereafter had studied in the German universities at Tübingen, Würzburg, and Breslau. He further stated that he was a member of several American and foreign scientific societies, the president of the American Chemical Society, and the author of a number of works on chemistry. His studies had been confined mainly to the lines of sanitary and physiological chemistry. Between 1885 and 1890 he was chemist for the board of health of Chicago and since 1885 had been chemist for the Illinois State board of health. (3984–3986.)

TABLE 51.—*Discharge of Illinois River as affected by its tributaries, based on discharge measurements at Peoria and ratios of drainage areas.* (6861.)

Subdivisions of Illinois River drainage basin.	Approximate distance from Lockport (miles).	Ratio of drainage area to that above Peoria.	Sum of ratios of drainage areas.	Discharge (cubic feet per second).[a] For Illinois River exclusive of Chicago River. Average 1890 to 1899, inclusive. Low.	Ordinary.	High.	Average 1900 to 1903, inclusive. Low.	Ordinary.	High.	For Illinois River including Chicago River. Average 1890 to 1899, inclusive. Low.	Ordinary.	High.	Average 1900 to 1903, inclusive. Low.	Ordinary.	High.
Chicago River to Lockport	0									600	600	600	3,801	4,162	4,162
Desplaines River to Dupage River	15	0.0656		60	214	1,141	178	407	1,753	660	814	1,741	3,979	4,569	5,915
Desplaines River to Kankakee River		.1027	0.1027	94	334	1,788	280	636	2,743	694	934	2,388	4,081	4,798	6,905
Kankakee River	19.5	.3813	.4840	444	1,577	8,424	1,328	3,000	12,934	1,044	2,177	9,024	5,129	7,162	17,096
Small streams to Fox River		.0735	.5575	513	1,816	9,703	1,530	3,455	14,899	1,113	2,416	10,303	5,331	7,617	19,061
Fox River	52.6	.2003	.7578	697	2,369	13,180	2,080	4,693	20.252	1,297	2,969	13.780	5,881	8,855	24,414
Small streams to Vermilion River		.0101	.7679	706	2,502	13,365	2,108	4.759	20.521	1,306	3,102	13,965	5,909	8,921	24,683
Vermilion River	62.1	.0977	.8656	796	2,820	15,066	2,376	5,364	23,132	1,396	3.420	15,666	6,177	9,526	27,294
Small streams to Peoria		.1333													
At Peoria	131.6		1.0000	920	3,258	17,406	2,745	6,198	26.724	1,520	3,858	18,006	6,546	10,360	30,886
Small streams to Mackinaw River		.0261	1.0261	954	3,343	17,859	2,816	6,360	27,421	1,554	3,943	18,459	6,617	10,522	31,583
Mackinaw River	140.5	.0903	1.1164	1,026	3,637	19,533	3,065	6,920	29,834	1,626	4,237	20,133	6,866	11,082	33,996
Small streams to Spoon River		.0400	1.1564	1,064	3,767	20,128	3,186	7.167	30,903	1,664	4,367	20,728	6,987	11,329	35,065
Spoon River	171.1	.1379	1.2943	1,191	4,216	22,527	3,552	8,021	34,589	1.791	4,816	23.127	7,353	12,183	38,751
Small streams to Sangamon		.0104	1.3047	1,200	4,250	22,708	3,581	8,085	34,866	1,800	4,850	23,308	7,382	12,247	39,026
Sangamon River	193.6	.4206	1.7253	1,587	5,621	30.030	4,735	10,692	46,107	2,187	6,221	30,630	8,536	14,854	50,269
Small streams to Crooked Creek		.0134	1.7387	1,599	5,665	30.262	4,771	10,776	46,465	2,199	6,265	30,862	8,572	14,938	50,627
Crooked Creek	207.8	.1027	1.8414	1,694	5,998	32,051	5,054	11,412	49,209	2,294	6,598	32,651	8,855	15,574	53,371
Small streams to McKees Creek		.0214	1.8628	1,714	6,067	32,424	5,112	11,524	49,780	2,314	6,667	33,024	8.913	15,686	53,942
McKees Creek	225.2	.0350	1.8978	1,745	6,181	32,933	5,209	11,761	50,716	2,345	6,781	33,533	9,010	15,923	54,878
Small streams to Macoupin Creek		.0879	1.9857	1,827	6,468	34,561	5,448	12,305	53,065	2,427	7,068	35,161	9,249	16,467	57,227
Macoupin Creek	268.1	.0738	2.0595	1,894	6,710	35.846	5,653	12,763	53.037	2,494	7.310	36,446	9,454	16,925	59,199
Small streams to Mississippi River		.0114													
Junction of Illinois River with Mississippi River	283.5		2.0709	1,904	6,747	36,045	5,681	12,834	55,341	2,504	7.347	36.645	9.482	16,996	59,503

[a] "Low" = average for low quarter; "high"—average for high quarter.

It is apparent that the witness had had a long and intimate experience with the general problems connected with the water supply and sewage disposal of the city of Chicage and the Illinois River basin, as his testimony contains a large amount of historical matter in connection with the development of both these improvements. (3986–3995.)

The investigations of the witness, begun in 1885, included the examination of a great many samples of water from the Chicago avenue, Evanston, Lakeview, and Hyde Park tunnels. (3995.)

The next examinations, in 1886, comprised a study of samples of the river and canal water taken weekly from Bridgeport, Lockport, Joliet, Ottawa, La Salle, and Peoria. Another series of examinations of water taken from the same points began in December, 1886, and was continued through the cold months into March, 1887. The results of these examinations were published in the reports of the State board of health for that period. (3996–3997.)

The next investigations were made two years later, beginning May 1, 1888, and extending to about the middle of November. The sampling points in this series were as follows, including, besides those above mentioned, several points below Peoria to the mouth of the river at Grafton: Bridgeport, Lockport, Joliet, Morris, Ottawa, La Salle, Henry, Peoria, Pekin, mouth of Copperas Creek, Havana, Beardstown, Pearl, and Grafton. During the same investigation a number of samples were taken from Dupage, Kankakee, Fox, Vermilion, Little Vermilion, and Sangamon rivers, tributaries of the Illinois. All these samples were taken from appropriate points above the confluence of each stream with Illinois River. These results were published in the preliminary report of the State board of health for 1889. The witness stated that he wished to explain this preliminary report, which had been extensively quoted by the witnesses for the plaintiff and attracted considerable attention at the time it was issued. It was brought out by the secretary of the State board of health for the use of some committee of the State legislature in a very great hurry. The work of printing the report was begun but a few days after the completion of the last analysis, so that the work must be regarded as only of a preliminary character, and while the details were complete the text and explanatory matter was comparatively meager. The full report, which was subsequently put into the hands of the secretary, was lost in some manner and never printed. The results in the preliminary report are essentially correct so far as they could be made so in the extremely limited time for preparation, and the averages of results are practically correct. (3996–3999.)

The next investigation was made of the water in the neighborhood of the Bridgeport pumps, Chicago, in the winter of 1890 and 1891, the object being to show the relative amounts of pollution coming from the stock yards and from the rest of the city. Samples were taken from the large sewers leading from the stock yards, and from the so-called Brennock sewer and the Ashland avenue, Halstead street, and Thirty-ninth street sewers, all representing the bulk of the sewage aside from that contributed by the stock yards. (3999–4000.)

The witness was then requested to take each series of investigations and describe fully how the samples were collected and delivered and where the analyses were made, stating in reply that those for the series of 1886 were collected by Doctor Rauch, secretary of the State board of health, through the health officers of various towns, and sent in jugs packed in boxes to the laboratory of the Northwestern University Medical School. The later samples were collected in the same way and sent to the Northwestern University School of Pharmacy. He then proceeded to describe the methods used in making and interpreting the analyses and the importance of the various determinations. (4000–4010, 4026–4027.)

The witness then recited the results of his examinations of the water of the Illinois and Michigan Canal and Desplaines and Illinois rivers, made in 1886. These results are given as averages of twelve samples taken at each of the sampling points and are included in Table 52. (4028–4029.)

TABLE 52.—*Average results of partial analyses of water from Illinois and Michigan Canal and Desplaines and Illinois rivers during the summer of 1886.*

[Parts per million.]

Place.	Distance below Bridgeport (miles).	Albuminoid ammonia.	Free ammonia.	Oxygen consumed.
Bridgeport	0	1.633	26.563	26.20
Lockport	29	.753	12.733	11.01
Joliet	33	.432	9.426	9.34
Ottawa	81	.243	.413	5.30
Peoria	159	.194	.027	4.81

In interpreting the results set forth in the above table, the witness stated that the analyses show beyond question a marked destruction of organic matter in the water flowing between Bridgeport and Peoria. In the opinion of the witness, this destruction was due mainly to bacterial oxidation. The water at Peoria was practically potable and actually used by a large number of people.

The results of the investigations in the winter of 1886–87 are set forth in Table 53. (4030–4031.)

TABLE 53.—*Average results of partial analyses of water from Illinois and Michigan Canal and Desplaines and Illinois rivers during the winter of 1886–87.*

[Parts per million.]

Place.	Distance below Bridgeport (miles).	Albuminoid ammonia.	Free ammonia.	Oxygen consumed.
Bridgeport	0	3.7	9.7	22.4
Joliet	33	2.2	6.5	11.3
Ottawa	81	.75	4.7	9.0
Peoria	159	.43	1.7	6.45

Referring to the above results, the witness stated that there was a very considerable destruction of organic matter in the water as it flows from Bridgeport to Peoria, but much less than that shown in Table 52, indicating unmistakably that oxidation is much less marked in cold than in warm weather.

The witness then presented a summary of the results of examinations made from May to October, 1888, and during 1889. (4031–4040.)

TABLE 54.—*Analyses of water from Illinois and Desplaines rivers at designated points, May to October, 1888, and during 1889.*

[Parts per million.]

	Number of analyses.		Total solids.		Suspended matter.		Albuminoid ammonia.		Free ammonia.	
	1888.	1889.	1888.	1889.	1888.	1889.	1888.	1889.	1888.	1889.
Bridgeport	29	9	471.2	376.6	129.2	27.2	2.558	2.806	12.253	8.925
Lockport	24	8	431.2	408.6	69.80	24.6	1.990	2.489	10.882	8.149
Joliet	26	8	442.7	432.8	107.9	55.5	1.681	2.666	8.932	8.488
Morris	24	8	355.9	325.2	30.85	29.1	.707	1.587	4.107	4.716
La Salle	23	9	345.7	417.6	50.30	93.8	.526	.637	.636	1.456
Henry	19	5	306.0	316.0	27.50	30.9	.481	.404	.467	1.059
Peoria	19	6	329.75	331.0	54.27	26.9	.522	.549	.210	1.637
Pekin	16	6	353.0	352.0	84.3	43.5	.650	1.015	.645	1.591
Havana	25	9	301.78	354.4	45.4	.8	.430	.585	.342	1.078
Beardstown	24	6	390.0	317.8	84.7	56.3	.380	.357	.202	.762
Grafton	12	9	301.6	410.8	50.3	44.6	.483	.722	.095	.875
Alton	15	8	278.6	309.9	75.2	61.3	.356	.396	.166	.422

	Nitrates.		Oxygen consumed.		Chlorine.		Hardness as $CaCO_3$.	
	1888.	1889.	1888.	1889.	1888.	1889.	1888.	1889.
Bridgeport	0	0	23.113	26.502	46.811	62.934	201.3	....
Lockport	0	0	16.230	22.820	46.120	56.083	207.7	....
Joliet	0	0	14.301	21.717	43.658	57.17	216.8	....
Morris	.380	0	10.92	10.696	32.149	28.748	214.8	....
La Salle	1.037	.942	8.558	8.582	19.717	13.105	211.7	....
Henry	.683	.962	8.657	8.626	17.660	11.691	202.4	....
Peoria	.892	.510	9.769	9.611	12.358	12.860	199.7	....
Pekin	.795	1.259	9.410	13.358	16.152	11.792	204.6	....
Havana	.731	.414	8.142	9.234	11.583	9.277	204.2	....
Beardstown	.620	.996	7.354	5.505	7.524	6.933	204.9	....
Grafton	.582	.087	7.300	9.818	9.205	7.523	242.4	....
Alton	....	.317	7.356	7.562	4.083	5.834	169.4	....

These results, according to the witness, show a purification of the river between Bridgeport and Grafton. The diminution in organic matter is due to two important factors—the dilution of the stream by water from various tributaries and the destruction of organic matters by oxidation, that term being used in a broad sense. Oxidation is much more important than dilution, as indicated by the change in chlorines, a condition being finally reached in which the organic matter is not greater in amount than in the unpolluted streams commonly found in that part of the country.

The witness then presented the results of the examination of samples of water taken from important tributaries of Illinois River at weekly intervals from May 4 to September 21, 1888. The means of these results are given in Table 55. (4040–4071.)

TABLE 55.—*Average results of analyses of weekly samples of water from Illinois River tributaries at designated points and dates in 1888.*

[Parts per million.]

Tributary.	Place of collection.	Period included in average.	Number of analyses.	Total solids.	Suspended solids.	Nitrogen as—			Oxygen consumed.	Chlorine.	Hardness.
						Albuminoid ammonia.	Free ammonia.	Nitrates.			
Dupage River...	Channahon...	Aug. 10–Sept. 21	7	294.7	14.1	0.346	0.417	0.307	4.743	5.786	244.8
Kankakee River.	Wilmington..	May 4–Sept. 21	19	251.4	35.6	.585	.114	.094	12.661	1.015	164.1
Fox River......	Ottawa.......	May 14–Sept. 17	18	330.3	46.3	.463	.278	.027	7.066	4.974	242.1
Vermilion River.	La Salle......	May 7–July 16	7	450.6	87.8	.341	.049	3.348	6.914	5.461	255.8
Little Vermilion River.	.....do........	.....do..........	7	375.1	30.8	.411	.180	.362	7.15	5.664	210.2
Sangamon River.	Chandlerville.	July 10–Sept. 3	8	317.8	70.7	.285	.053	.755	5.480	3.609	212.0

In explaining the mean of the determinations of samples from Dupage River the witness stated that the average given includes only the last seven determinations—namely, from August 10 to September 21—because there was some uncertainty about the point of collection of the samples taken prior to August 10, and therefore he had omitted them in making up the summary. Inasmuch as the results of the individual analyses are not given for Dupage River in this review, it should be stated that the samples taken previous to August 10 indicated a far higher degree of pollution than those which are actually included in the mean, and if all were included—that is, if the average was made from the results of the 21 analyses reported—the amounts would be greatly increased. The suspended solids, albuminoid ammonia, and oxygen consumed would be increased about 25 per cent, the nitrates 100 per cent, the chlorine 400 per cent, and the free ammonia 600 per cent. The mean actually used by the witness does not include the spring and early summer samples, and unless this is understood errors may arise in the comparison of the mean for Dupage River with that of the other tributaries. In order that there may be no errors from such a comparison, a statement of the period during which the samples were taken to make up each average is included in the table.

The witness then stated that a comparison of the results of the analyses of Illinois River water taken above Grafton with the results in Table 55 indicated that a condition of organic purification at its mouth had been reached comparable with or similar to that found in the tributaries; in fact, that this reduction had proceeded to a point at which apparently the limit of oxidation of the organic matter had been reached, and the organic residues that were left were of a stable type, very resistant to all oxidizing influences, a condition characteristic of organic matter of vegetable rather than of animal origin. It was further stated by the witness that the water at the mouth of Illinois River is better than that of Kankakee, Fox, and Little Vermilion rivers, and that the average of all the results from the tributaries showed a condition of organic impurity as great as that of the Illinois at its mouth. (4072–4076.)

Continuing his discussion of the results for 1888 and 1889, the witness stated that Table 54 shows a considerable reduction of organic contamination between Bridgeport and Grafton, although much less in 1889 than in 1888. The difference is particularly noticeable in the oxygen consumed and the albuminoid ammonia and in a less degree in the free ammonia. These three determinations are particularly instructive in the samples taken at Pekin during the winter. Whereas in the summer the amounts of organic matter as disclosed by these determinations do not appear to be excessive, during the winter of 1888 and 1889 the evidence shows a largely increased organic contamination, the explanation for which is not difficult. During the summer, in the stretch of river between Peoria and Pekin, which is nearly level for 8 or 10 miles, an enormous bacterial or fermentative decomposition of organic matter occurs, as is shown by the rapid evolution of gases and the general appearance of the stream, so that roughly this stretch may be compared to a great septic tank in which hundreds of tons of organic matter are constantly undergoing decomposition. This rate of decomposition varies according to the temperature, and therefore in the winter season the rate is much lower, so that at Pekin, below the distilleries and cattle sheds of Peoria, the enormous pollution, as shown by residual albuminoid ammonia and oxygen consumed, indicates fresh and recent additions. The consideration of these figures shows that beyond any question whatever the addition of filth at Peoria is a very important factor in accounting for the organic matter in the river below. Another feature of importance is the high free and albuminoid ammonia and oxygen consumed in the samples taken from Illinois River at Grafton, where the individual analyses show great variations. In the last examinations, made in March, 1899, these factors were unusually high. It is evident that at that time the river must have received a greatly increased amount of contamination, possibly from the breaking up of ice and the washing down of accumulated filth. (4079–4081.)

The witness then testified with reference to some investigations made in the winter of 1890 and 1891, to determine, if possible, the proportion of organic matter discharged from the sewers of the city to that from the stock yards and the proportion passing the pumps at Bridgeport. Altogether about 130 analyses were made. The water was collected daily through a considerable period at fifteen-minute intervals. The collections were united in large hogsheads, thoroughly mixed, and a composite sample taken each day for analysis. The analyses were made to determine the total organic matter as accurately as possible, and also the nitrogen, from which a check calculation was subsequently made. As a result of these examinations, the witness estimated that the organic matter discharged from the city and the stock-yard sewers in the neighborhood of the Bridgeport pumps amounted approximately to 240 tons daily. The examinations were made as follows: Measured portions of the sample were evaporated to dryness in a platinum dish and the residue incinerated by what is known as the Drown method. In all cases this test was made, from 500 cubic centimeters to 1 liter of sewage being used, according to its concentration. A determination of the total organic nitrogen was made by the Kjeldahl process. Similar examinations were made of the water as it passed the Bridgeport pumps to determine what part of the organic matter was probably decomposed within the city and what part actually passed through the pumps into the canal. It was found in one series of investigations that about five-sixths of the sewage passed through the pumps, the remainder being decomposed inside the city. In the warmer months a very much larger proportion of the organic matter was decomposed in the city than in the colder months. (4095–4098.)

The witness then stated that a comparison of the results obtained in the examinations of 1886 with those of 1888 and 1889 indicated increased pollution of Illinois River at Peoria. (4098–4099.)

In the summer of 1899 the witness was authorized to begin a chemical examination of the waters of Illinios River and its tributaries and the Illinois and Michigan Canal. Before beginning the analyses he made a trip of inspection down the river from Bridgeport to Grafton in company with Jacob A. Harman, engineer of the State board of health. The trip was made for the purpose of familiarizing the two officials with the locations and general conditions along the river and of engaging water takers to obtain samples of water from the various points and ship them to Chicago. The points selected are shown in Table 56. (4104–4108, 4121–4122.)

TABLE 56.—*Sampling points in Illinois River basin, 1899.*

Sampling point.	Collector.	Number of samples.	Remarks.
Illinois and Michigan Canal at Bridgeport.	Frank Wright	21	50 feet west of pumping station.
Illinois and Michigan Canal at Lockport.	P. O'Brien	22	200 feet east of main bridge.
Desplaines River at Libertyville.	Clare Sherman	4	
Desplaines River at Lockport	P. O'Brien	27	Above stone bridge north of town.
Desplaines River at Joliet	B. F. Long	17	Basin above city.
Illinois River at Morris	Dr. H. M. Ferguson	22	Wagon bridge south of city.
Illinois River at Ottawa	Dr. W. A. Pike	22	200 yards above mouth of Fox River.
Illinois River at La Salle	C. H. Nicolet	21	600 feet above Vermilion River.
Illinois River at Henry	H. J. Gregory	19	600 feet above dam above town.
Illinois River above Peoria	C. F. Hixon	15	At the Narrows, Averyville.
Illinois River below Peoria	Henry Ocker	21	Opposite Wesley.
Illinois River below Pekin	H. D. Jensen	19	Below outlet of cattle sheds.
Illinois River at Havana	S. F. Kyle	2	200 yards above wagon bridge.
Illinois River above Havana	do	16	Above Spoon River during remainder of sampling period.
Illinois River at Pearl	E. H. Chandler	18	At Alton Railroad bridge.
Illinois River at Grafton	F. M. Calhoun	21	1½ miles above town.
Kankakee River at South Bend, Ind.	Dr. G. W. Van Benschotten.	3	Near the city.
Kankakee River below Wilmington.	C. D. Cassingham	9	
Fox River at McHenry	Dr. C. H. Fegers	3	
Fox River at Ottawa	Dr. W. A. Pike	6	100 yards above Rock Island bridge, temporary station; afterwards from Fox River feeder.
Vermilion River at Pontiac	Dr. J. J. Stites	3	
Vermilion River at La Salle	C. H. Nicolet	8	2 miles above city.
Spoon River at Dahinda	Dr. J. B. Bedford	3	
Spoon River at Havana	S. F. Kyle	4	Several hundred feet above city.
Sangamon River at Mahomet	Dr. J. H. Gardiner	3	
Sangamon River 200 yards above mouth.	G. P. Hollingsworth	7	
Mississippi River at Grafton	F. M. Calhoun	13	Above mouth of Illinois River.
Dupage River at Wheaton	Dr. C. F. Blanchard	3	
Mackinaw River at Kappa	Dr. R. E. McKenzie	2	

In this series of investigations two samples of water were taken at each point, one in a gallon bottle for chemical analysis and the other in a 6-ounce bottle for the bacteriological examination. The methods of sampling and the precautions taken against infection coincided with those usually prescribed. The bacterial sample was placed in a small tin can and this in a larger can, the inner can being surrounded with ice. The samples were sent to Professor Long's laboratory by express, the quickest route being taken in every case. When the samples were received at the laboratory they were marked with serial numbers for identification. The large sample was immediately subjected to analysis, while from the smaller one was taken a portion of the water for that part of the biological examination carried on by Doctor Long and the remainder turned over to Dr. Robert F. Zeit, biologist, who occupied quarters in the same building. (4111–4114, 4119–4120.)

The witness then described the variations in the methods of analysis used in this period of the work from those described for former periods. The Gries method was used to determine nitrites and the phenolsulphonic method for nitrates. In some cases total organic nitrogen was determined by the Kjeldahl process. In addition to the generally recognized chemical tests, the witness made certain bacteriological examinations, such as the number of bacteria per cubic centimeter, the coagulation of milk, the amount of gas formed in the fermentation of glucose broth, and the production of indol. In Table 57 are contained averages of weekly analyses of water made according to the above-stated plan from each of the sampling points. The results recited by the witness consisted of the individual analyses, and the reader is referred to the record, pages 4130–4157, or to the special report of the Illinois State board of health for 1901 for a complete statement. The chemical averages given in Table 57 are in nearly all cases representative of the actual results. The bacteriological data, however, vary more widely and the averages given are of less value—so much less in the statements of bacteria per cubic centimeter that the extreme counts are given in all cases.

There was a great diminution in organic pollution of Illinois River between Bridgeport and Averyville, as shown by the decrease in the amounts of oxygen consumed, albuminoid ammonia, and free ammonia, and the increase in nitrates. The amount of oxygen consumed by the river water above Peoria does not differ appreciably from that shown by the tributaries of the Illinois. The same is true of the albuminoid ammonia, while the amount of this ingredient below Peoria is nearly as great as that at Bridgeport. It was further pointed out that after passing Peoria the free ammonia increased from less than 1 part to over 4 parts per million, while the oxygen consumed increased in unfiltered water from 6 to 17 parts per million and in filtered water from 5½ to 13 parts per million, showing that a very great amount of organic matter is added to the river from the industries at Peoria. Down the river from Peoria there is a gradual decrease in the amount of oxygen consumed by the water and in the free and albuminoid ammonia present, indicating that the same processes of purification are effectual in the stretch of the river below Peoria as above. The determinations show, according to the witness, that by the time the water reaches Grafton the organic pollution is not essentially different from that observed in the tributaries of the Illinois. Taken as a whole, the tables disclose two main sources of contamination, namely, the sewage from Chicago and the industrial wastes from Peoria. In the opinion of the witness, the Peoria industrial wastes, rather than the Chicago sewage, constitute the main factor in the contamination of Illinois River at its mouth. (4160–4162.)

TABLE 57.—*Averages of results of weekly analyses of water from Illinois River drainage area at stated points, 1899.*

[Chemical results in parts per million.]

Sampling point.	Number of samples.	Solids.			Ammonia.		Nitrites.	Nitrates.	Oxygen consumed.		Chlorine.	Bacteria per cubic centimeter.	Per cent of gas fermented.			Coagulation of milk.	Indol produced (per cent of samples).
		Total.	Suspended.	Dissolved.	Albuminoid.	Free.			Total.	Dissolved.			0.1 cc.	1.0 cc.	1.0 cc.		
Illinois and Michigan Canal at Bridgeport.	21	536.5	63.5	473.0	3.22	19.84	0.03	0	26.65	15.95	95.47	63,000 to 2,982,000	29.6	41.4	39.4	Rapid	71.4
Illinois and Michigan Canal at Lockport.	22	558	67	491	3.37	19.85	.03	.03	27.90	17.31	96.97	38,400 to 1,750,000	24.7	36.4	38.3	do	59.1
Desplaines River at Libertyville	4	527	15	512	.46	.081	.02	Trace.	5.18	4.88	3.30	1,400 to 9,000	30.0	6.2	......	Moderate	0
Desplaines River at Lockport	7	389	16	373	.559	.229	.009	.045	8.05	6.96	5.98	700 to 108,900	......	4.3	1.0	Slow	0
Desplaines River at Joliet	17	591	104	487	2.88	16.05	.015	.014	25.69	15.10	85.49	26,000 to 1,688,400	25.6	28.8	41.2	Rapid	41.2
Illinois River at Morris	22	445	25	420	1.20	10.99	.18	.07	9.16	8.07	61.8	10,200 to 3,514,500	26.7	28.4	35.5	do	31.8
Illinois River at Ottawa	22	445	11	434	.62	6.23	.61	.74	7.13	6.52	57.4	990 to 371,000	18.6	17.5	23.2	Moderate	27.3
Illinois River at La Salle	21	436	21	415	.58	4.66	.35	1.45	6.99	6.44	41.3	1,200 to 147,000	41.5	38.1	29.4	Rapid	42.9
Illinois River at Henry	19	451	25	426	.553	3.28	.517	1.39	7.00	6.28	43.2	750 to 3,591,000	31.8	36.6	32.5	do	36.8
Illinois River above Peoria	15	422	24	398	.572	.895	.141	1.10	6.86	5.46	33.04	200 to 864,350	18.2	32.7	31.2	Slow	6.6
Illinois River at Wesley	21	493	55	438	3.20	4.36	.026	.106	17.44	12.84	34.97	36,300 to 23,688,000	14.2	19.3	33.3	Very rapid	42.9
Illinois River at Pekin	19	419	26	393	.828	1.39	.273	.71	7.81	6.41	34.76	7,200 to 2,378,500	15.8	23.9	23.3	Rapid	44.0
Illinois River at Havana	18	432	51	381	.695	1.69	.21	1.02	7.18	5.96	29.17	1,800 to 363,000	37.5	37.0	30.0	do	33.3
Illinois River at Pearl	18	388	71	317	.672	.315	.06	.79	5.51	4.73	18.73	100 to 585,000	13.9	23.0	20.5	Slow	16.6
Illinois River at Grafton	21	362	56	306	.455	.247	.045	.59	5.61	4.65	17.50	350 to 2,709,000	28.0	20.0	5.5	do	9.5
Mississippi River at Grafton	13	278	109	169	.443	.080	.001	.03	8.52	6.82	1.77	1,050 to 5,859,600	20.0	25.4	9.4	do	0
Kankakee River at South Bend, Ind.	3	432	9	423	.29	.063	0	3.00	5.65	5.38	1.17	1,600 to 46,200	40.0	43.3	......	Moderate	66.6
Kankakee River at Wilmington	9	322	37	285	.337	.082	.014	.93	5.71	5.09	2.79	780 to 285,120	11.0	11.7	14	do	11.1
Dupage River (West Fork) at Wheaton.	3	515	31	484	.23	.136	.01	......	3.70	2.42	3.77	2,200 to 28,800	5.0	5.0	......	Slow	0
Fox River at McHenry	3	320	17	303	.421	.147	0	0	5.06	4.93	3.53	2,600 to 32,000	20.0	13.0	......	do	0
Fox River at Ottawa	6	349	35	314	.454	.145	.007	.11	7.30	5.58	3.78	1,400 to 42,000	5.8	4.0	2.0	do	0
Vermilion River at Pontiac	3	358	13	345	.24	.117	Trace.	.9	3.86	2.98	3.06	4,900 to 36,000	20.0	15.0	......	Rapid	33.3
Vermilion River at La Salle	8	914	40	874	.199	.286	.102	.61	3.60	2.95	38.35	600 to 77,000	......	25.0	22.5	Slow	0
Spoon River at Dahinda	3	384	31	353	.282	.098	0	.52	4.24	3.76	9.82	40,100 to 208,400	48.3	36.6	......	Rapid	66.6
Spoon River at Havana	4	440	207	233	.496	.302	.04	.27	7.84	4.94	4.17	1,100 to 6,200	27.5	14.0	......	Slow	0
Sangamon River at Mahomet	3	343	44	299	.36	.13	.002	......	4.88	3.62	1.85	4,500 to 27,700	33.3	20.0	......	do	33.3
Sangamon River near mouth	7	346	29	317	.320	.146	.03	.22	4.09	3.42	7.71	650 to 6,600	......	21.0	......	do	0
Mackinaw River at Kappa	2	356	45	311	.493	.165	.015	.70	6.04	4.96	2.83	14,000 to 30,300	32.5	25.0	......	do	50.0

The witness then compared the results of analyses of samples taken from Desplaines River at Joliet with those from Illinois River at Wesley, below Peoria, and pointed out that the amount of albuminoid ammonia is greater at Wesley. As indicated by the oxygen consumed, the amount of organic matter in the water at Wesley is nearly as great as that at Joliet. This apparent discrepancy was explained by the witness to be due to the fact that the albuminoid-ammonia determination is a measure of the nitrogenous matter, whereas the oxygen-consumed determination measures the carbonaceous matter. As the waste from Peoria is known to be largely nitrogenous, the albuminoid ammonia would be relatively greater at Peoria, while the carbonaceous matter would be predominant at Joliet. Concerning the water above Peoria the witness asserted that it was not essentially different from the waters of the ordinary streams of the State of Illinois and no more contaminated than might be expected of a water which had passed through soil rich in organic matter. He then compared the water from the Illinois above Peoria with that of Fox River and stated that the Fox at Ottawa contains as much organic matter as the Illinois at Peoria. Free ammonia in Fox River is very much less than that at Peoria, but the albuminoid ammonia is almost as great. Comparing conditions at La Salle and Pekin, the witness stated that the amount of organic matter at Pekin, as indicated by the albuminoid ammonia, is much greater than at La Salle, while the free ammonia at La Salle is greater than that at Pekin, indicating that the oxidation of organic matter at La Salle is the more nearly complete. If, however, the contamination be measured by the oxygen consumed, the condition at the two places is similar. Comparing the waters of Illinois River above Peoria with those above Grafton, the witness stated that, as measured by the figures for oxygen consumed and for free and albuminoid ammonia, there is somewhat more organic pollution indicated above Peoria than at Grafton. He then made a comparison between the water above Peoria and that of the Mississippi above Grafton, stating that the oxygen-consumed determinations show that Mississippi River water at Grafton contains more organic matter than the Illinois, while the two compare very closely when measured by the albuminoid-ammonia tests. Other determinations show that in the Illinois at Grafton there is evidence of a large amount of nitrogenous matter which has undergone oxidation. From all the above considerations the witness concluded that the organic matter discharged at Bridgeport into the Chicago drainage canal has undergone practically complete oxidation before it has reached the mouth of Illinois River, because at this point he could find no more organic matter than might readily be accounted for by that discharged from the tributaries and from contamination at Peoria. (4163–4166.)

The witness stated that the bacteriological results agree with the chemical results. (4167–4170.)

He then read into the record the results of his examinations during 1900. The averages are reproduced in Table 58. (4172–4205.)

The witness stated that Table 58 discloses considerably less organic contamination in both canals at Bridgeport than appeared during the series of 1899. At Morris, where there is a considerable mixing of waters from both canals, the amounts of free and albuminoid ammonia are lower than those for 1899. When Wesley is reached there is a great increase in the figures for all constituents, being more marked in oxygen consumed and free and albuminoid ammonia. At Pearl the condition of the water is as good as that shown in many of the tributaries, but at Grafton the amount of organic matter is slightly greater than at Pearl. In the opinion of the witness the point of greatest importance in the spring series of analyses was the very marked increase of organic matter at Peoria and Wesley, as compared with the amount found at points above during the same examination. The witness compared the conditions at Wesley and at Morris for the purpose of showing that the organic matter is greater at the former place; another comparison showed that the water at Morris is purer than at Grafton. Comparing the conditions at Morris in 1899 and the spring of 1900 the witness stated that the amount of organic matter was less at the later date. This was true at Wesley also and in general throughout the course of the river, except at Grafton, where more organic matter seemed to be present in 1900 than in 1899. The river was high during the spring of 1900, and therefore the comparison between the waters of the river at that time and during the summer conditions which prevailed in 1899 was not fair. (4181–4185.)

Continuing with a discussion of the results of examinations made during the summer of 1900, the witness stated that it was shown at the outset that there was a lower initial contamination of the water at Bridgeport than in 1899, and that the data further showed a gradual and continuous diminution in the factors, indicating organic contamination as the river was descended—a diminution far greater than could be accounted for by the amount of dilution entering the main stream from its tributaries. The water from Illinois River above Peoria, according to the results for oxygen consumed and for free and albuminoid ammonia, had no greater degree of contamination than is ordinarily found in the tributary waters of the Illinois. At Wesley there was a remarkable increase in the organic pollution, amounting to several hundred per cent, as shown by the free and albuminoid ammonia determinations. It is known that the contamination entering the river at Wesley is largely nitrogenous, and therefore there was at this point a much greater increase in the albuminoid and free ammonia than in the oxygen consumed.

TABLE 58.—*Averages of results of weekly analyses of water from Illinois River drainage area at stated points, 1900*

[Chemical results in parts per million.]

FEBRUARY TO APRIL.

Sampling point.	Number of samples.	Solids.			Ammonia.		Nitrites.	Nitrates.	Oxygen consumed.		Chlorine.	Bacteria per cubic centimeter.	Per cent of gas fermented.		Organic nitrogen.	Coagulation of milk.	Indol produced (per cent of samples).	Loss on ignition.	
		Total.	Suspended.	Dissolved.	Albuminoid.	Free.			Total.	Dissolved.			0.1 cubic centimeter.	1.0 cubic centimeter.				Total.	Dissolved.
Illinois and Michigan Canal at Bridgeport.	1	694	224	440	2.50	6.00	0.03	0.00	24.96	11.68	95.9	540,000	20	30	9.10	Rapid......	100	140	72
Drainage canal at Western ave..	7	221	23	198	1.04	1.78	.05	.11	7.82	4.77	11.7	26,500 to 810,000	17	33	2.78	.....do......	100	47	43
Illinois River at Morris..........	8	305	74	231	.69	3.13	.06	.57	9.26	6.07	12.3	54,000 to 3,820,000	30	57.5	......	Very rapid..	100	54	45
Illinois River at Wesley.........	8	342	98	244	2.21	3.06	.05	.37	16.93	11.48	9.1	9,600 to 2,752,000	24.4	32.5	......	.....do......	87.5	82	61
Illinois River at Havana........	9	268	50	218	.55	.86	.05	1.11	8.34	6.39	5.2	4,300 to 1,309,000	14	13.3	......	Rapid......	44.4	47	40
Illinois River at Pearl...........	8	458	262	196	.45	.46	.07	1.18	9.28	5.05	4.3	4,600 to 158,400	15.6	32	......	.....do......	28.6	53	39
Illinois River at Grafton........	11	600	407	193	.66	.50	.04	1.02	10.47	5.40	4.8	4,700 to 106,800	14.4	34	1.58	Moderate...	22.2	61	42
Spoon River at Havana.........	7	699	489	210	.87	.76	.07	.83	16.66	5.13	4.5	6,200 to 386,400	13	26	......	.....do......	28.6	71	31

MAY TO OCTOBER.

Sampling point.	Number of samples.	Solids Total.	Solids Suspended.	Solids Dissolved.	Ammonia Albuminoid.	Ammonia Free.	Nitrites.	Nitrates.	Oxygen consumed Total.	Oxygen consumed Dissolved.	Chlorine.	Bacteria per cubic centimeter.	0.1 cubic centimeter.	1.0 cubic centimeter.	Organic nitrogen.	Coagulation of milk.	Indol produced (per cent of samples).	Loss on ignition Total.	Loss on ignition Dissolved.
Illinois and Michigan Canal at Bridgeport.	15	447	64	383	2.55	15.26	0.17	0.13	16.31	9.11	89.7	306,000 to 2,460,000	17	19	13.85	Very rapid..	14.3	76	54
Drainage canal at Western ave..	14	203	25	178	.95	1.34	.11	.12	6.28	4.42	9.2	170,000 to 1,656,000	15	19	2.58	.....do......	35.7	44	38
Drainage canal at Lockport....	11	212	19	193	.76	2.16	.06	0.00	5.29	4.34	12.6	82,000 to 1,860,000	30.5	45	......	.....do......	40	42	34
Desplaines River at Joliet......	15	280	35	245	.85	4.66	.09	.02	6.97	4.52	31.4	4,500 to 896,000	29	27	......	.....do......	40	54	44
Illinois River at Morris.........	15	251	29	222	.63	2.84	.27	.17	6.40	4.66	17.8	2,000 to 550,000	26	35	......	Rapid......	26.7	44	39
Illinois River at Ottawa.........	15	266	28	238	.39	.81	.37	.92	5.94	5.03	17.2	2,500 to 127,200	37.7	36	......	Moderate...	15.4	50	44
Illinois River at La Salle........	15	278	26	252	.36	.55	.25	.77	5.60	4.83	15.8	1,800 to 150,000	38	36	......	Rapid......	35.7	48	44
Illinois River at Henry..........	15	283	35	248	.40	.41	.22	1.06	5.86	4.86	16.9	500 to 202,500	21	36	.....	Slow.........	13.3	51	44
Illinois River above Peoria.....	13	265	21	244	.34	.21	.12	.05	5.05	4.53	15.5	2,000 to 472,500	18.6	30	......	.....do......	9.0	49	43
Illinois River at Wesley.........	16	333	71	262	1.34	1.62	.11	.72	9.91	4.59	16.6	23,500 to 24,000,000	13.3	13	.....	Rapid......	13.3	65	52
Illinois River below Pekin......	15	326	76	250	.46	.39	.17	.74	7.01	5.31	15.0	6,500 to 450,000	23.5	23	1.34	.....do......	35.7	53	46
Illinois River at Havana........	15	322	77	245	.41	.41	.18	.77	6.46	4.14	15.0	2,500 to 345,600	37	40	......	Moderate...	14.3	55	48
Illinois River at Pearl...........	14	450	198	252	.43	.12	.07	.75	6.87	5.06	11.6	500 to 330,000	24.6	17	......	.....do......	0.0	55	59
Illinois River at Grafton........	17	331	88	243	.36	.07	.03	.87	5.85	4.82	10.6	1,200 to 161,000	26.5	28	......	.....do......	0.0	57	47
Mississippi River at Grafton...	6	347	195	152	.54	.07	.02	.03	11.73	7.8	2.0	2,000 to 62,000	20	26	1.49	.....do......	0.0	53	40
Fox River at Ottawa............	3	312	20	292	.50	.11	.02	0.00	6.77	6.32	4.9	6,500 to 2,232,000	25	27	1.25	Slow.........	0.0	79	72
Vermilion River at La Salle....	3	283	45	238	.32	.12	.10	.43	5.89	5.23	9.5	4,500 to 25,500	23.3	33	1.30	.....do......	33.3	63	48
Spoon River at Havana.........	4	328	104	224	.47	.27	.08	.08	7.96	5.56	4.4	14,800 to 193,000	34	35	1.41	.....do......	25	53	40
Sangamon River near mouth...	3	367	90	277	.35	.06	.20	.35	6.32	5.57	7.1	2,500 to 13,000	43	23	1.23	.....do......	0.0	61	49
Kankakee River at Wilmington.	3	299	55	244	.46	.10	.06	.77	9.20	7.68	1.8	1,200 to 45,500	37	33	1.40	.....do......	33.3	57	53

Below Wesley the pollution decreased steadily and at Pekin the albuminoid ammonia had been reduced to a point which was comparable with that found in ordinary river waters of the State, and beyond which the reduction does not commonly proceed for the reason that the organic substances remaining are of the comparatively stable types, which are not subject to great reduction by bacterial oxidizing agents. In the case of the free ammonia, however, the witness stated that as this substance does undergo change there was a progressive improvement or disappearance by oxidation to the mouth of the river. The figures for the oxygen consumption indicated a similar condition, the amount lessening from Pekin to Grafton, where it corresponded to that shown by the waters of the tributaries entering the Illinois. (4209–4210.)

The witness then drew several comparisons from his table, beginning with a calculation of the combined flow through the Chicago drainage canal and the Illinois and Michigan Canal. According to the observations of the engineering department of the sanitary district of Chicago, as reported by the chief engineer, 16 per cent of the flow of water from Lake Michigan into Desplaines River went through the Illinois and Michigan Canal and 84 per cent through the drainage canal. If it were assumed that all of the water passed through one channel, the volume being equivalent to the volume flowing through both, the constituents in that channel would be as follows, in parts per million: Albuminoid ammonia, 1.13; free ammonia, 3.9; oxygen consumed, 7.46; chlorine 23.5. These numbers may be taken as representing the composition of the total flow through the two channels. A comparison of these numbers with the data for the water at Joliet showed a discrepancy, which was accounted for by the witness as being due to an imperfect mixture of the Desplaines and canal waters. Because of this discrepancy the Joliet collection was not considered in preparing the series of charts that were then presented by the witness, based on the results of analyses made during the summer of 1900, showing amounts of albuminoid and free ammonia, oxygen consumed, and chlorine at the various sampling points from Bridgeport to Grafton. As the values expressed in these charts are included in Table 58, they are not reproduced. (4210–4223.)

Professor Long then testified that he had made further chemical surveys in 1901, from September to December, inclusive, and in 1902 during February and March, the sampling points being Illinois River above its confluence with the Mississippi, Mississippi River above the mouth of the Illinois, and Missouri River above its confluence with the Mississippi. The results of these examinations were read into the record and occupy pages 4230 to 4237, inclusive. The averages of these results are given in Table 59, and the reader is referred to the record or to the report of the Illinois State board of health for 1902 for more detailed information.

TABLE 59.—*Averages of results of analyses of water from Illinois, Mississippi, and Missouri rivers, 1901 and 1902.*

	Illinois River above Grafton, September 23 to December 12, 1901.	Mississippi River above Grafton, September 23 to December 12, 1901.	Missouri River at mouth, September 17 to December 12, 1901.	Illinois River above Grafton, February 21 to March 18, 1902.	Mississippi River above Grafton, February 24 to March 17, 1902.	Missouri River at mouth, March 10 to 21, 1902.
Number of samples	38	37	43	13	12	8
Total solids..........parts per million	261	183	1,294	445.7	280.8	1,594.5
Solids in suspension..........do	32	38	948	216.0	93.0	1,290.2
Solids in solution..........do	229	45	346	229.7	187.8	304.3
Loss on ignition:						
Total..........do	40	36	82	68.4	48.9	186.0
In solution..........do	36	33	29	45.8	49.3	54.0
Albuminoid ammonia..........do	0.413	0.39	0.60	0.452	0.283	0.849
Free ammonia..........do	0.238	0.07	0.10	1.344	0.244	0.295
Nitrites..........do	0.234	0.004	0.0006	0.003	0.003	0.011
Nitrates..........do	1.042	0.08	0.13	0.398	0.473	0.675
Oxygen absorbed:						
Total..........do	4.31	7.84	10.28	8.96	7.09	17.15
In solution..........do	3.21	6.53	3.17	4.88	4.84	4.96
Organic nitrogen..........do	0.81	0.74	1.61	1.46	1.24	3.27
Chlorine..........do	16.4	1.88	14.9	12.49	2.45	14.46
Bacteria per cubic centimeter	100 to 25,800	150 to 5,200	300 to 21,200	40 to 14,880	60 to 12,400	160 to 14,160
Fermentation:						
In 0.1 c. c..........per cent of gas	31.4	36.1	82.5	61.6	25.0	87.5
In 1 c. c..........do	48.6	51.4	88.4	40.0	9.0	....
Coagulation of milk at 38° C	Slow.	Slow.	Moderate	Moderate	Slow.	16.75 hrs.
Production of indol..per cent of samples	2.9	3.1	56.8	15	25.0	75

The witness made the following interpretation of the data contained in Table 59: The organic condition of Illinois River above Grafton is much better than that of the Missouri above its mouth. This is shown, according to the witness, first, by the factor of oxygen consumed, which for Illinois River is for the unfiltered water 4.31 parts per million and for the filtered water 3.21 parts, whereas the Missouri shows 10.28 and 3.17 parts, respectively; second, by the factor of albuminoid ammonia, as measuring the substances of comparatively complex composition yet undecomposed—in Illinois River 0.413 part per million, as against 0.6 part in Missouri River; third, by the factor of organic nitrogen, as determined by the Kjedahl process, which is 0.81 part per million in Illinois River and 1.61 parts in the Missouri. The chemical reactions due to living organic matter in Illinois and Missouri rivers being considered, it is evident, according to the witness, that the condition of Illinois River was greatly superior to that of Missouri River throughout the whole period, and especially is this shown by the biological work recorded in the table. The production of indol, for example, was very common in samples taken from Missouri River and rare in Illinois River samples. It is also shown by the greater abundance in the Missouri samples of those organisms which have the power of breaking down carbohydrates with the production of acid. The tests further show, according to the witness, that Missouri River is also contaminated to a far greater degree than Mississippi River above the mouth of the Illinois. (4239–4241.)

The witness was then questioned concerning investigations made by him on the character of the water of Kaw and Missouri rivers in the vicinity of Kansas City. He stated that in May, 1903, samples were taken under his direction from Kaw River at a point 1½ miles above its confluence with the Missouri and from Missouri River (a) above its confluence with the Kaw, (b) below the confluence with the Kaw and above Kansas City, and (c) below Kansas City. No determinations were made on these samples except that of chlorine. The results, together with the flow of Kaw and Missouri rivers, are recorded in Table 60. (4241–4246.)

Table 60.—*Volume of flow and determinations of chlorine in the water of Kaw and Missouri rivers at designated points, May 22–28, 1903.*

[Flow in cubic feet per second; chlorine in parts per million.]

	May 22.		May 23.		May 24.	
	Flow.	Chlorine.	Flow.	Chlorine.	Flow.	Chlorine.
Kaw River	....	....	....	....	51,000	....
Missouri River above Kaw River	....	10.22	....	11.64	....	....
Missouri River above Kansas City	125,000	10.95	145,000	11.62	184,000	....
Missouri River below Kansas City	....	16.59	....	11.72	....	....

	May 25.		May 26.		May 27.		May 28.	
	Flow.	Chlorine.	Flow.	Chlorine.	Flow.	Chlorine.	Flow.	Chlorine
Kaw River	49,600	....	39,100	10.29	63,500	9.89	72,200	8.95
Missouri River above Kaw River	....	9.81	....	....	....	....	....	....
Missouri River above Kansas City	198,000	10.31	226,000	....	242,000	....	310,000	....
Missouri River below Kansas City	....	11.96	....	....	....	....	....	....

It appears from Table 60 that the samples from Kaw River were taken subsequent to those from the Missouri, and therefore the amounts of chlorine as stated in the table are not absolutely comparable for the two streams. The dates May 26, 27, and 28, given in the record, are probably incorrect, owing to typographical error, and the proper dates are the 22d, 23d, and 25th, as in the case of the Missouri River samples. As this review is taken from the official record, however, this probable error can not be corrected, but it is here indicated.

Counsel for the defense stated that the testimony here given was partly for the purpose of rebutting that of Doctor Teichmann, who stated that the great part of the chlorine in Missouri River was derived from the Kaw. In response to questions, therefore, the witness interpreted the results as follows: The averages drawn from the table show a considerably larger figure for chlorine below Kansas City than in the Kaw or the Missouri above Kansas City. The excess of chlorine below Kansas City is more than can be accounted for by any addition from the Kaw, showing that a certain proportion must come from the stock yards and sewers of Kansas City. The volume of Missouri River was considerably greater than that of the Kaw throughout the period under discussion and the amount of chlorine in the Kaw, the volume of the river being considered, could not have increased the chlorine in the Missouri beyond the amount given for the latter river above Kansas City. Therefore, in the opinion of the witness, the chlorine at the mouth of Missouri River can be attributed only in part to the chlorine from Kaw River, the table showing that the additions from Kansas City are an important factor. (4241–4249.)

With reference to the effect of sewage from the Chicago drainage canal on the water supply of St. Louis, the witness stated that from all the examinations he had made of Illinois River and its tributaries, it was his opinion that no part of the original organic matter leaving Chicago through the drainage canal and finding its way into Illinois River could reach the mouth of the Illinois, much less the intake tower of the St. Louis waterworks; therefore it was his belief that the sanitary condition of the water supply of St. Louis was not and could not be injured by any pollution from Chicago. (4250.)

The witness then stated that the volume of water going down Illinois River is greater than it was before the opening of the drainage canal, and that inasmuch as the amount of sewage per given volume is necessarily less and at the same time this dilution produces no enforced decrease in the bacterial activity throughout the channel, there can be no decrease in the purification from these causes. Floods carry into the river an immense amount of organic matter and numerous living organisms from all the tributaries. This increases the organic contamination, irrespective of any original contamination which may have been present. A further effect of floods, inasmuch as the banks of Illinois River are very low, is to spread an enormous volume of water over an area of many hundreds of thousands of acres, providing for the sedimentation and oxidation to a marked degree of matters carried by the water at these periods. The conditions in Illinois River, because of the peculiar character of the banks, are unique in this respect. The overflow disposes in this manner of a vast amount of organic matter which in a stream with high banks would have to be carried forward. Inasmuch as by far the largest part of the water at flood times leaves the natural channel of the river and is distributed over a vast area of land, the original sewage or remnants of sewage carried by this water must be in like manner distributed, and thus made accessible to the purifying processes of sedimentation or oxidation. The witness then stated that the lakes which were backed up by the various dams across Illinois River offer large basins for oxidation and hold up the water to some extent for that purpose. He further stated that it was his belief that Mississippi River at Chain of Rocks is not a potable stream and had not been at any near period suitable for household use. (4250–4253.)

In response to questions, Professor Long stated that the addition of a large volume of Lake Michigan water and canal water flowing down the Illinois, which causes an increase in dilution, had produced the resultant effect that the water at the mouth of Illinois River after the opening of the canal was in far better sanitary condition than previous thereto. (4254.)

The following hypothetical question and the reply thereto appear in the record (pp. 4256–4260):

Q. Professor, assume that 107 barrels of 40 gallons each of culture of *Bacillus prodigiosus*, consisting of 1,000,000,000 bacilli per cubic centimeter as contained in said barrel, were deposited into the Chicago drainage canal at the town of Lemont on the afternoon and evening of the 6th day of November, 1901, during a period of from four to eight hours; assume further that immediately after said barrels were emptied into the drainage canal at the point aforesaid the laboratories established at Lockport, Joliet, Peoria, and Grafton, on the Illinois River, at the intake tower of the St. Louis waterworks at the Chain of Rocks, were notified, and that samples were collected at each of these places every hour of the day and night for the purpose of bacteriological analyses for the ascertainment of these *Bacillus prodigiosus;* and assume that at Lockport these hourly samples taken day and night were taken from November 7 to November 25, a period of eighteen days, the total number of samples taken being 432, or thereabouts; assume that at Joliet these hourly samples taken day and night were taken from November the 7th to November the 25th, a period of eighteen days, the total number of samples taken being about 432; and assume that at Peoria these hourly samples taken day and night from November the 8th to November 30, a period of twenty-two days, amounting to a total of 528, and assume that at Grafton these hourly samples were taken day and night from November 12 to December 15, a period of thirty-three days, the total number amounting to 732, of which 384 were analyzed by Dr. Ravold; and assume that the total number of samples taken hourly day and night was 720, and assume that at the laboratory tap these hourly samples taken day and night from November 20 until March 1, 1902, a period of one hundred days, amounting to a total of 2,400, and assume that the total number of samples analyzed at the different points for the period above mentioned was 5,304; and assume further that on December 4 at 8.45 a. m. one bacterium *Bacillus prodigiosus* was found at the intake tower at the Chain of Rocks; assume that on December the 5th at 9 a. m. one bacterium *Bacillus prodigiosus* was found at the intake tower at the Chain of Rocks; assume that on December the 8th at midnight one bacterium *Bacillus prodigiosus* was found at the intake tower at the Chain of Rocks; assume that on December 6 at 8 a. m. at Grafton one *Bacillus prodigiosus* was found; assume that on December 7 at midnight at Grafton one *Bacillus prodigiosus* was found; and assume further that these five organisms were all of the organisms of *prodigiosus* that were found in the examinations made from Lockport to the intake tower at the Chain of Rocks and the laboratory tap in the city of St. Louis, which were made during the progress of this investigation as hereinbefore set forth; that at no time was there more than one bacterium found in each of these places. Assuming all of the facts as hereinbefore stated to be true, what is your opinion as to the value of this experiment as indicating the probable longevity of the typhoid bacillus as measured by the longevity of the *Bacillus prodigiosus* and the probability that a typhoid bacillus entering the drainage canal from the sewers of Chicago would ultimately find its way through the Desplaines and Illinois rivers to the town of Grafton?

A. Considering the longevity of the typhoid bacillus as measured by the longevity of the *Bacillus prodigiosus*, which consideration in no way involves a knowledge of bacteriology, but simply a knowledge of arithmetic as set forth in this question, I would say that the suppositions advanced in this question indicate that the longevity of the *Bacillus prodigiosus*, and of the typhoid bacillus as compared with it, is so extremely slight as to make the probability of a germ of this character being able to survive a passage from the drainage canal to Grafton so remote as to be entirely unworthy of consideration. This conclusion depends on certain calculations which I have made and which I will present. As the various data are given in terms of the metric system, it is necessary to make certain reductions in order to be able to reach a proper conclusion. First, it is necessary to determine the concentration of the germs in the canal water at the time when they were dumped from the barrels as supposed in the question. At this period the flow in the canal was almost exactly 235,000 cubic feet per minute, which I have reduced to liters by use of the factor 28.3 liters per cubic foot, which is almost the exact factor, giving 6,650,000 liters, very nearly, per minute. Reducing this number of minutes to hours, I find that for four hours, or two hundred and forty minutes, assumed to be consumed in this addition of the bacteria to the water a volume of water flowed equivalent to 1,596,000,000 liters, or approximately 1,600,000,000 liters. As the calculations are finally based on the cubic centimeter rather than the liter, I have reduced this volume to cubic centimeters by multiplying by 1,000, giving as the volume of this water in cubic centimeters, into which the substance from the barrels was dumped, 1,600,000,000,000, or, expressed most accurately in the method now common among mathematicians, 1.6 x 10^{12}. This is the flow of the canal in cubic centimeters in four hours. I will say for the purposes of comparison it makes no difference whether we assume four hours or eight hours, as the same factor enters later into the calculation at the mouth of the river. We have next to consider from the assumptions of the question the number of bacteria mixed with this volume. One hundred and seven barrels of 40 gallons each gives the amount of 4,280 gallons, which when reduced to liters give us something over 16,000 liters—16,017 and more liters—but in round numbers I will use 16,000 liters, or 16,000,000 cubic centimeters. The number of bacteria per cubic centimeter, according to the assumption of the question, was 1,000,000,000. The total number of bacteria then discharged would be the product of 1,000,000,000 per cubic centimeter by the number of cubic centimeters, or 16,000,000 multiplied by 1,000,000,000, which multiplied out gives us the number 16,000,000,000,000,000, or, more accurately or definitely expressed, 1.6^{16}. We have therefore as the number of bacteria, following the assumption of the question, which must have been thrown into the canal, 1.6^{16}, as given. As the number of cubic centimeters into which this number was thrown was given as 1.6^{12}, the quotient of one of these by the other gives the concentration of 10 at the fourth power, or 10,000 bacteria to the cubic centimeter, on the assumption that the mixing or dumping took place through a period of four hours. We have therefore as concentration 10,000 to the cubic centimeter. Now, supposing this wedge of water to pass down the river absolutely unchanged, and supposing further that no increase or decrease in this number of bacteria should follow by death or by any other means, it is simply a statement of fact to say that we should find 10,000 per cubic centimeter at some corresponding time, in some part of the river below; but admitting the fact that a change by dilution follows by taking up the water of the tributaries and through the uneven flow of the water, the particles moving more rapidly in the center than along the sides of the stream, a certain dilution must be calculated—must be admitted as taking place in this volume. From the fact that these samples were all found within a four-day period, or rather these bacteria were all found in samples collected in a period of four days, as presented in the question, I have calculated this original volume of water as diluted with the volume of water which flows at the mouth of the river in a period of four days. On that assumption a number of at least 200 should be found per cubic centimeter for each cubic centimeter examined, on the assumption that no death or loss of these bacteria takes place anywhere in the course. As a matter of fact, not 200 were found in 1 cubic centimeter, but a very large number of examinations had to be made to find a cubic centimeter in which there was one contained. It is evident that an enormous destruction of these organisms must take place between the point at which the bacteria were thrown in and the mouth of the river, where the examinations were made. The actual finding is not over one ten-thousandth of what should be expected from 107 barrels on the assumption that these organisms did not die out; that is, we find less than one ten-thousandth of the expected amount. If we consider a number less than 107 barrels as added—one barrel, for example—the probability of any organism of this character reaching the mouth of the Illinois River is less than one chance in 1,000,000. If we consider one barrel or one one-hundredth of a barrel as added, the chance of one of these organisms reaching the mouth of the river and being found in a cubic centimeter becomes correspondingly reduced. Therefore, without involving any question of bacteriology, but simply a question of calculation, it is evident that the probabilities of any number of bacteria in a given small volume reaching the mouth of the Illinois River is extremely remote and not one which can be practically or seriously considered. (4256–4260.)

Continuing, the witness stated that the longevity of the typhoid bacillus being measured by that of the *Bacillus prodigiosus*, and the fact being taken into account that in the large number of examinations made at Lockport, Joliet, and Peoria no *B. prodigiosus* were found, and further that only the small number mentioned were obtained at the mouth of the river and from the intake tower at Chain of Rocks and in the water supply of St. Louis—none at all before December 4 and none after December 8—it is practically improbable that a typhoid bacillus with longevity and virility as measured by that of the *B. prodigiosus* would ever survive the passage down the drainage canal and Illinois River and enter the water supply of St. Louis. (4261.)

CROSS-EXAMINATION.

In reply to an inquiry concerning which tests, chemical or bacteriological, the witness considered most important, he stated that it was impossible to determine; both are of equal importance in some cases, while in others one will take precedence over the other. He stated further that his direct testimony on the sanitary condition of the water of Illinois River was not altogether based on chemical and bacteriological tests, but also on his general opinion of the sanitary condition of river water. (4264–4266.)

The witness made the following general statement of his opinion concerning pollution and the interpretations of analytical results: The most objectionable pollution in a river consists of the products of human excretion; as to which particular product the witness could not give an opinion as biologist or bacteriologist, but he concurred in general with the accepted opinion. With reference to the specific character of pollution the witness stated that the origin of the vegetable extracts can be pretty safely inferred, because they contain preeminently more bodies of the carbohydrates and their derivatives than the extracts of animal origin. Vegetable extracts give marked reactions with the permanganate solution, but not very marked reactions with the reagents measuring nitrogenous matter. This peculiarity is of value in distinguishing between the vegetable and animal extracts when the organic matter is fresh, but it does not appear to the same extent in the examination of older substances. It is not always possible to differentiate sharply between water polluted by sewage and that containing organic matter from swamps. In general, waters having the latter contamination contain very much less chlorine than those contaminated by sewage. The amount of nitrogen in different forms is also significant. The nitrogen as nitrites seems to be more characteristic of the breaking down of the products of animal than of vegetable origin. These are the most important factors and the ones usually considered; in addition it is always desirable to have as much knowledge as possible concerning the character of the watershed, the contribution of sewers in general, whether there are great industries and of what kinds, the drainage areas, and the rate and character of flow of the river. Inorganic pollution consists of the mineral salts, which are the combination of the so-called metallic elements, sodium, potassium, calcium, magnesium, and ammonium, with the elements described as chlorine, sulphuric acid, nitric acid, phosphoric acid, and carbonic acid. The substances known as organic are usually complex forms—carbon, nitrogen, hydrogen, and oxygen, with small amounts of sulphur and phosphorus. Organic substances are distinguished from the so-called inorganic matter by the fact that they undergo general decomposition by heat relatively more easily—in other words, the distinction is based on their degree of stability. The witness then related the conventional theory concerning the breaking down of organic matter and described in a general way the leading features of the Chicago sewerage system and its effects on Lake Michigan, Chicago River, and Desplaines River.

Throughout his cross-examination the witness was careful to state that he had confined his work and his interpretations to purely chemical and bacterio-chemical lines and had not attempted to determine the presence of infected matter in the water. He further stated that chemical analysis was beneficial to the sanitarian only to the extent of showing the amount of organic pollution regardless of its character, although under certain conditions it does give a clew to the kind of pollution.

Continuing along the general subject of infection and the relation between polluted waters and water-borne diseases, the witness expressed certain doubts concerning the conclusions of epidemiologists and stated that, while in some cases he was inclined to accept the opinion of sanitarians without advancing any original theories of his own, he had based his opinion concerning the condition of Illinois River almost solely on the results of examinations of a chemical and bacterio-chemical nature. The matter of possible infection was left out of consideration entirely. He did not consider it an important factor in his investigation, inasmuch as his purpose was not to determine whether or not the water was safe for drinking or domestic purposes, but to determine the extent and rate of destruction of organic pollution in the waters in question and to compare these several waters with each other. He further stated that it was not possible to assign any hard and fast limit to the amount of polluting substances in a water which would be necessary to make it unpotable and refused to be led into a discussion which would make it necessary for him to advance an opinion upon such a subject. In forming his conclusions concerning the water, he had not attached much importance to the opinion of epidemiologists, but had preferred to refer to the work of others who had made investigations parallel to his own. (4266–4298.)

The following hypothetical question was then asked:

Assuming that it required twenty days for the water in Illinois River to run from its source to its mouth prior to the opening of the canal, and that it requires ten days since the opening of the canal, I would like to ask you what effect this time limit has upon the determination of whether or not decomposition has more rapidly taken place during the previous period than the subsequent period.

To this and other questions the witness answered:

This time limit can have no possible bearing on the question of the determination of the fact whether the decomposition has taken place more rapidly or not. The chemical analysis is made irrespective of the rapidity with which the water comes down there. * * * But supposing this more rapid flow is due to enormously greater dilution, instead of being more dangerous for household consumption, inasmuch as we are concerned only with a small volume * * * and not with the gross condition, the final condition, instead of being worse, may be better as far as household use is concerned.

Continuing, the witness stated that dilution does not necessarily destroy but it renders less probable the deleterious effect in proportion to the extent of dilution. A comparison of the gross pollution of the Missouri with that of the Mississippi or of the gross pollution of the Illinois with that of the Mississippi is absolutely valueless and absurd. It makes no difference what the volume of the body of water is, the chemist is concerned only with that amount with which one is liable to come directly into contact in his daily usage and as drinking water, and the expression parts per million or grains per gallon is the only thing which a practical man has to take into consideration. In expressing results in parts per million, etc., the dilution factor goes in. The witness further insisted that it was impossible to determine in all cases the potability of a water from the analytical results, and that no fixed standards could be set with reference to the amount of this or that ingredient; in connection with this it was necessary to know all the conditions and the source of the water. The witness then stated that inasmuch as no one had been able to find the typhoid germs in the water, it was his belief that it is highly probable that there is no reason for assuming that they are there under any conditions. (4345–4369.)

ADOLPH GEHRMANN.

DIRECT EXAMINATION.

Adolph Gehrmann was called as a witness in behalf of the defense. In qualifying as an expert he stated that his residence was in Chicago; his profession, physician and bacteriologist. He had been connected with the Chicago department of health—during 1893 as bacteriologist and microscopist for the milk department; and from January, 1894, until June, 1902, as director of the laboratory and bacteriologist for the department. He received his medical degree from Northwestern University in 1890, and had been engaged as a teacher of bacteriology and hygiene in the medical department of the University of Illinois. At the time of his testimony he was professor of hygiene in the Dearborn Medical College and professor of bacteriology in the Harvey Medical College. In connection with his duties as director of the laboratory of the department of health in Chicago, he had conducted the bacterial examinations of samples of water received at the laboratory. During 1893 he made a weekly examination of the water from Lake Michigan from the four cribs, and of one sample from the laboratory tap. From the beginning of 1894 to the end of his service for the department of health samples were taken daily for bacteriological examination. (4744–4747.)

In the early months of 1899 he was instructed by the commissioner of health of Chicago to arrange for the examination of samples from the Illinois and Michigan Canal, Desplaines River, Illinois River and its tributaries, Mississippi River, and Missouri River, and in conjunction with Professors Palmer and Burrill of the University of Illinois and Professor Jordan of the University of Chicago elaborated plans for such examinations. The system of collection was determined and the work was taken up in the laboratories of these two universities and of the health department. It was arranged that from each of the sampling points three separate samples must be collected, each sample to be represented by a large and small bottle, making six bottles in all, and to be identified according to the usual procedure. The collectors were instructed in the customary manner. (4749–4758.)

The following were the sampling points:

Points at which water samples were taken for investigations of Chicago department of health, 1894 to 1902.

Illinois and Michigan Canal:
- Bridgeport, 500 feet west of pumping station.
- Lockport.
- North of Joliet.
- South of Joliet.
- Ottawa.

Desplaines River:
- Lockport.

Kankakee River:
- Wilmington.

Illinois River:
- Morris.
- Ottawa.
- La Salle.
- Henry.
- Above Peoria.
- Below Peoria.
- Pekin.
- Havana.
- Beardstown.
- Kampsville.
- Grafton, 2 miles above mouth of Mississippi River.

Fox River:
- Ottawa.

Vermilion River:
- La Salle.

Little Vermilion River:
- One sample every four weeks.

Sangamon River:
- Chandlerville.

Mississippi River:
- Grafton, above mouth of Illinois River.
- Alton, 100 feet from east bank.
- Alton, east of midstream.
- Alton, midstream.
- Alton, west of midstream.
- Alton, 100 feet from west bank.
- Chain of Rocks, 400 yards from Illinois shore.
- Chain of Rocks, main channel.
- Chain of Rocks, inlet tower.
- Chain of Rocks, 400 feet from Missouri shore.
- Jefferson Barracks, east bank.
- Jefferson Barracks, east of midstream.
- Jefferson Barracks, midstream.
- Jefferson Barracks, west of midstream.
- Jefferson Barracks, west bank.

Missouri River:
- Fort Bellefontaine.
- Water tap at St. Louis.

The witness then gave the names of the samplers, described the methods of collecting and identifying the samples, and presented the results of his examinations, together with those of D. B. Bisbee, who performed the chemical work in the department of health laboratory. (4756–4764.) Herewith are reproduced the average results of examinations made in the said laboratory of water taken from stated sampling points, July 3 to November 28, 1899. For more detailed statements the reader is referred to pages 4770–4807 of the official record.

Counsel for the defense directed the attention of the witness to the results contained in the final column of Table 61, namely, the number of bacteria per cubic centimeter, and in response to specific questions concerning his interpretations the witness testified as follows:

A comparison of the Illinois and Michigan Canal data at Bridgeport with the Illinois River data at Averyville (above Peoria) shows that there is a difference of 10 to 20 per cent in the number of bacteria present, and in some cases a difference of 100 per cent in favor of the Averyville samples, which show a much greater bacterial purity than those collected at Bridgeport. The number of bacteria is from 10 to 20 per cent less in the Averyville samples than in the Illinois and Michigan Canal samples, taken at Lockport, and in some cases the difference amounts to 100 per cent, indicating a greater bacterial purity at Averyville. A comparison of the Illinois River samples at Morris with those at Bridgeport and at Averyville shows that the number of bacteria is not materially different in the Morris and Bridgeport samples, and that those at Averyville contain from 10 to 20 per cent of the number found at the other two points, indicating again a greater degree of bacterial purity. There is no material difference between the samples collected at Henry and those at Averyville, except in two instances, August 8 and September 30, when the bacteria were much higher at Henry. The bacterial counts at these two points are from 10 to 20 per cent of the number at Morris, showing much greater bacterial purity at these points than at Morris. The samples from Kankakee River at Wilmington show only slight differences in number of bacteria from the Illinois River samples at Averyville. In some instances the count is in favor of Kankakee River and in others in favor of Illinois River, the interpretation being that there is no material difference in the bacterial purity of these two waters. The number of bacteria in the Averyville samples is about equal to that in the tributaries of the Illinois, and the zone of self-purification extends down to about the location of Averyville. The results of examinations of Illinois River water at Wesley (below Peoria) and Pekin clearly indicate an increase of pollution in the stream between these two points, the bacterial purity at Averyville being greater than at either. A comparison of the bacterial counts of the Illinois and Michigan Canal at Lockport and of Illinois River at Wesley and Pekin shows approximately the same amount of bacterial purity. The Illinois River water at Grafton contains from 10 to 20 per cent of the number of bacteria found at Wesley and Pekin, and is therefore of far greater bacterial purity than the Wesley and Pekin waters. The bacterial counts at Grafton and Averyville are about the same. The bacterial purity of Mississippi River at Grafton is practically the same as that of Illinois River at Grafton. The samples from Illinois River at Grafton and from Missouri River at Fort Bellefontaine show no great difference in the bacterial content. The series of samples taken along the cross section in Mississippi River at Chain of Rocks shows practically the same bacterial counts at all points and indicates a general distribution of bacterial purity or impurity along the cross section. There is no material difference in the number of bacteria in the samples taken at Chain of Rocks, 400 feet from the Missouri shore, and in those 400 yards from the Illinois shore. The bacterial content of the samples taken along the cross section at Jefferson Barracks, below the outlet of the St. Louis sewers, is practically the same as that of the samples taken from the cross section at Chain of Rocks. (4808–4819.)

TABLE 61.—*Results of analyses of water made in the laboratory of the department of health of the city of Chicago from stated points, July 3 to November 28, 1899.*

[Parts per million.]

Sampling point.	Number of samples.	Turbidity.[a]	Sediment.[a]	Odor.	Residue. Total.	Residue. Dissolved.	Residue. Suspended.	Chlorine.	Oxygen consumed. Total.	Oxygen consumed. Dissolved.	Oxygen consumed. Suspended.	Nitrogen as ammonia. Free.	Nitrogen as ammonia. Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.	Organic nitrogen. Total.	Organic nitrogen. Dissolved.	Organic nitrogen. Suspended.	Nitrogen as— Nitrites.	Nitrogen as— Nitrates.	Number of times B. coli communis was present.	Bacteria per cubic centimeter.
Illinois and Michigan Canal at Bridgeport..	17	VVH	M	Gassy .	537	464	73	112	38	19	20	15.64	2.23	1.17	1.05	4	1.89	2.11	0.069	0.16	16	1,300,000
Illinois and Michigan Canal at Lockport....	22	VVH	M	Gassy .	543	426.7	70.5	115.7	39	20.5	18.9	14.53	2.59	1.40	1.19	4.33	2.37	1.96	.05	.16	17	650,000
Desplaines River at Lockport..............	22	VVS	VVS	None...	359.5	348	14.5	8.8	11	10	.8	.07	.48	.43	.05	.83	.71	.13	.008	.26	16	170,000
Desplaines River above Joliet..............	22	VVH	M	Gassy .	560	479	80.9	107.8	31.6	16.5	15	15.98	2.24	1.22	1.02	4.10	2	2.08	.038	.15	18	700,000
Desplaines River below Joliet..................	12	VH	H	Gassy .	615	496.8	118.5	112.7	30.7	14	16.6	14.02	2.18	1	1.18	4.13	1.49	2.64	.027	.32	9	460,000
Kankakee River at Wilmington..............	22	H	VS	None...	309	269	41.9	3.9	9	7	1.9	.054	.36	.28	.08	.76	.55	.24	.013	.69	11	23,000
Illinois River at Morris.	21	M	S	None...	419	405	16	72.9	15	11.9	3	10.05	1	.67	.34	1.76	1.18	.58	.083	.43	17	400,000
Fox River at Ottawa..	21	VVS	VVS	None...	308	292.8	20	6	7.9	7	.9	.06	.37	.34	.07	.69	.57	.16	.008	.32	7	14,500
Illinois River at Ottawa.................	21	VVS	VVS	None...	400	386	15.6	65.5	10.9	10.5	1	5.67	.53	.47	.08	1.02	.93	.14	.57	1.57	16	43,500
Vermilion River at La Salle..................	22	S	S	None...	1,173	1,134	40.9	109	5.3	3.9	15.5	.27	.27	.18	.09	.59	.39	.23	.024	.82	12	23,500
Illinois and Michigan Canal at La Salle	22	M	S	None...	360.5	320	40	15	9.8	7	2.6	.52	.51	.39	.16	.98	.75	.23	.054	.46	17	110,000
Illinois River at La Salle..................	22	VS	S	None...	417	386	32	57	11	9	1.8	3.42	.53	.41	.12	1.10	.89	.25	.51	1.84	18	41,000
Illinois River at Henry.	21	S	M	None...	413	382	32	53	11.7	9	2.6	2.2	.70	.42	.28	1.39	.88	.54	.45	1.60	15	56,000
Illinois River above Peoria................	22	S	M	None...	395	365	30	49	10	8	2.2	.79	.55	.36	.19	1.10	.80	.37	.39	1.75	17	24,000
Illinois River below Peoria................	21	S	M	None...	408	372	36.4	51	13	9.9	3.7	1.08	.86	.50	.36	1.59	1.01	.58	.45	1.67	10	2,100,000
Illinois River at Pekin..	21	VS	S	None...	393	365	28	48.3	11.7	9	2.6	.93	.69	.43	.26	1.40	.88	.51	.34	1.46	17	900,000
Illinois River at Havana................	21	M	M	None...	406	357	50	43	11	8.6	2.7	1.18	.62	.42	.20	1.29	.82	.49	.35	.90	18	100,000

Sangamon River at Chandlerville	16	M	M	None	364	293	93	5.6	6	3.5	2.7	.11	.33	.20	.13	.68	.39	.33	.03	.66	11	23,500
Illinois River at Beardstown	22	M	M	None	379	331	47	33.8	8.7	7.1	1.6	.85	.47	.33	.13	.97	.69	.29	.18	1.36	16	20,500
Illinois River at Kampsville	18	M	S	None	351	300	51.7	27.3	8.1	6.5	1.6	.25	.44	.29	.15	.92	.63	.30	.09	1.02	10	24,500
Illinois River at Grafton	21	H	VS	None	335	287	48	23.2	8.1	6.6	1.5	2.1	.42	.30	.12	.83	.53	.28	.07	1.12	12	26,500
Mississippi River at Grafton	21	H	M	None	292	163	128	2.6	13.6	.65	3.8	.04	.44	.25	.18	.81	.46	.35	.004	.28	16	24,500
Mississippi River at Alton:																						
100 feet from Illinois shore	20	M	M	None	295	201	94	9	11.8	8.8	3	.06	.46	.27	.19	.88	.42	.41	.023	.42	16	30,000
One-fourth distance from Illinois shore	21	M	M	None	272	184	88	6.3	12.1	8.8	3.2	.037	.43	.27	.16	.77	.41	.38	.015	.31	15	26,000
Midstream	20	M	M	None	278	172	172	4.1	13	9.4	3.7	.028	.44	.27	.18	.81	.44	.38	.006	.25	13	26,500
One-fourth distance from Missouri shore	21	M	M	None	279	162	162	3	13.2	9.2	4	.04	.435	.25	.172	.79	.43	.79	.006	.24	12	19,500
100 feet from Missouri shore	20	M	M	None	264	161	161	3	13	9.3	3.7	.05	.43	.25	.18	.78	.44	.34	.005	.28	14	21,500
Mississippi River at Chain of Rocks:																						
400 yards from Illinois shore	21	VVH	VH	None	950	188	762	6.4	18	7.4	10.8	.049	.60	.23	.37	1.34	.43	.97	.009	.55	14	23,500
Midstream	21	VVH	VH	None	1,284	225	1,060	8.7	19.8	5.4	14.5	.05	.64	.162	.477	1.41	.31	1.1	.006	.48	16	150,000
Inlet tower	21	VVH	VVH	None	1,461	234	1,207	9.7	20.9	4.7	16.2	.046	.69	.14	.55	1.56	.30	1.22	.005	.56	17	27,500
400 feet from Missouri shore	21	VVH	VVH	None	1,584	243	1,341	10.7	21.8	4.14	17.7	.045	.70	.13	.57	1.58	.29	1.28	.004	.64	14	32,000
Missouri River at West Alton (Fort Bellefontaine)	19	VVH	VVH	None	1,479	275.7	1,089	13.75	17.3	2.3	14.1	.03	.56	.10	.46	1.33	.23	1.09	.003	.53	18	78,577
Mississippi River at Jefferson Barracks:																						
100 yards from Illinois shore	21	VVH	VVH	None	927.2	192.4	736	68.9	18.9	7.9	10.5	.053	.62	.21	.40	1.32	.38	.97	.015	.40	16	33,500
East of midstream	18	VVH	H	None	749.5	193.6	655	6.8	15.3	7.3	7.9	.37	.54	.22	.32	1.18	.38	.81	.009	.36	16	33,000
Midstream	21	VVH	VH	None	1,064.4	210	781	7.4	19.6	6.4	12.6	.042	.62	.20	.42	1.38	.35	1.03	.008	.46	17	29,500
West of midstream	18	VVH	VVH	None	1,043.1	236.8	806	9.2	15.7	5.3	10.3	.029	.55	.17	.38	1.30	.32	.98	.010	.47	14	43,500
100 yards from Missouri shore	21	VVH	VVH	None	1,271.3	236.9	1,034	10.3	18.7	4.9	13.7	.040	.65	.16	.49	1.45	.30	1.15	.009	.56	14	42,000
St. Louis tap water	18	VVH	VS	None	313	236.8	78	10.6	4.9	4	.9	.017	.17	.14	.03	.39	.29	.10	.005	.50	9	32,500

a H=heavy; VH=very heavy; VVH=very, very heavy; S=slight; VS=very slight; VVS=very, very slight; M=medium.

It should be noted in connection with the above testimony that the witness was careful to use the term "bacterial purity" and made no reference to the pathogenic bacteria or disease-producing material, his conclusions being based solely on the number of bacteria per cubic centimeter in the water, irrespective of their character.

The witness then testified that he had made examinations to determine the presence of the colon bacillus and the typhoid bacillus, and that the results for the colon bacillus are recorded in the tables of which Table 61 is an average. The typhoid bacillus was not found in any case. He further stated that he had found the *Bacillus prodigiosus* during an examination of waters, but that he could not positively state from such a result that it occurred normally in the waters found in the vicinity of Chicago. His opinion was that it was an accidental entrance upon the culture plate, indicating that this bacillus is occasionally present in the vicinity of Chicago and can be found by exposing suitable material for its growth. (4820–4821.)

CROSS-EXAMINATION.

The first portion of the cross-examination was devoted to questions of procedure in the bacteriological examination of water, in the course of which the witness stated that a whole cubic centimeter of water was very rarely used for the colony count, but the examinations were made by diluting 1 c. c. with a portion of sterile water and calculating the result by multiplying the amount found upon the plate by the degree of dilution. The degree of dilution was different in samples from various portions of the river, some being diluted 1 to 100 and others 1 to 1,000, according to the amount of dilution found necessary by preliminary experience. (4852–4854.)

After this testimony the witness was asked whether or not so minute a quantity of water examined was sufficient to determine with accuracy the bacterial condition of the whole canal or river at that point; to which he replied that it was not an exact demonstration in the sense that a mathematical demonstration would be, but it gave results that were comparable with other results reached similarly and at the same time, or in the same line of work. The bacterial count simply gave an idea of the numbers of bacteria present, without reference to the kinds, and was not sufficient to indicate the potability or unpotability of the water or the presence or absence of pathogenic bacteria. All of this led up to questions concerning statements made by the witness in his direct examination with reference to comparative bacterial purity, and he explained that the term "bacterial purity" is not recognized as indicating the sanitary condition of a water except so far as the general activity of decomposition is concerned, which has a slight bearing on the question of purity or impurity. (4854–4856.)

The cross-examiner then led up to a discussion of the quality of the pollution of Lake Michigan water at various points and its agency in producing typhoid fever in Chicago. On the admission of the witness that it was his belief that this disease in the city was caused by the pollution of the water supply by the city sewage, the cross-examiner attempted to demonstrate from the testimony of the witness that inasmuch as Chicago sewage could pollute the water of the lake, a quiescent body, for distances so far from the shore as had been demonstrated, it was reasonable to believe that the pathogenic organisms of typhoid might exist for great distances in a running stream—even for a distance as great as that intervening between Chicago and St. Louis by way of Illinois and Mississippi rivers. The witness replied in general that Lake Michigan is by no means a quiescent body of water, being subject to currents due to winds and other natural phenomena, and that, in addition to this, Lake Michigan is a large body of comparatively pure water, which, according to his experience, is much more favorable for the preservation of the life of typhoid organisms than the more highly polluted water of the drainage canal and upper Illinois River. (4857–4865.)

ARTHUR W. PALMER.

DIRECT EXAMINATION.

Arthur W. Palmer, called as a witness in behalf of the defendants, stated that he had been for fifteen years professor of chemistry in the University of Illinois. He was educated in the public schools of Illinois and at Illinois, Harvard, Berlin, and Göttingen universities, where he had specialized in chemistry. He had paid particular attention to water analysis, having been engaged in that work as a student, teacher, and investigator for a period of twenty-two years. (4903–4904.)

The witness then related the facts concerning the agreement between the department of health of Chicago, the University of Chicago, and the University of Illinois with reference to the examination of samples of water from the Illinois River system. These facts are as related in the testimony of Prof. E. O. Jordan. (4904–4905.)

The witness then stated the location of the various sampling points included in the accompanying tables and described the surroundings and pertinent facts in connection therewith. (4905–4922.)

The method of handling samples, the determinations made, and their significance were then described by the witness. (4922–4938.)

Pages 4939 to 4976 of the record are occupied by tabular statements of examinations made at selected sampling points along the stream during the period from April 28 to December 27, 1899. The results of examination of samples collected between January 11 and October 8, 1900, appear on pages 4977 to 5026. The witness then described the significance of the various entries in these tables. (5027–5039.)

He then presented tabular statements of the average results of the series of determinations. These results are reproduced in Table 62. (5040, 5042.)

TABLE 62.—*Average results of analyses of water from Illinois and Mississippi river systems, at selected points, 1899 and 1900.*

[Parts per million.]

No. of station.	Sampling point.	Date.	Number of samples.	Residue on evaporation. Total.	Residue on evaporation. Dissolved.	Residue on evaporation. Suspended.	Loss on ignition. Total.	Loss on ignition. Dissolved.	Loss on ignition. Suspended.	Chlorine.	Oxygen consumed. Total.	Oxygen consumed. Dissolved.	Oxygen consumed. Suspended.	Nitrogen as ammonia. Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.	Organic nitrogen. Total.	Organic nitrogen. Dissolved.	Organic nitrogen. Suspended.	Nitrogen. Nitrites.	Nitrogen. Nitrates.
		1899.																				
1	Illinois and Michigan Canal at Bridgeport	Apr. 27–Dec. 26	22	584.1	499.7	85.4	65.1	39.5	25.9	124.2	35.1	17.9	17.2	17.16	2.513	1.158	1.355	4.985	2.282	2.703	0.025	0.295
2	Illinois and Michigan Canal at Lockport	Apr. 24–Dec. 26	31	572.6	495.4	77.2	69.8	44.7	25.1	120.1	37.7	18.7	19	15.58	2.681	1.147	1.534	5.072	2.373	2.699	.015	.23
3	Desplaines River at Lockport	.....do	33	370.8	355.3	15.5	46.1	39.8	6.3	8.47	11.9	10.3	1.6	.077	.467	.374	.093	.986	.776	.21	.007	.29
4	Desplaines River at Joliet	May 23–Dec. 26	30	568.8	484.4	84.4	60.9	39	21.2	105.7	28.5	16.2	12.3	14.92	2.195	.831	1.364	4.502	1.732	2.77	.01	.208
5	.....do	May 23–Sept. 11	17	601.6	460.1	141.5	65.9	42.6	23.3	99.8	31.4	16.2	15.2	12.794	1.962	.621	1.341	4.35	2.999	1.351	.009	.26
6	Kankakee River at Wilmington	June 5–Dec. 26	29	302.7	262.5	39.4	57.8	29.7	5.6	3.9	11.1	9.2	1.9	.047	.372	.266	.106	.886	.643	.245	.011	1.084
7	Illinois River at Morris	May 29–Dec. 26	25	410.5	381.1	17.6	43.1	36.6	6	65.7	14.9	12.2	2.7	8.897	.911	.539	.372	1.916	1.116	.8	.026	.537
8	Fox River at Ottawa	May 29–Dec. 28	30	344.8	295.8	49	52.8	46.7	7.4	5.84	9.9	8.3	1.7	.056	.416	.27	.146	.94	.556	.384	.008	.373
9	Illinois River at Ottawa	June 19–Dec. 28	27	395.2	379.9	15.3	41.2	35.7	5.6	59.4	11.3	10.6	1	4.995	.498	.399	.099	1.111	.824	.287	.497	1.62
10	Vermilion River at La Salle	May 24–Dec. 26	32	1,023.1	992.8	30.3	91.5	83.4	8.1	64.9	6.4	4.9	1.5	.254	.244	.159	.085	.639	.406	.243	.022	.845
11	Illinois River at La Salle	May 5–Dec. 26	33	408.5	369.3	39.2	47.6	39.9	7.7	47.3	12.6	16.1	2.5	2.648	.503	.363	.14	1.216	.808	.408	.413	2.047
12	Illinois and Michigan Canal at La Salle	May 24–Dec. 26	32	367.6	331.8	35.8	51.2	44.9	6.3	16.95	10.9	8.5	2.4	.751	.499	.323	.176	1.244	.827	.417	.043	.62
13	Illinois River at Henry	May 30–Dec. 19	30	403.2	363.1	40.1	44.5	38.5	6	47.2	12.2	9.8	2.4	2.156	.594	.369	.225	1.382	.799	.583	.313	1.745
14	Illinois River at Averyville	May 1–Dec. 26	33	390.3	359.3	31	43.8	37.8	6	41.1	11.1	9.4	1.7	1.016	.49	.327	.163	1.143	.755	.388	.293	1.79
15	Illinois River at Wesley	May 29–Dec. 28	25	496.2	359.4	136.8	47.8	42.3	5.5	42.6	12.3	9.9	2.4	1.156	.691	.388	.303	1.603	.901	.702	.287	1.67
16	Illinois River at Pekin	May 24–Dec. 28	32	391.7	359.2	32.5	46.1	40.2	5.9	41.3	12.5	10	2.5	1.236	.681	.388	.293	1.532	.87	.662	.294	1.5
17	Illinois River at Havana	May 2–Dec. 20	33	386.5	343.9	42.6	42.4	36.6	5.8	35.8	12.1	9.6	2.5	1.203	.558	.36	.198	1.331	.816	.515	.227	1.12
18	Sangamon River at Chandlerville	May 31–Dec. 20	23	351.1	280.9	70.2	40.5	30	10.5	5.6	7.3	5	2.3	.115	.262	.154	.108	.72	.38	.34	.043	.62
19	Illinois River at Beardstown	May 24–Dec. 28	29	383.4	318	65.4	35.6	32.5	5.7	30.4	10.8	8.3	2.5	.89	.443	.284	.159	1.09	.655	.435	.147	1.08
20	Illinois River at Kampsville	May 2–Dec. 20	33	382.6	281.6	101	37.4	29.3	8.1	20.1	10.5	7.99	2.51	.27	.409	.241	.168	1.065	.645	.42	.054	.97
21	Illinois River at Grafton	May 3–Dec. 27	34	349.5	274.7	74.8	38.7	29.7	9	18.5	9.9	7.8	2.1	.221	.412	.217	.165	1.637	.609	.428	.051	1.07
22	Mississippi River at Grafton	May 3–Dec. 20	33	342.4	153.1	189.3	36.1	26.7	9.4	2.6	15.8	10.8	5	.039	.469	.218	.251	1.142	.489	.653	.01	.295
	Mississippi River at Alton:																					
23	Illinois shore	.....do	34	351	197.6	153.4	34.3	25.1	9.2	8.2	13.4	9.9	3.5	.062	.454	.241	.213	1.117	.552	.565	.019	.57
24	One-fourth distance from Illinois shore	.....do	34	343.8	178.3	165.5	34.4	26.1	8.3	5.8	14.5	10.6	3.9	.053	.569	.23	.239	1.147	.525	.622	.014	.422

25	Midstream	do	34	381	164.5	216.5	39.3	27.5	11.8	3.7	15.2	10.6	4.6	.041	.498	.218	.28	1.207	.484	.723	.009	.355
26	One-fourth distance from Missouri shore	do	34	402.9	157.3	245.6	40.8	27.1	13.7	2.7	15.2	10.8	4.4	.031	.512	.219	.293	1.269	.487	.782	.007	.344
27	Missouri shore	do	33	399.8	158.5	241.3	41.5	28.9	12.6	2.6	15.4	10.9	4.5	.032	.505	.232	.273	1.223	.498	.725	.009	.329
28	Missouri River at Fort Bellefontaine	July 8-Dec. 28	23	1,284.6	285.2	999.4	50.3	17.6	32.7	14.9	13.9	4.4	9.5	.03	.475	.102	.373	1.378	.272	1.106	.006	.337
	Mississippi River at Chain of Rocks:																					
29	Illinois shore	Apr. 28-Dec. 21	32	1,092.1	190.8	901.3	48.2	21.9	25.4	6	18.6	8.8	9.8	.039	.677	.201	.476	1.764	.45	1.314	.011	.442
30	Midstream	do	32	1,500.4	228.3	1,272.1	57.3	22.2	35.1	8	19.2	7.5	11.7	.027	.7	.162	.538	1.936	.383	1.553	.008	.387
31	Intake tower	do	32	1,109.6	232.8	876.7	60.2	20.6	39.6	9.1	19.5	6.8	12.7	.028	.726	.142	.584	2.174	.359	1.815	.007	.399
32	Missouri shore	do	32	1,909.3	247.1	1,662.2	61.8	19.9	41.9	9.8	19.9	6.3	13.6	.027	.817	.133	.684	2.358	.327	2.031	.007	.431
33	St. Louis tap water	June 6-Dec. 21	28	336	239.4	98.5	25.2	20	5.2	9.7	7.2	5.6	1.4	.022	.19	.125	.065	.57	.323	.247	.005	.342
	Mississippi River at Jefferson Barracks:																					
34	East shore	May 1-Dec. 21	31	1,104.9	196.2	908.7	49.8	24.3	26.3	6.2	19.1	8.6	10.5	.041	.682	.195	.487	1.789	.45	1.339	.01	.405
35	East of center	June 6-Dec. 21	28	1,174.6	197.1	977.5	53.8	22.5	31.3	6.4	19.9	8.6	11.3	.036	.678	.18	.498	1.852	.428	1.424	.008	.36
36	Center	May 1-Dec. 21	32	1,427.7	208.8	1,246.3	54.5	21.9	33.1	7	20.1	8.1	12	.031	.738	.175	.563	1.977	.396	1.581	.008	.366
37	West of center	June 6-Dec. 21	29	1,472.7	225.9	1,248.6	55.8	19.2	36.6	9	19.5	7.2	12.5	.031	.712	.151	.561	1.988	.338	1.65	.007	.367
38	West shore	May 1-Dec. 21	30	1,578	239.2	1,338.8	54.6	21.5	33.1	9.3	19.3	6.8	13	.037	.712	.143	.569	1.939	.356	1.583	.008	.35
		1900.																				
1a	Illinois and Michigan Canal at Bridgeport	Jan. 2-Oct. 8	29	449.3	405.8	43.5	38.8	26.6	12.2	118.5	17.7	9.5	8.2	10.614	1.632	.77	.862	3.466	1.436	2.025	.042	.296
1b	Sanitary canal at Kedzie avenue	Jan. 11-Oct. 8	51	212.8	172.1	40.7	25.6	18.3	7.3	14.2	9.8	4.9	4.9	1.247	.512	.176	.336	1.151	.398	.753	.015	.272
2	Illinois and Michigan canal at Lockport	Jan. 2-Sept. 24	36	518	451	67	42.7	30	12.7	135.2	20.7	11.1	9.6	13.4	1.814	.791	1.023	3.619	1.58	2.039	.016	.27
3	Sanitary canal at Lockport	Jan. 2-Sept. 28	58	264.6	241.5	23.1	30.6	24.7	5.9	12.3	8.9	6.5	2.4	9.986	.415	.232	.183	.918	.502	.416	.007	.39
4	Desplaines River at Joliet	Jan. 2-Oct. 8	41	265.2	231.9	33.3	29.8	22.4	7.4	30.4	11.1	7.3	3.8	2.971	.707	.402	.305	1.574	.83	.744	.031	.31
6	Kankakee River at Wilmington	Jan. 1-Sept. 27	34	334.4	259.5	74.9	38.4	31.8	6.6	3.3	11.3	8.2	3.1	.073	.371	.251	.12	.892	.567	.325	.014	2.208
7	Illinois River at Morris	Jan. 5-Sept. 25	39	287.7	237.2	50.5	29.5	23.9	5.6	23.5	10.4	6.7	3.7	2.374	.549	.275	.274	1.167	.635	.532	.1112	.761
8	Fox River at Ottawa	Jan. 4-Oct. 6	34	319.2	267.3	51.9	44.6	37.9	6.7	5.3	9.6	7.6	2	.13	.399	.251	.148	.816	491	.325	.008	.416
9	Illinois River at Ottawa	do	37	293.3	269.5	23.8	30.5	25.6	4.9	21.4	8.6	6.9	1.7	1.311	.39	.246	.144	.848	.537	.311	.051	1.624
10	Vermilion River at La Salle	Jan. 2-Oct. 2	40	480.7	409.9	70.9	52.3	42.8	9.5	16.4	7.3	4.8	2.5	.112	.259	.146	.113	.595	.314	.281	.018	3.522
11	Illinois River at La Salle	do	40	292.4	245.4	46.9	32	25.9	6.1	18.7	10.2	7.2	3	.963	.392	.251	.141	.944	.611	.333	.153	1.703
12	Illinois and Michigan Canal at La Salle	do	40	342.8	308.6	34.2	39.7	33.9	5.8	17.7	10.5	7.8	2.7	.944	.475	.327	.148	1.109	.697	.412	.049	1.005
13	Illinois River at Henry	Jan. 9-Oct. 1	37	293.3	243.8	49.5	31.9	25.1	6.8	16.7	9.9	7.2	2.7	.755	.4	.257	.143	.959	.572	.387	.118	1.551
14	Illinois River at Averyville	Jan. 2-Sept. 25	39	289.7	245.3	44.4	37.2	26.5	10.7	16.8	9.1	7.2	1.9	.653	.347	.233	.114	.781	.469	.312	.085	1.64
15	Illinois River at Wesley	Jan. 5-Oct. 3	38	325.1	246.4	78.7	34.9	26.2	8.7	17.5	10.1	6.9	3.2	.608	.386	.239	.147	.928	.547	.381	.07	1.535
16	Illinois River at Pekin	do	37	297.4	249.3	48.1	33.1	27.4	5.7	17.1	10.2	7.2	3	.672	.414	.244	.17	.924	.575	.349	.083	1.486
17	Illinois River at Havana	Jan. 11-Sept. 26	34	308	203.5	104.5	31.1	21.6	9.5	14.6	9.6	7.1	2.5	.616	.391	.235	.156	.921	.504	.417	.077	1.312
18	Sangamon River at Chandlerville	Jan. 3-Sept. 26	33	397.7	255	142.7	39.4	28.3	11.1	5	9.9	4.7	5.2	.107	.327	.146	.181	.783	.329	.454	.021	1.84
19	Illinois River at Beardstown	Jan. 4-Oct. 4	40	394.1	239.7	154.4	38.1	28.3	9.8	14.3	11.6	6.8	4.8	.507	.405	.236	.169	.966	.521	.445	.067	1.391
20	Illinois River at Kampsville	Jan. 3-Sept. 26	36	420.3	228	192.3	37.4	25.4	12	13.1	10.3	6.5	3.8	.394	.391	.208	.183	.97	.461	.509	.038	1.398
21	Illinois River at Grafton (see also below)	Jan. 4-Sept. 26	140	532	209.1	322.9	37.6	23.2	14.4	10.3	12.6	7	5.6	.401	.472	.233	.239	1.138	.481	.657	.021	1.426

TABLE 62.—*Average results of analyses of water from Illinois and Mississippi river systems, at selected points, 1899 and 1900*—Continued.

No. of station.	Sampling point.	Date.	Number of samples.	Residue on evaporation.						Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Organic nitrogen.			Nitrogen.	
							Loss on ignition.								Albuminoid.							
				Total.	Dissolved.	Suspended.	Total.	Dissolved.	Suspended.		Total.	Dissolved.	Suspended.	Free.	Total.	Dissolved.	Suspended.	Total.	Dissolved.	Suspended.	Nitrites.	Nitrates.
22	Mississippi River at Grafton (see also below)	Jan. 4–Sept. 28	90	440.8	150.5	290.3	39.9	23.8	16.1	3.78	15.8	8.9	6.9	.139	.537	.22	.317	1.208	.472	.736	.0076	.504
	Mississippi River at Alton:																					
23	Illinois shore	Jan. 4–Sept. 26	38	523.3	195.7	327.6	42.1	26.7	15.4	7.9	13.8	7.4	6.4	.269	.483	.212	.271	1.138	.477	.661	.017	1.063
24	One-fourth distance from Illinois shore	Jan. 4–Sept. 25	35	495.4	182.8	312.6	42.9	25.1	17.8	7.1	14.7	7.6	7.1	.259	.508	.196	.312	1.198	.434	.764	.014	.896
25	Midstream	Jan. 4–Sept. 26	37	418.3	161.1	257.2	40.7	25.1	15.6	4.8	15.3	8.8	6.5	.21	.514	.205	.309	1.15	.434	.716	.01	.56
26	One-fourth distance from Missouri shore	Jan. 4–Sept. 25	36	449.8	155	294.8	38.2	24	14.2	4.1	15.6	8.1	7.5	.175	.535	.21	.325	1.188	.433	.755	.01	.525
27	Missouri shore	Jan. 4–Sept. 26	38	436.3	154.7	281.6	39.1	23.5	15.6	4.1	15.2	9	6.2	.157	.507	.211	.296	1.144	.468	.676	.009	.535
28	Missouri River at Fort Bellefontaine	Jan. 4–Oct. 9	40	1,866.6	266.1	1,600.5	67.5	19	48.5	16.1	18.6	4.9	13.7	.092	.875	.134	.741	2.279	.325	1.954	.0072	.662
	Mississippi River at Chain of Rocks:																					
29	Illinois shore	Jan. 5–Oct. 4	61	769.7	180.3	589.4	44.7	23.6	21.1	6.86	15.9	7.8	8.1	.153	.542	.193	.349	1.288	.403	.885	.008	.698
30	Midstream	do	61	1,062.9	194.4	868.5	50	23.6	26.4	7.88	17.9	7.6	10.3	.115	.665	.181	.484	1.561	.411	1.15	.005	.579
31	Intake tower	do	61	1,545.9	215.3	1,330.6	57.5	20.5	37	10.9	19.6	6.1	13.5	.116	.774	.152	.622	1.938	.327	1.611	.005	.593
32	Missouri shore	Jan. 5–Oct. 1	59	1,406	241.2	1,164.8	55.1	20.9	34.2	13.3	19.7	4.9	14.8	.107	.825	.134	.691	2.131	.297	1.834	.005	.629
33	St. Louis tap water	Jan. 4–Oct. 4	40	340.9	243.6	97.3	28.1	20.6	7.5	11.9	7.5	5.7	1.8	.039	.205	.193	.012	.551	.309	.242	.005	.647
	Mississippi River at Jefferson Barracks:																					
34	East shore	Jan. 4–Apr. 20	15	671.4	185.4	486	38.6	18.6	20	7.02	15.2	7.6	7.6	.313	.631	.211	.42	1.545	.508	1.007	.017	1.016
35	East of center	do	14	653.4	187.7	465.7	39.4	19.6	10.8	7.6	14.9	7.5	7.4	.262	.604	.201	.403	1.463	.505	.958	.017	.963
36	Center	do	15	780.2	198.4	581.8	41	20.9	20.1	8.7	16	7.3	8.7	.302	.597	.232	.365	1.529	.475	1.054	.016	.853
37	West of center	do	14	977.6	268.8	688.8	38.4	17.5	20.9	11.7	15.7	7	8.7	.257	.685	.192	.493	1.611	.489	1.122	.015	.797
38	West shore	do	15	1,013.6	246.8	766.8	35.8	16	19.8	13.5	15.6	6.3	9.3	.242	.612	.178	.434	1.541	.409	1.132	.015	.76
21	Illinois River at Grafton	Jan. 4–Sept. 26	39	434.6	229.1	209.5	38.5	27.3	11.2	12.47	10.9	6.6	4.3	.37	.403	.205	.198	.931	.478	.453	.024	1.362
22	Mississippi River at Grafton	do	38	365	151.4	213.6	37.3	23.1	14.2	3.5	15.1	8.8	6.3	.111	.465	.216	.249	1.075	.453	.622	.007	.445

The witness then presented tables containing the averages of determinations made during the periods from June to September, inclusive, for 1899 and 1900, respectively, and following these read into the record two other tables showing, first, the average of determinations made during the four months, June to September, inclusive, 1899 and 1900, of samples taken from Illinois River at Grafton, Mississippi River at Grafton, and Missouri River at Fort Bellefontaine, together with the highest and lowest determinations during these periods at each of the points mentioned, also the averages for the same four-month periods for samples from a few other selected points; second, a similar statement based on all the determinations during the two years. (5047–5054.)

Evidence was then presented concerning the determination of dissolved oxygen in an extensive series of samples taken under special conditions from specified points in the canal and rivers under discussion. The determinations were made according to the Winkler and the Levy methods, and the results appear in a table occupying pages 5062–5068 of the record. The period covered by these examinations extended from the latter part of April, 1899, to the middle of October, 1900. With reference to the remark, "Test of keeping qualities," placed at certain points in the table, the witness explained that although most of the determinations were made on the spot at the time of collection it was desired to procure some information as to the changes taking place in the organic matter of the water during transportation from the sampling point to the laboratory. Therefore duplicate samples were taken, one being treated immediately and the other being reserved for a period varying from twelve hours to two days, after which the determination was made. Inasmuch as samples of waters containing organic matter suffer a loss of dissolved oxygen when they are allowed to stand out of their natural environment, a great diminution is regarded as an indication of inferiority in the water as compared with one in which the diminution is slight. In the samples so noted in the table the stability of the organic matter, or, in other words, the "keeping qualities" of the water, are indicated. (5055–5061.)

With reference to the results of the dissolved-oxygen determinations, the witness made the following statements: Illinois River water contains at all times a considerable percentage of the oxygen required for saturation, and at times is supersaturated. The supersaturation is due to the liberation of oxygen by chlorophyl-bearing organisms in the water. Samples shipped to the laboratory before being treated nearly always contained an amount of oxygen less than the amount of saturation, though those treated with mercuric chloride showed no diminution. It is certain that the actual content of dissolved oxygen expressed in the results is in many cases considerably less than the actual amount.

The witness then discussed these results in narrative form, calling attention to the various interpreting features. As these features are clearly apparent to the careful reader of the table they will not be repeated here. (5070–5079.)

Three diagrams were then presented and discussed, showing graphically the changes taking place in each of the constituents determined in samples of water taken from the established points hereinbefore designated during the two periods of investigations, 1899 and 1900. These diagrams merely show in another form the relations presented in Table 62 and therefore are not reproduced here. (5080–5097.)

The witness then introduced a series of plates, numbered 4 to 15, inclusive, showing graphically the average proportions of some of the more significant constituents of the waters of Illinois, Mississippi, and Missouri rivers, so that the conditions during similar periods in 1899 and 1900 might readily be compared. These plates are not here reproduced, because the facts that they are alleged to show may readily be taken from Table 62. (5097–5147.)

A series of tables containing the results of examinations made by the witness as director of the State water survey of Illinois was then presented. These analyses include weekly samples taken from the following points:

Lake Michigan at Chicago, 1897–1900.
Illinois and Michigan Canal at Lockport, 1897–1901.
Chicago drainage canal at Lockport, 1900–1901.
Desplaines River at Lockport, 1897–1901.
Desplaines River at Joliet (east and west sides), 1901.
Illinois River at Morris, 1897–1900.
Illinois River at Ottawa, 1899–1901.
Illinois River at La Salle, 1897–1900.
Illinois River at Averyville, 1897–1901.
Illinois River at Havana, 1897–1900.
Illinois River at Kampsville, 1897–1902.
Illinois River at Grafton, 1899–1902.
Mississippi River at Grafton, 1899–1901.
Mississippi River at Alton, 1897–1900.
Mississippi River at Quincy, 1897–1903.
Kankakee River at Wilmington, 1897–1900.
Fox River at Ottawa, 1898–1901.
Spoon River at Havana, 1897–1899.

These tables, with the subsequent explanations and reiterations for purposes of evidence, occupy pages 5166–5360 of the record. Averages of the results appear in Table 63.

The witness discussed the above results in part as follows: Up to the opening of the Chicago drainage canal the water in the old Illinois and Michigan Canal varied in character but little from year to year, but a great change followed the opening of the drainage canal. The relative proportion of organic matter in the old canal was greatly reduced, although the free ammonia became greater owing to the more speedy oxidation of the organic matter facilitated by the dilution. The proportions of ingredients in the water of the drainage canal show notable variations, due to various apparent causes, but the data show that the sewage discharged from the canal is far more dilute than that formerly discharged through the old Illinois and Michigan Canal. (5371–5372.)

After noting the changes in the character of the water, as shown by the determinations in Table 63, from the canals at Lockport down to Averyville, the witness stated that it was "highly probable" that the organic substances introduced at Chicago had been completely destroyed by the time the water reached Averyville, and that the organic matter remaining was of vegetable rather than of animal origin. The averages of the Averyville determinations show that the water at this point contains considerably less organic matter than is present in the water of the comparatively unpoluted tributary streams. (5388–5389.)

Calling attention to the averages of the Havana samples, the witness stated that enormous discharges from the distilleries and cow pens at Peoria and Pekin had created in the stretch of 45 miles of river lying between these two points and Havana what was practically an immense septic tank. This stretch of the river, especially the upper part, had been very offensive. Nevertheless, so active had been the natural processes of purification that at Havana the water was in practically as good condition as at Averyville, above the point of entrance of this pollution. The records after the opening of the drainage canal show, according to the witness, a greatly reduced proportion of organic constituents. (5392–5393.)

The testimony of the witness, found on pages 5394–5451 of the record, was devoted to a review of the data given in Table 63. The variations shown were narrated and the figures presented in manifold ways and groups, both tabular and diagrammatic. As nothing was added by way of evidence or deduction, beyond that which is readily apparent in Table 63, no digest of this portion of the testimony will be made.

Table 63.—*Averages of results of analyses of samples of water from designated streams at specified points and dates.* (*5362–5393*).

[Parts per million.]

Sampling point and date.	Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Organic nitrogen.			Nitrogen as—	
						Albuminoid.							
		Total.	Dissolved.	Suspended.	Free.	Total.	Dissolved.	Suspended.	Total.	Dissolved.	Suspended.	Nitrites.	Nitrates.
Illinois and Michigan Canal at Lockport:													
1896	119.1	39.2	14.7	24.5	14.99	2.55	1.17	1.38	5.17	2.19	2.98	0.007	0.195
1897	115.4	38.3	18.1	20.2	12.4	2.72	1.34	1.38	4.94	2.31	2.63	.039	.338
1898	116.8	42.2	19.1	23.1	12.7	2.86	1.48	1.38	5.52	2.5	3.02	.072	.417
1899	135.2	39.5	21.2	18.3	13.9	2.93	1.44	1.51	5.56	2.84	2.72	.013	.217
Average	121.6	39.8	18.3	21.5	13.5	2.77	1.36	1.41	5.3	2.46	2.84	.033	.292
1900	135	21	11.5	9.5	12.6	1.77	.77	1	3.62	1.51	2.11	.022	.272
1901	133.2	18.8	13.7	5.1	17.6	1.16	.7	.46	2.18	1.45	.73	.025	.208
Average		19.9	12.6	7.3	15.1	1.47	.735	.73	2.9	1.48	1.42	.023	.24
Chicago drainage canal at Lockport:													
1900	15.6	7.65	5.12	2.53	1.593	.421	.183	.238	.985	.442	.543	.006	.237
1901	14.5	9.29	6.76	2.53	1.715	.422	.238	.184	.99	.532	.58	.023	.183
Average	15	8.47	5.94	2.53	1.654	.421	.210	.211	.987	.486	.5	.015	.21
Desplaines River at Joliet:													
1899	105.7	28.5	16.2	12.3	14.92	2.195	.831	1.364	4.502	1.732	2.77	.01	.208
1900	30.4	11.1	7.3	3.8	2.971	.707	.402	.305	1.574	.83	7.44	.031	.31
1901 (east side)	29.7	9.7	7.4	2.3	3.335	.478	.269	.209	1.05	.574	.476	.031	.334
1901 (west side)	14.7	8.6	6.7	1.9	1.629	.359	.218	.141	.871	.515	.356	.03	.268
Average	22.2	9.1	7.0	2.1	2.492	.418	.243	.175	.96	.544	.416	.03	.296
Illinois River at Morris:													
January to December, 1896	29.7	14.5	....	....	3.55	.709	....	....	1.44	....	....	.149	1.72
January to December, 1897	45.7	15.9	10.3	5.6	5.78	.862	.46	.402	1.608	.895	.71	.15	1.097
January to September, 1898	34.7	17.3	....	....	4.109	1.398	....	....	2.491	....	....	.016	.893
May to December, 1899	65.6	14.7	12.1	2.6	8.9	.911	.59	.372	1.915	1.115	.8	.026	.553
Four years average	44.4	15.6	11.2	4.1	5.585	.97	.499	.387	1.8625	1.05	.756	.0965	1.0665
1900	23.1	12.3	6.7	5.6	2.075	.535	.269	.266	1.162	.631	.531	.108	.717
Fox River at Ottawa:													
March to December, 1898	7.93	9.3	7.1	2.2	.064	.407	.288	.119	.823	.553	.27	.027	.471
May to December, 1899	5.84	9.9	8.3	1.6	.055	.416	.27	.146	.94	.555	.385	.008	.373
January to October, 1900	5.3	9.6	7.5	2.1	.129	.399	.251	.148	.815	.491	.324	.008	.416
Average	6.36	9.6	7.63	1.96	.083	.407	.27	.137	.86	.533	.326	.014	.42

Illinois River at Ottawa:													
June to December, 1899	59.5	11.3	10.5	1.13	4.99	.498	.399	.099	1.111	.824	.287	.496	1.847
January to October, 1900	21.3	8.6	6.9	1.7	1.311	.39	.244	.147	.848	.537	.311	.25	1.62
July to October, 1901	28.5	6.6	5.8	.8	.97	.223	.173	.05	.898	.508	.39	.454	1.209
Illinois River at La Salle:													
January to December, 1896	19.6	12.3	9.04	3.26	.971	.612	.429	.183	1.260	.98	.28	.255	2.51
January to December, 1897	30.9	13.1	9.6	3.5	1.728	.6	.384	.216	1.234	.891	.343	.442	2.14
January to December, 1898	25.9	11.2	8.4	2.8	1.396	.488	.357	.131	1.158	.721	.437	.25	9.55
February to December, 1899	44.7	13.6	10.4	3.2	2.536	.482	.379	.103	1.285	.807	.478	.385	1.955
Four years average	30.28	12.55	9.36	3.19	1.658	.5455	.387	.158	1.234	.852	.386	.333	1.89
1900	18.7	10.1	7.2	2.9	.963	.391	.251	.141	.944	.611	.333	.152	1.7
Illinois River at Averyville:													
April to December, 1897	37.9	11.3	9.4	1.9	.843	.503	.367	.136	1.01	.794	.216	.254	1.69
April to December, 1898	21.4	9.3	7.5	1.8	.86	.403	.316	.087	.83	.646	.184	.124	.807
April to December, 1899	47.2	12.9	9.4	3.5	1.025	.494	.325	.169	1.11	.722	.388	.204	1.558
Three years average	30.2	11.1	8.76	2.4	.909	.466	.336	.13	.98	.72	.262	.194	1.351
1900	17.5	8.4	6.6	1.8	.639	.323	.226	.101	.767	.534	.233	.079	1.584
1901	17.5	7.7	6.7	1	.647	.249	.198	.051	.717	.575	.141	.081	1.337
Two years average	17.5	8.05	6.6	1.4	.643	.286	.212	.076	.742	.555	.187	.08	1.46
Illinois River at Havana:													
1896	15.1	10.9	....	....	.63	.49	....	....	1.17	....	....	.174	2.34
1897	24.8	10.8	9.6	1.2	.893	.46	.41	.05	.988	.717	.271	.203	1.66
1898	19.6	9.3	7.5	1.8	.95	.43	.32	.11	.92	.683	.237	.121	.809
1899	27.3	13.3	9.8	3.5	1.104	.56	.35	.21	1.303	.788	.515	.163	1.133
Four years average	21.7	11.1	8.97	2.16	.894	.485	.365	.12	1.095	.729	.341	.155	1.485
Three years average (1897–1899)	23.9	11.1	8.97	2.16	.982	.484	.365	.12	1.071	.729	.341	.162	1.2
1900	14.8	8.7	6.8	1.9	.585	.361	.23	.131	.839	.533	.306	.07	1.308
Illinois River at Kampsville:													
1897	19.3	10.9	7.7	3.2	.351	.509	.303	.206	1.024	.691	.333	.08	1.553
1898	12.6	11.7	6.8	4.9	.372	.484	.278	.206	1.018	.579	.439	.069	.764
1899	16.5	12.4	8.2	4.2	.392	.473	.257	.216	1.129	.623	.506	.052	.988
Three years average	16.1	11.7	7.5	4.1	.371	.488	.279	.209	1.057	.631	.426	.069	1.101
1900	14.1	11.5	6.1	5.4	.382	.36	.206	.154	.904	.481	.423	.038	1.436
1901	15.6	9.4	7.2	2.2	.375	.338	.218	.12	.999	.579	.42	.044	1.221
1902	10.2	11.3	8.1	3.2	.424	.349	.23	.119	....	....	....	.039	1.219
Three years average	13.3	10.7	7.1	3.6	.393	.349	.218	.131	.951	.53	.421	.04	1.292

The witness then presented a diagram showing the relative proportions of upper Mississippi River water and Illinois River water at five points in a cross section of Mississippi River, 16 miles below the mouth of Illinois River and 7 miles above the mouth of Missouri River, calculated from the average chlorine content at those points as determined from weekly analyses throughout 1899 and 1900. From this diagram it appears that in 1899 the average chlorine in Mississippi River above Grafton was 2.9 parts per million and in the Illinois above Grafton 15.2 parts. At the cross section above mentioned the water at the Missouri shore contained 3.2 parts, equivalent to 2.4 per cent of Illinois River water. At one-fourth the distance from the Missouri shore the water contained 3.5 parts of chlorine, equivalent to 4.8 per cent of Illinois River water. In midstream there were 4.3 parts of chlorine, equivalent to 11.3 per cent of Illinois River water. At three-fourths the distance from the Missouri shore, or one-fourth the distance from the Illinois shore, there were 5.8 parts of chlorine, equivalent to 23.5 per cent of Illinois River water, while at the Illinois shore there were 7.5 parts of chlorine, equivalent to 38 per cent Illinois River water. The record for 1900 was given as follows:

Average chlorine in Mississippi River water above Grafton, 3.1 parts per million; in Illinois River water above Grafton, 13.1 parts. Proportions and percentages at the five points in the cross section, taken in the same order as for 1899, 3.5 parts, equivalent to 4 per cent Illinois water; 4.1 parts, or 10 per cent; 4.4 parts, or 13 per cent; 7.1 parts, or 40 per cent; 7.6 parts, or 46 per cent.

From these figures the witness expressed the opinion that the waters of Mississippi and Illinois rivers were by no means commingled by the time they reached the mouth of Missouri River. (5452–5454.)

The witness then expressed the opinion that there is no satisfactory basis on which a calculation of the relative proportions of water from Mississippi, Illinois, and Missouri rivers entering the intake at Chain of Rocks could be made, but for all such calculations the chlorine determination would be the most satisfactory, because chlorine is not, like the various forms of nitrogen, a variable constituent. It would not be practicable to determine these proportions from free ammonia or from nitrites because the amounts of these constituents change by reason of decomposition processes going on within the water. The comparative proportions of total solids might be used for this purpose if the amounts in the three waters differed sufficiently, but even then errors would arise because total solids include both dissolved and suspended matter. Variations in the amount of solids in suspension, caused by variations in velocity of flow or in character of material underlying the stream bed and constituting the banks, would take place without any corresponding changes in the amount of water contributed by the stream. Estimates of proportional contribution based on suspended matter would be unsatisfactory for the same reason. (5452–5457.)

Further testimony of the witness, occupying pages 5459–5511, inclusive, comprised the narration of chemical facts given in Table 63, together with amplifications of the same, accompanied by diagrams. Included in this part of the testimony were diagrammatic representations of the stages of water in Illinois, Mississippi, and Missouri rivers, scaled in with coincident analytical records, the purpose of which was to show that increase in the determinations, such as total organic nitrogen, free and albuminoid ammonia, etc., were the result of or were attended by increased flow in the rivers, and were not caused by increase in polluting material. The witness believed that the fact that these changes took place in the water of Mississippi and Missouri rivers as consistently as in that of the Illinois was important evidence that the apparently unfavorable changes in the composition of the Illinois water were not the result of pollution from the Chicago drainage canal. In other words, he was of the opinion that such pollution had not changed the character of the water of Mississippi River at Chain of Rocks. (5511–5512.)

The witness offered in evidence the results of analyses of special cross-section samples taken as follows:

Illinois River at Averyville, July 21, 1899, and November 26, 1901.
Illinois River at Wesley, July 22, 1899.
Illinois River at foot of Terminal Bridge [Pekin], November 26, 1901.
Illinois River below Pekin, November 26, 1901.
Illinois River at Grafton, January 5, and July 28, 1899.
Mississippi River at Grafton, January 5 and 18, February 15, May 24, and July 28, 1899.
Mississippi River at Hartford, July 7 and August 17, 1900.
Mississippi River at Chain of Rocks, April 14 and December 7, 1899.
Mississippi River at Alton, December 6, 1899.

He then made the following statements: At Averyville the waters are substantially uniform in quality throughout the entire section. At Wesley the waters are not uniform, the greatest amount of pollution being near the west shore. The same is true at the Terminal Bridge. Substantially uniform conditions prevail throughout the cross sections in Illinois River at Grafton. The waters of Illinois and Mississippi rivers are not perfectly commingled at Hartford, that of the Illinois persisting mainly along the Illinois shore. The cross-section samples at Mitchell, 2 miles below the mouth of Missouri River, show that the three bodies of water remain distinct. (5515–5525.)

Pages 5532–5558 of the record contain the analytical results of further examinations made during October, November, and December, 1901, of samples taken from the following points:

Illinois River at Averyville.
Illinois River at Pekin.
Illinois River at Grafton.
Mississippi River at Grafton.
Missouri River at Fort Bellefontaine.
Mississippi River at Chain of Rocks (Illinois shore, midstream, intake tower, and Missouri shore).

Concerning the figures the witness stated that the waters of the three rivers—Mississippi, Illinois, and Missouri—show great differences, and that water from the Illinois is deflected toward the eastern shore of the Mississippi and only small proportions of it come into immediate contact with water from the Missouri. In total oxygen required the waters from the three rivers rank from highest to lowest in the following order: Missouri River, Mississippi River, Illinois River. In oxygen required by matter in solution they rank from highest to lowest in the following order: Mississippi River, Illinois River, Missouri River. Comparison of the results from the three rivers in 1901 with results in 1899 showed improvement in the Mississippi and Illinois River waters and deterioration in the Missouri River water. (5559–5563.)

With reference to the amount of organic matter in the water of Illinois River before and after the opening of the drainage canal, the witness stated that the results of determinations of organic nitrogen by the Kjeldahl process on samples taken from Illinois River at Kampsville during 1897 to 1902, inclusive, showed an average of 1.087 parts per million before the opening of the canal and 0.8966 part per million afterwards. This represents a decrease of 17.48 per cent. Similar data for dissolved organic nitrogen showed a decrease of 17.92 per cent for the three years after the opening of the canal. During the same period there was 25 per cent decrease in the albuminoid ammonia, 6 per cent increase in free ammonia, 40 per cent decrease in nitrites, and 15.67 per cent increase in nitrates. (5567–5573.)

The witness then entered into a long and very much involved discussion of the amounts of organic nitrogen discharged into Desplaines River during the years immediately before and subsequent to the opening of the canal, and the persistence of the same downstream. Numerous tables were given, showing amounts in tons, etc., all of which made an interesting and clever discussion of the nitrogen question, but can hardly be said to be particularly relevant to the case at hand. The matter occupies pages 5575–5627 of the record.

In closing his direct testimony the witness drew the following conclusions:

First. The opening of the Chicago drainage canal improved the condition of the water in Illinois River all along its course.

Second. The waters of the Illinois above its mouth, of the Mississippi above the mouth of the Illinois, and of the Missouri above its confluence with the Mississippi are unfit for drinking purposes in the raw state.

Third. The discharge of sewage from the Chicago drainage canal does not injuriously affect the water of the Mississippi along the eastern border of the State of Missouri, but, on the contrary, the influx of pure water from Lake Michigan into Illinois River has caused a more complete destruction of the organic matter from Chicago sewage than under former conditions, when said sewage was discharged through the Illinois and Michigan Canal. (5640–5643.)

CROSS-EXAMINATION.

With reference to the accuracy and significance of his analytical work on the streams of Illinois, the witness presented the following opinions:

The analyses placed in the record throw much light on the sanitary condition of the water, but do not directly determine the absence or presence of disease organisms. They do, however, show the presence or absence of sewage, and therefore indicate the possible presence or absence of substances which as a class are objectionable in drinking waters for the reason that they themselves or the substances which accompany them are deleterious to health when introduced into the system through drink. "The basis for the detection of the presence and the kind and the characteristics of the disease-producing organisms and substances which in sewage and waters at times accompany the chemical constituents found in these fluids rests mainly upon the various chemical reactions and decompositions which said organisms and substances produce and the chemical substances which result from their action." Without a recognition of the significance of the chemical changes which disease-producing organisms bring about, there would be no means of determining their presence in running water, but this branch of the science is called bacteriology. (5644–5647.)

The substances whose presence and proportion are shown by the ordinary sanitary analysis include those which serve as the food supply of micro-organisms, together with the substances of which those micro-organisms, both the good and the bad, are made up. Chemistry does determine the harmful substances or the toxins, but in ordinary analytical work no practicable method is known for separating these substances and determining their proportions. The chemist can distinguish between those nitrogenous organic matters that are of a proteid character and serve as a food supply for micro-organisms and other nitrogenous organic matters that are not proteid in character, but are the products of vital processes, such as toxins. (5650–5652.)

With reference to the frequency of the determinations, the witness said:

While it is always desirable to have as many analyses as is possible, and even more than the number which I made for, say, * * * Kampsville, practical reasons * * * prevented my making more * * * during the periods covered in my testimony, and it is my opinion that the evidence * * * submitted covers the case reasonably well. * * * The water of Illinois River at Kampsville has not been at other times during the period in question materially different from the condition revealed by the analyses which I have submitted in evidence. * * *

It is quite possible, in the opinion of the witness, that different samples taken at the same point at the same time and by the same collector would show a material difference in chemical constituents when analyzed by different chemists, but the averages of a considerable number of such samples would not be materially different, although no table of averages would give a correct representation of the water in this stream at all times. (5660–5661.)

The witness stated that the analytical methods used by Professor Jordan of the University of Chicago, by Mr. Bisbee of the Chicago health department, and by himself were substantially the same. (5658–5659.)

The following questions and answers appear on pages 5663–5666 of the record:

Q. Professor, referring to Table No. 20, of the series of Tables 1 to 80, inclusive, introduced and read in evidence by yourself, and to Table 178, being tables introduced by the defendants and known as defendants' tables of streams examinations, 1 to 196, which constitute a part of the testimony of Mr. Bisbee, we find upon comparison of these tables that during the month of September, 1899, there were samples collected by the water takers at that point, and these samples are known in the evidence of these water takers as companion samples, one of each of which was shipped to you and the other shipped to Mr. Bisbee, and of these samples you analyzed four, the analyses of which were made by you September 7, September 14, September 21, and September 28; and of these samples Mr. Bisbee analyzed three, to wit, September 7, September 14, and September 21. These samples were collected on the 6th, 13th, 20th, and 27th days of September, 1899. Upon your determination of the chemical constituents of those samples, you found that on September 7 to contain 1.0 of organic nitrogen; of the samples analyzed on the 14th of September you found 0.84 of organic nitrogen, and of the sample analyzed on the 21st of September you found 1.0 of organic nitrogen, and the sample examined by you on the 28th of September you found 0.82 of organic nitrogen. Mr. Bisbee in his analyses found contained in the sample analyzed by him on September 7, total organic nitrogen, 0.60; that analyzed on the 14th of September, organic nitrogen, 1.04, and that analyzed by him on the 21st day of September, total organic nitrogen, 0.76, no analyses having been made by him of the sample collected on the 27th of September so far as organic nitrogen was concerned. All these samples were taken from the Illinois River at Kampsville. Now, do not these analyses show upon comparison a material difference with reference to the constituent known as total organic nitrogen in the waters of the Illinois River at Kampsville for the month of September, 1899, comparatively speaking?

A. They do not, in my opinion, show a substantial difference in the content of total organic nitrogen in the water of the Illinois River at Kampsville during the month of September, 1899, for the reason that they are, in my opinion, partly the result of differences in the details of the method used in the determination of the total organic nitrogen, although the method employed was in general the same in both cases, that is, in the analyses made by Mr. Bisbee and those made by myself, and for the further reason that the averages for the month—that is, the average proportion for the three analyses made by Mr. Bisbee—namely, those made upon samples collected upon the 6th, the 13th, and the 20th of September, 1899, respectively, and those made by me upon samples collected upon the same days in the same month of 1899, which samples were collected simultaneously with those analyzed by Mr. Bisbee, for I find that the average for the three determinations made by Mr. Bisbee were 0.8 part per million, the average for the three samples analyzed by me corresponding to the three examined by Mr. Bisbee were 0.95, a much less difference than is indicated between certain of the individual determinations included in these six analyses.

Q. I will ask you, Professor, if that difference, taking the average difference between the examinations made by Professor Bisbee and those made by yourself, does not amount to 18.8 per cent, counting yours as 100 per cent, or as being accurate?

A. Assuming as the basis for the calculation my own average, 0.95, the difference between the two averages is 15.78 per cent, while taking Mr. Bisbee's average of 0.8 as the basis of the calculation the difference is 18.75 per cent.

Q. Now, may not these same differences of 40 per cent, 23.8 per cent, and 24 per cent have occurred, even though you had made the analyses in both instances, for the month of September instead of having been made one by yourself and the other by Mr. Bisbee?

A. In my opinion they would not.

Q. Is it a fact that Mr. Bisbee's results are always higher or lower than yours, or do they not vary first one way and then the other?

A. So far as I am aware they vary in both directions, some of them being higher and some of them being lower than my own.

Q. Now I will ask you, Professor, if it is not a fact that a comparison of the analytical results of the samples of water collected in September, 1899, at Kampsville and examined by yourself and by Professor Bisbee do not show either a very rapid change in the chemical condition of that water or do not show extensive variations, chemically speaking, in the water at that time and place and even on the dates and at the hour of collecting the samples?

A. In my opinion, these variations in the results of the analyses do not indicate similarly considerable variations in the actual content of the total organic nitrogen in the water samples collected at the same date and hour, nor do they show rapid variations in these substances contained in the water; but, in my opinion, the variations in the determinations as recorded in the tables you have quoted are very largely the result of differences in the details of the method employed in making these determinations, to which I have referred in my answer to the preceding question.

Q. Do those variations—to wit, variations comparatively speaking, shown between the analyses made by yourself and those made by Mr. Bisbee—result from differences in accuracies or differences in inaccuracies?

A. Doubtless they are in part due to both; but in my opinion in the main they are due to variations in the details of the processes to which I have referred in my answers to the two preceding questions.

No allowance had been made in reporting the analytical results presented in the evidence of the witness for errors resulting from changes in organic matter during the period of transit from sampling point to laboratory, because the conditions governing these changes were similar throughout the six-year period. Consequently such changes as had occurred would affect all the samples, and therefore the basis of comparison of the first half with the last half of said period would not be affected. The variations arising from considering a sample taken at any time as representative of the water in the entire stream are, in the opinion of the witness, eliminated in a long series of analyses, and a series of results is afforded that may be considered strictly comparable. (5680–5683.)

Q. Professor, assuming that there is discharged into the Illinois River, by means of the drainage canal, the sewage from the city of Chicago, which contains certain organisms which produce typhoid fever; assuming that those organisms are of a living character and that they live in the sewage of Chicago, the drainage canal, and the waters of the Illinois River from five to thirty days or more, disappearing by death gradually at from five to thirty days or more, until at the end of thirty days or more all have become innocuous; assuming further that they flow down the canal to the Illinois River with the water and with the same velocity as the water in the canal and the river. Assume that the mean velocity from Chicago to St. Louis is eighteen days: assume that the average life of these organisms has expired at some point between Averyville and Grafton, but assume also that, as heretofore stated, the extreme life limits will carry them in thirty days or more to a point far below St. Louis. State whether or not a table of averages upon the life limit of these organisms, which shows that such average took place at some point in the river between Averyville and Grafton, can be used by a sanitarian or by a sanitary chemist as proof, from a practical sanitary standpoint, that no such disease-producing organisms pass a given point between Averyville and Grafton and do not reach the St. Louis intake at the Chain of Rocks and pass beyond the city of St. Louis.

A. It, in my opinion, can not; but the conditions prevailing in the Mississippi River between Grafton and the Chain of Rocks as to the mixing of the waters in the Illinois with the waters of the Mississippi and the waters of the Missouri render it, in my opinion, highly improbable that any considerable proportion of such pathogenic germs as may be contained in the waters of the Illinois at Grafton—that is, if we grant the assumption of the question—passes down the Mississippi to the point below, St. Louis, and is taken into the intake of the St. Louis waterworks. (5694–5697.)

THOMAS J. BURRILL.

DIRECT EXAMINATION.

Thomas J. Burrill, called as a witness in behalf of the defendants, stated that he had graduated from the Illinois State Normal University in 1863, having specialized in biology, and that since that time he had been engaged continuously in botanical studies, especially cryptogamic. He had been teaching botany at the University of Illinois for thirty-five years and at the date of testimony was professor of botany there. He had lectured before different societies in this country and in England and had received the degrees of M. A., Ph. D., and LL. D. He had made numerous official water studies in the State of Illinois. (5711–5716.)

Beginning in May, 1899, the witness made a series of bacteriological examinations of samples from selected points on Illinois River and tributaries, including the Chicago drainage canal, in collaboration with Professors Palmer and Jordan. The results of these examinations are set forth in Table 64. (5724–5725.)

In introducing the above results, the witness stated that the decrease in the number of bacteria between Morris and Ottawa is out of all proportion to that which would be caused by the dilution received from tributary streams, indicating that there has been a considerable degree of purification. The decrease is maintained to Averyville, where the number equals that of ordinary river water not subject to contamination, proving that the pollution from Chicago has practically disappeared. The same is true at Grafton. The figures further show that there is practically no difference in bacteriological purity between the waters of Illinois River above Grafton and of Mississippi River above Grafton, but that the water from Missouri River at Fort Bellefontaine has greater contamination than the other two. The witness could not state probable causes, but noted that the temperature of Missouri River was lower than that of the Mississippi, which had something to do with the lessened rate of decrease—that is, in lowering the activity of the bacteria that destroy the organic matter. (5748–5749.)

The witness then gave the results of his tests for *Bacillus coli communis* during June, July, August, and September, 1899 and 1900. The figures in Table 65 are based on the diagrams, page 5754, and there may be some small errors due to incorrect reading of the scales. They are probably not significant, however.

TABLE 64.—*Monthly averages of determinations of the number of bacteria per cubic centimeter in samples of water taken at designated points.*

Sampling point.	Year.	January	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Drainage canal at Kedzie avenue	1900					1,474,000	377,000	863,888	1,233,700	1,186,665			
Illinois and Michigan Canal at Bridgeport	1899						1,035,500	3,895,555		2,483,333	2,150,000	2,497,000	2,151,666
Do	1900	3,862,000	6,063,333	4,240,000	6,037,500				1,215,000	315,000			
Illinois and Michigan Canal at Lockport	1899						3,885,750	5,323,750	3,215,000	696,666	1,335,000	582,000	746,250
Do	1900	2,256,000		4,405,000	3,891,250	1,649,000	997,500	731,250	790,000	3,290,000			
Desplaines River at Lockport	1899						14,912	11,162	38,850	24,160	25,783	9,640	16,300
Do	1900	42,370		167,500	21,375	5,647	40,162						
Drainage canal at Lockport	1900							601,250	1,205,666	651,666			
Desplaines River at Joliet	1899						1,445,000	2,848,666	3,220,000	217,000	1,145,000	1,023,000	1,026,250
Do	1900	973,000	1,448,333	2,000,000	1,655,000	485,000	18,000	170,000	134,750	203,330			
Desplaines River south of Joliet	1899						1,369,375	3,201,666	4,611,666	985,000			
Kankakee River at Wilmington	1899						22,837	4,720	4,000	5,387	11,075	11,650	25,300
Do	1900	5,790	102,000	75,250	52,000	3,300	3,650	950	1,975	4,950			
Illinois River at Morris	1899						999,875	930,750	4,882,375	2,186,100	505,000	747,000	170,000
Do	1900	2,737,500	1,731,250	1,593,750	392,500	46,200	246,125	42,375	76,600	624,750			
Illinois River at Ottawa	1899						20,550	9,298	7,512	40,100	33,050	18,070	261,766
Do	1900	256,250	228,000	116,750	68,500	15,125	14,237	2,950	18,830	34,875			
Fox River at Ottawa	1899						11,027	3,670	4,560	4,822	5,475	5,900	7,000
Do	1900	12,275		84,166	49,250	5,800	2,412	3,266	2,962	9,375			
Illinois River at La Salle	1899						17,800	6,370	11,875	9,700	27,112	11,910	101,400
Do	1900	192,400	278,750	367,666	96,125	13,050	12,275	3,500	13,000	17,412			
Illinois and Michigan Canal at La Salle	1899						170,050	157,766	241,000	166,375	131,250	164,400	223,000
Do	1900	193,300	169,625	212,000	157,750	25,300	31,062	38,375	17,200	73,775			
Vermilion River at La Salle	1899						7,062	4,510	1,480	3,102	3,987	14,050	12,757
Do	1900	13,750	45,912	103,125	33,000	22,270	8,550	5,475	7,000	2,200			
Illinois River at Henry	1899						64,350	22,362	26,350	11,100	8,575	5,880	59,966
Do	1900	41,462	160,500	183,625	39,875	14,260	3,487	40,433	1,850	136,700			
Illinois River at Averyville	1899						8,700	9,358	4,000	3,100	3,768	1,640	9,300
Do	1900	27,570	129,500	93,375	13,087	15,920	1,637	4,233	8,060	4,466			
Illinois River at Wesley	1899						1,476,480	3,925,000	2,355,000	484,575	2,373,750	705,000	20,666
Do	1900	89,000	95,666	107,750	22,750	70,400	58,625	96,000	99,250	264,375			
Illinois River at Pekin	1899						1,500,000	737,625	1,928,333	391,250	1,047,500	812,000	69,000
Do	1900	128,100	84,000	125,125	27,250	106,500	150,625	313,375	286,500	1,061,875			
Illinois River at Havana	1899						6,816	5,950	5,725	6,137	12,433	159,040	301,333
Do	1900	124,166	79,575	181,875	26,500	23,850	15,000	24,125	21,362	50,662			
Sangamon River at Chandlerville	1899						7,125	9,900	19,783	20,300	3,683	7,100	10,266
Do	1900	10,620	101,433	105,875	13,625	11,850	29,562	13,900	4,450	4,316			
Illinois River at Beardstown	1899						4,400	1,352	10,287	3,039	5,000	26,070	114,100
Do	1900	239,750	420,500	145,750	28,375	12,880	7,962	4,275	15,090	5,550			
Illinois River at Kampsville	1899						5,316	3,161	6,225	3,480	1,717	5,065	28,850
Do	1900	36,725	202,666	155,625	15,825	5,038	2,425	1,850	10,700	5,850			
Illinois River at Grafton	1899						4,155	2,628	1,806	793	743	7,210	40,344
Do	1900	46,600	191,500	159,500	14,550	6,850	6,875	3,911	2,708	5,274			
Mississippi River at Grafton	1899						5,017	915	1,379	2,356	2,406	8,380	15,912
Do	1900	13,750	69,625	227,750	66,750	10,580	3,650	3,027	3,291	3,932			

Mississippi River at Alton:														
100 feet from Illinois shore	1899						2,475	1,242	3,319	3,612	2,575	9,600	23,750
Do	1900	20,470	86,500	119,750	18,125	17,620	13,125	3,266	3,180	6,687			
One-fourth distance from Illinois shore	1899						6,087	809	2,355	3,000	2,112	17,630	22,533
Do	1900	18,940	98,125	175,000	46,625	18,180	7,875	4,800	6,180	5,500			
Center of channel	1899						5,775	2,021	2,465	3,725	2,425	7,160	18,300
Do	1900	23,380	105,125	166,250	66,000	26,000	4,375	6,966	6,710	8,200			
One-fourth distance from Missouri shore	1899						5,725	1,753	2,647	2,525	2,375	6,390	8,416
Do	1900	19,040	88,500	149,875	48,500	16,040	6,750	9,050	5,640	6,400			
100 feet from Missouri shore	1899						7,250	2,927	2,215	2,562	2,200	5,730	4,183
Do	1900	18,620	104,100	144,875	85,500	24,080	5,875	3,862	7,610	4,433			
Mississippi River at Chain of Rocks:														
400 yards from Illinois shore	1899						19,706	5,737	11,700	5,325	3,075	5,037	9,816
Do	1900	35,087	113,100	98,166	17,500	21,800	14,875	26,191	6,110	4,357			
Center	1899						12,883	6,830	15,850	12,063	11,775	25,075	15,183
Do	1900	70,075	95,150	97,000	60,125	34,200	21,625	24,250	8,725	13,310			
Inlet tower	1899						18,100	6,275	20,437	14,737	14,462	26,612	31,650
Do	1900	76,525	66,800	125,833	58,375	31,300	23,750	27,045	13,300	9,170			
400 yards from Missouri shore	1899						16,650	5,902	32,275	9,250	10,187	30,125	25,233
Do	1900	64,925	50,300	143,333	57,500	64,125	25,375	29,275	10,256	12,927			
Missouri River at Fort Bellefontaine	1899							20,000	32,695	23,417	16,325	28,510	10,475
Do	1900	84,960	40.066	179,750	77,000	66,200	63,375		12,450	25,187			
Mississippi River at Jefferson Barracks:														
East shore	1899						66,250	10,050	87,825	69,250	59,500	5,750	6,133
Do	1900	19,750	97,500	130,875	54,666								
East of center	1899						37,475	13,400	45,712	43,750	33,625	9,000	9,241
Do	1900	24,460	136,500	145,375	25,500								
Center	1899						41,100	6,962	29,837	18,787	11,833	11,600	6,675
Do	1900	28,720	79,666	129,750	48,333								
West of center	1899						55,350	5,737	54,525	42,125	45,250	25,900	19,087
Do	1900	44,460	79,750	130,500	56,500								
West shore	1899						33,637	12,050	63,125	60,125	52,875	22,562	16,350
Do	1900	23;500	61,666	154,750	55,333								
St. Louis tap	1899						14,392	851	810	1,990	1,710	8,952	2,433
Do	1900	4,865	8,233	10,137	5,233	6,300	2,625	1,650	1.950	10,125			
Chicago tap	1900		2,425	850	750	140	88	96	95	213			

TABLE 65.—*Identification of Bacillus coli communis in Illinois and Mississippi rivers and tributary streams, 1899–1900, by percentage of total tests.*

Sampling point.	Per cent positive. 1899.	Per cent positive. 1900.
Desplaines River at Joliet	100	45
Kankakee River at Wilmington	37	58
Illinois River at Morris	71	33
Illinois River at Ottawa	43	20
Fox River at Ottawa	30	22
Illinois and Michigan Canal at La Salle	90	46
Vermilion River at La Salle	43	40
Illinois River at La Salle	40	13
Illinois River at Henry	27	31
Illinois River at Averyville	23	17
Illinois River at Wesley	100	88
Illinois River at Pekin	91	87
Illinois River at Havana	50	46
Sangamon River at Chandlerville	27	36
Illinois River at Beardstown	45	47
Illinois River at Kampsville	45	64
Illinois River above Grafton	17	53
Mississippi River above Grafton	30	38
Mississippi River at Alton	26	45
Missouri River at Fort Bellefontaine	....	62
Mississippi River at Chain of Rocks	91	74

In discussing the diagrams, the witness pointed out that *Bacillus coli communis* was found more frequently in Missouri River at Fort Bellefontaine than in Illinois River above Grafton, and somewhat less frequently in Mississippi River above Grafton than at either of the other two places. The least number of positive results was found at Averyville. (5756.)

The witness then gave the following results of examinations made during October to December, 1901. (5761–5769.)

TABLE 66.—*Average results of examinations of water from designated points, October to December, 1901.*

Sampling point.	Average number of bacteria per cubic centimeter.	Per cent B. coli communis.
Illinois River at Averyville	13,691	6.2
Illinois River at Pekin	299,000	7.6
Illinois River above Grafton	8,441	10.7
Mississippi River above Grafton	5,407	11.5
Missouri River at Fort Bellefontaine	127,353	57.1
Mississippi River at Chain of Rocks (average of four points)	63,402	41.1
Illinois shore	52,177	21.7
Midstream	43,185	50
Intake tower	127,862	36.3
Missouri shore	32,845	57

The witness then stated that the conclusions to be drawn from the above results are the same as those from the series of 1899 and 1900. He pointed out that the cross-section samples at Chain of Rocks show that the pollution is least at the Illinois shore and increases to the Missouri shore. (5773.)

The witness then stated that the sewage of Chicago does not produce any effect on Mississippi River. (5774–5775.)

CROSS-EXAMINATION.

From experiments made on the longevity of *Bacillus prodigiosus* the witness had come to the conclusion that the germ does not persist in water for a great length of time, especially when associated with water bacteria. He had never observed them to live longer than five days. (5792.)

No further new facts were brought forward in the cross-examination of Professor Burrill.

EDWIN OAKES JORDAN.

DIRECT EXAMINATION.

Edwin Oakes Jordan, called as a witness in behalf of the defendants, qualified by stating that he was associate professor of bacteriology at the University of Chicago and had been connected with that university in various positions from associate through the various grades to his present appointment. He graduated from the Massachusetts Institute of Technology in 1888 and then studied for a time at the College of Physicians and Surgeons in New York. After this he was for nearly two years in the employ of the Massachusetts State board of health in connection with work being done at the Lawrence experiment station. Subsequent thereto he went to Clark University, at Worcester, Mass., where he received the degree of doctor of philosophy. He remained there until he went to Chicago in 1892. During his term of service at the Lawrence experiment station he had charge of the bacterial work and was familiar with the chemical work, having received training therein at the Massachusetts Institute of Technology. He had taught public hygiene at the University of Chicago for several years, and in lectures on that subject had been obliged to deal with the classic epidemics of this country and abroad; he had also studied several epidemics at first hand. He was at Lowell for a short time with Professor Sedgwick during the typhoid epidemic there, and since had visited Stamford, Conn., where there had been an epidemic of typhoid fever, attributed to infected milk. More recently he had visited Ithaca, N. Y., and examined the watershed of the stream which was the source of water supply for that town. He had given considerable attention to what is known as bacteriological sanitary science, including epidemiology and water chemistry. (5805–5807.)

In connection with his work on Illinois River he stated that there were three periods of investigations, one extending from April, 1899, to the end of the year; the second from January 1 to the end of June, 1900, and the third from October, 1901, to January 1, 1902. These investigations included samples from the Illinois and Michigan Canal; the Chicago drainage canal; Illinois River and its branches, the Desplaines, Kankakee, Fox, Vermilion, and Sangamon; Mississippi and Missouri rivers, and Lake Michigan. The location of the sampling stations which were maintained during these investigations will be indicated in the tabular statement of analytical results. (5807–5809.)

The third series of investigations at designated points was undertaken by agreement with the authorities of the State of Missouri. Branch laboratories were established under direction of the witness at Peoria, Grafton, and St. Louis. That at Peoria was in charge of F. W. Schule, that at Grafton in charge of W. S. Sayer, and that at St. Louis in charge of E. E. Irons and W. G. Sackett. All four of these men qualified in testimony. They sent in written reports of their work at weekly intervals, keeping duplicate copies of these reports on file at the separate laboratories. The greater part of the work was carried on in the laboratory of the University of Chicago by the witness with the assistance of Prof. F. L. Stevens and by W. G. Sackett and E. E. Irons, except during the periods when they were engaged in the branch laboratories. The witness stated that in selecting the men to take samples at the various stations a special effort had been made to obtain the services of trustworthy persons. Full directions and instructions were given to these men, a reproduction of which appears on pages 5811–5812 of the record. The witness then related the various methods of procedure and discussed the determinations. The routine work in the bacteriological analysis consisted of a determination of the number of bacteria capable of forming colonies upon a nutrient agar plate and a determination of the relative abundance of the *Bacillus coli communis*. (5809–5814.)

The witness then gave the results of the determinations made in the first and second periods, the evidence being read into the record in tables designated from 81 to 158, inclusive. (5818–5950.)

The average results of these examinations are given in Table 67. (5958–5959.)

The witness then gave his interpretations of the results of the analyses in the series of 1899 as follows:

The water in the Illinois and Michigan Canal at Bridgeport and Lockport, as well as that of Desplaines River at Joliet and of Illinois River at Morris, contains a large amount of nitrogenous organic matter in the early stages of decomposition. The high proportion of chlorine indicated the greatest pollution during the period cited; also the large amount of bacteria present in the samples showed that there were in the water substances capable of serving as food for this great abundance of organisms. The tables further show that at Ottawa a very great change has taken place in the composition of the river water, due to dilution from Kankakee River as well as to oxidation and sedimentation. This change is manifested especially by the diminution in the amount of albuminoid ammonia, the increase in the amount of nitrites and nitrates, and particularly by the enormous diminution in the bacterial content. This purification continues with the passage of the river downstream, and by the time the water reaches Averyville its character has so improved that its quality is comparable with ordinary surface waters in the United States, and especially with that of the tributaries of Illinois River. (5819-5845.)

Below Averyville the analyses show the influence of the large influx of polluting material from Peoria and its stockyards and distilleries, evidenced by the increase in albuminoid and free ammonia and in the number of bacteria. Additional pollution is shown in the Pekin samples, but from this point to the mouth of the river the purification follows a generally progressive course until at Grafton the amount of free and albuminoid ammonia and the oxygen consumed, the number of bacteria, and the relatively high amount of nitrites all bear witness to the practically complete oxidation of the enormous amount of organic matter with which the river water is laden at Lockport and Peoria. (5847–5859.)

Concerning the analyses made in 1900 the witness stated that the samples taken from the Chicago drainage canal showed considerable dilution as compared with the water in Chicago River. Examination of the analyses of samples of water from Illinois River at Morris showed that the river is charged with a large amount of organic matter, as is evidenced by the large amount of nitrogen in the form of albuminoid and free ammonia, by the oxygen consumed, and by the high number of bacteria. Considerable purification is shown by the Ottawa samples, all the ammonia and oxygen consumed determinations being smaller and the number of bacteria being a little more than one-fourth of the number in the river water at Morris during the same period. At Averyville a still greater purification is shown; the same polluting influences at Peoria and Pekin as in 1899 are apparent in this series, and, finally, a nearly complete purification is shown in the determinations at Grafton. The self-purification of Illinois River during the whole period 1899–1900 is noticeable in character and extent, both at high and low water and at high and low temperature, and shows convincingly that under the conditions prevailing in the Illinois Valley the self-purification of streams "is not an interesting biological myth but an actual and definite occurrence." (5963–5965.)

TABLE 67.—*Average results of analyses of water from Illinois and Mississippi river systems at designated points, 1899–1900.*

[Parts per million.]

Sampling point.	Date.	Residue on evaporation.			Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Nitrogen as—		Bacteria, per cubic centimeter.
										Albuminoid.					
		Total.	Dissolved.	Suspended.		Total.	Dissolved.	Suspended.	Free.	Total.	Dissolved.	Suspended.	Nitrites.	Nitrates.	
Illinois and Michigan Canal at Bridgeport	April–December, 1899	562.7	481.8	80.9	119.2	30.3	15.2	15.1	15.9	2.64	1.25	1.39	0.016	0.166	1,245,000
Do	January–April, 1900	421.8	389	33	96.6	16.6	9.57	7.03	8.05	2.05	1.04	1.05	.0214	.074	631,000
Illinois and Michigan Canal at Lockport	May–December, 1899	562	485.1	76.9	117.4	32.1	17.5	14.6	15.7	2.42	1.29	1.13	.002	.18	650,000
Do	January–June, 1900	491	451.8	39.4	124.5	18.1	11.1	6.8	10.9	2.07	.962	1.15	.0133	.0664	1,755,000
Desplaines River at Lockport	May–December, 1899	371	353.4	17.6	7.9	10.1	8.8	1.3	.072	.452	.378	.074	.011	.167	9,380
Do	January–June, 1900	363.8	334	29.7	6.1	9.08	7.8	1.1	.143	.384	.291	.097	.0138	.3467	12,500
Desplaines River at Joliet (above town)	May–December, 1899	561	480.1	80.9	104.8	25.4	14.4	11	14.7	2.12	.97	1.15	.007	.12	492,000
Do	January–June, 1900	307	274	32	41.5	10.4	7.1	3.3	4.22	.833	.474	.359	.0215	.086	744,286
Kankakee River at Wilmington	June–December, 1899	307.4	271.3	36.1	3.4	8.5	7	1.5	.054	.352	.290	.062	.010	.733	5,000
Do	January–June, 1900	343.8	268	76	2.9	9.4	7.2	2.13	.099	.327	.222	.106	.174	1.58	16,100
Illinois River at Morris	May–December, 1899	413.1	394.2	15.9	68.1	13.2	8.9	4.3	9.33	.863	.533	.330	.025	.31	400,600
Do	January–June, 1900	313	242.8	73	24.46	9.6	6.8	3.2	2.458	.599	.315	.24	.075	.424	445,000
Fox River at Ottawa	May–December, 1899	345	297.7	47.3	4.99	8.3	5.9	2.4	.074	.470	.280	.190	.010	.26	6,500
Do	January–June, 1900	326.7	264	62	3.9	8.97	6.87	2.1	.111	.42	.262	.158	.0136	.345	20,600
Illinois River at Ottawa (above town)	June–December, 1899	395.8	380.6	15.2	58.5	9	7.4	1.6	4.17	.503	.381	.122	.37	.98	27,470
Do	January–June, 1900	320	292	28	15.3	8.5	6.9	1.59	1.555	.414	.277	.1366	.197	.966	116,000
Big Vermilion River at La Salle	May–December, 1899	996.6	957.3	39.3	61.2	4.9	3.6	1.3	.224	.247	.153	.094	.017	.57	7,970
Do	January–June, 1900	441	353	87	10.1	6.4	3.8	2.5	.1	.285	.12	.164	.044	.227	19,200
Illinois River at La Salle	May–December, 1899	417.6	368.1	49.5	46.1	9.4	7.7	1.7	27.72	.496	.364	.132	.32	1.38	8,870
Do	January–June, 1900	307.7	250.9	56.9	17.5	9.06	6.95	2.1	1.046	.4228	.258	.164	.109	.979	94,000
Illinois River at Henry	May–December, 1899	399.1	370.1	29	44.2	9.9	7.7	2.2	2.008	.548	.376	.172	.255	1.12	13,290
Do	January–June, 1900	306	250	52	13.26	8.8	6.9	1.9	.916	.378	.235	.142	.102	.8	64,200
Illinois and Michigan Canal at La Salle	May–December, 1899	375.6	336.1	39.5	15.6	8	6.3	1.7	.715	.454	.311	.143	.042	.62	49,550
Do	January–June, 1900	351	313	38.8	16.7	8.2	7	1.4	1.244	.447	.286	.159	.0658	.88	54,600
Illinois River at Averyville	May–December, 1899	387.6	360.5	27.1	40.9	8.6	7.1	1.5	.929	.452	.331	.121	.256	1.11	3,670
Do	January–June, 1900	303	247	52.2	13.55	8.1	6.56	1.7	.8147	.366	.226	.139	.064	1.15	51,800
Illinois River at Wesley	May–December, 1899	394.9	362.4	32.5	40.9	10.1	7.7	2.4	1.26	.693	.411	.282	.249	.97	758,000
Do	January–June, 1900	348	244	104	11.98	9.1	6.47	2.6	.562	.415	.213	.202	.083	1.03	36,800
Illinois River at Pekin	May–December, 1899	388.6	355.4	33.2	38.4	9.2	7.2	2	1.096	.615	.376	.239	.231	.960	492,300
Do	January–June, 1900	351	237	96	12.3	6.6	6.5	2.5	.699	.429	.258	.19	.06	.99	68,400

Illinois River at Havana	May-December, 1899	390.4	343.7	46.7	36.2	8.6	6.9	1.7	1.235	.529	.353	.176	.194	.87	17,470
Do	January-June, 1900	303	243	58	11.2	7.5	6.07	1.38	.597	.361	.218	.142	.065	.57	23,100
Sangamon River at Chandlerville	May-December, 1899	335.1	267.2	67.9	4.52	5.5	3.4	2.1	.052	.239	.149	.090	.020	.61	5,080
Do	January-June, 1900	409	260	148	4.75	7.6	3.92	3.68	.096	.308	.135	.174	.026	1.32	24,200
Illinois River at Beardstown	May-December, 1899	385.6	326.9	58.7	29.3	7.6	5.9	1.7	.83	.528	.301	.127	.151	.81	14,080
Do	January-June, 1900	460	249	196.1	10.7	10.7	6.28	4.4	.691	.441	.217	.224	.106	.685	28,200
Illinois River at Kampsville	May-December, 1899	369.3	296.8	72.5	22.9	7.4	5.6	1.8	.309	.425	.262	.163	.075	.76	4,810
Do	January-June, 1900	500.5	233	266	11.3	9.8	5.9	3.9	.659	.445	.195	.25	.044	.87	33,700
Illinois River at Grafton	May-December, 1899	473.1	385.1	88	18.3	7.8	6	1.8	.253	.400	.257	.143	.044	.71	10,210
Do	January-June, 1900	503	240	260	9.8	9.8	5.7	4.1	.463	.423	.1931	.2299	.031	1.06	21,000
Mississippi River at Grafton	May-December, 1899	407.3	165.8	241.5	2.8	12.7	8.6	4.1	.082	.492	.226	.266	.005	.24	7,600
Do	January-June, 1900	444	155	247	5.3	13	7.6	5.45	.123	.522	.177	.346	.007	.3	30,600
Mississippi River at Alton:															
East bank	May-December, 1899	353.2	202.4	150.8	7.6	10.4	7.3	3.1	.076	.417	.249	.168	.042	.45	7,900
Do	January-June, 1900	587	204	371	7.2	10.9	6.1	4.8	.242	.489	.171	.318	.0165	.69	30,300
East of center	May-December, 1899	326.2	182.9	143.3	5.4	11.4	8	3.4	....	.442	.236	.206	.026	.33	7,720
Do	January-June, 1900	535	178	357	5.8	12.1	6.5	5.6	.251	.509	.173	.336	.013	.65	47,000
Midstream	May-December, 1899	379.2	164.9	214.3	3.7	11.5	8.4	3.1	.054	.465	.228	.237	.008	.28	6,650
Do	January-June, 1900	508	162	346	4.9	13.2	7	6.6	.224	.528	.187	.34	.01	.429	51,800
West of center	May-December, 1899	412	168	244	2.7	12.6	7.7	4.9	.047	.482	.222	.260	.004	.23	6,350
Do	January-June, 1900	499	155	348	4.6	13	6.9	6.3	.194	.544	.174	.365	.0098	.396	55,200
West bank	May-December, 1899	391.2	163.8	227.4	2.74	11.9	7.7	4.2	.041	.498	.241	.257	.005	.26	7,760
Do	January-June, 1900	489	153	336	4.3	13	6.6	6	.159	.495	.179	.316	.0102	.379	42,500
Missouri River at Fort Bellefontaine	July-December, 1899	1,124.5	294.7	829.8	15.4	8.7	2.9	5.8	.035	.377	.079	.298	.002	.27	8,170
Do	January-June, 1900	1,736	294	1,446	15.4	13.9	3.7	10.1	.065	.754	.111	.643	.0066	.56	43,100
Mississippi River at Chain of Rocks:															
East bank	May-December, 1899	1,203.1	198.6	1,004.5	5.1	14.5	6.8	7.7	.057	.697	.199	.498	.011	.42	12,480
Do	January-June, 1900	917	199	723	6.7	13.7	6.2	7.4	.211	.586	.16	.426	.0151	.58	36,200
Midstream	April-December, 1899	1,612.2	224.8	1,387.4	7	15.6	5.8	9.8	.048	.744	.159	.586	.005	.34	12,390
Do	January-June, 1900	1,269	209	1,055	8.6	14.8	5.7	9.1	.145	.697	.138	.559	.0096	.43	46,600
Intake tower	April-December, 1899	1,945.9	246.4	1,699.5	7.8	15.7	5.5	10.2	.051	.806	.147	.659	.002	.35	12,920
Do	January-June, 1900	1,626	227	1,399	10.3	14.7	5.4	9.3	.117	.679	.125	.574	.0845	.38	41,000
West bank	April-December, 1899	1,993.2	240.8	1,752.4	8.8	15.3	4.6	10.7	.049	.904	.139	.765	.003	.37	11,960
Do	January-June, 1900	2,056	265	1,791	12.8	14.9	4.1	10.7	.081	.714	.106	.608	.0083	.46	49,700
St. Louis tap water	June-December, 1899	342.2	251.6	90.6	8.8	5.8	4.6	1.2	.024	.168	.126	.042	.003	.37	2,330
Do	January-June, 1900	351.6	254	101	13.4	6	4.4	1.6	.028	.196	.12	.075	.0052	.4	7,760
Mississippi River at Jefferson Barracks:															
East bank	May-December, 1899	1,228.1	202.2	1,025.9	5.6	15	6.5	8.5	.048	.744	.188	.556	.005	.35	17,590
Do	January-April, 1900	686	194	492	7.2	12.6	6.3	5.8	.263	.612	.179	.435	.016	.76	65,600
East of center	June-December, 1899	1,311.7	205.1	1,106.6	5.8	15	6.3	8.7	.045	.729	.190	.539	.006	.37	13,120
Do	January-April, 1900	722	189	533	7.2	12.9	6.05	6.9	.285	.639	.173	.447	.015	.6	59,700
Midstream	May-December, 1899	1,502.2	215.4	1,286.8	6.4	15.2	5.9	9.3	.049	.710	.163	.547	.004	.34	13,320
Do	January-April, 1900	837	197	641	8.4	12.8	5.8	7	.223	.607	.167	.44	.013	.565	69,500
West of center	June-December, 1899	1,633.1	233.3	1,399.8	7.9	14.9	4.9	10	.048	.686	.143	.543	.003	.51	21,850
Do	January-April, 1900	1,077	227	857	11.3	12.8	5	7.7	.206	.647	.1605	.486	.012	.53	74,800
West bank	May-December, 1899	1,792.5	232.6	1,559.9	8.2	15.8	4.8	11	.058	.838	.148	.690	.005	.43	25,180
Do	January-April, 1900	1,087	248	776	12.6	12.3	4.7	7.5	.259	.608	.139	.468	.012	.48	69,900

TABLE 67.—*Average result of analyses of water from Illinois and Mississippi river systems at designated points, 1899–1900*—Continued.

Sampling point.	Date.	Residue on evaporation.			Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Nitrogen as—		Bacteria per cubic centimeter.
										Albuminoid.					
		Total.	Dissolved.	Suspended.		Total.	Dissolved.	Suspended.	Free.	Total.	Dissolved.	Suspended.	Nitrites.	Nitrates.	
Drainage canal at Kedzie avenue	April-June, 1900	215.8	188	28.7	9.87	8.05	5.01	2.9	1.31	.499	.22	.279	.0296	.289	1,332,000
Drainage canal at dam at Lockport	do	196	183	12.9	12.7	6.27	4.97	1.3	1.33	.347	.185	.161	.0185	.118	1,167,000
Desplaines River at Joliet (below town)		597.5	486.7	110.8	97.6	25.5	14.5	11	.128	.245	1.05	1.41	.011	.066	766,700
Desplaines River at Joliet (below Rock Island bridge or Jefferson street)		250	224	28	24.5	8	5.9	1.9	.387	.521	.255	.266	.0383	.287	1,054,000

So far as the chemical and bacterial conditions show, the condition of Illinois River at Kampsville, Averyville, and Grafton differs but slightly and in insufficient particulars from the water of the tributary streams. The witness then made the comparisons shown in Table 68. (5963–5967.)

TABLE 68.—*Comparison of samples from Illinois River and from its tributaries at stated points, 1899–1900.*

Sampling point.	Albuminoid ammonia (parts per million).		Oxygen consumed (parts per million), May to December, 1899.	Bacteria per cubic centimeter.	
	June to December, 1899.	January to June, 1900.		June to December, 1899.	January to June, 1900.
Kankakee River at Wilmington	0.352	0.327		5,000	16,100
Fox River at Ottawa		.42	8.3	6,500	20,600
Vermilion River at La Salle		.285		7,970	19,200
Sangamon River at Chandlerville		.239		5,080	24,200
Illinois River at Averyville	.447	.366	8.6	3,670	51,800
Illinois River at Kampsville		.445		4,810	33,700
Illinois River at Grafton	.400	.432	7.8	10,210	21,100

In considering the two cycles of self-purification which Illinois River undergoes in its course, the witness pointed out the similarity in the character of the water at Kampsville and Averyville, the former being about 124 miles from the great source of pollution at Peoria and the latter about 130 miles from the great source of pollution at Lockport. Throughout the period the presence of sewage from Chicago at Kampsville is not shown by any of the chemical determinations except that of chlorine, which is absolutely devoid of sanitary significance so far as purification of the stream is concerned, because it would be possible for a stream in the condition of Illinois River at Kampsville to be passed around the world several times in a closed conduit, consuming years or decades in the process, without materially altering the amount of chlorine in the water; and, in the judgment of the witness, on the supposition that the water were at the outset injurious to health, in the course of such a passage and in such a time it would become entirely free from any injurious qualities it might have originally possessed. (5968–5969.)

The witness then presented charts showing the amounts of chlorine, albuminoid ammonia, and free ammonia, and the number of bacteria per cubic centimeter at the various sampling points in Illinois River during the two periods, and also a chart showing a comparison between the number of bacteria in Mississippi and Illinois rivers above Grafton during the entire period. These charts are reproduced herewith. (Figs. 1 to 5.) The witness pointed out that they show the condition of the water throughout the river in 1900 to be superior to that in 1899 and that the chart showing the comparison of the number of bacteria in Mississippi and Illinois rivers is favorable to the Illinois. (5971–5980.)

The witness then took up the discussion of certain bacteriological determinations which he made along Illinois River between Morris and Ottawa, at Wesley, and at Grafton, the interval between the examinations in each series being one hour. The first of this series was made at Morris, October 7, 1899. The day was clear and sunny, the temperature of the air being 7° C. at 6 o'clock in the morning and

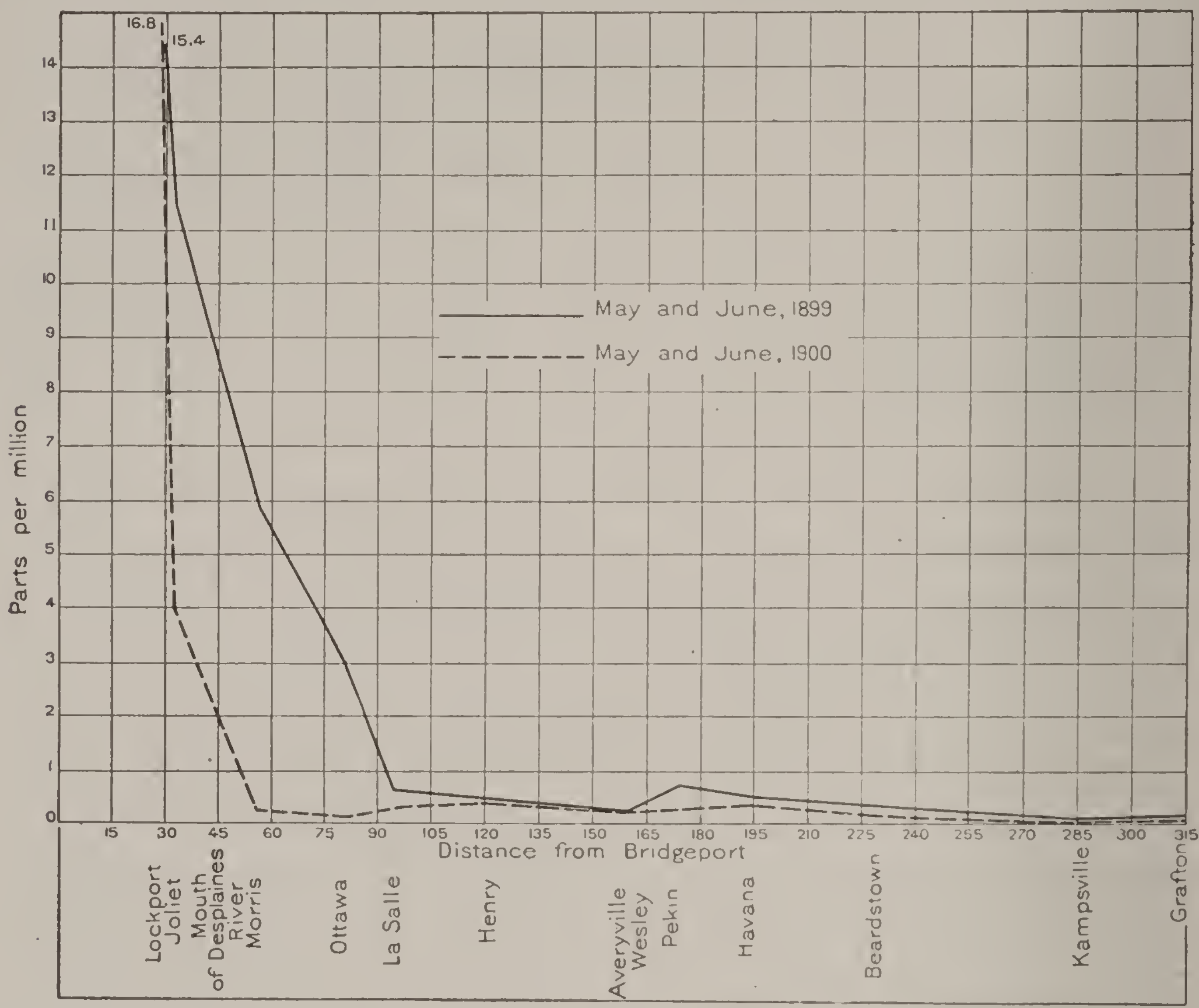


FIG. 1.—Diagram showing average chlorine in Desplaines and Illinois rivers, May and June, 1899 and 1900.

20.5° C. at midday. A slight breeze ruffled the surface of the water in the middle of the day, but was at no time strong. The river was low and the current exceedingly sluggish. Two cross sections of the river were selected and three samples were taken hourly at approximately equidistant intervals from one another and from the shores. The upper cross section was at a point just above the confluence of Mazon River with the Illinois, the lower about three-fourths of a mile below the mouth of Waupecan Creek. Little, if any, water was passing into the Illinois from these tributaries on this date. The stretch defined by these two cross sections is almost exactly 3 miles, and the rate of flow, as determined by floats and fluorescein, was found to be very close to one-half a mile per hour. The samples were plated immediately after collection. In Table 69 are given the results of the work. (5984–5986.)

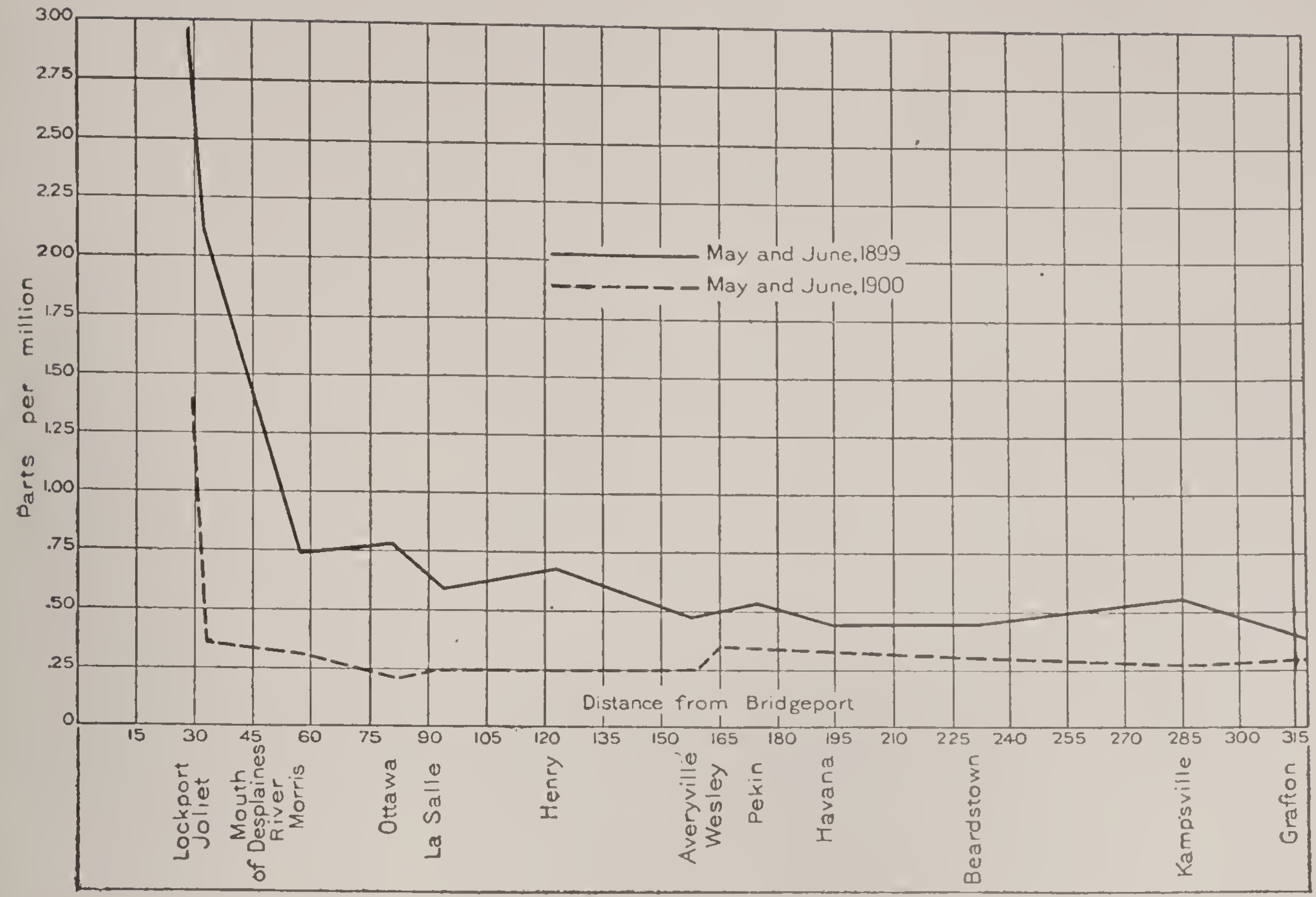


FIG. 2.—Diagram showing average albuminoid ammonia in Desplaines and Illinois rivers, May and June, 1899 and 1900.

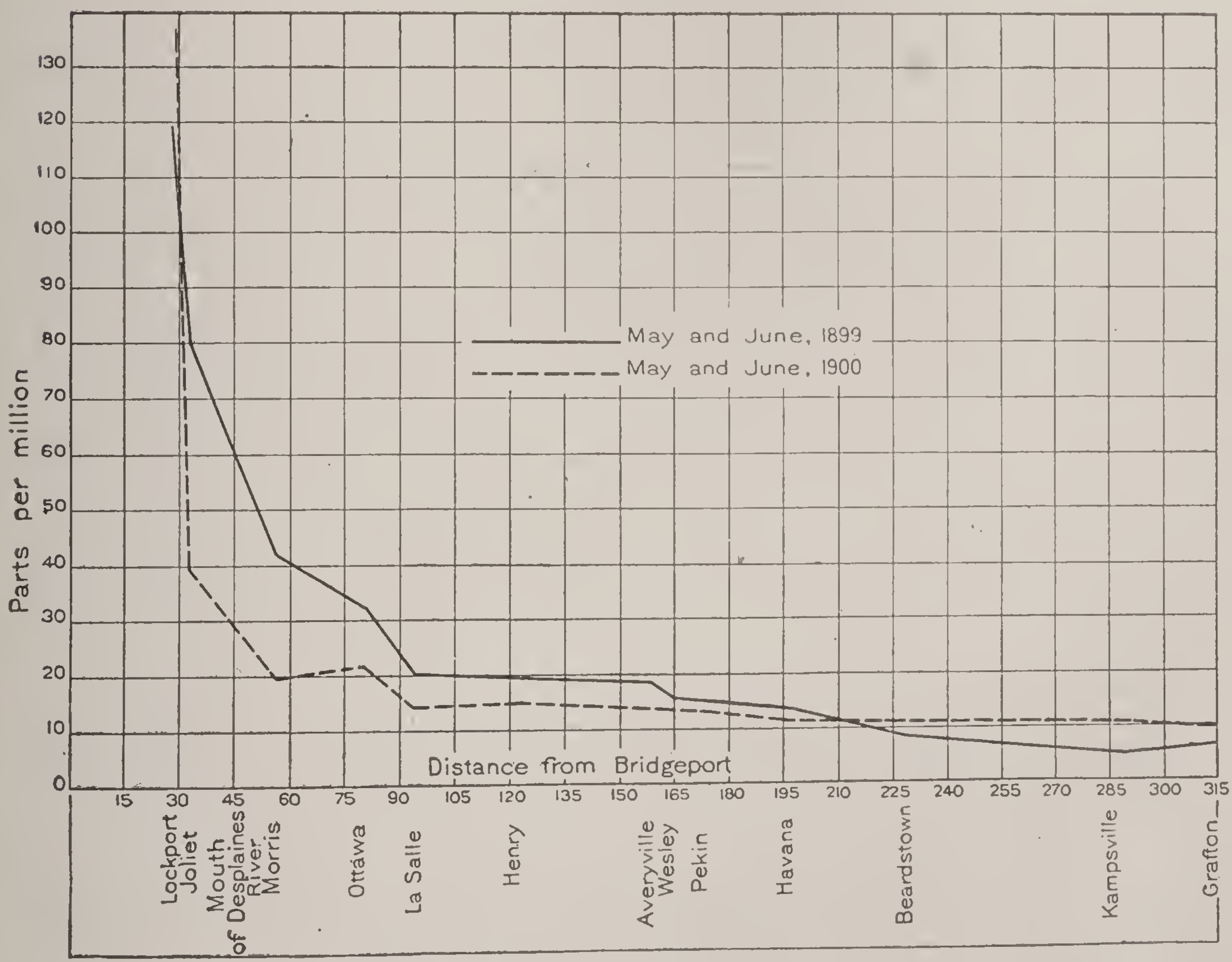


FIG. 3.—Diagram showing average free ammonia in Desplaines and Illinois rivers, May and June, 1899 and 1900.

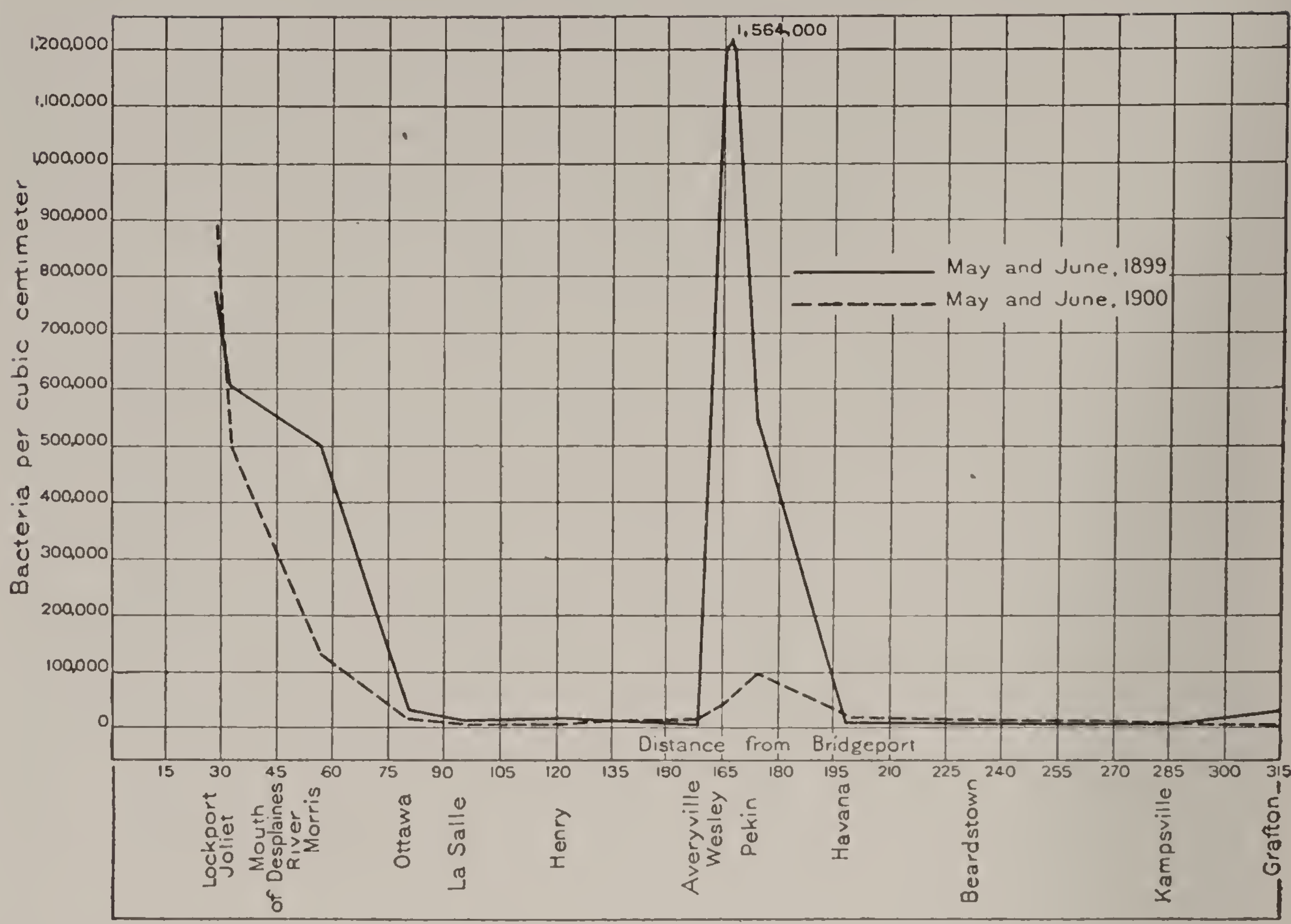


Fig. 4.—Diagram showing average bacteria in Desplaines and Illinois rivers, May and June, 1899 and 1900.

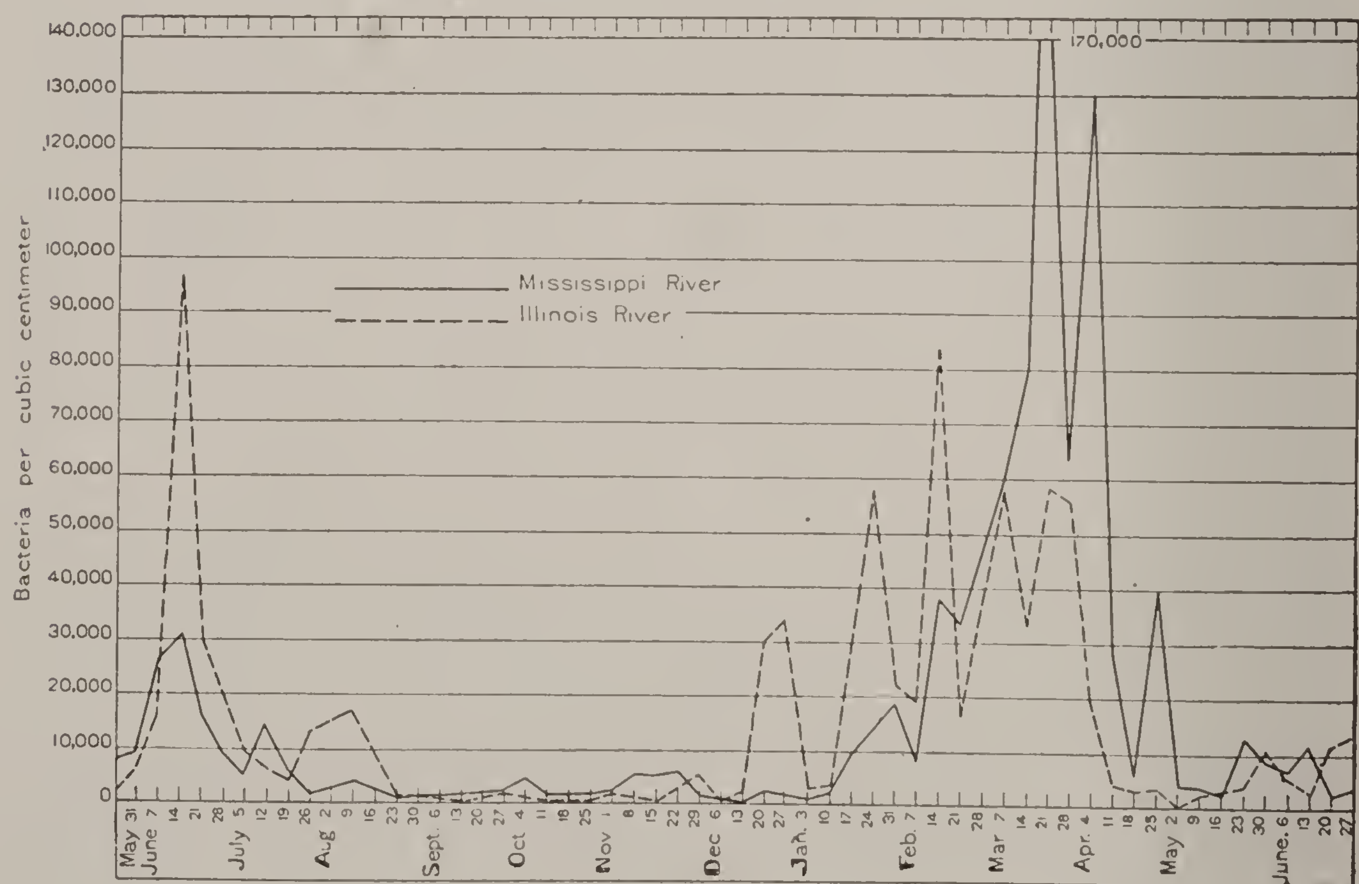


Fig. 5.—Diagram showing bacteria in Mississippi and Illinois rivers at Grafton, Ill., May 24, 1899, to June 29, 1900.

TABLE 69.—*Results of bacteriological determinations at Morris, October 7, 1899.*

UPPER STATION.

Time.	Sampling point.	Bacteria per cubic centimeter.	Turbidity (Hazen's scale).	Temperature of water (°C).	Chlorine (parts per million).
6.15 a. m	Right bank	500,000	0.16	13	....
	Center	378,000	.12	13	....
	Left bank	42,000	.075	13	....
7:15 a. m	Right bank	368,000	.17	13	....
	Center	344,000	.125	13	....
	Left bank	35,000	.0775	13	....
8.15 a. m	Right bank	752,000	.16	13.5	91
	Center	364,000	.11	13	69
	Left bank	30,000	.0675	13	45
9.15 a. m	Right bank	554,000	.16	14	....
	Center	472,000	.11	14	....
	Left bank	79,000	.075	14	....

LOWER STATION.

Time.	Sampling point.	Bacteria per cubic centimeter.	Turbidity (Hazen's scale).	Temperature of water (°C).	Chlorine (parts per million).
12.15 p.m	Right bank	480,000	0.13	16	....
	Center	327,000	.15	16	....
	Left bank	87,000	.05	16.5	....
1.15 p.m	Right bank	281,000	.1475	16	....
	Center	102,000	.09	16	....
	Left bank	19,000	.042	16	....
2.15 p.m	Right bank	400,000	.13	17	87
	Center	249,000	.09	16	72
	Left bank	22,000	.045	16	52
3.15 p.m	Right bank	412,000	.136	17	82
	Center	416,000	.12	16	78
	Left bank	11,000	.0433	17	53

AVERAGES.

	Bacteria per cubic centimeter.			Number of hourly analyses.
	Right bank.	Center.	Left bank.	
Upper station	543,700	389,700	46,500	4
Lower station	393,250	273,500	34,750	4
Percentage of decrease	27.6	29.8	25.3	....

In discussing the above table, the witness directed attention to what he believed to be a great bacterial purification between the two stations and pointed out that the determinations show a much better water along the left bank, which is due to the fact that at these two stations the water from Kankakee River predominates along that side of the stream and the mixing of this water and that from the Desplaines is incomplete.

The second series of observations was conducted November 9, 10, and 11, 1899, and was similar to that already outlined, except that it covered a more extended stretch of the river, namely, from Morris to Ottawa, the two being about 24 miles apart. At the time these observations were made the rate of flow averaged about one-half mile per hour. At Seneca, a point about midway between these two stations, a third cross section was selected. During the observations the sun was wholly obscured by clouds, but no rain fell. (5986–5988.)

TABLE 70.—*Results of bacteriological determinations at Morris, Seneca, and Ottawa, November 9–11, 1899.*

MORRIS (NOVEMBER 9).

Time.	Sampling point.	Bacteria per cubic centimeter.	Turbidity (Hazen's scale).	Temperature of water (°C.).	Chlorine (parts per million).
7.15 a. m.	Right bank	433,000	0.153	7	....
	Center	337,000	.13	7	....
	Left bank	30,000	.046	7	....
11.30 a. m.	Right bank	177,000	.17	7.25	67.5
	Center	145,000	.18	7.25	47.5
	Left bank	17,000	.02	7.25	8
2 p. m.	Right bank	174,000	.15	3	....
	Center	131,000	.135	3	....
	Left bank	49,000	.05	3	....

SENECA (NOVEMBER 10).

Time.	Sampling point.	Bacteria per cubic centimeter.	Turbidity (Hazen's scale).	Temperature of water (°C.).	Chlorine (parts per million).
9 a. m.	Right bank	134,000	Less than 0.09.	9.5	51
	Center	47,000	More than 0.07.	9.5	44
	Left bank	23,000	....	9.5	35
1.30 p. m.	Right bank	67,000	....	11	....
	Center	52,000	....	11	....
	Left bank	52,000	....	11	....

OTTAWA (NOVEMBER 11).

Time.	Sampling point.	Bacteria per cubic centimeter.	Turbidity (Hazen's scale).	Temperature of water (°C.).	Chlorine (parts per million).
10 a. m.	Right bank	11,000	Less than 0.04.	9.5	49
	Center	10,500		9.5	46
	Left bank	3,900		9.5	43
1 p. m.	Right bank	12,000	....	9.5	....
	Center	11,000	....	9.5	....
	Left bank	18,000	....	9.5	....

AVERAGES.

	Bacteria per cubic centimeter.			Number of analyses.
	Right bank.	Center.	Left bank.	
Morris	261,000	204,000	29,000	3
Seneca	100,000	49,000	35,000	2
Ottawa	11,500	10,700	13,500	2

In discussing the above results the witness stated that, according to the figures, Illinois River, during this flow of 24 miles became nearly free from the great mass of sewage bacteria with which it was originally laden—in fact, the bacterial content of the Illinois at Ottawa on the above date was not greatly in excess of that of the local tributary streams.

He then reviewed the results of the chemical determinations made during the regular examinations at the Chicago laboratory during the period between October 23 and November 20, 1899, the points of collection being Morris and Ottawa. These results, according to the witness, show that a considerable degree of nitrification takes place in the river between these two stations.

The third series of observations was made at the same points as the second series, May 24, 25, and 26. The sun was partially obscured May 25, but shone brightly on the remaining two days; no rain occurred during the period. The results are presented in Table 71. (5988–5990.)

TABLE 71.—*Results of bacteriological determinations at Morris, Seneca, and Ottawa, May 24–26, 1900.*

MORRIS (MAY 24).

Time.	Sampling point.	Bacteria per cubic centimeter.	Temperature of water (°C.).	Chlorine (parts per million.)
7.30 a. m.	Right bank	45,000	15.5	20
	Center	74,000	17.5	13
	Left bank	42,000	18	8
9.30 a. m.	Right bank	60,000	15.5	.....
	Center	34,000	17	.....
	Left bank	39,000	18	.....
11.30 a. m.	Right bank	98,000	15.75	.....
	Center	62,000	17	.....
	Left bank	30,000	18	.....
2 p. m.[a]	Right bank	70,000	16	21
	Center	63,000	17	14
	Left bank	48,000	18	6

SENECA (MAY 25).

Time.	Sampling point.	Bacteria per cubic centimeter.	Temperature of water (°C.).	Chlorine (parts per million.)
7.30 a. m.	Right bank	13,800	16.5	19.5
	Center	11,700	.....	16
	Left bank	4,100	.....	13
9.30 a. m.	Right bank	12,700	17	.....
	Center	14,000	.....	.....
	Left bank	16,000	.....	.....
11.30 a. m.	Right bank	4,500	17.5	.....
	Center	4,100	.....	.....
	Left bank	3,000	.....	.....
1.30 p. m.	Right bank	5,500	18.5	16
	Center	6,700	18.8	15
	Left bank	13,100	19.7	12

OTTAWA (MAY 26).

Time.	Sampling point.	Bacteria per cubic centimeter.	Temperature of water (°C.).	Chlorine (parts per million.)
8.30 a. m.	Right bank	7,400	18.5	15
	Center	10,000	18.5	14
	Left bank	8,300	18.5	13
11 a. m.	Right bank	8,100	19	17
	Center	6,800	19.2	15
	Left bank	6,400	19.2	14
2.00 p. m.	Right bank	9,000	19.5	17
	Center	6,300	19.5	16
	Left bank	4,200	20	14

[a] Samples were taken at this time and submitted to chemical examination, with the following results stated in parts per million:

	Right bank.	Center.	Left bank.
Residue on evaporation:			
Total	232	246	308
Dissolved	230	244	285
Suspended	2	2	23
Chlorine	21	14	6
Oxygen consumed:			
Total	6.6	7.2	8.8
By dissolved matter	6.1	6.0	4.7
By suspended matter	.5	1.2	4.1
Free ammonia	2.28	1.08	.24
Albuminoid ammonia:			
Total	.256	.296	.240
Dissolved	.224	.224	.168
Suspended	.032	.072	.072
Nitrites	.072	.050	.040
Nitrates	.4	1.1	.95

TABLE 71.—*Results of bacteriological determinations at Morris, Seneca, and Ottawa, May 24–26, 1900*—Continued.

AVERAGES.

	Bacteria per cubic centimeter.			Number of analyses.
	Right bank.	Center.	Left bank.	
Morris	68,200	58,200	39,800	4
Seneca	9,100	9,100	10,300	4
Ottawa	8,200	7,700	6,300	3

The witness stated that the above results show a more complete mixing of the Kankakee and Desplaines waters, also a smaller number of bacteria, than in the determinations made in 1899. It should be remembered in this connection that this last series of examinations was made after the opening of the Chicago drainage canal. The witness then made the following statement:

I see no escape from the conclusion that in this flow of approximately 24 miles the Illinois River, which at Morris contained a large number of bacteria, in all probability derived more or less directly from the sewers of Chicago, freed itself from these bacteria to a remarkable and impressive degree in a short distance and in a relatively short space of time. (5991.)

These observations on the bacterial content of the river at Morris and Ottawa indicated that a very large proportion of the bacteria entering at Lockport do not survive long enough to reach Ottawa, which fact renders it improbable that disease germs can pass down the stream as far as this point. Since the sewage bacteria disappeared so largely, it is fair to assume that the various nonspore-forming pathogenic bacteria must die out at least in the same proportion. In giving this opinion, the witness stated that he was taking into consideration all the knowledge that he possessed of the life of pathogenic germs and their relation to sewage bacteria. (5993.)

The witness then described some cross-section experiments which he had made at Wesley, June 13, 1900, the results being as follows:

TABLE 72.—*Results of bacteriological determinations at Wesley, June 13, 1900.*

	Free ammonia (parts per million).	Albuminoid ammonia (parts per million).	Bacteria per cubic centimeter.
Right bank	0.504	0.864	4,340,000
Center	.144	.248	40,000
Left bank	.168	.240	2,400

According to the witness, the large amount of pollution entering the river from Peoria on the right bank is clearly shown in this series of samples, the quantity of free and albuminoid ammonia and the number of bacteria being very much greater on the right than on the left bank of the stream. He then stated that on a number of occasions both in 1899 and 1900 similar cross-section samples were taken from Illinois River at Grafton, but only the determination of bacteria per cubic centimeter was made. In a general way the results showed that the samples taken near the right and left banks of the stream were not materially different from those taken at the center, the mixing of the water being complete at this point. Slight variations were sometimes noticed, but they were not confined to any particular portion of the stream. (5992–5993.)

The witness then took up the discussion of *Bacillus coli communis*, and in response to leading questions gave the following testimony:

Bacillus coli communis in large numbers inhabits a portion of the alimentary tract known as the colon. It is sluggishly motile and does not form spores. It is found in the intestinal discharges of man and of other higher animals and also in soils and waters contaminated with animal excreta. Sometimes it is found in the dust of the streets, its occurrence there being probably due to infection from horse droppings. The colon bacillus is in many ways similar to the typhoid bacillus. It resembles the latter in shape, size, motility, and lack of spore formation so closely that bacteriologists have some difficulty in distinguishing between the two organisms. The growth of both upon beef broth and gelatine agar is apparently identical. In fact, both bacteria belong to a group in which there are both pathogenic and nonpathogenic organisms. Although the typhoid and the colon bacillus are thus intimately related, there are, nevertheless, certain constant characteristics which enable an experienced observer to distinguish between them. Some of the main points of difference are that the colon bacillus is able to ferment dextrose with gas production, while the typhoid bacillus does not under any circumstances produce gas. When grown in milk the colon bacillus produces acid from the milk sugar and curdles the milk, while the typhoid bacillus is not able to do this.

The colon bacillus is much more hardy than the typhoid bacillus. Comparative tests of viability have shown the following:

1. Ninety-nine and nine-tenths per cent of *Bacillus coli* and 100 per cent of *B. typhosus* were removed by an intermittent water filter, and 99.8 per cent of the former and 99.9 per cent of the latter were removed by a continuous filter.

2. After the infected water had been applied to these filters, *B. coli* was found to continue in the effluent from the intermittent filter for twenty-four to thirty-six hours, while the *B. typhosus* continued only for two or three hours.

3. In a water subjected to a temperature of 33° F. about 90 to 95 per cent of both species were destroyed in twenty-four hours. A

few organisms of each species may, however, live for a considerable number of days.

4. About 55 per cent of *B. coli* and 75 per cent of *B. typhosus* were destroyed by about fifteen minutes freezing. After one hour 85 per cent of the former and 98 per cent of the latter were killed. At the end of twenty-four hours over 99 per cent of all the organisms had disappeared.

5. Both species resist temperatures up to 45° C. for five minutes; between 45° and 50° C. all but a few individuals of each species are destroyed. These few individuals, however, resisted temperatures up to 85° C, at which all organisms of both species were destroyed.

The witness further stated that, according to some experiments made by him on the typhoid bacillus when introduced into sterilized Lake Michigan water, the organism does not multiply, but may under certain conditions maintain its vitality for upward of ninety-three days. *Bacillus coli communis*, on the other hand, multiply rapidly in this water and may remain alive for upward of two hundred and sixty-three days. (5995–5997.)

Summing up the above, the witness stated that it is clear that while the two species resemble each other in many important points, the colon bacillus has been proved to possess a greater resistance than the typhoid bacillus.

Concerning the significance of the *Bacillus coli communis* determination in sanitary water analyses, the witness stated that this bacillus is one of the prevailing bacterial forms in fresh sewage, and for this reason its presence and relative abundance in water are regarded as constituting one of the most significant indications of recent sewage pollution. He then cited experiments made by Dr. William G. Bissell, of Buffalo, and Dr. William G. Savage, of University College, Cardiff, Wales; also a report of a committee of the laboratory section of the American Public Health Association, all of which showed the significance of the presence of *B. coli communis* as indicating sewage pollution. He then cited the work carried on in connection with the establishment of a water-purification system at New Orleans in 1903, and made a quotation from page 47 of this report as follows:

> In waters which contain unpurified sewage the test for this intestinal organism is of the utmost importance. In the Mississippi River at New Orleans, however, there is evidently so much self-purification effected by natural agencies, such as dilution, sedimentation, etc., that this normal intestinal bacillus was one of the least common forms isolated. In about 100 tests with a volume of water varying from 1 to 300 c. c. its presence was demonstrated only three times, although the larger samples of water were concentrated in a centrifuge before being seeded into the media conveyed in fermentation tubes.

Further quotation was made from the report, contrasting the above evidence with that of the water from the Merrimac at Lawrence, the Hudson below the Mohawk, the Ohio at Cincinnati, the Schuylkill, and the Potomac, and a further observation was made that the conditions in Mississippi River above New Orleans are so favorable for self-purification during the last few hundred miles of its flow that the normal bacteria of surface water effectually crowd out those derived from populated and cultivated areas. This instance was regarded by the witness as especially significant of the ability of streams to purify themselves, especially in view of the fact that countless millions of colon bacilli are contributed by the cities in the Ohio, Illinois, upper Mississippi, and Missouri basins. (6000–6004.)

The witness then outlined the methods used for isolating the colon bacillus (see pp. 6005–6008 of the record) and gave an account of experiments made on the water of the Illinois and Mississippi systems at various points. The results of the experiments and the points of collection are shown in Table 73. (6009–6035.)

TABLE 73.—*Results of presumptive tests for Bacillus coli communis on samples of water from designated points before and after the opening of the Chicago drainage canal.*

Sampling point.	Date.	0.00001 c. c.		0.0001 c. c.		0.001 c. c.		0.01 c.c.		0.1 c. c.		1 c. c.		5 c. c.	
		Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days. B. coli found.	Number of days water examined.	Number of days B. coli found.
Illinois and Michigan Canal at Lockport	1899	8	2	9	9	1	1	1	1	1	1	....	....	....	....
	1900	20	5	24	19	10	7	3	3	1	1	....	....	....	....
Drainage canal at Kedzie avenue	1900	3	0	7	1	8	3	7	4	3	3	....	....	....	....
Drainage canal at Lockport	1900	2	0	10	1	11	3	10	6	4	4	....	....	....	....
Desplaines River at Lockport	1899	....	....	....	....	....	....	1	0	8	1	5	2	....	....
Kankakee River at Wilmington	1899	....	....	....	....	....	....	....	....	6	3	5	4	....	....
Illinois River at Morris	1899	....	....	3	1	5	5	5	5	....	....	....	....	....	....
	1900	....	....	....	....	15	6	25	15	23	20	9	8	....	....
Fox River at Ottawa	1899	....	....	....	....	....	....	....	....	9	0	8	1	....	....
	1900	....	....	....	....	....	....	....	....	13	2	15	5	13	10
Illinois River at Ottawa	1899	....	....	....	....	....	....	8	4	12	7	10	6	....	....
	1900	....	....	....	....	....	....	14	2	22	12	22	14	6	4
Vermilion River at La Salle	1899	....	....	....	....	....	....	....	....	6	1	9	3	....	....
Illinois River at La Salle	1899	....	....	....	....	....	....	....	....	7	2	8	3	....	....
Illinois River at Henry	1899	....	....	....	....	....	....	1	0	6	2	8	3	....	....
	1900	....	....	....	....	....	....	....	....	2	2	3	3	....	....
Illinois River at Averyville	1899	....	....	....	....	....	....	....	....	5	1	9	2	....	....
	1900	....	....	....	....	....	....	1	0	23	3	22	11	....	....
Illinois River at Wesley	1899	....	....	1	0	....	....	3	0	7	3	4	2	....	....
	1900	....	....	6	1	....	....	19	3	19	10	14	11	....	....
Illinois River at Havana	1899	....	....	....	....	....	....	....	....	4	2	8	6	....	....
Sangamon River at Chandlerville	1899	....	....	....	....	....	....	....	....	3	2	5	3	....	....
	1900	....	....	....	....	....	....	13	4	22	12	22	18	....	....
Illinois River at Grafton	1899	....	....	....	....	....	....	3	1	10	4	13	7	....	....
	1900	....	....	....	....	....	....	1	0	25	10	25	19	4	2
Mississippi River at Grafton	1899	....	....	....	....	....	....	2	0	10	1	11	6	....	....
	1900	....	....	....	....	....	....	....	....	24	9	24	17	4	3
Mississippi River at Alton:															
East bank	1899	....	....	....	....	....	....	....	....	7	0	7	1	....	....
East of center	1899	....	....	....	....	....	....	....	....	7	1	7	1	....	....
Center	1899	....	....	....	....	....	....	....	....	7	1	7	1	....	....
West of center	1899	....	....	....	....	....	....	....	....	7	2	7	2	....	....
West bank	1899	....	....	....	....	....	....	....	....	5	0	5	2	....	....
Missouri River at Fort Bellefontaine	1899	....	....	....	....	....	....	....	....	6	0	6	1	....	....
	1900	....	....	....	....	....	....	6	3	26	13	25	20	....	....
Mississippi River at intake tower	1899	....	....	....	....	....	....	....	....	5	2	5	3	....	....
	1900	....	....	....	....	....	....	2	2	17	11	17	14	....	....
St. Louis tap water	1899	....	....	....	....	....	....	....	....	5	0	5	3	....	....
	1900	....	....	....	....	....	....	....	....	24	5	25	12	....	....
Total for Illinois River	....	....	....	....	....	....	....	....	....	62	17	69	39	....	....
Tributaries of Illinois River	....	....	....	....	....	....	....	....	....	66	21	69	36	....	....
Mississippi and Missouri rivers	....	....	....	....	....	....	....	....	....	66	23	66	44	....	....

Referring to the above results, the witness made the following statements:

On comparing the number of days on which *Bacillus coli* was found in 1 c. c. of water taken from Illinois River at Averyville and Grafton, from the Mississippi at Grafton, from the Desplaines, from the Kankakee, from the Fox, from the Vermilion, from the Sangamon, and from the Missouri, it appears that, so far as the colon-bacillus content enables one to pass an opinion on the sanitary quality of these waters, Sangamon River at Chandlerville is one of the more highly polluted streams.

The Illinois at Grafton, the Mississippi at Grafton, and the Missouri at Fort Bellefontaine appeared to be on substantially the same footing with one another in respect to their colon-bacillus content, while the Fox contained a smaller proportion of colon bacilli than any other of the streams under consideration.

The Illinois at Averyville compares in respect to its colon-bacillus content very favorably with the Illinois and Mississippi above Grafton and the Missouri above its mouth and is perceptibly less highly contaminated than the Sangamon at Chandlerville.

To sum up these facts, it is seen that samples of water taken on sixty-nine different days from Illinois River at Averyville and at Grafton contained *Bacillus coli communis* on thirty-nine days, while samples taken from the various tributaries of the Illinois on sixty-nine days contained the colon bacillus on thirty-six days. Samples taken from the Missouri on sixty-six days contained the colon bacillus on forty-four days.

It appears, therefore, from these tables that if the opinion expressed by the witness regarding the sanitary significance of the colon bacillus in water is correct, the water of Illinois River at Averyville and Grafton was not materially different from what it would have been if the tributaries of the Illinois, exclusive of Desplaines River and its sewage content, had alone fed the basins of this stream. The colon-bacillus content of such a stream at Averyville and at Grafton would have been substantially what it is at present. (6038–6039.)

In connection with the discussion of these results, the witness made the interesting statements reproduced below in response to specific questions:

Q. Professor, I desire to call your attention to the testimony of Doctor Ravold. On page 150 of his testimony given in this case Doctor Ravold testified that the colon bacillus was found in 72 per cent of the samples taken from the Bear Trap dam at Lockport in the month of March, 1900, and at page 320 of his testimony he testified that the *Bacillus coli communis* was found in 71 per cent of the samples collected from the St. Louis settling basins during the period from May 1 to October 31, 1900. Would you infer from those statements that colon bacillus was present in the water of these settling basins in St. Louis in anything like the same proportion that it was in the water of the drainage canal at Lockport?

A. I certainly should not.

Q. Give your reasons.

A. It is very important in making the test for the colon bacillus, especially when a polluted water is being dealt with, to use dilutions of the water high enough to prevent the overgrowth of the colon bacillus by other sewage forms. I have frequently in my own experience found that by the use of so large a quantity of water as 1 c. c. * * * apparently negative results are obtained, while by examination of a smaller quantity of the same water positive results invariably appear. The explanation for this phenomenon, which may prove very misleading, is that when a large quantity of sewage-polluted water is introduced into fermentation tubes other forms of bacteria, such as some of the anaerobic bacteria, are present. These overgrow the colon forms, leading to an apparently negative result, and thus completely obscuring the true interpretation. I have frequently encountered this difficulty in dealing with highly polluted waters in using quantities as large as 1 c. c. It is my opinion that if the colon determination be carried out properly, with due regard to the difficulties here mentioned, the colon bacillus would be found to be present in every cubic centimeter of the water in the drainage canal. Indeed, my examinations have shown no fewer than several hundred colon bacteria per cubic centimeter in the water of the drainage canal, and generally several thousands, while in the water of the Mississippi River which is pumped into the settling basins at St. Louis and in the tap water drawn from the tap in St. Louis the number of colon bacteria never approximate anything like these figures.

For these reasons I am compelled to assume that the statements to which you refer are based on defective analytical methods and do not indicate that the actual number of colon bacilli in the water of the drainage canal and in the St. Louis settling basins are at all comparable. (6012–6014.)

The witness then took up the discussion of the work performed from October to December, 1901, and stated that three extra laboratories were equipped at the direction of the defendants, one at Peoria, on Illinois River; one at Grafton, at the mouth of the river, and one at St. Louis. The work carried on at these three laboratories consisted chiefly in plating daily samples of water for bacteriological examination and in making colon determinations. Data were also procured concerning the temperature of the water and air at times of collection, and all the laboratory men were instructed to select from the colonies of bacteria appearing on the plates all the different kinds that could be distinguished by the peculiarities of their growth. Those colonies thus picked from the plates were transferred to agar tubes and shipped to the witness at the bacteriological laboratory of the University of Chicago, where they were studied in detail. (6041–6042.)

The sampling points were as follows: For the Peoria laboratory, at Averyville, above Peoria, and at Pekin, below Peoria, the precise points of collection being approximately those used during the investigations of 1899 and 1900; for the laboratory at Grafton, from Illinois River above its confluence with the Mississippi and from the Mississippi above the mouth of the Illinois; for the laboratory at St. Louis, five daily samples, four along the cross section at Chain of Rocks and the fifth from Missouri River at Fort Bellefontaine. The bacteriological work consisted of, first, the determination of the number of bacteria in the samples, as shown by the ordinary colony counts; second, the number of germs of the colon group, as shown by the dextrose fermentation tube test, and, third, the study of bacterial flora. The first two determinations were carried on in the respective branch laboratories and the third was performed at the laboratory of the University of Chicago. (6042–6043.)

The methods used for the chemical estimation were those recommended by the committee on standard methods of the American Public Health Association. Several different decimal dilutions of the water were usually employed, and the dilution that was selected for record was the one showing from about 25 to 125 colonies per plate. (6043–6044.)

The results of the various examinations are reported in detail on pages 6046–6080 of the record. A summary is given in Table 74.

TABLE 74.—*Average results of bacterial determinations on water from Illinois, Mississippi, and Missouri rivers, October to December, 1901.*

Sampling point.	Number of determinations.	Average number of bacteria per cubic centimeter.
Illinois River at Averyville (above Peoria)	69	5,800
Illinois River at Pekin (below Peoria)	50	90,000
Illinois River at Grafton	73	6,900
Mississippi River at Grafton	73	1,300
Mississippi River at Chain of Rocks:		
Illinois shore	54	2,400
Midstream	53	5,200
Intake tower	52	21,200
Missouri shore	53	17,000
Missouri River at Fort Bellefontaine	51	21,000

Concerning the above results, the witness stated that the number of bacteria found at Averyville and at Grafton were not dissimilar. The averages were higher than the average for this period in Mississippi River, owing to the fact that the usual winter increase which occurs in river waters took place that year earlier in Illinois River than it did in Mississippi River. Up to the middle of December, 1901, the two waters were very similar as regards their bacterial content. Throughout the period studied the average number of bacteria, as shown by the colony count, for Missouri River at Fort Bellefontaine was several times as great as in the water from either Illinois River at its mouth or Mississippi River above Grafton. The number of bacteria in Illinois River water at Pekin was greatly in excess of that found at any of the other collecting stations—a fact which, in the opinion of the witness, naturally follows the entrance of sewage and refuse into the river at Peoria, just above this point. (6081.)

The witness then presented a table showing the comparative number of bacteria in samples from Mississippi River taken along the cross section at Chain of Rocks and from Missouri River at Fort Bellefontaine. This table appears on pages 6082–6083 of the record. The witness said that the figures show that during the period covered by the investigation, the number of bacteria in the water of Mississippi River along the cross section was much lower on the Illinois shore than on the Missouri shore, and further that the water at the intake tower partook of the character of the waters of Missouri River and of Mississippi River on the Missouri shore. In other words, during these three months of 1901 little, if any, water from Illinois River entered the intake tower of the St. Louis waterworks, and it was also evident from the bacterial count that if any of the water from the Illinois shore did pass into the intake it must have improved the condition of the water, so far as reducing the number of bacteria per cubic centimeter was concerned. (6084.)

The witness then introduced into evidence three series of photographs of bacterial plates, showing the number of bacteria in samples taken from Mississippi River at four points in the Chain of Rocks section—Illinois shore, mid-channel, intake tower, and Missouri shore—and from Missouri River at Fort Bellefontaine. The first series represented plate samples taken October 28; the second, November 20, and the third, December 13. The plates were all agar platings, and the photographs represented the number of colonies developing in 0.1 c. c. of the water. The number of colonies visible on each plate from each sampling point agreed with the statements made by the witness concerning the relative appearance of bacteria and the proportions shown in Table 74. (6084–6089.)

The witness then discussed the tests for *Bacillus coli communis* made during this period, stating that he considered that the relative abundance of this organism afforded the most satisfactory test of the sanitary quality of the water, and citing various authorities in substantiation of his opinion.

The detailed report of these tests appears on pages 6097–6116 of the record. A summary of the results appears in Tables 75 and 76. (6118–6120.)

TABLE 75.—*Presence of bacteria of the colon group in samples from designated points, October to December, 1901.*

Sampling point.	0.0001 c. c.		0.001 c. c.		0.01 c.c.		0.1 c. c.		1 c. c.		2 c. c.		5 c. c.	
	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.
Illinois River at Averyville	....	....	3	0	49	3	60	38	41	34	....	....	....	....
Illinois River at Pekin	17	4	44	14	44	40	17	17	....	....	....	....	....	....
Illinois River at Grafton	....	....	52	4	64	6	64	12	53	19	13	5	16	8
Mississippi River at Grafton	....	....	52	0	64	6	62	25	54	25	12	4	16	11
Mississippi River at Chain of Rocks:														
Illinois shore	....	....	25	0	41	3	41	8	42	25	....	....	7	5
Midstream	....	....	27	0	41	4	41	16	42	35	....	....	7	6
Intake tower	....	....	27	0	43	11	42	30	43	36	6	6	5	5
Missouri shore	....	....	27	1	41	8	41	24	41	36	....	....	4	4
Missouri River at Fort Bellefontaine	....	....	32	1	44	13	44	31	43	34	....	....	8	7

TABLE 76.—*Number and percentage of results showing presence of bacteria of the colon group in samples from designated points, October to December, 1901.*

Sampling point.	0.0001 c. c.			0.001 c. c.			0.01 c. c.			0.1 c. c.		
	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.
Illinois River at Averyville	25	7	28	3	0	0	72	4	6	114	49	43
Illinois River at Pekin	.....	.....	.....	75	16	21	77	60	78	17	17	100
Illinois River at Grafton	.....	.....	.....	72	5	7	117	6	5	125	16	13
Mississippi River at Grafton	.....	.....	.....	69	0	0	115	6	5	125	29	24
Mississippi River at Chain of Rocks:												
Illinois shore	.....	.....	.....	25	0	0	66	3	5	80	8	10
Midstream	.....	.....	.....	27	0	0	68	4	6	82	18	22
Intake tower	.....	.....	.....	27	0	0	71	14	20	84	48	57
Missouri shore	.....	.....	.....	27	1	4	68	9	13	81	33	41
Missouri River at Fort Bellefontaine	.....	.....	.....	34	1	3	84	16	19	95	48	50

Sampling point.	1 c. c.			2 c. c.			5 c. c.		
	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.
Illinois River at Averyville	54	39	72	......	......	......	......	......	......
Illinois River at Grafton	71	21	30	15	5	33	17	8	47
Mississippi River at Grafton	74	28	38	12	4	33	16	11	67
Mississippi River at Chain of Rocks:									
Illinois shore	42	25	60	......	......	......	7	5	71
Midstream	43	36	81	6	6	100	7	6	86
Intake tower	43	36	84	......	......	......	5	5	100
Missouri shore	42	37	88	......	......	......	4	4	100
Missouri River at Fort Bellefontaine	44	35	79	......	......	......	8	7	88

In discussing the above results the witness stated that the fact that the colon bacillus was found to be present in but 43 per cent of the 0.1 c. c. samples from Illinois River at Averyville, while it was present in 100 per cent of the 0.1 c. c. samples from the same river at Pekin and in only 13 per cent of the 0.1 c. c. samples from Illinois River at Grafton, shows not only the extreme delicacy of the test for sewage pollution, but also a very considerable improvement in the sanitary quality of water between Pekin and Grafton. A comparison of the water of Mississippi River above Grafton with that of Illinois River above the same point indicates that the colon bacillus was present in 5 per cent of the 0.01 c. c. samples of water from these two places. Of the samples from the same points containing 0.1 c. c. of water, 24 per cent of those from Mississippi River and only 13 per cent of those from Illinois River yielded positive results, and a similar difference was noted in the 1 c. c. samples, all of which showed, in the opinion of the witness, that the water of Mississippi River above Grafton during the period of examination was, if anything, less wholesome than that of Illinois River above Grafton. With reference to the results found in waters from Mississippi River at Chain of Rocks and Missouri River at Fort Bellefontaine, the witness stated that the water from Missouri River during this period was distinctly more dangerous and unwholesome than that of either the Illinois or the Mississippi at Grafton. (6121–6123.)

The witness then introduced photographs of fermentation tubes, showing the results of inoculations with quantities of water varying from 0.001 to 1 c. c., taken from the designated sampling stations. The illustrations show that the colon bacillus was not so abundant in the water of Mississippi River near the Illinois shore as it was at the intake tower of the St. Louis waterworks.

From all the foregoing tables and illustrations the witness concluded that the effect of any mixture of Illinois River water with Missouri River water at the intake tower would tend to diminish the colon content of the water at such point, thereby rendering it less dangerous for human use. (6132.)

The attention of the witness was then called to that part of the testimony of Allen Hazen in which he stated that the mixing of water from Illinois and Mississippi rivers by the time it reaches the mouth of the Missouri River is more complete at low water than at high water, to which the witness replied that the total number of bacteria in the water at the intake tower and near the Missouri shore at Chain of Rocks, as well as the number of colon bacteria in the water at these two points, shows conclusively that during the period of low water the water collected at these two stations was almost wholly, if not altogether, Missouri River water and was mixed little, if any, with that of the Illinois. If it be true, therefore, that the mixing is more complete at low water than at high water, it would certainly follow that the amount of Illinois River water present in the Mississippi at these two points at high-water stages must be exceedingly small. (6132–6133.)

The witness then discussed his work in the identification of bacteria of various species in the samples collected during the investigation of 1901. The organisms studied were isolated from four different kinds of culture media—(1) from forty-eight-hour gelatine plates incubated at 20° C.; (2) from forty-eight-hour dextrose-broth fermentation tubes incubated at 37°; (3) from litmus lactose agar plates at 35° after passing through carbol broth at 37°; (4) from neutral red broth at 37°. In this way 543 cultures were isolated and classified. The results are contained in Table 77. (6134.)

Table 77.—*Species of bacteria isolated by E. O. Jordan, 1901.*

Species.	Illinois River.		Mississippi River.						Missouri River at Fort Bellefontaine.	Total.
					Chain of Rocks.					
	Averyville.	Pekin.	Grafton.	Grafton.	Missouri shore.	St. Louis intake.	Channel.	Illinois shore.		
Bacillus coli communis	3	22	1	7	4	2	1	3	3	46
B. lactis aerogenes	7	8	1	5	......	3	1	1	1	27
B. coli communis and B. lactis aerogenes	6	12	1	......	4	1	......	3	2	29
Proteus	13	4	5	7	2	3	2	2	2	40
B. cloacæ	5	1	5	1	2	4	1	2	......	21
B. enteritidis	3	2	......	......	1	......	......	......	......	6
B. fluorescens liquefaciens	8	3	7	9	1	......	2	3	......	33
B. fluorescens nonliquefaciens	7	1	2	2	4	1	5	1	2	25
B. subtilis	6	2	12	4	4	6	4	2	6	46
B. gelat.-liquef., milk acid	19	11	10	15	4	6	......	1	8	74
B. gelat.-liquef., milk alkaline	7	10	7	2	2	1	......	1	......	30
B. nongelat.-liquef., milk acid	6	8	2	......	3	2	6	4	1	32
B. nongelat.-liquef., milk alkaline	17	1	1	......	2	1	4	2	1	29
B. nongelat.-liquef., milk amphoteric	17	6	2	1	......	1	......	1	2	30
Chromogenic bacteria [a]	7	3	1	1	2	1	1	1	......	19
Chromogenic staphylococci	2	2	5	1	1	1	1	1	......	14
Nonchromogenic staphylococci	4	17	3	2	2	......	4	1	2	35
Sarcinæ	2	......	......	1	......	......	......	......	......	3
Streptococci	......	2	......	......	2	......	......	......	......	4
	139	115	65	58	40	33	32	29	30	543

[a] Two cultures of the red chromogenic group are without data as to place or mode of isolation.

Referring to the above results, the witness stated that the detailed study shows that the forms regarded by bacteriologists as characteristic of sewage pollution are found more abundantly in the water of Illinois River at Pekin than elsewhere. The streptococcus forms, which are believed to be especially characteristic of recent sewage pollution, were found in only four cases, namely, two in Illinois River at Pekin and two in Mississippi River at Chain of Rocks, near the Missouri shore. (6135.)

In response to a question concerning the necessity for examination of samples collected hourly or even daily, the witness cited several standard investigations, such as those carried on by George W. Fuller at New Orleans, Louisville, and Cincinnati, and by Allen Hazen at Pittsburg, together with certain others in European countries. He stated that in his opinion the usual practice is based on the belief that an adequate opinion as to the character of the water can be formed by examinations made at intervals of one week, provided the total period of investigation extends over a sufficient length of time. In the present investigation the weekly, daily, and hourly determinations made by the witness, together with those made concurrently by Professors Palmer, Long, Zeit, Gehrmann, and Burrill, were unquestionably sufficient to permit a satisfactory conclusion to be drawn as to the character of the water, and they constituted the most extensive study of river water, in connection with the subject of self-purification of streams, ever made anywhere in the world. (6135–6137.)

Taking into consideration all the analytical data obtained throughout the seventeen months covered by the investigations, the witness concluded that one of the most remarkable facts brought out is the entire concurrence of the results derived from the chemical and the various bacteriological determinations. The amount and rate of nitrification in the water of Illinois River at various points along its course are in line with what the experience of water analysts has shown to accompany real purification. On the bacteriological side the evidence is wholly confirmatory, as under certain conditions Illinois River becomes nearly free from the great mass of sewage bacteria with which it is laden at Lockport in so short a distance as 24 miles, as shown by the examinations made at Morris and Ottawa. (6138–6140.)

Concerning the occurrence of *Bacillus prodigiosus* in the rivers of the country, the witness stated that on November 6, 1899, he isolated from the water of Illinois River collected at Morris an organism which resembled in all specific characteristics the standard *B. prodigiosus*, and verified his diagnosis by comparing its culture characteristics with those of two other strains obtained from the University of Michigan and Yale University. In addition to these, he isolated from the water of Mississippi River near the Missouri shore at Chain of Rocks on November 16, 1901, an organism that in many respects was typical of *B. prodigiosus* and might have been mistaken for it, but was markedly different in other characteristics, inasmuch as it did not produce gas in dextrose broth nor liquefy blood serum nor curdle milk—three very important respects in which it differed from the true *B. prodigiosus* type. Other germs were isolated on other occasions from Illinois and Mississippi rivers, which also bore certain resemblances to *B. prodigiosus*, but which on investigation were found not to be the true form. (6143–6144.)

In response to the hypothetical questions hereinbefore outlined concerning the experiment of Doctor Ravold in depositing 107 barrels of *B. prodigiosus* culture in the Chicago Drainage Canal, the witness stated that this experiment gave a certain amount of information on the probable longevity of the typhoid bacillus under the conditions as stated. It constituted a demonstration of the power of self-purification in streams, from the fact that along the upper collecting stations maintained by the city of St. Louis in Illinois River this organism was not discovered, although according to the testimony very frequent examinations were made. The findings of a few individual bacteria in Mississippi River at Chain of Rocks were not positive, inasmuch as the identification did not, from the records, appear to be altogether complete. On the assumption, however, that the identification was correct, the relatively insignificant number found indicated that the bacterium does not live long in the river water, and that the typhoid bacillus, which is beyond doubt a more highly specialized parasitic form, would not survive as long as the *B. prodigiosus*. In other words, since *B. prodigiosus* dies off so speedily in such large numbers, the typhoid bacillus would be less likely to survive exposure to these same conditions. (6148–6151.)

Referring to established instances where the typhoid bacillus has been detected in river water, the witness stated that although the evidence which connects polluted water with outbreaks of typhoid fever is entirely convincing both in character and mass there have been relatively few instances in which bacteriologists have succeeded in isolating a specific typhoid bacillus from suspected waters. Accounts of actual identification are of doubtful value, especially since more recently organisms that were similar to but by no means identical with the true typhoid bacillus have been discovered in water. After citing accounts of several cases of alleged identification of the typhoid bacillus in foreign countries and remarking on the insufficiency of the evidence the witness stated that the meagerness of those found, despite the thousands of examinations made by skilled bacteriologists in every part of the world, is in his opinion explained chiefly by the relatively short duration of the life of the bacillus in water. The period elapsing between the moment of infection and the beginning of the bacterial investigation is usually at least two or three weeks, owing chiefly to the time occupied by the incubation of the disease and perhaps tardy recognition of it. Some time is also consumed in the preliminary work necessary in carrying on a competent investigation. The history of most outbreaks of typhoid fever shows that the bacillus had disappeared from the water by the time a search was inaugurated, and for this reason a negative finding is the usual result of such an examination. (6156–6159.)

Concerning experiments made to determine the longevity of the typhoid bacillus in water, the witness stated that examinations made with the bacillus in sterilized water and kept in glass bottles showed, among other things, that the age of the culture influences the longevity, freshly isolated stock exhibiting distinctly greater vitality than stock which had been under cultivation for some months. When introduced into sterilized Lake Michigan water, typhoid bacilli were alive under some circumstances up to ninety-three days, but did not multiply during this period. The colon bacillus, on the other hand, multiplies rapidly and has been kept alive in sterilized Lake Michigan water for two hundred and sixty-two days. There is no evidence to show that the typhoid bacillus multiplies in natural waters. On the contrary, there appears to be an overwhelming evidence that the organisms once discharged from the human body undergo a constant diminution in number. Conditions in laboratory experiments for testing the longevity of this bacillus are usually much more favorable to its life than those which it meets in nature. The witness was fully of the opinion that the organisms will live longer in pure than in polluted waters, because of the fact that in polluted waters they have to compete with various saprophytic bacteria, while in unpolluted waters they are not injuriously affected by these microbes. From what he knew of the chemical composition and bacterial content of the waters of Illinois River at various points along its course it was his opinion that the life of the typhoid bacillus introduced into Illinois River at the upper end of the drainage canal would not be more than three or four days. (6159–6161.)

The witness then testified concerning his familiarity with the physical conditions existing along the Illinois River basin, and stated that Desplaines River from Lockport to Morris has a rapid flow, but the lower part of Illinois River, especially from La Salle to Grafton, is very sluggish and consists of a series of pools, so that the body of water as a whole is almost entirely quiescent. If it were true that any of the infectious matter from Chicago persisted as far down even as Peoria, the conditions existing there and farther down the stream would be such as to bring about a further diminution in the amount of such substances. This state of semistagnation prevailing in Illinois River affords opportunity for the destruction of such infectious matter as may be introduced into the river either directly or through the tributaries. (6161–6164.)

While it is true that bacteria in a turbid water are sedimented more quickly than in a clear water, the turning into Illinois River of the clear water from Lake Michigan does not interfere with sedimentation, because in that portion of Illinois River where most sedimentation occurs the amount of suspended matter introduced into the water from the tributaries and entering the river directly is sufficient to effect the same degree of sedimentation that would occur if the present amount of dilution with water from Lake Michigan were absent. Therefore while the introduction of Lake Michigan water might probably interfere with sedimentation in the upper part of the river it would have no such effect in the stretch of the stream from La Salle to Grafton. (6165–6166.)

Concerning the effect of dilution on the purification of streams, the witness stated that although dilution does not cause any actual destruction of infectious material it does diminish the danger of infection arising from the drinking of such water. If, for example, infectious material were introduced into water to such an extent that each tumblerful contained one typhoid bacillus and this water were diluted with nineteen times its bulk of pure and uninfected water it would then be true that out of one hundred tumblerfuls of this mixture only five tumblerfuls would contain typhoid bacilli instead of the whole one hundred, as was originally the case. In other words, the effect would be the same as if 95 per cent of the typhoid bacilli perished. In this way dilution unmistakably diminishes the danger from infection. Such dilution as is turned into Desplaines River from the drainage canal has, however, little effect on the infectious quality of the water in Illinois River at Grafton, because, in the opinion of the witness, the infectious bacteria in the Chicago sewage would have perished long before the mouth of Illinois River would be reached. (6167–6168.)

The witness then said that Professor Sedgwick, in his testimony recorded on page 2207 of the record, made a misquotation from the report of the river commissioners of Great Britain published in 1874, giving their statement as "there is no river in the United Kingdom long enough to purify itself from any sewage admitted to it, even at its source," whereas the statement in reality was, "It will be safe to infer * * * that there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation." The witness explained that there was a material difference in the two statements, because at the time the aforesaid report was published the knowledge of sanitarians regarding the quality of a water was based on chemical rather than on bacteriological data; practically nothing was known then concerning the elements in sewage that imparted to it its dangerous character. It had been determined empirically that a certain relation exists between the oxidation of sewage and the loss of its dangerous qualities, but it was not known what this relation was nor on what it depended. The modern conception of the purification of a sewage-polluted stream is based on the disappearance and destruction of disease-producing bacteria. There is, therefore, a wide difference between stating that the purification of a stream is effected within a certain distance and that the destruction of sewage by oxidation is effected within a certain distance. It does not follow that because complete destruction by oxidation of the organic matter in a polluted water does not occur within a specified distance, the real purification, namely, the destruction of dangerous bacteria, may not be accomplished within that distance. The process of nitrification or oxidation and the processes leading to the disappearance of dangerous bacteria do not always run a strictly parallel course, either in sewage tanks or polluted rivers. (6172–6174.)

The witness then took up the discussion of an elaborate series of experiments made to determine the longevity of the typhoid bacillus under natural conditions in the water of the drainage canal and of Illinois River. The experiments were conducted with the cooperation of Professor Russell, of the University of Wisconsin, and Professor Zeit, of the Northwestern Medical School. The serious and misleading effect on the longevity of the typhoid bacillus produced by laboratory conditions had impressed itself upon the witness, and with a view to removing this objection, receptacles were planned for imprisoning the bacilli in the water of the drainage canal under normal conditions of life and temperature.

Five different bodies of water were selected for these experiments, namely, Lake Michigan, Chicago River, the drainage canal at Lockport and at Robey street, and Illinois River at Averyville. Professor Zeit carried on the experiments with Lake Michigan and Chicago River water, Professor Russell undertook those with the water of Illinois River at Averyville, and the witness conducted those on the drainage canal. Parchment sacks were employed instead of glass tubes. These sacks had a capacity of about 800 c. c., and when suspended in the water by floats permitted the passage of certain substances in solution, but did not allow the bacteria to pass through their walls. The conditions to which the typhoid bacilli introduced into the sewage in these sacks were subjected are almost precisely those prevailing in nature, inasmuch as the bacteria inside and outside of the sacks can not pass through the walls, and yet they are subjected to the action of the toxic products and the saprophytic microbes in the sewage. The sacks were fastened to the points of glass tubes about 6 inches in length and were sealed with a mixture of tallow and rosin. They were then weighted so as to swing freely in the water when filled with sewage and suspended in a framework covered with a wire screen that permitted free circulation of the outside water. This frame was made of fine strips of wood, and was 4 feet long and 3 feet wide by 3½ feet deep. The bottom, top, and lower five-sixths of the sides and ends of this frame were covered with wire screen. The upper 6 inches of the sides and ends were of 1-inch pine fencing. The top opened with a hinge and was fastened in place by a hasp and padlock. It was balanced in such a way that it floated with the water level up to the height of the lower margin of the upper solid portion of the body. The part above the water was thus of boards and served to break the effect of the waves over the sacks. The witness was confident that the water within the frames differed in no essential way from that in the open channel. The sacks were tested for cracks or defects before they were taken from the labratory and again when they were filled in the field. To the lower end of each sack a small weight was attached, which served to keep it in an upright position in the water. A cord was also fastened to the lower end, by means of which the sack was brought to the surface of the water and the contents agitated at the time of taking samples. In carrying forward these experiments three cultures were employed, designated as *x*, *y*, and *z*, all taken from patients suffering from the disease. They were therefore in an active and virulent condition. Into the sacks was introduced a quantity of sewage, together with a strong culture of the typhoid bacilli. Sixteen such sacks were placed in the Chicago drainage canal at Robey street and 12 at Lockport. Other sacks which were not inoculated with typhoid bacilli but contained samples of raw sewage taken from the canal at the respective points were used for parallel experiments. Samples of water from these control sacks were placed at frequent intervals and examined as to their bacteriological content. After the culture sacks were inoculated and set in place samples were collected from them in sterilized glass bottles, with all proper aseptic precautions, and accurately measured quantities were mingled with sufficient nutrient media of various kinds, and when the growth had sufficiently developed were examined for the identification of the typhoid bacillus. The results for the two stations in the drainage canal are included in Table 78. The full discussion of these important experiments occupies pages 6180–6238 of the record.

TABLE 78.—*Results of experiments with Bacillus typhosus infection in Chicago drainage canal, 1903.*

Station.	Date.	Bacteria per cubic centimeter (initial count).			
		Sewage bacteria.	Colon bacilli.	Streptococci.	B. typhosus infection.
Lockport	October 5-14	110,000	4,000-6,000	1,000	12,000
Do	do	110,000	4,000-6,000	1,000	600
Do	do	110,000	4,000-6,000	1,000	180
Do	October 14-27		1,000	2,000	30,000
Do	do		1,000	2,000	1,500
Do	October 17-27		1,000	2,000	360,000
Robey street	October 9-23	390,000	4,000-6,000	2,000	11,500
Do	do 9-23	390,000	4,000-6,000	2,000	670
Do	do	390,000	4,000-6,000	2,000	18,000
Do	do	390,000	4,000-6,000	2,000	900
Do	October 18-23	113,000	1,000	2,000	25,000
Do	do	113,000	1,000	2,000	16,800
Do	October 25-November 4	240,000	1,000	1,000	285,000
Do	do	240,000	1,000		285,000
Do	do	240,000	1,000		857,000
Do	do	240,000	1,000		857,000

TABLE 78.—*Results of experiments with Bacillus typhosus infection in Chicago drainage canal, 1903*—Continued.

Station.	Typhoid bacilli found after inoculation.																
	10 minutes.	1 hour.	20 hours.	28 hours.	1 day.	2 days.	3 days.	4 days.	5 days.	6 days.	7 days.	8 days.	9 days.	10 days.	11 days.	12 days	14 days.
Lockport	....	....	....	....	0	0	0	....	0	....	0	....	0	....	....	....	....
Do	....	....	....	....	0	0	0	....	0	....	0	....	0	....	....	....	....
Do	....	....	....	....	0	....	0	....	0	....	0	....	....	....	....	....	....
Do	....	....	....	....	....	....	0	....	0	0	....	0	....	0	....	....	....
Do	....	....	....	....	....	....	0	....	0	....	....	....	....	....	....	....	....
Do	63	....	....	....	....	0	0	....	0	....	0	....	....	0	....	....	....
Robey street	....	....	....	....	....	....	....	0	....	0	0	....	....	....	0	0	0
Do	....	....	....	....	....	0	....	0	....	....	0	....	....	....	....	....	....
Do	....	....	....	....	....	....	....	0	....	0	0	....	....	....	0	0	0
Do	....	....	....	....	....	0	....	0	....	0	....	....	....	....	....	....	....
Do	....	....	....	....	....	0	0	....	0	....	....	....	....	....	....	....	....
Do	....	....	....	....	....	0	0	....	0	....	....	....	....	....	....	....	....
Do	....	41	21	46	....	1	0	0	0	0	0	0	....	....	....	....	....
Do	....	....	....	....	....	....	0	0	0	0	0	0	0	....	....	....	....
Do	....	....	20	43	....	9	0	0	0	0	0	0	0	....	....	....	....
Do	....	....	....	....	....	....	....	0	0	0	....	....	0	....	....	....	....

From the results of the experiments above recorded and those conducted by Professors Russell and Zeit, the witness submitted the following conclusions: Experiments under conditions closely simulating those in nature indicate that the typhoid bacillus introduced into unsterilized Lake Michigan water does not survive for a period longer than four days after such introduction. It is probable that specially resistant individual cells may survive longer, but in any case the maximum period would be eight to ten days. The experiments in the drainage canal indicate that the bacillus was not isolated after two days, except in one anomalous case, in which three typhoid bacilli were isolated on the tenth day from a single plate in a single sack. The reasonable explanation for this, according to the witness, was that at times when the contents of the sack were heavily infected, during the process of tilting and agitation some particles in the sewage to which typhoid bacteria were adhering were deposited and became dried upon the walls of the sack above the water line and were subsequently washed off and dropped into the water of the sack. Taking into consideration all the experiments made in the drainage canal, the witness was of the opinion that the typhoid bacilli could not live for a period longer than four days after infection. The experiments in Illinois River led him to believe that they would not live in that stream under natural conditions for a period longer than five or six days. Summing up, the witness stated that specific infection of typhoid fever discharged into the drainage canal might live as long as three or four days after leaving the body of the pollution, but that at any rate it would perish long before Averyville was reached. (6238–6241.)

The witness then cited experiments made by Dr. William G. Savage, of University College, Cardiff, Wales, in which it was shown that the colon bacillus lives for some time in soils but disappears as time goes on, the ordinary soil organisms invading the material and taking the place of the colon bacillus. It is more resistant than the typhoid bacillus, and therefore it is a fair assumption that the latter would rapidly die out in soils. (6241.)

The witness stated that the experiments above outlined show that the colon bacillus and sewage streptococci die out rapidly in polluted streams, and attributed the death of the typhoid bacillus in such water to the poisonous action of the products of other microbes, and this is the reason why the germ will not live as long in polluted as in pure water. He then expressed the opinion that the life of the typhoid bacillus would not continue any longer in the sediment of a polluted stream than in the water of that stream, because in the sediments the germs are in very much the same surroundings that they would be in the water, except that it is fair to assume that the organic matter is more abundant on the bed of the stream in the sediments. This condition would encourage the growth of saprophytic bacteria, and therefore the toxic products fatal to the typhoid germ would be in more concentrated form. There is a difference in the conditions that prevail in moist soil and those in the sediment of a running stream. In the former the bacilli are not exposed to the action of toxic products for the reason that such products can not act on the bacillus through the intervening air space or through the interstices of the soil. A continuous layer of fluid is needed for the diffusion of these toxic products, and unless the typhoid bacilli are in contact with them the conditions in ordinary damp soil are different from those prevailing in the sediment at the bottom of a river. Therefore the time that the typhoid bacilli will live in moist soil furnishes no criterion for its longevity in the sediment of a running stream. (6242–6244.)

Referring to the case in which the presence of typhoid germs was demonstrated in the mud of Lake Geneva, cited in the testimony of George W. Fuller, the witness stated that considerable doubt had been thrown on the work of the observer because his methods of identification were not satisfactory. He further said that he knew of no experiments or observations which demonstrate that this germ can live in the sediment of a running stream for a period up to a year, as stated by Mr. Fuller. (6246–6248.)

With reference to the statement made in the testimony of Professor Sedgwick that typhoid fever sometimes prevails in a city drawing its supply of water from a reservoir of a storage capacity equal to thirty days' consumption, the witness stated that it is not true that in such cases all the water pumped into this reservoir would remain there for a period of thirty days. In point of fact, some of it might be drawn from the reservoir within a very short time after its entrance therein. It does not follow that because a reservoir or settling basin holds a thirty days' supply all the typhoid bacilli introduced therein remain for thirty days. (6252.)

The witness laid special stress on the importance of the interpretation of vital statistics. It is not a matter of indifference how the figures so collected are viewed by statisticians. Statistical pitfalls are numerous, and certain fallacies of interpretation exist, the introduction of which may vitiate any conclusion drawn from figures that are in themselves exact. For example, it is commonly assumed that the death rate of a city is a correct measure of its healthfulness. The death rate among individuals of different ages and nationalities varies so much that a statement of deaths without regard to age, sex, or distribution of racial characteristics does not afford any helpful information and is frequently misleading. A community having a large percentage of infants or of aged persons would have a larger number of deaths per thousand than a community having a larger proportion of individuals of more resistant age; yet the two places may be equally healthful. It is well known, too, that certain races of mankind manifest weakness or lack of resistance to various diseases. For example, persons of Irish parentage are much more liable to consumption and pneumonia than Russian and Polish Jews. Therefore in making a statement of death rates from these two diseases in any city account should be taken of the proportion of each of these races involved in the estimate. (6260–6261.)

The method of expression of the fatality rate of any particular disease according to the mortality-percentage method described in the testimony of Messrs. Sedgwick and Fuller frequently fails, in the opinion of the witness, to give correct information as to the progress of the disease. Quoting from Newsholme, Vital Statistics, page 186, he gave the following example:

> Suppose a town of 100,000 with 2,000 annual deaths, of which 500 are caused by phthisis. Here the general death rate is 20 per 1,000; the death rate from phthisis is 5 per 100 living, and the deaths from phthisis form one-fourth of the total deaths. In another town having the same population the total deaths are 4,000, and therefore the death rate 40 per 1,000 inhabitants; the deaths from phthisis are 1,000, and therefore the death rate from phthisis is 10 per 1,000; but the proportion of the phthisical to the total mortality is one-fourth, as before. In the second town, however, there is by the latter test apparently no worse condition, so far as phthisis is concerned, than in the first, though matters are really twice as bad. (6261–6262.)

With reference to the value of chemical and bacterial data in water examination, the witness was of the opinion that such analyses furnish important evidence, and that while they often supplement and confirm the results of observations they also at times reveal conditions that mere ocular inspection would fail to bring to light. It is sometimes true that chemical and bacteriological data are the only data obtainable. In the study of the self-purification of streams such analyses afford a material aid in determining the rate and extent of the process of purification and make it possible to trace the successive changes that take place in the amount and condition of the organic matter. (6266–6267.)

Assuming that the reports of the St. Louis board of health show an apparent increase in typhoid fever during the years 1900 to 1903, inclusive, the witness stated that he did not regard it as a justifiable conclusion that the apparent increase was due to any infectious matter passing into the sewers of Chicago and thence to the St. Louis intake by way of Illinois and Mississippi rivers. An increase in the infection of Mississippi River water from points near at hand would seem to afford a more satisfactory explanation. The rural population on the watershed is an important factor to be considered, because typhoid fever is far more prevalent in rural than in urban districts. (6270–6275.)

The witness then compared the records of typhoid fever by months from 1890 to 1903, inclusive, in Chicago and St. Louis, and stated that he was unable to discover any relation between the monthly death rates in the two cities. The month showing the largest number of deaths in Chicago precedes the maximum in St. Louis by eleven months in 1892, by eight months in 1903, by six months in 1891, by five months in 1896 and 1898, by three months in 1899, and by two months in 1902. The Chicago maximum coincides with the St. Louis maximum in five years—namely, 1893, 1895, 1896, 1897, and 1900. The minimum monthly typhoid fever in Chicago precedes the minimum in St. Louis in five years—namely, 1891, 1893, 1898, 1900, and 1902, while the Chicago minimum coincides with the St. Louis minimum in 1890 and 1892 and follows it in 1894, 1895, 1896, 1897, 1901, and 1903.

The witness stated that he would expect in general that if the typhoid-fever conditions in St. Louis were dependent on those in Chicago, a large number of deaths from typhoid fever in the latter city would be followed within three or four months by an increase in the number in the former. No such relation appears, and therefore in his judgment the typhoid conditions in St. Louis are unaffected by those in Chicago. (6279–6281.)

The witness then presented some comparisons of the readings of gage heights in Illinois River at Kampsville and the death rate from typhoid fever in St. Louis, the object being to show that the contentions of the plaintiff concerning the effects of floods in Illinois River in raising the typhoid rate in St. Louis were not true. As a result of these comparisons the witness stated that in 1899 high water occurred at Kampsville in March and low water in September, while the maximum typhoid death rate in St. Louis occurred in November and the minimum in May. Again, in 1900 the high-water period was in

March and the low-water period in January, while the maximum typhoid fever occurred in St. Louis in October and the minimum in April and May. In 1901 high water occurred in April and the maximum typhoid fever rate in October, while low water occurred in October and the minimum typhoid in April. In 1902 high water occurred in July and low water in January, while the maximum typhoid occurred in October and the minimum in June. During July to November, inclusive, 1902, Illinois River averaged twice as high as during the same period in 1901, yet the typhoid-fever rate in St. Louis was almost exactly the same in the two years. From a detailed comparison of the entire record the witness stated that he was unable to discover any connection between the stages of water at Kampsville and the rate of typhoid at St. Louis, and he therefore concluded that the contention that high water in Illinois River washed down the infected matter from Chicago more quickly and resulted in high typhoid in St. Louis was unfounded. (6282–6284.)

The witness then discussed the characteristics of typhoid and malarial fevers at some length and stated that the diseases ordinarily termed intermittent fever, remittent fever, typho-malarial fever, congestive and continuous fevers are not distinct types, but that most of the infections designated by these terms are true typhoid or malaria, and in his opinion the deaths so classed should be transferred bodily to the column of deaths from typhoid fever, since malaria in temperate countries is rarely fatal. He further stated that he found in the records of the health department of St. Louis a very considerable number of deaths under these headings and believed that they were all genuine typhoid, and in his opinion no city in the United States has so large a death rate from genuine malaria as would be indicated by the official records of St. Louis. He then summed up the statistics for typhoid fever and the poorly defined disorders above noted, as shown in Table 79. (6287–6294.)

TABLE 79.—*Deaths from typhoid and so-called malarial fevers in St. Louis, 1895–1903, inclusive.*

Month.	1895.		1896.		1897.		1898.		1899.		1900.		1901.		1902.		1903.	
	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
January	12	10	4	13	7	5	4	6	10	4	19	6	8	5	14	5	15	4
February	3	7	4	10	9	5	6	10	7	8	5	3	14	0	16	6	15	1
March	3	8	3	6	7	11	7	9	4	6	16	9	11	4	11	9	20	4
April	7	7	4	11	4	13	6	8	5	6	4	7	4	7	14	3	17	4
May	6	9	9	10	7	8	2	8	2	12	4	7	8	7	11	8	15	8
June	6	14	6	7	9	18	7	10	5	8	8	12	16	9	7	4	18	8
July	9	8	13	23	10	17	9	13	9	18	15	9	13	15	14	12	27	10
August	17	15	29	34	18	20	(9)	(14)	6	30	20	20	31	5	26	7	37	10
September	9	32	13	27	17	31	14	18	16	28	13	20	24	9	21	16	42	17
October	15	24	9	20	17	24	12	12	15	16	30	9	32	11	32	17	29	17
November	13	8	7	14	15	13	7	13	32	8	15	3	27	5	31	9	24	3
December	7	13	5	2	5	5	12	13	20	4	19	7	20	3	25	6	31	5

A. Typhoid fever.
B. Remittent, intermittent, typho-malarial, congestive, and simple continued fevers.

The witness stated that the above table shows a close parallel between the number of deaths reported from the two causes. During the period July to October the number of deaths reported from both causes is high, while during April and May the number was low. During the latter part of the period an interesting change is noted. For the first five years the number of deaths under the heading B was greater than under A, but beginning with 1901 the reverse is true, showing that during the last four years there had been a transfer from column B to column A, the effect being to diminish the number of deaths from the so-called malarial fevers and increase the number from typhoid. The witness then presented Table 80, which is in part a summary of Table 79. (6294–6296.)

Table 80.—*Deaths from typhoid fever and reported deaths from remittent, intermittent, typho-malarial, congestive, and simple continued fevers in St. Louis, 1890–1903.*

Year.	Deaths from typhoid.	Deaths from other fevers.	Total.	Year.	Deaths from typhoid.	Deaths from other fevers.	Total.
1890	140	226	366	1897	125	172	297
1891	165	216	381	1898	95	134	229
1892	441	326	767	1899	131	148	279
1893	215	284	499	1900	168	112	280
1894	171	179	350	1901	198	80	278
1895	107	155	262	1902	222	102	324
1896	106	177	283	1903	288	91	379

The witness pointed out the fact that the above table shows that during the first ten years the number of deaths reported from typhoid fever was generally less than those from remittent fever, etc., but during the last four years the situation is reversed, and it is evident that some cause has been at work tending to produce a more accurate diagnosis on the part of the physicians. He believed it reasonable to suppose that the letters issued by the health commissioner to the physicians in 1900 and 1901, calling attention to the opening of the drainage canal and the necessity for reporting typhoid cases in the city, had caused them to pay closer attention to diagnosis, which had resulted in the marked change in reporting deaths. Citing so-called malarial records of other cities, such as Chicago, Albany, and Baltimore, the witness stated that there was a general correspondence by months and years with what had been noticed in the St. Louis record, namely, that the proportion of deaths from malarial fevers has been lower during recent years than previously, while that from typhoid has been higher. In support of his contention that the deaths from so-called malarial diseases should be placed in the typhoid column, he cited the experience of Albany, where a sand filter was put into operation in September, 1899. During the ten years previous to this date 777 deaths were reported from typhoid fever, or an annual average of 86, and during the four years after the installation of the filter, the number of deaths amounted to 106, or an annual average of 26. An exactly similar decline was noticed in the number of deaths reported from malarial diseases. Prior to the opening of the filter, these amounted to 61, or an annual average of 7, while during the four years since the filter was opened only 2 deaths had been reported, or an average of one-half. In the opinion of the witness, the inference was plain that both the above reported causes of death had been affected by the opening of the filter and only one conclusion could be drawn, namely, that the deaths reported as occurring by reason of malarial diseases were really genuine typhoid cases. Summing up all of the evidence, including that of the so-called malarial diseases, the witness stated that he was of the opinion that the average death rate from typhoid fever in St. Louis had been less during the four years from 1900 to the date of the testimony than previous thereto—excluding the year 1892, during which occurred the great epidemic—and that no portion of the typhoid fever mortality occurring in St. Louis since January, 1900, could be attributed either directly or indirectly to the effluents from the Chicago drainage canal. (6296–6309.)

With reference to the statement of Professor Sedgwick that inasmuch as typhoid germs coming from Chicago sewage are deposited in large quantities in the lakes and slack-water portions of Illinois River above Peoria, flood conditions such as would scour these deposits from the bed of the stream would cause the water leaving Lake Peoria to contain at times more infectious and dangerous pollution than is present in the diluted sewage entering the river at the foot of the drainage canal, the witness asserted that typhoid fever germs live so short a time under such conditions that there is no danger that the water leaving Lake Peoria can at any time contain more infectious material than exists in the diluted sewage flowing through the foot of the drainage canal. On the contrary, he was satisfied that there is a much smaller proportion in the water of Lake Peoria than in that of the canal. It is possible that where deposits of sewage matter are fresh, as they are in the bed of Chicago River, the sudden flushing out of such a stream may lead to an outbreak of typhoid fever within two or three days' distance from such deposits; but the witness knew of no instance where an epidemic of typhoid fever had been traced to the removal or flushing out of such sewage matter that had been allowed to remain undisturbed for a period of several weeks without receiving any addition of fresh material. In this connection, he declared that the cause of the epidemic at Detroit cited in the testimony of Messrs. Sedgwick, Whipple, Williams, and others had not been established beyond a reasonable doubt as coming from Black River at Port Huron. (6316–6319.)

On the assumption that an increase in typhoid fever since the opening of the drainage canal had actually occurred, which appeared to the witness to be contrary to the facts, it would be more reasonable to attribute such an increase to other causes than the canal, such as an infection of the water supply at some point nearer the intake, infection of the milk supply, or some other factor. (6323.)

It was the judgment of the witness that the water supply of St. Louis during the period from 1895 to 1899 was not satisfactory, because of the great amount of typhoid fever in the city, together with the typho-malarial and other so-called malarial troubles which should have been classed as typhoid. All these being taken into consideration, the rate during the years mentioned was much higher than it ought to be in a city having a pure and satisfactory water supply. (6327.)

The witness stated that it was impossible to draw a fair comparison between the conditions on the Potomac River between Cumberland and Washington and those on the streams between Chicago and St. Louis. The relatively rapid flow from Cumberland to Washington and the relatively short space of time required to travel this distance represent a very different set of conditions than those prevailing in Illinois River, because in the lower portion of the Illinois the current is sluggish and the time required for a body of water to pass very much greater than in the Potomac. (6334.)

Chicago pollution is manifest at the mouth of Illinois River chiefly in the increased amount of chlorine and nitrogen present in the water, but so far as the original polluting matter and pathogenic bacteria are concerned, there are no grounds for adopting the opinion that these substances persist in their original condition as far down as Grafton. It is quite possible that some of the very stable compounds introduced at Chicago may reach Grafton, but such compounds have no sanitary significance. (6336.)

The dams and slack-water basins in the Illinois River materially facilitate the process of sedimentation, but the removal of all the dams would not materially affect the purification of the Chicago sewage, because the elimination of the typhoid bacilli takes place in the upper portion of the stream. Such removal might, however, have some effect in retarding the purification of dangerous materials discharged by various communities in the lower stretches of the river. (6338–6339.)

CROSS-EXAMINATION.

The witness stated that in his opinion the best evidence of the purity of a water supply is the effect which it produces on the health of the community using it for domestic purposes. (6345.)

While nothing is definitely known as to the number of typhoid bacilli necessary to produce typhoid fever in man, it is well known, through experimental work on animals, that a single germ is rarely able to produce infection. In all cases of inoculation not one germ alone but many hundreds must be used in order to produce infection, even when these bacteria are introduced into the most delicate portions of the body. Reference was made to a case in which a laboratory worker attempted suicide by swallowing typhoid cultures. Several tubes of virulent culture produced only a mild attack of the disease, and while it is true that this person may not have been susceptible, there are very few data on which to base an opinion concerning susceptibility. Persons between the ages of 15 and 35 are more liable to typhoid fever than younger or older persons, but there is little information showing on what this variation in susceptibility depends. (6350–6351.)

With reference to the significance of sanitary analyses, the witness stated that there are cases in which light may be thrown on the sanitary quality of a water by the chemical examination, when the bacterial count at the time the examination is made fails to give information. For example, well water is often found to be high in chlorine and nitrates, which are indicated by the conditions to have originally come from sewage pollution. The number of bacteria in such a water may be low at the time the examination is made, but owing to the dangerous character of the surroundings the water would be condemned by the prudent sanitarian, although the bacterial count had not been high, inasmuch as it would be subject at any time to another influx of pollution, which would then be shown by the bacterial count. In the light of all the experience of the witness in the chemical examination of water, the amount and rate of nitrification in Illinois River between Lockport and Grafton are such as have been found in the experience of water analysts to accompany the disappearance of disease-producing elements, and while it is not possible to establish absolutely from the results of chemical examinations that any point where samples had been taken is free from disease-producing elements, such analyses afford a certain kind of evidence that must be weighed in forming judgment as to the sanitary quality of the water. (6359–6363.)

The cross-examiner then pointed out several instances in which the results of the witness' chemical examinations and those of Professor Palmer, made on samples of water taken at the same time and from the same point in the river, varied widely. The witness admitted these variations, but stated that the determinations are so delicate that even experienced water analysts obtaining samples of water under the same conditions would be expected to arrive at results that would differ, but such variations of 50 or even 100 per cent have no sanitary importance. The averages of a considerable series of analyses constitute the important factor, and little weight is attached to a single determination. (6366–6369.)

The witness stated that he did not wish to put himself in the position of recommending the introduction of sewage of any degree of staleness into a river from which a public water supply was immediately taken. The esthetic as well as the sanitary side is to be considered, and although he had stated that two days was about the limit of longevity of the typhoid bacillus in sewage, this time ought to be doubled or trebled to insure safety. It was his firm opinion that if the sewage contained in the Chicago drainage canal was from four to six days old typhoid bacilli would not be alive in it. (6375.)

LUDWIG HEKTOEN.

Prof. Ludwig Hektoen, called as a witness on behalf of the defendants, stated that he was a physician and surgeon, graduated from the College of Physicians and Surgeons in Chicago in 1887, had made a specialty of pathology in various hospitals and institutions in Cook County, Ill. and had studied extensively in Europe. His testimony, given on pages 6700–6716 of the record, was in general a confirmation of that part of the testimony of Professor Jordan relating to the typhoid and malarial death rates in St. Louis and the probable identity of the two classes of diseases. He expressed the opinion that under that interpretation there had been no increase in typhoid in St. Louis.

H. L. RUSSELL.

DIRECT EXAMINATION.

H. L. Russell, a witness called in behalf of the defendants, stated that he was in charge of the department of bacteriology in the University of Wisconsin, having occupied that position since 1893. He had received his bachelor's degree from that university in 1888, remained there as fellow in bacteriology until 1890, and then studied in Koch's Institute in the University of Berlin, in the zoological station at Naples, and in the Pasteur Institute at Paris. He returned to America in 1891 and took the degree of doctor of philosophy at Johns Hopkins University. Since 1894 he had been bacteriologist of the Wisconsin State board of health, and in that capacity, as well as in a private capacity, had had to do with the analyses of waters from a bacterial point of view for sanitary purposes. In connection with this work he had made examinations of all the waters submitted for public analysis in the State and had been specially engaged in the examination of the water supplies of Superior, Ashland, Marinette, Merrill, Stevens Point, Wausau, Eau Claire, Portage, Green Bay, Beloit, Baraboo, Wis.; Menominee, Mich., and Dubuque, Iowa. He had studied outbreaks of typhoid fever and made investigations of the subject at Baraboo in 1901 and at Ashland, Superior, Menominee, and Marinette. He professed to have an extensive acquaintance with the literature bearing on typhoid fever epidemics and other water-borne diseases. (6467–6469.)

The witness stated that he had examined and studied the bacterial and chemical analyses of the waters of Lake Michigan, the drainage canal, and Desplaines, Illinois, Mississippi, and Missouri rivers, as made and introduced into the testimony by Professors Jordan, Gehrmann, Palmer, and Burrill. In addition to this, he made a journey in September, 1903, from Chicago to St. Louis by way of the above-named water courses, which had given him special opportunities for the physical examination of those streams. (6469–6470.)

With reference to the *Bacillus prodigiosus* experiment, an account of which was introduced into the testimony by Doctor Ravold, the witness stated that, assuming all the premises to be true and taking into consideration all the knowledge which he possessed concerning the distribution of this organism under normal conditions, he was of the opinion that the experiment did not in any way throw light on the probable longevity of the typhoid bacillus as measured by that of *B. prodigiosus*, and he was led to believe it to be highly improbable that the organisms reported to have been found in the water taken from the intake tower at Chain of Rocks were the same or were derived from the organisms placed in the water of the drainage canal. The witness based this conclusion on the fact that a series of examinations made of samples taken from Illinois River at Lockport, Joliet, Peoria, and Grafton between November 7 and December 15, amounting in all to 1,752 samples, and also of samples taken from the intake tower at Chain of Rocks and from the laboratory tap in St. Louis between November 20 and March 1, amounting in all to 3,120 samples, failed to reveal the presence of *B. prodigiosus* until twenty-eight days had elapsed from the time the cultures were placed in the drainage canal. If the organisms reported to have been isolated from the waters of Illinois River at Grafton and Mississippi River at Chain of Rocks had been the same as those deposited in the canal, or their progeny, it would have been natural to expect that in the numerous preceding analyses that had been made organisms of this species would have been found, as there is reason to believe that the flow of water from the canal through Illinois River to St. Louis would not have consumed a period of twenty-eight days. It is not uncommon to find in the water of this region organisms which possess characteristics similar to those of *B. prodigiosus* by reason of the red pigment that they produce when grown upon the ordinary nutrient media, and which therefore might be mistaken for *B. prodigiosus* unless the characteristics of the germs isolated were studied in detail. (6473–6476.)

The witness then described various pathogenic bacteria and other methods of identification, and stated that the typhoid bacillus is capable of retaining its vitality in soil for a varying period of time, depending on the influences to which it is subjected. When deposited in soil by burial the organism rapidly loses its vitality, so that at the expiration of a short period, measured by a few days, it can no longer be detected in the upper layers of the soil. When the soil is moist and the organism is deposited in typhoid dejecta, the germ is capable of retaining its vitality for a longer period of time, which may be measured by months. When deposited in water the life of the bacillus is materially shorter than in soil. Where it is brought into contact with a medium containing normal saprophytic bacteria, such as would naturally be found in sewage or polluted waters, the vitality of the typhoid germ is greatly impaired and its longevity would not normally be more than three or four days; but in waters of a great degree of purity, where saprophytic life is not so abundant, the longevity would be increased, so that it may possibly be found at the end of one or two weeks. (6477–6481.)

The witness then described an extensive series of experiments conducted by him to determine the longevity of the typhoid organism. These experiments indicate that the germs of typhoid fever are capable of retaining their vitality for a period of time measured by months in water which is ordinarily pronounced pure and which has first been sterilized by heat and thus deprived of its ordinary germ life and possibly of the metabolic products of bacterial activity. When, however, the typhoid organism is introduced into such water that has been deprived of its bacterial life by filtration and under conditions where soluble products of bacterial growth remain in the water, the life of the germ is considerably shorter than it is in water sterilized by heat. (6481–6482.)

In the opinion of the witness the conditions under which laboratory experiments have been performed to determine the longevity of the typhoid organism are, as a rule, more favorable for the prolongation of vitality than natural conditions, because when the typhoid organism is exposed under natural conditions—in flowing waters, for example—it is subjected to a number of factors of a detrimental character which often can not be readily simulated under laboratory conditions. (6482.)

From his knowledge of the conditions in the waters of the drainage canal and Illinois River the witness gave it as his opinion that the longevity of the typhoid organism in those waters would not be greater than three to four days, because of the great number of conditions exercising prejudicial effects on its vitality. He stated that this assertion had been proved by experiments in which cultures of the typhoid organism were placed in celloidin sacks, which, being germ tight, would not permit the passing out or in of any organisms but which would, on the other hand, permit the passage of the soluble products of the growth of these organisms. These sacks were placed in cultures made of nutrient material, to which was added various other kinds of material containing divers forms of saprophytic bacteria. Under such conditions bacterial growth was abundant in the outside medium, but the organisms inside of the sacks were unable to grow and in many instances were actually killed. (6483–6484.)

The dams in Illinois River, especially in the lower reaches, where the normal fall is slight, have a considerable effect in producing marked sedimentation of suspended matter in the water, and such sedimentation carries to the bottom much of the bacterial life, thus purifying the water. Inasmuch as the specific gravity of bacteria is only a trifle above that of water, the sedimentation of such organisms must necessarily accompany the sedimentation of suspended matter, which is at its maximum under quiescent conditions. It is extremely improbable that sufficient clear water from Lake Michigan could be discharged through the drainage canal to interfere with the normal sedimentation taking place in the river behind dams and in other practically quiescent portions of the channel. (6486–6489.)

Dilution of any polluted water with any pure water greatly diminishes the danger of infection from the use of such water. The infection of the human system from disease bacteria requires in some cases a simultaneous introduction of more than one specific organism. When water which is infected with such bacteria is diluted with pure water the danger which might arise from the ingestion of such water is diminished. Therefore, on the assumption that the danger of infection from sewage comes from the presence of pathogenic bacteria, a dilution of the sewage would diminish the number of bacteria of a specific kind per unit quantity of water. Thus the discharge of pure water from Lake Michigan into Illinois River, through the drainage canal, greatly minimizes the danger of infection which might come from the Chicago sewers, and when considered from the standpoint of dilution alone the injection of Lake Michigan water into Illinois River must be beneficial. Considering the conditions in Illinois River with reference to sedimentation and dilution and all other observable factors which permit chemical and bacterial changes in the sewage, as revealed by the analytical results presented by the defendants, the witness did not believe that the sewage of Chicago could have any material effect on the waters of Mississippi River, except possibly to increase the amount of such undissolved salts, as chlorine, which are not taken out of solution and which would therefore find their way downstream, and thus increase the chlorine content of the waters of Mississippi River as it passes the shores of Missouri. Basing his opinion on results of investigations on the longevity of typhoid-fever bacilli in natural waters, the witness stated that dangerous pollution in Chicago sewage could not exert any influence on the character of the waters of Illinois River at its mouth, because it had been shown that organisms capable of causing typhoid fever will not live in the waters of Illinois River for a sufficient period of time to be carried from Chicago to Grafton. (6489–6494.)

The witness then gave an account of his joint experiments with Professors Jordan and Zeit for the purpose of determining the longevity of typhoid bacilli by confining them in impermeable sacks and exposing them in the waters of the Chicago drainage canal and Desplaines River. The technique of these experiments is described in the testimony of Professor Jordan (pp. 235–236) and will not be repeated here. Professor Russell's account can, however, be found on pages 6496–6509 of the record. His work was carried on at Peoria. The results are discussed on pages 6509–6516 of the record and are reported in tabular form below.

TABLE 81.—*Results of longevity experiments with typhoid bacilli in water of Illinois River at Peoria by the impermeable-cell method.*

No. of laboratory sack.	Strain of culture used.	Number of typhoid organisms per cubic centimeter inoculated.	1st day.		2d day.		3d day.		4th day.		5th day.		6th day.		7th day.	
			Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.
1	X	1,000	12	1	....	....	9	0	....	....	11	0	....	....	....	....
2	X	2,000	....	....	....	....	....	....	8	0	....	....	....	....	....	....
3	X	4,000	....	....	....	....	....	....	....	....	....	....	12	0	....	....
4	X	10,000	....	....	....	....	....	....	13	0	3	0	....	....	8	0
5	X	20,000	6	0	....	....	13	2	....	....	9	0	8	0	7	0
6	Y	1,000	8	3	....	....	6	2	....	....	....	....	....	....	....	....
7	Y	2,000	....	....	....	....	....	....	9	0	....	....	....	....	....	....
8	Y	4,000	....	....	....	....	....	....	....	....	....	....	8	0	....	....
9	Y	10,000	....	....	....	....	....	....	11	0	....	....	....	....	7	0
10	Y	20,000	8	4	....	....	16	10	....	....	18	0	....	....	6	0
11[a]	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
12	Z	540	{3[b] 17	3 15	}12	6	....	....	....	....	8	0	....	....	....	....
13	Z	540	....	....	....	....	....	....	....	....	....	....	....	....	3	0
14	Z	5,400	3[b]	3	....	....	....	....	....	....	....	....	....	....	1	0
15	Z	10,800	15	14	13	6	....	....	....	....	12	0	....	....	....	....
Number of colonies daily examined from all sacks			72	....	25	....	44	....	41	....	61	....	28	....	32	....
Number of typhoid colonies found on successive days			....	43	....	12	....	14	....	0	....	0	....	0	....	0
Total number of sacks examined on different days of exposure			8	....	2	....	5	....	4	....	6	....	3	....	6	....
Total number of sacks in which typhoid was found			....	7	....	2	....	3	....	0	....	0	....	0	....	0

[a] Control sack. [b] At end of 1 hour.

TABLE 81.—*Results of longevity experiments with typhoid bacilli in water of Illinois River at Peoria by the impermeable-cell method*—Continued.

No. of laboratory sack.	Strain of culture used.	Number of typhoid organisms per cubic centimeter inoculated.	9th day.		10th day.		12th day.		14th day.		16th day.		17th day.		Total.
			Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	
1	X	1,000	....	....	10	0	....	....	....	....	....	....	....	....	....
2	X	2,000	....	....	....	....	....	....	....	....	....	....	....	....	....
3	X	4,000	....	....	....	....	....	....	....	....	....	....	....	....	....
4	X	10,000	....	....	....	....	....	....	....	....	....	....	....	....	....
5	X	20,000	....	....	12	0	12	0	11	0	....	....	15	0	....
6	Y	1,000	....	....	....	....	....	....	9	0	....	....	....	....	....
7	Y	2,000	....	....	....	....	5	0	5	0	6	0	....	....	....
8	Y	4,000	....	....	6	0	4	0	....	....	8	0	....	....	....
9	Y	10,000	....	....	11		....	....	....	....	....	....	....	....	....
10	Y	20,000	....	....	7	0	6	0	....	....	....	....	....	....	....
11 *a*	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
12	Z	540	....	....	....	....	2	0	....	....	....	....	....	....	....
13	Z	540	4	0	....	....	7	0	....	....	....	....	....	....	....
14	Z	5,400	....	....	....	....	....	....	....	....	....	....	....	....	....
15	Z	10,800	14	1	....	....	2	0	....	....	....	....	....	....	....
Number of colonies daily examined from all sacks			18	....	46	....	38	....	25	....	14	....	15	....	459
Number of typhoid colonies found on successive days			....	1	....	0	....	0	....	0	....	0	....	0	70
Total number of sacks examined on different days of exposure			2	....	5	....	7	....	3	....	2	....	1	....	54
Total number of sacks in which typhoid was found			....	1	....	0	....	0	....	0	....	0	....	0	14

The witness then described another experiment, as follows:

Nonnutrient agar from which all soluble products had been removed by washing was prepared in rectangular blocks about one-half inch square and 2 inches long. These blocks were inoculated in the center with freshly grown typhoid cultures forced into them by a platinum wire. After removing the wire the point of entry was sealed from contamination by searing the surface with a hot iron. According to Oswald, such agar possesses the property of allowing diffusion to take place quite as rapidly through its substance as through water. Hence it follows that typhoid organisms inclosed in the interior of such an agar mass, if exposed in an aqueous medium containing bacteria of various kinds, would be subjected to the same influences arising from the growth and development of water and of sewage bacteria as they would if they were placed directly in the water, but with the difference that the typhoid organism would not come into actual contact with extraneous water and sewage organisms. These blocks, inoculated with the three strains of typhoid bacilli mentioned in the testimony of Professor Jordan and designated as *x*, *y*, and *z*, were placed in the waters of Illinois River in small galvanized-iron cylinders, the top and bottom of which were covered with coarse wire netting.

Under these conditions the water had free access to the individual blocks. The results were as follows:

Series 1, inoculated with culture *x*, was examined on the first day by taking one of these agar blocks and tearing off the upper surface and attemping to transfer any material which was in the line of the inoculation previously made. Similar transfers were made on the third, fifth, ninth, twelfth, fourteenth, sixteenth, and seventeenth days after immersion. In no case did any growth occur on these subcultures.

Series 2 was inoculated with the same organism and subcultures were made immediately and on the first, second, third, sixth, eighth, tenth, and thirteenth days. Growth was produced from the cultures made immediately and on the second day.

Inoculation of series 3 was with the *y* strain and tests were made immediately after inoculation and on the first, third, fifth, seventh, tenth, twelfth, fourteenth, and seventeenth days. In no case were positive subcultures transferred except immediately after inoculation and on the fifth day.

The fourth series was inoculated with the *z* strain and subcultures were transferred immediately and on the first, second, third, sixth, eighth, tenth, and thirteenth days. No positive results were found except in the transfers made immediately after inoculation and on the first day.

The above experiments were conducted in the waters of Illinois River at Peoria. Subsequently two experiments were made in the waters of Lake Mendota at Madison, Wis., where cultures were removed on the third, seventh, tenth, eleventh, twelfth, fifteenth, and twenty-first days after immersion, but the typhoid-fever organism was isolated only in the samples removed on the third and seventh days. The experiments as a whole showed a variation in the vitality of the typhoid organisms and a rapid destruction of them when exposed, not to the water nor the extraneous bacteria themselves, but merely to the soluble products which these germs are capable of producing. Control experiments were instituted with these agar blocks inoculated with the typhoid bacilli, the blocks not being exposed in the water but kept in the air. The results showed that the organism was capable of retaining its vitality for at least two weeks, and on some occasions for a longer period. (6516–6519.)

The witness stated that from the results of his experiments, taken together with those of Professors Jordan and Zeit, he would conclude that the typhoid organism would live when immersed in the waters of Lake Michigan for a period of six or eight days, in Chicago River from two to three days, and in Illinois River from three to four days at the longest. In view of the results obtained by the experiments, and the fact that in the judgment of the witness typhoid organisms deposited in Chicago River, the drainage canal, and Illinois River would be subjected to influences even more detrimental than those existing under the conditions of the experiments, he was of the opinion that it would take a much longer period of time for the Chicago sewage to pass down Desplaines and Illinois rivers and finally reach Chain of Rocks than is required to kill typhoid organisms when placed in such an environment as that existing along these watercourses. The conditions under which the experiments were made approach more nearly the actual conditions to which the typhoid-fever organism is subjected when exposed in a flowing river, and therefore from a scientific standpoint a greater value may be attached to conclusions based on these experiments than to any conclusions that had been previously drawn from the experiments of other investigators. The results show that typhoid bacilli live longer in pure water than in polluted water. The experiments also shed light on the longevity of typhoid bacilli in the sediment of polluted streams. Under such conditions the pathogenic bacteria are brought into contact with even a larger number of other organisms than when they are exposed in the waters of a river, and therefore they are presumably in contact with increased amounts of unfavorable metabolic products, so that such conditions are certainly not less prejudicial than those found in the water of the stream itself. The witness expressed the opinion that if the longevity of the typhoid bacillus is impaired by the action of sewage and of water bacteria in a polluted stream, at least the same if not a greater effect would be produced if such typhoid organisms were in contact with these bacteria and the products of their growth in the sediment of the stream. (6519-6523.)

The witness differentiated between the conditions prevailing in moist soil and in the sediment of running streams as follows:

In the case of moist soil the interstices between the particles are not entirely filled with water, but a considerable amount of these spaces is filled with air. In the sediment found in running streams or lakes such interstices are entirely filled with water. Under the latter conditions the unfavorable products of the growth of bacteria would be greatly diffused among the typhoid bacilli deposited there, while under the former conditions such ready diffusion could not take place, and therefore the typhoid bacteria would acquire a longer lease of life. Therefore, observations of the longevity of the typhoid germ in moist soil are not reliable bases to determine its longevity in stream sediment. The conditions are not comparable. (6525–6530.)

With reference to the evidence cited by George W. Fuller concerning the persistence of typhoid germs in the sediment of Lake Geneva, the witness, after reviewing the conditions, stated that the results were doubtful, because early findings with reference to the discovery of the typhoid organism must be regarded as more or less unreliable, for the reason that no bacteriological data were given concerning the technical methods employed, and therefore the conclusions presented are not justified from an experimental point of view. (6530–6536.)

The attention of the witness was then directed to the typhoid statistics of St. Louis and Chicago and the general drainage areas of Mississippi and Missouri rivers above St. Louis. He cited the two methods of interpreting statistics known as the mortality percentage and the rate per unit of population methods, and expressed a preference for the latter, for the reason that in his opinion the former is liable to introduce errors which might readily vitiate the accuracy of the statistics. When the number of deaths from any particular disease is compared with the total number of deaths, a wrong basis of comparison is involved. What is wanted in any given community is to know whether a disease is increasing more rapidly than the increase in population. The fatality rate of any disease should not be based on the ratio between the death rate from that disease and the total death rate, because the variation which often occurs in the total death rate may be subject to many conditions. Suppose, for example, that a serious epidemic of some disease like bubonic plague or yellow fever should occur. It would be manifestly improper to compare the typhoid death rate in that community with the total number of deaths because in such case it would be shown that the typhoid rate was decreasing; whereas it might actually be on the increase, but by reason of the unusual number of deaths due to the epidemic of the other disease it would appear to be less by comparison. (6540–6542.)

The witness then expressed the opinion that the liability of typhoid epidemics arising by infection from rural populations was often underestimated and cited a number of well-known cases—notably those at Lausanne, Switzerland; Plymouth and Butler, Pa.; Lowell, Mass., and Ithaca, N. Y.—all of which were attributed to isolated points of infection in rural communities. Such infection is especially to be feared on account of the carelessness which prevails in such communities in the disposition of the dejecta. Disinfection is not maintained as faithfully in the country as in cities. (6542–6543.)

The witness then gave it as his opinion that the evidence to be adduced from the chemical and bacteriological studies of river waters affords the best possible means known to determine whether such waters are likely to serve as carriers of infection. The analytical evidence that can be gathered from samples of such waters taken at frequent intervals for a considerable period of time should show the progress of self-purification in such running streams, and the data furnished become the foundation on which a sanitarian or epidemiologist must base his conclusions, although it has been abundantly proved that water supplies are not the only means by which typhoid epidemics may be disseminated. (6543–6545.)

With reference to the apparent increase of typhoid fever in St. Louis during 1900 to 1903, inclusive, as compared with previous years, the witness stated that, assuming that these statistics are true and taking into consideration the conditions which prevailed in the drainage basins of the three rivers mentioned and the fact that there are sources of pollution from which typhoid organisms might arise which are not so far removed from St. Louis as Chicago, and taking into consideration further the results of typhoid experiments which have been made, as detailed in the testimony, he thought that there was no scientific reason justifying the conclusion that the increase reported by the St. Louis board of health for the period above mentioned is due to infectious matter derived from the sewers of Chicago by way of the drainage canal. (6545–6546.)

The terms remittent, intermittent, typho-malarial, congestive, and simple continued fevers are relics of old methods of description which attempted to differentiate these febrile changes merely on the basis of the symptoms most evident. They are not recognized by bacteriologists or clinicians of the present time as being satisfactory names for specific types of fevers. The witness was then asked a hypothetical question, based on the assumption that the number of deaths reported as occurring from typhoid fever and from remittent, intermittent, typho-malarial, congestive, and simple continued fevers during the period from 1890 to 1903 in St. Louis was as shown in Table 80 (p. 242). In reply he expressed the opinion that the record for typhoid fever did not represent the total number of deaths from that disease occurring in the city, and that the large number of deaths reported from the remittent fevers was due to improper diagnosis. If the deaths attributed to the other diseases had been diagnosed according to modern methods they would in the large majority of cases have been found to be typhoid fever, and it was the opinion of the witness that they should all be included in the statistics as such. The death rate from the malarial fevers indicated in the second column is comparatively insignificant in the United States, and of necessity it follows that no city has so high a death rate from these diseases as is represented in the number of deaths reported in the St. Louis statistics. It would be practically impossible for anyone to give an accurate idea as to what percentage of the deaths reported as due to those diseases should be certainly charged to typhoid fever, but it would undoubtedly be safe to attribute a large proportion to this disease. It is noteworthy that in regions where malaria is known to be common, and where the best modern methods of diagnosis are employed, the large number of deaths reported as due to genuine malarial fever has been greatly reduced since the introduction of those methods. (6549–6556.)

Taking into consideration the fact that the typhoid statistics as reported to the health commissioner of St. Louis did not represent the actual conditions in that city with reference to the disease, but that these statistics should be increased by a large proportion, if not all, of the deaths reported under the captions remittent, intermittent, typho-malarial, congestive, and simple continued fevers, the witness expressed the opinion that when such additions are made for the period covered by the statistics presented, and when the corrected statistics are compared with the typhoid-fatality statistics of other cities where similar types of water supply are used for municipal purposes, they show that there had been no increase in the actual number of typhoid deaths occurring in St. Louis from 1900 to 1903, inclusive, as compared with the rate prevailing for the period 1890 to 1900, inclusive. (6559–6560.)

The water supply ot St. Louis is not less valuable for drinking purposes nor more liable to carry water-borne diseases since the opening of the Chicago drainage canal than it was before, because experiments have shown that the typhoid organism is killed in Illinois River in a period of time less than that which is necessary for the water to flow from Chicago to St. Louis; and, the destruction of typhoid organisms being assumed as an index of the destruction of all pathogenic organisms in water, it is safe to assert that the same statements are true tor the cholera germ. (6560–6561.)

The increase in the speed of the current of Illinois River caused by the added volume of water discharged into it from the drainage canal probably alters the manner of sedimentation occurring in the river. The added water carries with it a larger amount of suspended organic matter and therefore increases the amount of suspended material, the result being an increase of sedimentation. If this increase did not cause an overflow of the banks, the speed of the current would carry the suspended matter farther downstream, but it was the opinion of the witness that the removal from the river of the sewage from Joliet, Peoria, and other places along the banks would be effected before such sewage reaches the Mississippi, so that it would not materially alter the condition of the Mississippi, except in the case of such salts as chlorides and nitrates, which are not eliminated from the water in the purification of sewage. In case, however, the water is made less turbid by the addition of the discharge of the Chicago drainage canal the sedimentation that would normally occur in the river would be lessened. From the experimental evidence previously adduced concerning the limited period of life of the typhoid organisms it would follow that an additional volume of water discharged from the drainage canal, causing an increase in the speed of the current of Illinois

River, would not have any effect in increasing or diminishing typhoid fever among the inhabitants of the State of Missouri who use the waters of the Mississippi below the mouth of Illinois River. (6561–6562.)

The witness then contradicted the assertion of Professor Sedgwick concerning the longevity of the germ of typhoid fever, namely, "My belief is that in a sewage-polluted stream the typhoid germ might live in gradually diminishing numbers for weeks, or months, or even years," stating that it has been shown by experimental evidence that the typhoid organism dies out with special rapidity in sewage-polluted waters. He also considered untenable the assumption of Professor Sedgwick that typhoid fever germs could pass from the sewers of Chicago by way of the drainage canal to Lake Peoria and be deposited there in the bed of the lake for a period of one month and afterwards be swept out and contaminate the water supply of St. Louis. He further stated that he knew of no evidence justifying Professor Sedgwick's conclusion that there might at times be a larger number of typhoid organisms in Lake Peoria, due to accumulations there, than would actually be passing out of the drainage canal at the Bear Trap dam. On the contrary, there was every reason to believe that the typhoid organisms present at the Bear Trap dam would be entirely discharged before reaching Lake Peoria. (6562–6566.)

The witness expressed the opinion that the five dams erected across Illinois River would act in a material way in aiding the sedimentation of dangerous matters deposited in that stream, but in view of the fact that the sewage of Chicago is practically purified before it reaches these dams they actually have no effect on purification of the river so far as Chicago sewage is concerned. (6577–6578.)

Missouri River, draining a large area on which many cities are located which discharge sewage into the stream, must be regarded as very liable to carry pollution for varying distances, and therefore can not be considered as a safe source of water for drinking purposes at Fort Bellefontaine. Illinois River above Grafton was also considered unsafe, but the opening of the drainage canal did not make it more unsafe than it was previous to the date of the opening. The witness then closed his direct testimony with the following statement:

In view of the fact that the conditions which obtain in the city of St. Louis and the conditions of the watersheds which are immediately adjacent to this city; in view of the fact that the typhoid-fever death rate in that city is dependent upon other conditions than those due to the water supply of that city and may be materially influenced by operation of many other factors; in view of the conditions which obtain in the Illinois River with reference to the process of purification which would occur in the sewage of Chicago when deposited in the drainage canal; and taking into consideration all the knowledge which I possess with reference to all data which bear directly or indirectly upon the question involved, it is my opinion that the increase in the typhoid deaths, as reported in the city of St. Louis, assuming such increase to be true, which have occurred since the opening of the drainage canal, can not beyond all reasonable doubt be attributed as a direct, immediate, and approximate cause for said increase to the opening of that drainage canal. (6581.)

CROSS-EXAMINATION.

With regard to the index of sewage pollution in surface waters, the witness stated that it is generally conceded that the presence of bacteria belonging to the colon type is significant. A water supply containing a large number of these organisms can be regarded by bacteriologists as having been more or less polluted with sewage at no distant date. He did not recall any cases where under natural conditions a water had been infected with disease-producing organisms to such an extent as to be able to produce epidemic disease and where such water had failed to reveal the presence of the colon organisms in considerable numbers, although he could conceive of cases in which infection was sporadic and discontinuous, where the evidence of such infection might not be revealed by bacteriological examination and still that water may have previously been the cause of an epidemic of disease. (6583–6584.)

Bacteria of the colon type might be found in water that had been unexposed to sewage. The colon organism is a normal inhabitant of the intestinal tract of higher animals and therefore its mere presence in a surface water can not be regarded as direct evidence of human pollution; but the intimate relation existing between pathogenic organisms capable of producing disease and certain well-known bacteria which do not belong to the distinctive pathogenic class, but which are always present in intestinal discharges, makes it advisable and necessary to resort to the colon test. (6585.)

E. G. HASTINGS.

E. G. Hastings, called as a witness on behalf of the defendants, stated that he was an instructor in bacteriology. His testimony was a corroboration of that of H. L. Russell with reference to the experiments on the longevity of the typhoid baccillus when exposed to sewage. The witness was Professor Russell's assistant in connection with the experiments on parchment cells and made inoculations therefrom in the work carried on in Illinois River at Averyville. (6716–6733.)

F. ROBERT ZEIT.

DIRECT EXAMINATION.

F. Robert Zeit, a witness called in behalf of the defendants, stated that he was a teacher in the Northwestern University medical school and post graduate medical school of pathology and bacteriology, having occupied the position for five years; he had received his early education in Switzerland and Germany, and had taken the regular medical course at the Western Reserve University at Cleveland, Ohio, from 1884 to 1887; afterwards for three years he was instructor and collaborator in the private laboratory of Professor Klebs, instructor of pathology in the Rush Medical College; he was then called to the Northwestern University as teacher in bacteriology; after one year was made professor of bacteriology in the university medical school, and later was placed in charge of the entire department of pathology and bacteriology. During the entire seven years in which the witness was engaged exclusively in teaching bacteriology and pathology he had made special studies of these questions. Before engaging in the profession of teaching, he had practiced medicine and surgery in Wisconsin and in Chicago for ten years. (4396–4398.)

The witness stated that from February 6 to October 1, 1900, he had made bacteriological examinations of the waters of the Chicago drainage canal and Illinois River, samples being furnished to him by Professor Long. He stated that in this series of investigations his province had been merely the determination of the presence or the absence of pathogenic bacteria. He did not make any counts of colonies or any of the usual tests. The samples when received from Professor Long were plated out on gelatine and agar; from three to sixteen dilutions were made in Petri dishes. Glucose agar plates for the growth of anaerobes were also made. All the gelatine plates were kept at a temperature of 20° to 22° C. and the agar plates in the incubator at 37° C. The plates were examined daily and pure cultures obtained on agar from the various colonies, between the second and eleventh days. The pure cultures were then subjected to such further study as was necessary. The results of the examinations are set forth in Table 82. (4398–4421.)

TABLE 82.—*Results of bacteriological examinations of waters of the drainage canal and Illinois River, taken from designated points, 1900.*

	Lake Michigan, tap water.	Drainage canal at Western avenue.	Illinois River at Bridgeport.	Illinois River at Lockport.	Illinois River at Joliet.	Kankakee River at Wilmington.	Illinois River at Morris.	Illinois River at Ottawa.	Fox River at Ottawa.	Illinois River at La Salle.	Illinois River at Henry.	Illinois River at Averyville.	Illinois River at Peoria.	Illinois River at Havana.	Spoon River at Havana.	Illinois River at Pearl.	Illinois River at Grafton.
Number of samples examined	7	13	7	7	6	2	10	5	4	6	5	5	11	12	8	10	10
PATHOGENIC BACTERIA.																	
Bacillus anthracis														2			
B. coli communis	3	9	6	4	3		6	2	1	2	2	1	8	3	1	1	2
B. enteritidis		3	2	1	2					2							
B. lactis aerogenes	1	4	4	2									2	1			
B. pyogenes			2														
B. tetani							1				1				1		
Micrococcus rhizopodiformis	1																
Proteus mirabilis				1			1							1			
P. vulgaris		6	6	2	3		4	1		3	1		5	1	2	1	2
Staphylococcus pyogenes aureus											1			2			1
NONPATHOGENIC BACTERIA.																	
Bacillus acidi lactici		2	2	2									3	1		1	2
B. aerogenes			1														
B. albus putidus		1															
B. aquatilis	2	3	1	1		1	3		3	2	2		2	1	3	4	2
B. aquatilis sulcatus				1												2	
B. aquatilis sulcatus I		3	1		1				1	3	1			2			
B. aurantiacus																1	1
B. circulans													1				
B. cloacæ				1	2		1	1		1	1		2	3			
B. cloacæ Jordan		3															
B. cyanogens			1		1												
B. delicatulus Jordan		1															
B. flavescens Pohl	1																
B. flavocoriaceus									1							1	
B. fluorescens liquefaciens	1		2		1								2	1			2
B. fulvus					1			1		1							
B. liquidus	2		1						3			1					3
B. liquefaciens								1									
B. megaterium							2			2	1			3	3	2	3
B. mesentericus	3	2	1		1	1		1			4	1	2	2	3	1	
B. mucormucedo				1	1												
B. mycoides	1	2	1	1	3	1	4		1	3			2	3	1	5	2
B. ochraceus										1							

B. plicatus			1	1	2	1	2		1	4			2	2			
B. reticularis	1												2				
B. reticularis Jordan		1															
B. rubidus			1	1	1					1					1	1	
B. rubifaciens											1			1			
B. striatus flavus											1						
B. subflavus										1	2						1
B. subtilis	4	3	2	1	1	1	3	1			1		5	5	4	3	5
B. superficialis			2		2												
B. ubiquitus				2									2				
B. ubiquitus Jordan		1															
Diplococcus citreus									1								
D. roseus								1	1								1
Micrococcus aerogenes					2			1									
M. agilis		1															
M. albicans										1							
M. aquatilis	2				2								4		1	1	1
M. candicans		3	2	2			2	1								1	
M. citreus												1					
M. flavus desidens			2														
M. flavus liquefaciens	1			1													
M. luteus				1	1								1		2		1
Oidium lactis				1						1							
Orange-red water bacteria				1					1								
Pink yeast								1		1		1					
Saccharomyces cerevisiæ					1							1					
Sarcina aurantiaca				1								1					
S. lutea		2		2	3		1		1	2						1	2
S. rosea	1						1				1	1				1	
Vibrio aquatilis										1							
V. aqatilis Gunther	2	1															
V. aureus	1																
V. flavus								1									
Yellow water bacillus		1															
Yellow water bacillus (Lustig)												1					

The witness stated that in connection with the foregoing investigations experiments were made on guinea pigs by injecting in each 4 c. c. of water from each of the stations where samples were procured. Another set of experiments was made in the same manner with cultures obtained from the samples submitted by adding 1 c. c. of the water to 5 c. c. of nutrient bouillon and keeping the mixture in an incubator at a temperature of 37° C. for twenty-four hours. The guinea pigs inoculated with the specimens of the Lake Michigan tap water all recovered, and of three guinea pigs inoculated by intraperitoneal injections with cultures obtained from this water only one died of sepsis, and subcutaneous injections caused only local abscesses, from which the animals all recovered. Intraperitoneal injection of the guinea pigs with water taken from the drainage canal at Western avenue did not prove fatal in any instance, but the animals injected with cultures invariably died. Injection of the water obtained at Bridgeport did not produce death, but all the cultures were fatal, though in only one instance did death result from subcutaneous injection. Water taken at Lockport produced no results, while the effect on animals inoculated with cultures from these samples was varied—some of them recovered, one died of sepsis, and one that had apparently recovered died after a period of about two weeks, though post-mortem examination failed to disclose bacteria. In the blood of the animal which died promptly proteus forms were most prominent. All those which recovered had an elevated temperature and lost rapidly in weight for several days. Water taken at Joliet when injected intraperitoneally produced no effect, and of all the animals inoculated with cultures only one died of sepsis, the others recovering. Both the water and cultures taken at Wilmington, on Kankakee River, produced no results by intraperitoneal injection. Direct intraperitoneal injection of the water taken at Morris, on Illinois River, in one instance caused death in eleven days, while other samples did not produce fatal results. Experiments with mixed cultures gave uncertain results, some of the animals dying and some not. Samples of water taken from Illinois River at Ottawa and cultures obtained therefrom proved not to be virulent. Samples from Fox River at Ottawa and mixed cultures obtained from them were nonproductive of fatal results. Illinois River water taken at La Salle in one case proved fatal, the animal dying of sepsis. The cultures of this water, however, were very virulent. Direct injection of the water taken at Henry did not cause death, though the mixed cultures from these samples were virulent. The cultures obtained from Averyville samples were entirely nonvirulent. The witness stated that the evidence of bacterial self-purification afforded by the examination of these samples showed that there was a gradual decrease in the number of disease-producing as well as sewage bacteria from Chicago to Averyville. He believed that the experiments on the guinea pigs constituted sufficient proof that the zone of self-purification must be reached somewhere above or near that place. With regard to the samples received from Peoria, he testified that direct injection of the water caused death in eleven days, while another animal died of sepsis within twenty-four hours after inoculation, and that the bacteria markedly increased at this point. Both the water taken from Illinois River at Havana and the cultures made with it were shown to be highly productive of disease in guinea pigs and white mice when injected intraperitoneally. A number of the animals died of anthrax bacteremia within forty to forty-eight hours, and the blood of all of them contained numerous anthrax bacilli. Water taken from Spoon River at Havana, however, did not prove fatal in any instance, nor were the cultures virulent. Samples taken at Pearl and Grafton and the cultures obtained therefrom were nonvirulent. (4403–4421.)

With reference to the relative longevity of disease-producing organisms and the ordinary water bacteria and saprophytes in Illinois River and the drainage canal, the witness stated that the growth and multiplication of the ordinary water bacteria depend very little on organic matter in the water or its temperature, but the condition and growth of the saprophytic or sewage bacteria are largely governed by the presence or absence of dead organic matter, and they usually require a somewhat higher temperature than the ordinary water bacteria. The existence or disappearance of the pathogenic or disease-producing bacteria (including the typhoid and cholera bacilli) is dependent on dilution, light, temperature, and the presence or absence of large numbers of saprophytes. Where the saprophytes are numerous, the typhoid and similar pathogenic bacteria are rapidly overgrown by them and disappear in five or six days. Where conditions are favorable to the production and multiplication of water bacteria, the existence of the pathogenic bacteria reaches eight to ten days. If typhoid bacilli, however, are placed in water containing none of the other two types of bacteria, they can live for weeks, even in the absence of food. The higher the temperature the more favorable the conditions are for the growth of the disease-producing bacteria, while low temperatures make their multiplication impossible. According to the witness the typhoid bacilli, in the absence of many water bacteria and saprophytes, will live for some time; the smaller the number of saprophytes the longer the existence of the typhoid bacilli. (4421–4422.)

The witness further stated that the typhoid bacillus will multiply only in a favorable temperature, the optimum being 37° C., or about blood heat, and only where there is organic matter for food. While the typhoid bacillus can grow in as low a temperature as 24° C., a mixture with other rapidly growing bacteria at this temperature will result in its overgrowth and disappearance. (4423.)

He then expressed the opinion that the number of bacteria is not of so much importance in determining the purity or impurity of a given body of water as their character. The number of water bacteria may be very great and not have much significance, whereas if they are sewage or pathogenic bacteria the number may be very small and the water might be called perfect chemically, but could not be called perfect bacteriologically. Furthermore, to judge solely by the number of bacteria present, a water containing less than 50 germs per cubic centimeter would have to be called a good water, and yet if these 50 germs happened to be disease producing the water should be condemned. The number of bacteria is significant only in determining, after the normal condition has been ascertained, whether pollution in a given body of water is increasing or diminishing. The essential point is the quality of the germs and whether they are sewage or water bacteria. (4426.)

The witness stated that he had not found any typhoid bacilli in his examinations of the waters of Illinois River or the drainage canal, but that this was by no means strange, because it was frequently the case that sewage contaminated with typhoid bacilli got into comparatively large bodies of water where the dilution would be so tremendous as to make it difficult or impossible to relocate the germs. The typhoid bacillus does not multiply at the normal temperature of river or lake water, and in case of contamination of such waters by sewage the typhoid germs are overgrown by water bacteria and ultimately disappear. The witness stated that even where it is known that a water supply has been contaminated by sewage containing typhoid bacilli, bacteriologists have been unable to find these germs, the reasons being, first, that the unfavorable temperature of the water prevents multiplication of pathogenic organisms; second, that sewage bacteria undergo rapid multiplication and overgrow the parasitic bacteria; and, third, that extensive dilution takes place and separates the bacilli so far that they can not be found. Furthermore, in most epidemics where search has been made for typhoid bacilli and they have not been found, the time of infection or of contamination has no doubt been passed by several weeks, and the typhoid bacilli which might have been found earlier have entirely disappeared during that period. (4427.)

Being asked what significance was to be attached to the gradual disappearance of sewage and pathogenic bacteria in running water, the witness expressed it as his opinion that by reason of the overgrowth of saprophytes in the presence of organic material, together with a temperature favorable to their rapid multiplication, the pathogenic bacteria in such water are destroyed entirely. In other words, by the rapid multiplication of sewage bacteria, the disease-producing bacteria, which grow best at the temperature of the body, will be overgrown and will perish, so that by the time the sewage bacteria and organic matter has disappeared the purification of the water of pathogenic bacteria must be complete. (4431.)

Assuming that the dejecta of typhoid-fever patients in Chicago are carried into the drainage canal through the sewers of the city; that the waters in that canal contain immense numbers of saprophytes and ordinary water bacteria, to the number of 70,000 and frequently as many as 4,000,000 per cubic centimeter; that it requires at least twenty-four hours, and at times as much as forty-eight hours, for the water to pass from the Chicago sewers into Chicago River and the drainage canal and reach the Bear Trap dam; and assuming further, that the flow in Desplaines and Illinois rivers is equal to 40 miles in twenty-four hours, the witness expressed the opinion that the typhoid bacilli would not survive as far as Peoria, for the reason that the saprophytic bacteria increase at such a tremendous rate in the drainage canal as to actually overgrow and annihilate any pathogenic bacteria in the water. (4456–4458.)

With reference to the conclusions to be drawn from his experiments, set forth in Table 77, as to the relative bacterial purity of the respective streams at the time of examination, the witness stated that he would regard Missouri River as more polluted than the Mississippi or the Illinois, and the Mississippi as more polluted than the Illinois. (4459.)

The relative longevity of the typhoid bacillus as compared with that of *Bacillus prodigiosus* was stated by the witness to be ordinarily very similar, though it depends entirely on the surrounding conditions. It was his opinion that in the waters of Illinois River and the Illinois and Michigan Canal *Bacillus prodigiosus* would live longer than the typhoid bacillus. (4463–4464.)

The witness stated that in his examinations of the waters of Lake Michigan, Chicago River, Illinois River, and the drainage canal he had never discovered *Bacillus prodigiosus*, but that he had, during the early part of his work in 1900, occasionally obtained in Lake Michigan a few red colonies which appeared to have all the characteristics of this germ, differing, however, in that they grew very well on sterilized banana slices, were larger than the ordinary *B. prodigiosus*, and occasionally produced gas. No description of another organism could be found in literature corresponding to these bacteria, and so he had been inclined to call them *B. prodigiosus*, but while on culture media they seemed almost identical with *B. prodigiosus*, on agar they had the appearance of red sealing wax. For this reason he had called them the sealing-wax organisms. (4465.)

The zone of bacterial purification of a river, according to the witness, is that part of a sewage-polluted stream where saprophytic organisms and pathogenic bacteria have disappeared and where the normal bacterial flora of the river before it received the pollution is again established. This zone varies in different rivers and in different localities between distances of 9 to 40 miles. As examples of rivers in which the zone of purification has been determined by bacteriologists, the witness cited the following:

The River Seine, after receiving all the sewage of Paris, purifies itself within a distance of 70 kilometers, or 43 miles, having the same number of organisms and the same bacterial flora that it had before receiving the sewage.[a] The River Oder receives the sewage of Breslau and 20 miles below the city contains the same number of bacteria that it did previous to receiving the sewage.[b] The city of Zurich, Switzerland, discharges its sewage into the River Limmat, which flows from a lake of very pure water, containing between 100 and 200 bacteria per cubic centimeter. Fourteen kilometers, or 9 miles below the city, this river has again established its bacterial purity.[c] The River Isar receives all the sewage of Munich and purifies itself within a distance of 33 kilometers, or 20 miles.[d] The River Spree, after receiving the sewage of Berlin, which is so great as to cause the bacteria to increase to about 1,000,000 per cubic centimeter, flows through the small lake of Havel, and on its exit from the lake at Sacrow has practically the same bacterial condition that it had previous to receiving the Berlin sewage[e]. The distance traveled by the sewage-polluted water was believed by the witness to be about 9 miles. (4466–4468.)

The witness expressed the opinion that typhoid bacilli, after lying in the bed of a stream for a period in excess of sixty days, would be unable to cause typhoid fever when taken into the human system, and when asked if a substance coming from the sewers of Chicago through the drainage canal and deposited on the bed of Illinois River could remain for any considerable length of time and still retain its dangerous qualities and pathogenic bacteria, he stated that he believed such pathogenic bacteria would die in the drainage canal, owing to the increase of saprophytic bacteria. It was his opinion that the sewage discharged by Chicago into the drainage canal could not and did not constitute a menace to St. Louis or to the inhabitants of Missouri. From all the examinations he had made of Illinois, Mississippi, and Missouri rivers during October, November, and December, 1901, and February and March, 1902, it was his opinion that bacteriologically the Illinois was less polluted than either of the other two rivers. (4471–4473.)

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[a] Rubner, Hygiene, Berlin, 1901.

[b] Frankland

[c] Schlatter, Zeitschrift für Hygiene, vol. 190, p. 56.

[d] Prausnitz, Hygiene, 1900 or 1901.

[e] Zeitschrift für Hygiene, vol. 3 ,p. 355.

With reference to the *Bacillus prodigiosus* experiment described in the testimony of Doctor Ravold, for the complainant, the witness stated that there should be considerable doubt as to the identity of the few *prodigiosus* bacilli reported to have been discovered after the discharge of the cultures into the drainage canal, for the reason that the isolation of these bacteria was based on the red reaction test alone, which is not sufficient to establish their identity beyond question. Therefore, taking into consideration the many millions of these bacilli discharged into the canal, their practical absence afterwards would be an indication of the purification of the water; and since the typhoid bacillus would not live as long under these same conditions as *B. prodigiosus,* it would follow that typhoid bacilli discharged into the drainage canal from the sewers of Chicago would not survive the passage down Illinois and Mississippi rivers and into the intake tower of the St. Louis waterworks at Chain of Rocks. (4477–4478.)

CROSS-EXAMINATION.

During the cross-examination the witness stated that he had made experiments on the life of the typhoid germ in samples of water from Illinois River at Grafton, Missouri River above its mouth, and Mississippi River above its confluence with the Illinois. The river water was first inoculated with different known quantities of twenty-four-hour bouillon culture of typhoid bacilli and placed in the refrigerator at a temperature of 10° to 12° C. It was then plated out daily on agar in a number of dilutions. Fifteen to twenty plates were made, and from these the one showing the most distinct colonies was selected and all the colonies thereon that looked like typhoid were marked for examination. It was then determined whether or not the colony was a bacillus and if so whether or not it was motile. If not a motile bacillus, it was thrown out. The Widal reaction would be obtained with a motile bacillus by the use of the serum of an immunized rabbit or the blood of a typhoid patient. A positive reaction was considered satisfactory evidence of the presence of the typhoid bacillus, but where no such reaction could be obtained the usual cultures were made of the suspicious motile bacilli. In these experiments, the witness was unable to find the typhoid bacillus after five or six days, even where large quantitles of bouillon culture were inoculated into the water. (4482–4483.)

The witness stated that when the water of a river was at the freezing point, as it is in the coldest part of the year, both saprophytes and typhoid bacilli would probably remain as they would in ice; that as the temperature became lower than that of the air the saprophytes would increase less and less, and that, in his opinion, conditions in water polluted by sewage are more favorable for the life of the typhoid bacillus than the conditions would be in laboratory experiments, owing to the greater amount of organic matter present in the polluted water. (4485–4487.)

In comparing the effects of the injection of typhoid and colon bacilli, the witness stated that if typhoid culture is injected into an animal no infection results, but death follows from poisons producing a toxic effect, all animals being immune from typhoid fever. Injection of the colon bacilli may result in death through toxic causes, but injection is usually followed by an infection, the animal dying of septic peritonitis after a period of five to ten days. (4536–4537.)

In response to a direct question the witness admitted that it would be possible for typhoid germs which had been frozen into a block of ice in the drainage canal, on the passage of the ice down the canal and into Illinois River, to reach the intake of the St. Louis waterworks if the bacteria had survived the freezing process. (4609.)

REDIRECT EXAMINATION.

Four months later Professor Zeit was recalled for further direct testimony and stated that since having previously testified in the case he had, in conjunction with Professors Jordan and Russell, made experiments on the longevity of the typhoid bacillus, his part of the work having been the examination of samples of water from Lake Michigan and Chicago River. Two plans were adopted. The first involved the use of parchment sacks and the second the use of celloidin sacks, both intended to allow osmosis and both containing typhoid bacilli in the presence of the saprophytes normally present in the waters, the object being to allow the saprophytic bacteria to multiply and yet not retain within the sack their excretions, which would destroy the typhoid bacilli. There was a free interchange of conditions inside and outside of the sack, the one difference being that within the sack were imprisoned the typhoid bacilli. (6421–6422.)

The sacks were inoculated with typhoid bacilli that had been grown upon agar slants for twenty-four hours in the incubator, enough of the bacilli being placed in the sacks to produce a mixture of about 500,000 typhoid bacilli per cubic centimeter of water. One strain of typhoid bacilli, received from Professor Jordan, was obtained from the blood of a typhoid-fever patient in the Cook County hospital. A second strain, received from Parke, Davis & Co., of Detroit, had been used to immunize a horse. With this strain the serum of the immunized horse was also received. The sacks were suspended in Chicago River at the Ashland Avenue Bridge in boxes similar to those described in the testimony of Professor Jordan, and in Lake Michigan similar sacks were suspended in a jar through which the fresh lake water was constantly flowing. From the time the sacks were suspended in the two localities agar plates from both samples were made daily. (6423–6424.)

In the experiments conducted with the parchment sacks a typhoid suspension, made by distributing material from colonies grown upon agar slants for twenty-four hours, was used. The sacks were first filled with 800 c. c. of river water, to which was then added enough of the suspension of typhoid bacilli to make in the sack a mixture of 200,000 to 1,500,000 typhoid bacilli per cubic centimeter of water. The average mixture used contained 500,000 bacilli per cubic centimeter of water. After infection samples were plated out at once and on the following day a sample of the water was removed from the sack by means of a sterile pipette, the sack having been first examined for leaks. This sample was immediately taken to the laboratory and plated out. For each agar plate from 0.001 to 5 c. c. was used. Eight experiments were made at each of the sampling points, and a number of examinations were made for each experiment, the first being usually twenty-four hours after the placing of the sack in the water and the others daily thereafter. (6424–6425.)

In the parchment-sack experiments only one sack was placed in the water for each experiment, and samples were removed daily for examination, but in those with the celloidin sacks a number of sacks were placed in the water at the same time and one sack was removed each day for the examination. In no case was a sample of water removed from the celloidin sack for examination, the object being to avoid all possible chance of contamination. (6426.)

After the samples of water had been taken to the laboratory and plated out the agar plates were placed in the incubator over night. They were examined from day to day and any suspected typhoid colonies were inoculated into the Hiss medium. The colonies which in the medium proved to be nonmotile bacteria or which produced gas were thrown aside. The motile colonies which showed no gas were then tested with the serum of the immunized horse. In all the experiments it was found that although during the first twenty-four hours the total number of bacteria increased greatly the typhoid bacilli could still be detected. Then a decrease would set in, and in no case were the typhoid bacilli found after a period of three days. The results of the experiments with the two types of sacks were practically the same. The parchment sacks were examined for fifteen to twenty days, while the examination of the celloidin sacks was limited to the number of sacks available, the minimum being eight days. It was found that after two weeks' use the parchment sacks were damaged, and, since in no case were the typhoid bacilli discovered after three days, the conclusion was reached that ten days was sufficient for each experiment, and this was made the limit for future work. (6430–6432.)

Experiments were also made in which the river water was filtered through a Pasteur filter and then plated out to make certain that no water bacteria had passed through the filter. Such raw filtered river water was inoculated with typhoid bacilli and here also it was found that these organisms would not live more than three days. Therefore it appears that there is something in this river water itself which destroys the typhoid bacilli even if they are not subjected to the action of the saprophytes. The witness stated that he brought out this point for the reason that in his former testimony he had made the statement that the disappearance of typhoid bacilli in river water was probably due to the overgrowth of saprophytic bacteria, whereas from these later experiments he had concluded that the river water itself contains some substances, possibly the excretions of saprophytes, which alone are sufficient to destroy the typhoid bacilli within a few days. Experiments were also made by inoculating a typhoid bacillus into boiled river water. In these experiments the bacillus lived three days longer than it did in the raw filtered water. (6432.)

The witness described another experiment in which he added to the water from a parchment sack immune serum from a horse and collected the precipitate in a conical glass tube and added to this precipitate peptone solution, the object being to concentrate the bacteria so that any typhoid bacilli which had escaped detection by the other method might be discovered. Although unsuccessful in this instance, owing no doubt to the fact that all the typhoid bacilli had been discovered by the previous treatment, the witness stated that he considered this a very valuable method in finding the typhoid bacilli, because larger quantities of water can be used. The immune serum agglutinates the bacilli but will not kill them, and they are precipitated and can be grown again on agar plates. (6433.)

The witness said that as a result of the experiments conducted by Professors Jordan and Russell and himself, it was his opinion that typhoid bacilli can not live in the drainage canal, Chicago River, or Illinois River for more than three days, and therefore those discharged from the Chicago sewers can not live to reach the intake of the St. Louis waterworks at Chain of Rocks and thereby constitute a menace to the citizens of St. Louis. (6437.)

During all his examinations the witness had found Illinois River to be less polluted, bacteriologically, than either the Mississippi or the Missouri. Consequently the effect of the addition of the Illinois River water at Grafton would undoubtedly be a tendency to improve the condition of Mississippi River and of the mixture of waters entering the intake tower of the St. Louis waterworks. In conclusion, the witness stated that it was his opinion that the contamination discharged into the drainage canal by the city of Chicago would be bacterially purified before reaching Averyville and therefore he could not consider it a menace to the health of the citizens of St. Louis. (6441–6442.)

No new facts were brought out on cross-examination.

ROBERT SPURR WESTON.

DIRECT EXAMINATION.

Robert Spurr Weston, a witness called in behalf of the defendants, stated that he graduated at Amherst College in 1891 and for three years thereafter was employed as a chemist in commercial work, after which he became a student at the Massachusetts Institute of Technology and in the University of Berlin; besides this he had been engaged as a volunteer worker in the laboratories of the Massachusetts and the German Imperial boards of health. In 1895 he was connected with experiments on water purification at Louisville and subsequently with similar experiments at West Superior, Wis., and Washington, D. C. In 1900 he was in charge of the water-purification station at New Orleans and conducted an investigation lasting eight months to determine the feasibility of purifying the Mississippi River water. (6869–6870.)

The witness stated that he was well acquainted with the drainage area of Mississippi River above New Orleans, and presented a table showing the distances above that city of cities lying tributary to Mississippi River, as follows:

Distances above New Orleans of cities tributary to Mississippi River.

	Miles.		Miles.
Baton Rouge, La	132	Cincinnati, Ohio	1,415
Natchez, Miss	265	Pittsburg, Pa	1,875
Vicksburg, Miss	366	St. Louis, Mo	1,159
Memphis, Tenn	735	Mouth of Missouri River	1,165
Cairo, Ill	965	St. Paul, Minn	1,823
Louisville, Ky	1,305		

The United States census for 1900 shows that the population in cities and towns containing more than 4,000 inhabitants in Mississippi Valley is about 9,000,000. The witness then presented some data concerning the amount of sewage discharged into the different rivers which make up the drainage area. He assumed that cities which have a population of 25,000 and over will discharge 175 gallons of sewage per capita per day, and that the remainder of the urban population—that is, in cities of 4,000 to 25,000 inhabitants—will produce 100 gallons of sewage per capita per day. This assumption was based on the general water supply. According to a table prepared by John R. Freeman, in a report concerning the water supply of the city of New York, the large cities of the country consume about

100 gallons of water per capita per day, and 75 gallons per day is added for sewage from the streets for ground water flowing into the sewers and for contaminated water from other sources. In smaller cities the daily consumption is approximately 60 gallons per capita, and as a large percentage of these cities are not sewered a correspondingly smaller estimate must be made for the difference between the amount of water consumed and the amount of sewage produced. Taking all the above into consideration, the witness estimated that the amount of sewage from large cities—that is, those above 25,000 population—is 1,174,250,000 gallons per day, and from the remainder of the urban population 342,000,000 gallons per day, making a total of 1,516,250,000 gallons. This amounts to a flow of 2,310 cubic feet per second at New Orleans. The volume of the river at New Orleans being taken into account the maximum dilution is 1 part of sewage to 586 parts of water; the minimum, 1 of sewage to 83 of water, and the average, 1 of sewage to 296 of water. Expressed as cubic feet per second of sewage per thousand of population the maximum is 150, the minimum 21, and the mean 75; and as gallons of water per day per capita of the urban population the maximum is 16,160, the minimum 2,262, and the mean 8,190. (6870–6873.)

The witness then presented Table 83, showing the composition of Mississippi River water at New Orleans from December, 1900, to August, 1901, based on the chemical and bacteriological data. (6877.)

With reference to the figures in Table 83 the witness stated that the analyses, apart from the nitrogen as nitrates and nitrites, show that the water is characteristic of the nonpolluted water for the region. An abundance of oxygen is always present, showing that the organic matter has been decomposed, while the number of bacteria is very low, and they are chiefly associated with the suspended matter. Tests were made for *Bacillus coli communis* during the flood season; that is, from December, 1900, to April, 1901. The volumes used for these tests varied from 1 to 300 c. c., and the bacilli were found only on three occasions during the five months, all during the first week in December. The presence of the organisms at this time only is explained by the fact that on the bank of the river immediately above the intake of the water-purification station where the samples were taken a number of house-boat men and squatters were quartered. The feces deposited by them on the bank during the low-water season were probably washed into the river at the time of high water, and this would account for the presence of *B. coli* in the samples. In all, 100 tests were made during the five months, and the general absence of *B. coli communis* leads to the conclusion that no unpurified sewage was present in Mississippi River at New Orleans. (6878–6879.)

TABLE 83.—*Composition of Mississippi River water at New Orleans, December, 1900, to August, 1901.*

	December.	January.	February.	March.	April.	May.	June.	July.	August.
Temperature .... °C.	....	8.8	8.1	10.8	13.6	19.6	25.0	29.3	29.6
Silica turbidity .... parts per million.	679	187	227	369	630	423	457	515	161
Color	13	11	12	13	14	13	9	11	11
Oxygen consumed .... parts per million.	8.3	4.7	3.5	6.8	11.3	6.9	7.5	7.1	2.9
Nitrogen as—									
Albuminoid ammonia:									
Dissolved .... do.	.104	.063	.056	.054	.077	.060	.045	.055	.046
Suspended .... do.	.228	.088	.140	.196	.358	.185	.195	.167	.032
Total .... do.	.332	.151	.196	.250	.435	.245	.240	.222	.078
Free ammonia .... do.	.017	.017	.013	.013	.005	.006	.004	.005	.005
Nitrites .... do.	.014	.010	.012	.008	.001	.000	.000	.001	.001
Nitrates .... do.	.24	.11	.12	.11	.17	.12	.12	.16	.13
Chlorine .... do.	10.2	9.4	8.5	10.0	7.0	9.3	14.8	8.9	8.3
Incrusting constituents .... do.	19	15	15	11	17	9	11	17	....
Alkalinity .... do.	67	79	70	84	71	75	82	84	98
Residue on evaporation:									
Dissolved .... do.	142	149	127	146	126	137	157	181	226
Suspended .... do.	549	223	294	425	713	436	469	527	....
Total .... do.	691	372	421	571	839	573	626	708	327
Iron .... do.	17.0	11.6	14.9	15.6	27.0	12.5	22.6	18.6	10.2
Carbon dioxide:									
Free and half-bound .... do.	....	58	68	68	51	66	66	47	33
Free .... do.	....	23	37	31	21	33	32	13	0
Dissolved oxygen .... do.	....	10.5	10.5	10.0	8.3	7.0	6.0	6.7	5.9
Bacteria per cubic centimeter	2,020	1,315	2,870	1,790	3,590	2,050	2,010	1,835	910

In connection with the above conclusions the witness stated the fact that if the velocity of Mississippi River is assumed to be 4 miles per hour, which is neither the maximum nor the minimum, the sewage from Baton Rouge would reach New Orleans in thirty-three hours, showing the rapidity of disappearance of contaminating matter in the river. He then gave the flow of Mississippi River at New Orleans, taken from the report of the Mississippi River Commission, as follows: Maximum, 1,353,000 cubic feet per second; minimum, 191,000 cubic feet per second; mean, 685,000 cubic feet per second. (6879.)

The witness then presented a chart based on the computation already introduced, showing the relative pollution of Mississippi River at various points, with data for determining it. The evidence contained in this chart is given in Table 84. (6883.)

TABLE 84.—*Relative pollution of Mississippi River water at various points.*

Point.	Mean flow in second-feet.	Population above point.	Dilution in second-feet per 1,000 population.
New Orleans	675,000	9,000,000	75
Mouth of Red River	655,000	8,984,626	73
Mouth of Yazoo River	579,000	8,913,944	65
Mouth of Arkansas River	516,000	8,901,358	58
Mouth of Ohio River	383,000	8,706,902	44

The witness stated that in the above table no allowance had been made for the self-purification of the stream at different points. He then presented a chart showing accessions of sewage to Mississippi River from Cairo to New Orleans. The data of the chart is contained in Table 85. (6887.)

TABLE 85.—*Sewage contributed to Mississippi River, Cairo to New Orleans.*

District.	Mean flow in second-feet.	Urban population of district.	Dilution in second-feet per 1,000 urban population.	Dilution in second-feet per 1,000 sewered.
Below Red River	675,000	15,374	59,900	43,900
Below Yazoo River	655,000	70,682	11,700	9,200
Below Arkansas River	579,000	12,586	4,610	4,610
Below Ohio River	516,000	194,476	2,710	2,650
Above Ohio River	383,000	....	44	....

In discussing the information contained in Table 85 the witness stated that the fresh additions of sewage poured into the stream below the mouth of Ohio River are very small in amount. In this table, as in the preceding one, no allowance had been made for self-purification.

The witness then introduced into evidence a chart showing the relative dilution of flow in cubic feet per second of Mississippi River compared with Connecticut and Merrimac rivers. The chart is inserted in the record opposite page 6889. It illustrates diagrammatically the relative dilutions of Mississippi River at Cairo, mouth of

Arkansas River, mouth of Yazoo River, mouth of Red River, New Orleans; of Merrimac River above Lowell, below Lowell, below Lawrence, and below Haverhill; and of Connecticut River above Holyoke, below Holyoke, and below Springfield. The purpose of the diagram was to contrast the two Massachusetts streams with the Mississippi. No allowance had been made for self-purification. The Massachusetts streams receive so much sewage in the form of fresh acquisitions below the points of observation that as the sewage proceeds down the rivers between the limits named it is in constantly greater proportion, while, on the other hand, as sewage is carried down Mississippi River below Cairo it is always in increasing dilution, the fresh acquisitions never being sufficient to maintain the concentration which exists at Cairo. The reasons for this state of affairs are that the Mississippi below Cairo is leveed and the population is relatively small. In the opinion of the witness there is not the slightest evidence that any unpurified sewage exists in the water at New Orleans other than the small amount that might occasionally have been washed in from the banks of the stream outside of the levees. (6889–6890.)

CROSS-EXAMINATION.

On cross-examination the term "unpurified sewage" was defined by the witness as that sewage which has not undergone the cycle of changes which take place when sewage is mixed with an adequate quantity of water in a running stream—in other words, sewage which has not lost its previous bacteriological character. The main effect of dilution is to furnish an adequate amount of oxygen for the oxidation of the organic matter contained in the sewage. This can also be obtained by aerating sewage by passing it over dams, though not in the same degree. The witness was of the opinion that the element of dilution does not have more to do with the small quantities of bacteria contained in the waters of Mississippi River at New Orleans than other bacterial or chemical elements known in sanitary science, because in any other river with which he was acquainted in which the dilution of the sewage approximated the dilution at New Orleans he had been able, by increasing the volume of the samples taken, to demonstrate the presence of *Bacillus coli communis*, but at New Orleans he had been unable to do so. (6890–6892.)

WILLIAM PITT MASON.

DIRECT EXAMINATION.

William Pitt Mason, professor of chemistry in Rensselaer Polytechnic Institute, New York, was called as a witness on behalf of the defendants and stated that he had been connected with the said institute for over twenty years and had given particular attention during most of the time to the examination of water for city supplies. This work involved especial study of sanitary problems as related to water supply, and he had written and published books on the subject. He further testified that he had acted in a consulting capacity and testified in legal cases regarding the water supply of many cities and towns in the United States. He had also examined the water supplies of many foreign cities. He was acquainted with the literature bearing on the subject of typhoid-fever epidemics and had made examinations involving study of such epidemics in Bath and Waterville, Me.; Cohoes, Albany, and Buffalo, N. Y.; and other places. He had also made some study of Asiatic cholera in Sicily and Italy. (6903–6906.)

The witness then stated that he had examined and studied the bacterial and chemical analyses of the waters of Lake Michigan, the drainage canal, and Illinois, Mississippi, and Missouri rivers as made by Professors Jordan, Palmer, Gehrmann, and Burrill; had taken a journey by boat from the water front to Lockport down the drainage canal by daylight, and had followed the course of the river by trolley and train as far as La Salle, where he took a steamer and went by daylight to St. Louis, tying up at night so that no places were passed in the dark. (6907.)

The hypothetical question concerning Doctor Ravold's experiment with 107 barrels of culture of *Bacillus prodigiosus*, already cited, was given to the witness and in reply he stated that in view of the large number of bacilli introduced into the canal, the small number found showed a very considerable death rate of the germ and, by inference, at least as large a death rate of the bacillus of typhoid fever under the same circumstances. (6908–6910.)

With reference to the longevity of the typhoid bacillus witness stated that it may remain alive in the human body for many months, and in soil at least some weeks and possibly months. In water it dies out quickly en masse, although some individual cells, being more resistant, may remain alive for a longer period. The character of the water affects the longevity. In a relatively pure water the longevity of the typhoid bacillus is greater than in one where it has to fight for existence with saprophytic bacteria. It does not increase in nature outside the human body, although it may live saprophytically for a period of time varying according to its surroundings. The witness stated that the vessels in which laboratory experiments are performed, being usually small and of glass, for some reason seem to give conditions favorable to the life of the germ. Where the conditions resemble more closely those of nature, as, for instance, where a large tank is employed, the length of life of the colon and typhoid bacilli does not seem to be so great. He quoted in support of this statement some experiments made on *Bacillus coli* by the Massachusetts State board of health. The vessel containing the germs was a very large one, about 12 feet deep, and was suspended in Merrimac River water. Under those circumstances it was found that the longevity of the colon bacillus was limited to eleven days. It was his belief that the typhoid bacillus would live in the water of the drainage canal and Desplaines and Illinois rivers for a shorter period of time than in sterilized water or water of greater purity from a bacteriological standpoint, and that its life would be limited to a few days. (6910–6912.)

If a river is intercepted by dams they will increase the opportunity for sedimentation, although not to an important extent. He did not believe that the amount of improvement obtained through the influence of the dams in Illinois River was very great, although it undoubtedly amounted to something. The great factor of sedimentation in Illinois River is the slope of the stream, especially in high stages, when the water overflows its banks and settles back to the right and left so that great areas of quiescent water are present and sedimentation is very marked. (6913.)

The sedimentation of bacteria was then discussed by the witness, who stated that in a clear water they will settle because they have a greater specific gravity than the water, though not much greater. This settlement is easily interfered with by currents and eddies. If the stream in question is turbid, however, the falling particles causing turbidity will unquestionably, by attaching themselves to bacteria which may be present, drag them down. The clear water from Lake Michigan discharged into Illinois River will not affect sedimentation there, because there is sufficient turbidity present in the Illinois River system to offset it. (6914–6915.)

With reference to the sanitary significance of dilution the witness stated that simple dilution is really purification, in that it diminishes the chance that the person who drinks the water, which is supposed to be polluted, will thereby contract disease. On the assumption that a glassful of water contains 100 typhoid germs, the person drinking it would run a risk that may be described by the number 100. Should 50 per cent of the germs in the water be killed the person drinking that water would drink 50 germs and his risk would be half what it was before, namely, 50. Should conditions prevail whereby no bacteria were destroyed but the volume of the stream was doubled by the inflow of pure water, then a person drinking a glassful of the mixture would have in his glass 50 germs and his risk would be 50; therefore such dilution would be productive of just as much purification as the killing of half the disease germs. The addition of Lake Michigan water to the sewage of Chicago is a benefit to the sanitary condition of Illinois River, considered both from the standpoint of dilution and from that of the chemical and bacteriological changes taking place therein. (6915–6916.)

The witness then expressed the opinion that the water of Illinois River does not have any appreciable effect, good or bad, on that of the Mississippi, although it is possible that it may slightly improve the Mississippi water, because if there is any difference between the Illinois at Grafton, the Mississippi at the same point, and the Missouri above its mouth, that difference is in favor of Illinois River. (6917.)

The witness further expressed the opinion that in his belief typhoid bacilli passing down Illinois River would die before they reached Grafton. He confined this, however, to the great mass of them. It was possible, in his opinion, that some specially resistant germs might make the journey, but most of the bacilli would perish before the Mississippi was reached. The typhoid bacillus will not live as long in polluted as in pure water, because in polluted water it has to live in the presence of many saprophytic germs, which not only monopolize the food supply but produce toxic products that are poisonous to it. There would be no material difference between the lengths of time that a typhoid bacillus would live in the sediment of a polluted stream and in the water of the same stream. The time that the bacillus would live in moist soil furnishes no criterion for its longevity in running streams; the two cases are not parallel. (6917–6919.)

If the capacity of a reservoir is equivalent to thirty days' supply of the city which it serves, it is not, according to the witness, to be assumed that the water remains stored in the reservoir for thirty days. Much depends on its construction. Many reservoirs are of the standpipe type, receiving their water and discharging it through the same orifice. Under such conditions the pumps deliver direct to the mains, and the surplus is carried to the reservoir. (6921.)

With reference to the occurrence of typhoid fever in St. Louis, the witness stated that he had noted that for the years 1899 to 1903, inclusive, the deaths from this disease had been reported as uniformly increasing, whereas in Chicago they were rather variable, indicating that there is no relation between the two places, so far as Chicago sewage being a factor in the occurrence of typhoid at St. Louis is concerned. He had noted, also, that the reported deaths from typhoid for 1900 on the three great drainage areas, exclusive of Chicago, were 503, which is more than in the preceding year. This is in accord with the reported deaths in St. Louis for 1900, which also showed an increase over those in 1899. It is not, however, in accord with the number of deaths reported in Chicago, which was smaller than in the preceding year. (6922–6923.)

The witness stated that he employed the method of giving the typhoid death rate according to the population—the number of deaths per 100,000. This is more correct than to give the percentage of typhoid deaths to total deaths, which does not enable the sanitarian to pass judgment on the conditions in a given city as to whether there is an increase or decrease in typhoid fever. Should a certain locality have an increase in typhoid and a greater increase in tuberculosis, the report from that place would show an improvement in typhoid conditions, whereas the case would be quite the reverse. (6923–6924.)

He then presented a series of charts showing the deaths from typhoid fever in St. Louis and Chicago during each month of 1900 to 1903, inclusive. Inasmuch as by reason of the remoteness of one city from the other, an outbreak of typhoid fever in Chicago would not be reflected in St. Louis until the following month, the St. Louis tables were compiled one month in advance; that is, the February deaths in St. Louis were plotted against the January deaths in Chicago, and so on. The witness pointed out, in reviewing the evidence contained in these charts, that there is no parallelism in the curves representing the death rates in the two cities. In many instances the rise of the curve for Chicago is coincident with the falling of the curve for St. Louis, demonstrating absolutely that the one is independent of the other. (6925–6932.)

The witness presented a chart prepared from Professor Jordan's data, showing in graphic form the number of times that *Bacillus coli communis* was found in Illinois River at Pekin, Averyville, and Grafton; in Missouri River at Fort Bellefontaine, and in Mississippi River at Grafton, and at the intake tower, Missouri shore, midstream, and Illinois shore, Chain of Rocks, when operating on volumes of water varying from 0.001 to 1 c. c., and pointed out that according to the occurrence of this organism the following was the proper order of purity: Illinois River at Grafton, Mississippi River at Grafton, Illinois River at Averyville, Missouri River at Fort Bellefontaine, Mississippi River at the intake, Chain of Rocks, and Illinois River at Pekin. With reference to the sanitary significance of the colon bacillus determination, the witness stated that inasmuch as this bacillus is a constant inhabitant of the human intestine it is a valuable indicator of the presence in the water of intestinal discharges, although it bears no evidence as to whether those discharges came from a healthy or a diseased person. When this germ is found persistently in small quantities of water, such water is looked on with more suspicion, the presumption being that where *B. coli communis* is so constantly present disease germs may be associated with it. While it is true that this bacillus is widely distributed and can generally be found if enough water is examined, it is considered important to have some notion as to the volume of water examined in order to obtain an idea of the number of these germs present in the water. (6934–6935.)

As bearing on the importance of noting the interval of time elapsing between the infection of a water supply and the drinking of the infected water the witness presented the results of his review of 205 British epidemics. He had divided them into three portions—those produced by well water, those produced by stream and reservoir water, and those produced by milk. There were a few out of this number that could not be so classified, and they were left out of consideration. In 33 epidemics due to stream and reservoir water the death rate was 9.85 per cent of the cases; in 75 epidemics due to well water the rate was 11.83 per cent; and in the 20 epidemics due to milk the percentage of deaths was 12.79, showing that a well-water epidemic is distinctly more serious in character than one caused by stream water that had carried the typhoid germ for some distance from the point of infection to the point where the water was used for drinking. He further cited an examination which he had made of 357 cases of typhoid fever at Waterville, Me., where he was able to follow the course of each case and to obtain the physician's statement as to whether it was severe or not. Some of these patients used the city water supply from a contaminated stream, others used water from contaminated wells, and some used both sources. Among those who used city water only 41.41 per cent were severe cases, but among those using well water 61.29 per cent were severe cases, thus showing that the fever produced by city water was a mild type. The witness' explanation of that was that in a river the typhoid germ had to struggle for existence under adverse conditions and was not capable of producing so much poisonous material when it found its seat of infection in the patients. (6936–6937.)

Taking into consideration the 4,846 wells in use in St. Louis, together with the fact that in 1895 the city chemist had condemned all he had examined, namely, 59, the witness stated that he believed the water of those wells was responsible for a portion of the typhoid of St. Louis, because he considered there was greater danger in water from a polluted well than from a polluted stream. If, however, the typhoid conditions in St. Louis during the last ten years are in part attributable to the city water, it was his opinion that when there is typhoid fever at places on the drainage area of Missouri River and Mississippi River above Grafton, nearer in point of time than Chicago, such places would be dangerous and undoubtedly the cause of the disease. (6937–6939.)

The witness was of the opinion that the typhoid bacillus lying in the sediment of a polluted stream for a period of thirty to sixty days would not be able to retain its dangerous qualities and produce typhoid fever when discharged from the bottom of the river. He did not know of any instance recorded in the literature of bacteriology where one had lived for a period of one to three years. (6939–6941.)

He then stated that the water of Mississippi River at Chain of Rocks was not, either before or after the opening of the drainage canal, fit for domestic purposes in its raw state, and expressed the same opinion with reference to Illinois River at Grafton, although he thought the water had been improved since the opening of the canal. (6943–6944.)

The witness then gave opinions in disagreement with those of Professor Sedgwick, which were noted in connection with the testimony of Professor Jordan (p. 257). He made the observation that epidemics of typhoid fever due to infected water do not usually take place after great floods such as would result in the washing out of typhoid germs from the sediment of the stream, as claimed by Professor Sedgwick, and he cited the Hudson Valley as an instance where there are high floods in the spring resulting from melting snows, but the epidemics do not occur at that time of the year. In such cases as that of Tees River the conditions were quite different, inasmuch as there were great deposits of fecal matter in privies and in heaps along the shore which were washed off during high water and caused typhoid fever. But with the conditions prevailing in the Illinois River basin such a thing would not be possible. (6947.)

The witness then stated that he had information pertaining to the Detroit epidemic, given to him at the time by Prof. Gardiner S. Williams, but that he had always had doubt concerning the connection between the disease in Detroit and the dredging of Black River. With reference to the germs of Asiatic cholera and the liability of infection reaching St. Louis, should that disease become prevalent in Chicago, the witness stated that the germs would have greater difficulty in finding their way than the typhoid germs, because the latter were more hardy. (6951.)

In his opinion, the discharge of Chicago sewage by way of the drainage canal and the Illinois River system would not cause any additional expense in the purification of Mississippi water by filtration, should such a system be set up at Chain of Rocks. (6956–6957.)

CROSS-EXAMINATION.

The cross-examiner endeavored to show by a series of hypothetical questions a parallelism between the persistence of *Bacillus prodigiosus* emptied into the drainage canal and isolated from water collected at the Chain of Rocks intake and a similar presumable typhoid infection, and drew from the witness the opinion that if hourly examinations of the water at Chain of Rocks covering a period of one month should disclose the presence of typhoid bacilli on three occasions such water would unquestionably be infected with the disease. Pursuing this line the cross-examiner sought to discover why, if such were the case, the persistence of *B. prodigiosus* under like conditions, as related in the testimony of Doctor Ravold, would not show a parallelism, and therefore indicate that the water at St. Louis was polluted by the Chicago sewage. The witness replied that in his opinion a water sampled at Chain of Rocks 720 times during the month with the identification of typhoid bacilli only twice would certainly be shown to contain typhoid infection, but not to such an extent as to be prejudicial to the city supply provided it was filtered before being used. (6957–6958.)

Summing up his opinion on the longevity of typhoid bacilli and taking into consideration the various detrimental factors naturally occurring in streams, the witness stated that the germs of typhoid fever from Chicago sewers would be destroyed en masse by the time the mouth of Illinois River was reached, although some resistant organisms might get beyond that point. They would, however, be small in number and low in vitality. The longevity of a typhoid bacillus depends, in the first place, on its parentage and next on the conditions under which it is grown. For example, a person may come from a healthy parentage and live in a healthful manner, but because of adverse conditions his vitality may be greatly lowered. In the same way the typhoid germ might struggle for existence over long periods of time, but would lose its vigor and be incapable of producing its normal amount of infection. It is, however, impossible to determine the longevity of specially resistant cells. It is probable that such cells are at the time of their departure from the human body more capable of producing disease than the greater numbers of less resistant organisms with which they start on their journey. Whether, after the interval that may be chosen for the period of investigation, they arrive in a condition to produce disease, may be open to question, because the mere fact that they are resistant and have arrived in a living condition does not mean that they will have enough toxin-producing powers left to produce that serious poison that may cause disease. All this is, however, a matter of speculation. (6958–6962.)

If a gallon of typhoid dejecta were deposited in the waters of Lake Michigan at a point free from sewage contamination, the typhoid bacteria would disappear, because they would be surrounded by myriads of ordinary saprophytic bacteria, which would set up conditions prejudicial to the life of the typhoid germs, although it is true that the life of the latter would be increased somewhat, but at all events they would disappear before the ordinary sewage saprophytes would. While it is true that the longevity of the ordinary saprophyte depends in a large measure on its environment and it dies as soon as its part in the purification of the water is finished and its food supply is gone, its disappearance takes place subsequent to that of the typhoid germ, because the latter is merely a foreigner in that locality and has no purpose to fulfill. (6963–6964.)

In analyzing the relationship between the typhoid fatality in St. Louis and Chicago the witness merely accepted the facts without reference to the temperature of the water, the variable physical conditions, or anything that happened between the two cities. Were there no Illinois River in existence, the facts would stand, and nothing is shown in the charts which enters into the question of longevity of the specific germ in passing down the stream between the two points. In the opinion of the witness such conditions are immaterial, because the typhoid figures are based on actual occurrence. (6969–6970.)

Taking into consideration all the facts with reference to the discharge of Chicago sewage in Illinois River, the witness stated that in his opinion some of the colon bacilli in the water at Averyville come from the Chicago drainage canal, but he was unable to state the proportion. (6972.)

The total number of deaths in St. Louis from 1890 to 1903, inclusive, was then recited to the witness, together with the recorded number of deaths from typhoid fever, and he was asked if it would in his opinion make any difference in the interpretation of such data whether the deaths were expressed as rate per 100,000 persons living or as percentage of typhoid deaths to total, to which he replied: "Basing my reply on the numerical data submitted in the question, it is my opinion that there is no material difference between the two methods of stating the result." (6973–6974.)

LEONARD P. KINNICUTT.

Leonard P. Kinnicutt, called as a witness on behalf of the defendants, stated that he was director of the chemical department of the Worcester Polytechnic Institute, Worcester, Mass. He graduated from the Massachusetts Institute of Technology in 1875, with the degree of bachelor of science. He studied in the University of Heidelberg for two years thereafter, under the direction of Professor Bunsen, and for two years at the University of Bonn, Germany, in the laboratory of Professor Kekule. He then studied for four months at Johns Hopkins University and later at Harvard University, where he obtained the degree of doctor of science. He was then appointed instructor of chemistry at Harvard University, and three years afterwards was called to the Worcester Polytechnic Institute. He was consulting chemist to the Connecticut sewage commission. For fifteen years he had been a fellow in the American Society for the Advancement of Science, and was a member in several American, English, and German professional societies. He had made a special study of sanitary problems since 1882, including the chemical and bacterial analysis of water, together with the interpretation of such results. He had been called to pass on the quality of water supplies in numerous cities. He had made a study of the typhoid bacillus as related to water supplies and of the colon bacillus in the determination of the potability of water. He had thoroughly examined the physical conditions of Chicago River, the drainage canal, and Desplaines and Illinois rivers and had made extended investigations on the problem of sewage disposal, especially that of purification by means of septic tanks. It was his practice to go to England every other year to study the sewage-disposal systems there and the progress made from time to time. (7336–7339.)

The witness described the septic tank and the process of purification which takes place therein, and discussed the sewage-disposal problem in some detail. He then gave the results of his observations on the Chicago drainage canal, and compared it to a septic tank. He stated that as he passed along the canal in a truck boat, he observed the indications of septicity therein. He noted that gas was being given off from the liquid at the upper end of the canal, typical of septic-tank gas, and that after passing Lemont the odor changed to that of the effluent of a sedimentation tank. He then presented a series of tables to bring out these facts. The data in table 86 were taken from the results of examinations by Professors Jordan, Palmer, and Long, and show the comparative conditions at the upper and lower ends of the canal. (7340–7348.)

TABLE 86.—*Analyses showing changes in the character of sewage during its passage through the Chicago drainage canal, being the mean of results obtained by Professors Jordan, Long, and Palmer.*

[Parts per million.]

Constituents.	Kedzie and Western avenues.	Lockport.	Parts removed.	Per cent removed.
Solids:				
Total	207.0	200.7	6.3	3.0
Soluble	179.2	184.4	+5.2	+ 2.9
Suspended	27.8	16.3	11.5	41.3
Oxygen consumed:				
Total	7.93	6.26	1.67	21.0
Soluble	4.77	4.63	.14	2.9
Suspended	3.16	1.63	1.53	48.4
Nitrogen:				
Free ammonia	1.20	1.57	+.37	+30.8
Total albuminoid ammonia	.58	.45	.13	22.4
Nitrites	.050	.024	.026	52.0
Nitrates	.23	.097	.133	57.8
Albuminoid ammonia (mean of Jordan's and Palmer's results, Long not determining soluble and suspended albuminoid ammonia):				
Total	.48	.37	.11	22.9
Soluble	.20	.165	.035	17.5
Suspended	.28	.205	.075	26.7

TABLE 87.—*Comparative action of the septic tank and the Chicago drainage canal on removal of sewage.*

[Per cent removed.]

Constituents.	Birmingham.	Exeter.	Leeds.	Manchester.	Worcester (Kinnicutt, 1900–1901).	Lowell (Clark, 1900–1901).	Drainage canal.
Solids:							
Total	26.0	24	34	27	22	....	3.0
Soluble	8.0	7	12	15	21	....	+ 2.9
Suspended	60.0	60	70	57	26	....	41.3
Oxygen consumed:							
Total	33.6	....	....	....	36	45	21.0
Soluble	25.4	....	....	....	29	....	2.9
Suspended	57.1	....	....	....	44	....	48.0
Nitrogen:							
Free ammonia	+24	....	22	....	+20	0	+32.7
Albuminoid ammonia	41.6	17	59	....	33	55	21.8
Albuminoid ammonia:							
Total	....	....	....	....	33	....	22.8
Soluble	....	....	....	....	8	....	17.5
Suspended	....	....	....	....	43	....	26.7

Commenting on the above tables, the witness stated that if analyses are made of crude sewage and of effluents from the septic tank it is found that the amount of free ammonia in the effluent is greater than in the sewage, but the amount of total or soluble albuminoid ammonia is less in the effluent. The nitrogen as nitrates and nitrites is very small in the effluent as well as in the sewage, but there is a reduction in both. The results in the tables indicate very strongly that septic action has taken place during the passage through the canal of water containing sewage, as is shown by the increase in free ammonia and oxygen consumed. The results agree in other general characteristics with those that have been obtained from septic tanks at various places, as shown in Table 87. In other words, the canal has a purifying effect and renders substances that still remain in the sewage more easily acted on when they are discharged into the river. The purification of the sewage by the canal consists of the removal of a part of the solid matter by throwing some of it down to the bottom of the canal and by changing some of it to gases. Very little work has been done with reference to the effect of the septic tank on bacterial life. The second report of the royal commission on sewage disposal of Great Britain quotes experiments made in Manchester, England, showing that the *Bacillus coli communis* diminishes during the septic period, and the same effect must be felt by the similar and more delicate bacteria such as that of typhoid fever. Similar results are shown at Leeds. The witness's opinion was that the septic tank reduces the number of *B. coli* and the more delicate pathogenic germs, and that the total number of bacteria is diminished by 10 or 15 per cent. (7348–7350.)

The witness then took up in detail the results of examinations presented in evidence by Professors Jordan, Palmer, Burrill, Zeit, and Long, assembling the data according to the average determinations and according to various combinations in many tables and charts and discussing in connection therewith the significance of the results. This discussion appears in the record, pages 7354–7446.

In his final summing up of the evidence contained in the tables and charts just referred to, the witness stated that about 20 per cent of the organic matter discharged into the drainage canal from the sewers of Chicago disappears in the canal, this percentage being measured by both the loss in albuminoid ammonia and the loss in oxygen consumed. A certain amount of suspended matter also is removed and further amounts are rendered soluble and converted into gases. This not only purifies a part of the sewage, but changes the remainder so that further purification will take place more easily on its discharge into Desplaines River. Undoubtedly, in the upper stretches of the river near Joliet, both aerobic and anaerobic action are taking place. Farther downstream—at Ottawa, for example—the action is principally aerobic, and in both 1899 and 1900 this point was the center of the zone of greatest decomposition. Purification continues until Averyville is reached. Below Peoria the process is repeated, until at Grafton all the original organic matter which was in the river at Pekin has been decomposed and changed. The effect of emptying the sewage of Chicago into Desplaines River is to increase the amount of organic matter in the upper stretches, but such addition is not noticed at Averyville except in the increased nitrogen contained in the river. At Grafton the effect of the addition of sewage to Illinois River can be seen only in the high chlorine and nitrogen as nitrates. This nitrogen is very different from that at or above Ottawa, having been changed over and over again from its original character. The chart representing Illinois River, May to August, 1899 and 1900, before and after the opening of the drainage canal, shows that the purification took place in almost exactly the same way during those two periods. Such nitrogen and chlorine as are found in the river at Grafton are not in the slightest degree dangerous to public health and can have absolutely no effect on the human system. (7446–7449.)

The witness stated that he had studied the determinations of *Bacillus coli communis* given in the testimony of Professor Jordan and also the experiments on the viability of typhoid germs made by Professors Jordan, Russell, and Zeit, and as a result thereof was convinced that no deleterious matter persisted down Illinois River as far as Grafton. All the data that he had examined showed that the water at Grafton does not contain undecomposed matter, and it was therefore his opinion that the water of Mississippi River at the Chain of Rocks intake had not been made less valuable for drinking purposes or more liable to carry water-borne diseases than before the opening of the drainage canal. He considered that an increased speed of Illinois River caused by the addition of water from the drainage canal would not have any effect in increasing or diminishing the number of typhoid germs or the liability to typhoid and other water-borne diseases on the part of the inhabitants of St. Louis. (7449–7450.)

The witness then expressed his disagreement with Professor Sedgwick's statement that the typhoid germ may live in sewage-polluted streams for weeks, months, or even years, because all the experiments with which he was familiar showed that the typhoid germ will live a shorter time in polluted water than in pure water. He further disagreed with Professor Sedgwick by stating his belief that a typhoid bacillus would not live from the time it left the Chicago sewers until it entered slack waters at Peoria, and that even should it survive the passage to this point and be deposited upon the bed of Lake Peoria, it would not live for a period of a month in such a deposit. In this connection he cited an experiment described in the Thirty-fourth Annual Report of the Massachusetts State board of health, in which polluted water was allowed to stand in a large storage reservoir without further pollution and the colon bacilli rapidly decreased and none were found after eleven days. He also disagreed with Professor Sedgwick's statement that the waters leaving Lake Peoria would at times, by reason of the accumulation of bacteria in the lake, be more infectious than those discharged from the Bear Trap dam, and declared that he knew of no evidence, scientific or other, that would show that germs of typhoid fever would remain upon the bottom of streams, lakes, or slack-water basins for a long period and then be washed out in a virulent state and be dangerous to people consuming the water. (7451–7453.)

The witness stated that the analytical evidence presented by the defendants showed that Mississippi and Illinois rivers above Grafton contain practically the same amounts of impurity and that Missouri River at Fort Bellefontaine contains a much larger amount than either of the others. Therefore the mixing of the waters of the first two streams with that of the Missouri would improve it as a water supply for St. Louis. (7459.)

In the opinion of the witness, the water of Mississippi River at the Chain of Rocks intake was not suitable for drinking purposes in its raw state, either before or after the opening of the Chicago drainage canal. (7462–7463.)

The cross-examination was waived.

THEOBALD SMITH.

Theobald Smith, a witness on behalf of the defendants, stated that he was a professor in the Harvard Medical School and pathologist of the State board of health of Massachusetts, which position he had held since 1895. Prior to that he was bacteriologist in charge of the investigations of the Bureau of Animal Industry, United States Department of Agriculture, and at the same time professor of bacteriology in the medical department of Columbian University. He graduated from Cornell University in 1881, spent two years in the study of medicine at Albany Medical College, spent six months in special work at Cornell, and went to Washington in the fall of 1883. He had become interested in the bacteriology of water in 1886, when he made observations on Potomac River, and in 1891 he was engaged for a number of months on a sanitary survey of Hudson River between Schenectady and Albany. During the year previous to the date of testimony he was engaged in looking over the bacteriological and general sanitary status of Charles River basin, around Boston. During all this period of investigation the main question involved had been the bearing of drinking water on typhoid fever and other intestinal infections. (7288–7290.)

The witness then stated that in considering the sanitary condition of a water he had taken it for granted that the most important indication of its pollution would be the presence of fecal matter, because the bacilli of typhoid fever, dysentery, Asiatic cholera, and various diarrheal diseases are involved, and any test that would indicate the relative number of these bacteria would bring the observer as nearly as possible to an exact determination of the condition of the water. In the study of fecal bacteria there is one bacillus of intestinal origin the isolation of which affords as accurate a judgment as possible of the sanitary quality of a water. This is *Bacillus coli communis*, a species closely allied to and a probable progenitor of *B. typhosus*. In view of the fact that bacteriological methods are still unsatisfactory in the isolation of the typhoid bacillus, it is not practicable to attempt such determinations on a large scale, but the presence of the colon bacillus affords information nearly as conclusive. He then described the tests for distinguishing between the two organisms. With reference to their comparative longevity, he stated that the typhoid bacilli are more perishable under a variety of conditions. (7290–7292.)

The witness defined the bacterial self-purification of streams as a reduction in the number of bacteria in a stream, which is not due simply to perfect or imperfect sedimentation, but to the complete disappearance or destruction of the bacteria in the water. He did not know of any general principles involved, and was of the opinion that each stream has certain special local conditions that require investigation and that depend on a number of factors which vary from stream to stream, so that an individual investigation of each stream by itself is necessary. He expressed the belief that the study of Illinois River between Chicago and Grafton was the most extensive ever made, and laid stress on the examination for *B. coli communis* as especially applicable to such a problem. (7295–7296.)

With reference to the failure to find the colon bacillus in Mississippi River above New Orleans, the witness stated that the results would lead to the belief that all the other closely related bacteria, such as the typhoid and dysentery bacilli, had also disappeared. (7296.)

The typhoid bacillus will not reproduce its kind in ordinary water, but will grow rapidly in milk until the milk becomes very acid. In general the typhoid bacillus does not increase outside of the human body except in favorable culture media. (7297.)

The witness stated that he would assume, from the data introduced in the testimony of Professor Jordan relative to the numbers of colon bacilli in the waters of the drainage canal and Illinois, Mississippi, and Missouri rivers, that these bacilli had so largely disappeared in their passage down Illinois River that they were less numerous in this stream at Grafton than in the Mississippi above Grafton or in the Missouri at its mouth. Therefore it would seem to him that the water at the mouth of Illinois River was certainly not inferior to that in the other two streams, but, on the contrary, more pure. If virulent typhoid bacilli should actually pass from Chicago to the mouth of Illinois River, such passage would be made according to conditions and laws of which the profession knows nothing; but, basing his opinion on the close relationship of the colon bacillus to the typhoid bacillus and to this entire group of disease germs, he believed that he was justified in stating that virulent typhoid bacilli would be very largely destroyed before reaching Grafton. If a typhoid bacillus should be discovered in the water supply of St. Louis or in Mississippi River at Chain of Rocks, it would be utterly impossible to identify its source, but the presumption would be that it had come from the nearest town discharging sewage. On the whole, the passage of a typhoid bacillus from Chicago to St. Louis was entirely out of probability. (7297–7301.)

The witness then stated that the question concerning the effect of polluted water on the life of the typhoid bacillus is very difficult to answer categorically, inasmuch as it depends on the temperature and the amount of pollution. It is probable that if the pollution were very great the typhoid bacilli under very favorable temperature might begin to multiply after a short period of time, and in the course of this multiplication would become destroyed, because they would render themselves vulnerable to destruction—that is to say, it is possible that sewage might offer enough stimulus to these bacteria to induce them to multiply and then become destroyed. The history of typhoid epidemics had shown that typhoid bacilli can be carried by relatively pure water, as in the epidemics at Ithaca and Plymouth, but whether polluted water is a hindrance to the destruction of the bacteria or favors it is a question concerning which he did not feel competent to make a positive statement. (7301–7303.)

If it were true that Chicago sewage was the cause of typhoid fever in St. Louis, there would be a relationship between the occurrence of the disease in the two cities in point of time. The curves diagrammatically representing typhoid deaths would be synchronous, although the St. Louis curve would be slightly retarded, because of the distance between the two cities and the period of incubation of the disease. He was unable to see any connection between these two cities along this line. The upward curve in the St. Louis charts seems to correspond with the usual summer and fall increase manifested throughout the civilized world, but there is no relation to the occurrence of the disease in Chicago. (7303.)

Referring to the occurrence of typhoid fever on the three great drainage basins above St. Louis, the witness stated that he would not consider the St. Louis water fit for public use without previous purification, and if he were to attempt to trace out the sources of infection in this water he would first look to points nearer than Chicago. Because of the vulnerability of the typhoid bacillus in water, the farther away the area of infection the less would be the danger of disease originating therefrom. A few bacteria discharged into the stream near the intake would be much more dangerous than a large number at a much greater distance. (7304.)

With reference to the experiments of Professors Jordan, Russell, and Zeit on the longevity of typhoid bacteria as determined by the use of permeable cells, the witness stated that a new factor had been introduced into the problem by this work and that they had defined, for the first time, perhaps, the viability of the bacterium in polluted water. If the experiments were correct, and he stated that he felt prepared to take the risk of acceptance, it was his opinion that it would be physically impossible for a typhoid bacillus starting from Chicago to reach St. Louis. (7305.)

No new important facts were brought out on cross-examination.

ERASTUS G. SMITH.

Erastus G. Smith, called as a witness on behalf of the defendants, stated that he was professor of chemistry at Beloit College, Beloit, Wis., and had occupied that position since 1881. He had graduated from Amherst College in 1877, and for a year studied under private tutelage. He was then called as instructor in chemistry to Williston Seminary at Easthampton, Mass., remaining there for three years and then going to Beloit College. He took the degree of doctor of philosophy at Georgia

Augusta University, Germany, in 1883, and had taken a course in bacteriology during one summer at the Massachusetts Institute of Technology. Since 1885 he had given practically all his available time to the study of sanitary problems, especially those related to watercourses. In connection with his studies he had been called to investigate many public water supplies, including those from both surface and underground sources. He had investigated typhoid fever epidemics at numerous places and gave extended accounts of each during his testimony. In addition to this he had acted as consulting chemist in connection with water-filtration plants at Rock Island and Kankakee, Ill.; Ashland, Eau Claire, Oshkosh, and West Superior, Wis.; Independence and Burlington, Kans.; Cedar Rapids and Burlington, Iowa; Beaver Falls, Pa.; Warren, Ohio; Brooklyn and Binghamton, N. Y.; and Denver, Colo. He had also studied filtration systems at London, Paris, Antwerp, Berlin, and Hamburg. (6736–6745.)

The witness stated that he had studied the chemical and bacterial analyses of the waters of Lake Michigan, the drainage canal, Desplaines, Illinois, Mississippi, and Missouri rivers, as presented in the testimony of Professors Jordan, Gehrmann, Palmer, and Burrill, and was thoroughly acquainted with all the bodies of water mentioned. He had made a trip from the mouth of Chicago River along the entire course as far as Eads Bridge, St. Louis. (6745–6746.)

The attention of the witness was directed to the *Bacillus prodigiosus* experiment made by Doctor Ravold on behalf of the complainant. He stated that this bacillus is an organism not widely distributed in nature, although it occasionally does occur. He was not sure whether he had found it himself in river waters, but had found a form closely allied to it. In his opinion the *prodigiosus* experiment did not possess value with reference to the probable longevity of the typhoid bacillus. The longevity of *B. prodigiosus* is not necessarily a measure of that of the typhoid bacillus, and the results of the experiment, on the assumption that the facts as presented by Doctor Ravold are true, do not contribute to the probability that a typhoid bacillus entering the drainage canal would find its way to the intake of the St. Louis waterworks. On the contrary, it seems highly improbable that such would be the case, because, although *B. prodigiosus* is known to flourish in water under ordinary temperature when the proper nourishment is available, there is no evidence showing that the typhoid organism flourishes under similar conditions. With reference to the experiment itself, the witness stated that there was nothing in the results to show that the bacilli alleged to have been found were those that were placed in the water of the canal, because there is evidence that they are occasionally found in natural water. On studying the question, it seemed to him that if these bacilli had remained in the water for any length of time they would have been found farther up the river, but no such identifications were made above Grafton, although they were diligently searched for in the water at Joliet. (6747–6750.)

The presence of the colon bacillus in water is very significant because it is the constant inhabitant of the intestinal tracts of man and of most domestic animals and is not present, certainly in any number, in a natural unpolluted water. There is a question whether some fish do not excrete them in small numbers and therefore the colon bacillus is occasionally found in an unpolluted water. Under ordinary circumstances, however, the discovery of this organism in a natural water is presumptive evidence that fecal matter as sewage has found its way into that water. (6751.)

According to the work of Doctor Frankland, the typhoid bacillus has been observed in water previously sterilized after a period of one hundred days, and this may be taken as the maximum recorded time. In unsterilized water it would diminish in numbers and disappear after a few days, some records specifying it at six or seven days and some as high as twenty-six days. The bacillus does not multiply and increase in water. Laboratory conditions are rather more favorable for its longevity than those met with in nature. One of the reasons for this is that the glass itself seems to affect the water. There are other conditions, such as uniformity of temperature and environment, neither of which prevail in a running stream. Experiments show that the typhoid-fever germ will not live as long in polluted as in sterilized water, the reason probably being that the organism in polluted water is subject to certain enemies, namely, the toxins thrown off by the other bacterial forms, as well as the varying conditions of the stream. (6752–6753.)

The witness stated that from such study as he had been able to make of the quality of water in the drainage canal and Desplaines and Illinois rivers and from a study of the work of Professor Jordan it was his opinion that the duration of life of the typhoid bacillus must be brief in those streams, amounting to but two or three days. This he believed to be due to the toxic effects on the typhoid organisms of the other organisms in the stream. (6753–6754.)

The effect of the dams erected across Illinois River would naturally be to increase the amount of sedimentation by bringing the water into a more quiescent condition. A high water always tends to increase the amount of sediment contained in a river, but the physical surroundings of Illinois River compensate for this increase of sediment, because during high water the stream overflows and there is an enormous amount of sedimentation on the overflowed lands. Bacteria will respond to the law of gravity, for they are somewhat heavier than water, but this response takes place slowly except in water practically quiescent. The tendency of bacteria is downward, however, even in a running stream. The settlement of matter in suspension greatly assists the sedimentation of bacteria because the organisms fasten on the particles of suspended matter and are carried downward. (6754–6755.)

In reply to a question concerning the effect of the discharge of clear water from Lake Michigan on the rate of sedimentation in Illinois River, the witness stated that the amount passing through the drainage canal could not produce a condition of sufficient clearness in the river water to preclude the possibility of the opportunity for sedimentation. Even if the entire sewage of Chicago could be diverted into the drainage canal and 800,000 cubic feet of water per minute from Lake Michigan should pass over the Bear Trap dam the dilution caused thereby would not be sufficient to prevent the sedimentation of bacteria in the river. (6756.)

The dilution of the water of a river with another water of pure quality is one of the well-recognized factors in the problem of self-purification of streams. It separates the different micro-organisms, and thus diminishes the liability of their being taken into the animal economy. Sewage-laden water diluted with water of a better quality is thereby rendered less liable to communicate disease by infection. Therefore the addition of the pure Lake Michigan water to the Chicago sewage improves its quality, because the dangerous micro-organisms in the sewage are more widely separated from each other, and also because it gives the river greater room for facilitating the sedimentation of the solid matter in suspension, thereby decidedly improving the sanitary condition of Illinois River from the standpoint of the chemical and bacteriological changes taking place. (6757–6758.)

In the opinion of the witness, it seemed very clear that there is no pollution dangerous to public health from the drainage canal persisting in Illinois River as far as Grafton, for the reason that the natural conditions of the stream are such as to facilitate the dilution, sedimentation, and oxidation of the sewage matter. In addition to this, experimental work shows that the life of the typhoid bacillus in this stream probably does not exceed three days. The result of all this is that the water of Illinois River at Grafton appears, from all chemical and bacteriological standpoints, to be equal in quality to that of tributary streams in the valley. These conditions would persist even in the event of low water in Missouri River at a time when Illinois River was in flood stages, because even under such flood conditions the purifying agencies would still be effectual. Therefore, in the light of all the conclusions above given, the witness stated that the sewage from Chicago could not affect the water supply of St. Louis nor the waters of the Mississippi as they pass along the border of the State of Missouri. (6760–6762.)

The witness stated that in his opinion the typhoid bacillus would live longer in the sediment at the bottom of a stream than it would in the water itself, for the reason that the changes taking place in the sediment are not so great nor so constant as in the water. Of course a bacterium deposited in such sediment would be affected by the same agencies, namely, the toxic products of other bacteria, as in the water of the stream itself, but probably to a less degree, so that the absence of these destructive agencies would prolong the life of the organism in the sediment of the stream, but not for any great length of time. (6764.)

The witness expressed agreement with Professors Jordan and Russell in stating that the typhoid organisms would live longer in moist earth than in the sediment of a stream, because of the fact that the particles of moist soil are separated by thin layers of air, which tend to diffuse the toxic agencies of other bacteria less rapidly than water. The particles of sediment in the bottom of the stream are all surrounded by water and the conditions of diffusion are practically the same as in the water of the stream itself. It was his opinion, however, that the period during which the typhoid bacillus will live in moist earth does not furnish any criterion for its longevity in the sediment of a running stream and that the two conditions are in no way comparable. (6764–6765.)

In giving mortality statistics, the witness's preference was for the use of the rate per unit of population rather than the mortality percentage method, for the same reason as had been expressed by other witnesses for the defense. He also thoroughly agreed with Professor Russell in his opinion of the danger of typhoid-fever infection from rural communities, and gave various cases in which such infection had caused epidemics. (6767–6770.)

With reference to the position occupied by the science of bacteriology in regard to the ascertainment of the purity of river waters, the witness stated that it is commonly accepted that diseases are caused by certain specific organisms and that among these organisms which can be borne by water are those of typhoid fever and cholera. These are intestinal diseases, and therefore it is very important to determine whether or not fecal matters find access to the water. The presence or absence of the intestinal bacteria can be used, therefore, as the most important index in determining the purity or impurity of the supply. (6770.)

The witness then stated that the science of chemistry as applied to river water has to do with the determination of the presence or absence of organic matter in that water. It is necessary to know the chemical constituents of water from a sanitary standpoint and whether or not the water contains organic matter. It may or may not be possible to determine the bacterial forms present in the water, but the presence or absence of organic matter can be determined. Another application of chemistry is to determine what changes the organic matter undergoes after a period of time. A sanitarian could hardly form a proper opinion regarding the quality of a river water did he not have chemical and bacteriological data on which to base such an opinion. As an example of this witness cited the South Platte River, at Denver, Colo.—a bright, clear, stream flowing from a mountain spring through unoccupied land. The water is entirely satisfactory in appearance, but on bacteriological examination is found to be polluted with sewage. Chemical evidence is confirmatory of this, and it is thereby shown that the water is unfit for domestic consumption in its raw state. (6771–6772.)

In the opinion of the witness, the chemical and bacterial data submitted by the defendants show that the waters of Illinois River have become practically purified of Chicago sewage before reaching Peoria, and therefore could not become a menace to the inhabitants of the State of Missouri. This being the case, the same would be true at the mouth of Illinois River, and in his opinion the Illinois River water at Grafton discloses a smaller amount of impurity than that of the Mississippi above the mouth of the Illinois or that of the Missouri above its confluence with the Mississippi. Therefore, if the data show that there is a gradual mixing of Illinois River water with that of the other two rivers, the tendency would be to improve the quality of the combined waters. (6772–6775.)

The witness then reviewed the facts with reference to sewage pollution in Mississippi River above the mouth of Illinois River, stating the extent to which polluting materials were discharged and their effect on Mississippi River water. In his opinion, the Mississippi water is unfit for drinking and domestic purposes in its raw state. (6775–6785.)

With reference to the opinion expressed by Professor Sedgwick, that the germs of typhoid fever could lie in the sediment of the drainage canal and upon the bottom of Illinois River for a period of one to three years and then be washed out and pass down the river in a virulent condition, the witness said:

From the experiments already given upon the life of the typhoid-fever germs in the Illinois River after the same has received the sewage of the city of Chicago, from the fact that the germs which may have been precipitated to the bottom of the river in the sediment of the river would be measurably subject to the same agencies, the same tending to its rapid destruction, it is my opinion that there is no probability or possibility of a germ remaining at the bottom of the river for a period of from one to three years. I know of no instance on record or in literature where a typhoid bacillus has lived for a period of from one to three years in the sediment of a polluted stream or in the water of the same; but on the contrary, the records of all the experiments which I have been able to read and from all information I have been able to gather upon the subject of the duration of the life of a typhoid-fever germ in a polluted water is that it is brief, being limited to that of a few days, six or seven, perhaps, at the outside. (6785–6786.)

The water from Mississippi River at Chain of Rocks was not prior to the opening of the Chicago drainage canal a safe and potable water for domestic purposes in St. Louis. The opening of said canal had not created any greater necessity for the purification of this water for municipal purposes than existed prior to such opening, and in the event that a filter should be established at St. Louis the cost of operation would not be increased by the discharge of Chicago sewage into the Illinois River basin. (6791–6796.)

The witness then reviewed the analytical data presented by Professors Jordan, Long, and Palmer, and introduced into the record and discussed tables of averages, his conclusions being the same as those already submitted by the above-named witnesses. (6796–6811.)

In response to leading questions the witness discussed further the improbability of there being any damage caused to the St. Louis water supply by reason of the discharge of sewage into the Illinois River basin, but as the matter is largely repetition it will not be reviewed here. (6811–6828.)

No important new facts appear to have been established on cross-examination.

GEORGE DOCK.

DIRECT EXAMINATION.

George Dock, a witness called in behalf of the defendants, qualified as an expert by saying that he had been connected with the medical faculty of the University of Michigan for thirteen years, and at the time of the testimony held the chair of theory and practice of medicine. He graduated from the medical department of the University of Pennsylvania in 1884; spent one year after graduation in St. Mary's Hospital, which is situated in and receives the patients from the most afflicted typhoid district in Philadelphia. He gave especial attention to this disease during his period of service in this hospital. He then went to Germany and for two years studied medicine at Leipzig, Berlin, Vienna, and Frankfort. During his attendance at Leipzig and Berlin typhoid fever was epidemic and excellent opportunities were afforded him for the study of this disease. Returning to Philadelphia, he became connected with the hospital of the University of Pennsylvania, and during the period of his service there he had an unusually large practice among typhoid-fever cases. At this hospital he began the study of malaria, and in order that he might have a good opportunity to study that disease he went to Galveston, Tex., and became professor of pathology in the Galveston Medical School and physician in the hospital. After his services at Galveston he accepted a position at the University of Michigan, where he had remained up to the date of the testimony. During the Spanish-

American war he was engaged by the Surgeon-General of the United States Army to visit the military hospitals at Chickamauga, Knoxville, and Camp Meade, and there added to his already ripe experience in the diagnosis of malaria and typhoid fever. (7044–7050.)

The witness then entered on a discussion of the diagnostic difficulties in typhoid fever and malaria. He found at Galveston practically no typhoid fever reported, but an unusually large amount of malaria, nearly all of which proved on examination to be typhoid fever. On going to Ann Arbor he found this experience repeated, with the difference that although he had in Galveston found a few cases of actual malaria, he found not a single fatal case among all those reported as such in the State of Michigan. (7045–7046.)

The entire subject of the occurrence of malaria throughout the Mississippi Valley had been thoroughly studied by him and he had given, special attention in years past to St. Louis by visiting the city frequently, inspecting and conferring personally and by letter with the physicians there. He found that in St. Louis malaria was very rare, and it was likely that nearly all the supposed cases were typhoid. (7046–7049.)

In his examination of the army hospitals in 1898 he found that at Chickamauga out of 400 cases diagnosed as malaria there was only one actual case, the remainder being typhoid. At Camp Meade there were during his period of inspection several hundred cases diagnosed as malaria, all of which except one were typhoid, while at Knoxville he found not a single case of malaria. (7049–7050.)

Continuing, he stated that the terms "intermittent," "remittent," "typho-malarial," "congestive," and "simple continued" fevers were entirely unsatisfactory and did not represent specific types and that they nearly all mean typhoid fever in the vital statistics reports. Malaria appears as remittent and sometimes as intermittent, but so does typhoid, and therefore any of the symptoms noted under the above terms were not, as specified, all malarial exclusively. (7051–7053.)

Hypothetical questions were then asked, based on a statement of the number of deaths reported from typhoid and the malarial diseases, above named, in St. Louis. These figures are given in Table 80 (p.242). In reply the witness made the following comments:

From 1895 to 1903 the record shows a steady and gradual increase in the number of cases, but no sudden or disproportionate increase. Since 1898 there had been a much larger number of typhoid cases reported all over the country, owing to an increased knowledge of the disease, resulting from the lessons of the war with Spain. At that time the attention of the profession generally had been called to the diagnostic procedure in typhoid cases, which had resulted in more accurate observations and, consequently, more typhoid reports. This explained in a large measure the increase in the number of St. Louis cases since 1898. (7054–7055.)

The witness stated that typhoid tables should contain most, if not all, of the so-called "malarial" deaths. The malarial rate shown in Table 80 is entirely too high for every year, and the probability of these being actual typhoid cases is apparent. As an example, he noted the great increase in typhoid in 1890 to 1892 due to specific causes and, together with that, the concurrent increase in so-called "malarial" diseases. During that period there was no reason, according to the witness, for believing that malaria should rise to so great a height, and the increase was undoubtedly due to mistaken diagnosis, the cases being really a part of the typhoid epidemic. In addition to this, he made the point that fatal malaria or remittent malaria occurs rarely above the latitude of Arkansas. North of this parallel nearly all the malarial cases are intermittent and almost never fatal. Therefore the impossibility of so many deaths from malaria at St. Louis was evident; they must have been from typhoid fever. The only city in the United States showing so much malaria is New Orleans, where conditions for the encouragement of this disease are extraordinarily good and where the physicians are subject to the same diagnostic errors as in St. Louis. Statistics and his own experience show that 50 to 90 per cent of the so-called "malaria" in the United States is really typhoid, and only 2 or 3 per cent actually malaria. (7055–7059.)

On the assumption that all the deaths represented in Table 80 were typhoid, there was no marked increase in any one year, although the total had gradually increased since 1898, for reasons already explained. With reference to Table 79 (p. 241), introduced into evidence by Professor Jordan, showing the monthly distribution of deaths from typhoid and malarial diseases, the witness stated that it showed even more clearly the probability that the most of the so-called "malarial" diseases were actually typhoid, because so many of the alleged malarial deaths occurred during January, February, March, and April. No one, in the opinion of the witness, dies of malaria in the latitude of St. Louis during those months. Even in the Philippines malaria is not fatal throughout the year. The circular letters sent to the physicians of St. Louis by the local health commissioner in 1900 and 1901, calling attention to the fact that the law requires them to report cases of deaths from typhoid, would explain the rise that had occurred in the last two years. These circulars were issued approximately at the opening of the Chicago drainage canal, and the result would make it appear that the discharge from that canal was responsible for the increase. Nevertheless, the increase was not as great as might be expected, and considerably less than had been found to take place in other cities in which similar circulars had been sent. (7059–7063.)

The witness considered it especially significant that the number of recorded deaths from malarial diseases should have decreased as shown by the death table, and he testified strongly to the effect that the errors made by physicians in diagnosis had been in a large measure corrected and that the cases formerly charged to malarial diseases were now to some extent being given their correct designation. (7063.)

Another table was introduced into evidence, showing the population and deaths per 100,000 of typhoid fever alone during 1890 to 1893, together with the record of typhoid fever, plus 50 per cent of the deaths recorded under the heading "intermittent fever," etc., and of "typhoid fever," plus all the deaths recorded under that heading. The witness repeated his opinion that such tables showed only the slight increase that would be ascribed to increased care in diagnosis rather than to any outside conditions. One of the most serious sources of typhoid fever in St. Louis, according to the witness, was the water from wells. (7064–7066.)

The following appears in the record, page 7066:

Q. Assuming that on April 1, 1895, the total number of wells in the city of St. Louis was 4,846, and assuming that pursuant to an order of the board of health of St. Louis directing an examination of these wells, the city chemist, after examining 59 wells, condemned them as unsanitary, and assume further that in August, 1895, upon the report of the city chemist, condemning 7 more of these walls, the board of health of St. Louis passed a resolution that the city should make no further examination of the wells in question, and since August, 1895, none of these wells have been condemned, what effect would this number of wells in the city of St. Louis have, in your opinion, upon the typhoid conditions existing in said city, assuming that the water of these wells was used by the inhabitants for drinking and domestic purposes?

A. It would be a very serious source of typhoid fever.

In concluding his direct testimony the witness stated his opinion that the increase in typhoid fever indicates rather a change in the conditions of the city of St. Louis itself rather than in the main water supply. If the main water supply comes from the river, a change for the worse in the conditions of the river water is always indicated by a more marked increase in the disease. As to such an increase as was shown here, it is altogether compatible with changing local conditions, such as wells, and the ordinary course of typhoid epidemics. (7066–7067.)

CROSS-EXAMINATION.

The witness admitted, in response to leading questions, that he had never practiced medicine in St. Louis, and that the only investigations of mortality which he had made were those of the figures submitted to him, including a study of the published reports. While he would not state that all the physicians in St. Louis were not competent to make a distinction between typhoid and malaria, he did contend that a large number did not make correct diagnoses. (7067–7070.)

While the witness admitted that the records for typhoid-fever deaths showed during the four years prior to the opening of the canal an average of 22.8 per 100,000 and during the four years immediately following an average of 36 per 100,000, indicating an increase of about 74 per cent, this was not what he would call a large increase. Although it would be an increase for the town and from the standpoint of the people who were sick, it would not necessarily indicate a radical difference in the matter of infection. Where a change takes place in the method of infection in a town that always has typhoid, the change is much greater than this, usually several hundred per cent, and at least more than 100 per cent. For example; a difference of seventy-odd per cent might easily occur in a place like Chicago or Philadelphia and mean no increase in the method of infection. (7073–7077.)

REDIRECT EXAMINATION.

On redirect examination the witness objected to observations based on averages for the entire four years preceding and the four years succeeding the opening of the canal and stated that the increase did not occur in a single year, but was spread over a series of years. If the 73 per cent had occurred between 1899 and 1900, it would be his opinion that there must be a new focus of infection, but inasmuch as it was spread over four years, and the ascent was gradual, he adhered to his statement that it was not a great increase. A correct idea of the increase could be gained only by calculating the relationship existing between each year. The percentage for long periods is a doubtful one. There might be local conditions in any one year that would offset the average too much. In all such specifications there is a very serious error, depending on the comparatively limited number of cases considered. (7077–7079.)

The witness further mentioned the fact that during the years 1901, 1902, and 1903 the Louisiana Purchase Exposition affected the rate, in that the desire was to maintain a low record of typhoid and the tendency was therefore to report typhoid fever by some other name, so that the increase according to the record was probably not as great as the actual increase. (7058.) This was conceded by counsel. (7081.)

LEWELLYS F. BARKER.

Lewellys F. Barker, called as a witness on behalf of the defendants, stated that he was professor of anatomy in the University of Chicago, and had been in charge of that department for three years. Previous to going to Chicago he was for nine years associated with the medical faculty of Johns Hopkins University, being for the first year assistant to Prof. William Osler in the department of internal medicine, for the next two years a fellow in pathology and bacteriology with Prof. William H. Welch, then associate in anatomy with Professor Mall, next assistant professor of anatomy, and finally associate professor of pathology. He had graduated from the University of Toronto and had served one year as house physician at the Toronto General Hospital. During his services in Baltimore he was on leave at various periods studying in Germany and on various commissions. His first commission was one established by the State board of health of Maryland when he and Prof. Simon Flexner were sent to study an epidemic of cerebro-spinal meningitis. In 1899 he and Doctor Flexner were sent by Johns Hopkins University to study tropical diseases in the Philippine Islands and incidentally the epidemics of plague and beriberi in Hongkong, India, and Japan. While in Manila he had abundant opportunity for the study of typhoid fever, malaria, and acute tropical dysentery. Subsequently he was appointed by the Secretary of the Treasury on a commission with Professor Flexner, of the University of Pennsylvania, and Professor Novy, of the University of Michigan, to study the bubonic plague in San Francisco. (7082–7087.)

The witness stated that the terms remittent, intermittent, typhomalarial, congestive, and simple continued fevers were all clinical rather than pathological and date back to the time when classification of diseases had to be made by symptomatology rather than by pathology. He defined the various terms and stated that they had all been given up by good clinicians at the present time. They all represent either typhoid, malaria, or acute tuberculosis, but most often they represent typhoid. (7090.)

The witness presented the St. Louis statistics covering the years 1890 to 1902, inclusive, giving deaths in which the cause was diagnosed as typhoid fever and the total deaths the cause of which was diagnosed as the febrile diseases mentioned in the preceding paragraph. These figures are given in Table 80, in the testimony of Professor Jordan (p. 242). He then introduced another table, giving the St. Louis death rate per 100,000, covering the period from 1890 to 1893, inclusive, and made some comparisons with similar statistics for Baltimore from 1899 to 1902, inclusive. In discussing these tables he stated that the febrile diseases should all be included under typhoid, although some of them might have been acute tuberculosis. The addition to the number of deaths from typhoid of those from the febrile diseases mentioned would give, in the opinion of the witness, a truer typhoid rate than any other statistics available. He stated that were the deaths from remittent, intermittent, typho-malarial fevers, etc., examined by skilled clinicians they would be definitely diagnosed as specific diseases. Unless physicians are trained in the most modern methods of diagnosis it is extremely difficult for them to decide between cases of malaria and typhoid. (7091–7094.)

The most important clinical test for typhoid is the Widal reaction or agglutinative test, while that for malaria is the demonstration of the malarial parasite in the blood or tissue of the patient by microscopic observations. (7095.)

The witness then stated that it was absolutely certain that if the statistics presented by the St. Louis health department for typhoid and malarial diseases were reliable, there had been no increase in the typhoid rate. The total deaths from these various causes run along together at a tolerably constant figure. They show in the typhoid-fever column alone a well-marked increase during the years 1900 to 1902, inclusive. They also show a marked diminution in the remittent and intermittent group, and there had evidently been a transfer from the remittent to the typhoid column. This indicates an improvement in the diagnoses of the practitioners and had no significance so far as any possible increase in typhoid was concerned. (7096–7097.)

With reference to the distance over which the infection of typhoid fever had traveled in a stream, the witness stated that if the extreme statement of one investigator were accepted, the distance would be 70 to 75 miles, but that assertion had not met with general acceptance. (7099.)

In his opinion, a typhoid bacillus which had lain in the sediment of a stream for a period in excess of fifty days would be harmless if taken into the human system. The germs of typhoid fever entering Desplaines River from the Chicago drainage canal would not be a menace to the citizens of St. Louis after passing through the rivers intervening between Lockport and the intake tower at Chain of Rocks. He further stated that there was no evidence that would make it seem probable that the sewage and other matter entering Illinois River below Lockport would prolong the life of such disease germs. In his opinion the introduction of the organic matter from the stock yards and distilleries of Peoria would favor the disappearance of these organisms. He then rendered a similar opinion with reference to the specific germs of Asiatic cholera, tetanus, anthrax, and other water-borne diseases. (7100–7102.)

The witness stated that the probable life of typhoid bacilli introduced into the drainage canal was from five to seven days. (7103.)

The death rate from typhoid fever in St. Louis, compared with that for many other American cities, does not indicate the use of an excessively polluted water supply. (7104.)

The important probable sources of infection of the St. Louis water supply, according to the witness, are those places within a mean flow of five to seven days from the Chain of Rocks intake, and the probability of infection from distances requiring more than twelve days would be remote. (7108.)

The cross-examination brought out no important new facts.

VICTOR C. VAUGHAN.

Victor C. Vaughan, called as a witness on behalf of the defendants, stated that he was a physician and teacher in Ann Arbor, Mich., and had been connected with the University of Michigan since 1876. He had graduated from that University in 1875 and received his medical degree there in 1878. He had made a specialty of hygiene and physiology and had studied with Dr. Robert Koch, in the University of Berlin. He was at the time of his testimony serving his third term as a member of the Michigan State board of health and had been called on frequently to examine into epidemics in the State. In 1898 he was appointed by the President of the United States on a special commission, consisting of Maj. Walter Reed, Major Shakespeare, and the witness, to investigate the spread of typhoid fever in military camps. He had investigated typhoid fever in Camps Alger, Fernandina, Jacksonville, Huntsville, Chattanooga, Knoxville, and Meade, and during that experience had examined probably 4,000 or 5,000 cases of typhoid fever. As a member of this commission he had been engaged practically ever since in writing up the statistics and studying the spread of typhoid fever, and had extensive experience both in the laboratory and on the clinical side of the disease. (7313–7315.)

The witness then defined typhoid, malarial, intermittent, remittent, typho-malarial, congestive, and simple continued fevers, and stated that all except the first two were not distinct types of disease and almost without exception should be interpreted in the vital-statistics reports as true typhoid. Reviewing the number of deaths reported from typhoid fever and from the other febrile diseases mentioned in St. Louis from 1890 to 1903, inclusive, he stated that the typhoid rate was undoubtedly too low and the malarial-fever rate too high. His experience had shown that malaria is not a common disease in Missouri or in that section of the country and that death from it is exceedingly rare—so rare, in fact, that it practically does not occur. He based his statement on his investigations in connection with the Army Medical Commission. Missouri sent six regiments to the Spanish-American war in 1898, and a careful study of the records of all these regiments showed that, although in some of them many cases of malarial fever were diagnosed, these were not malarial cases but typhoid fever. One of these regiments was quartered at Jefferson Barracks, practically a part of St. Louis, until July, 1898. While malaria was frequently reported by the medical officers in charge, more careful examination showed that there were no such cases. The Sixth Missouri regiment developed 286 cases of typhoid fever, from which 19 deaths resulted. This regiment was stationed at Jefferson Barracks until early in August. It then went to Jacksonville, Fla., where the cases were studied by the Medical Commission, and from the records of this and other regiments it was developed that 96 per cent of the cases diagnosed as malaria were true typhoid. In connection with this, the witness stated that he was born and reared in Missouri and returned to that State every year. He knew something of the malarial and typhoid conditions there, and felt convinced that malaria was a rare disease throughout the State and that practically all the reported cases were true typhoid. In connection with such erroneous reports, the witness stated that many of the physicians were honestly misled. Typhoid fever, in its earliest stages, is often a remittent disease; that is, fever persists for a few hours and then the temperature is reduced to normal for a short period. These conditions would easily mislead a physician who was not accustomed to resort to modern diagnostic methods. He further stated that physicians are frequently actuated by policy in pronouncing a disease as malaria when they are certain that it is typhoid, principally for the purpose of allaying the fears of their parents. In no city in the United States are there so many deaths from malarial diseases as are reported from St. Louis, and while some of the cases may not have been typhoid fever, the inclusion of them all in the typhoid rate would not introduce any significant or material errors. (7315–7320.)

The witness then examined the monthly distribution of deaths during the years 1895 to 1903, inclusive, from typhoid fever and from the other malarial diseases noted, and stated that without knowing anything of the local conditions of St. Louis and simply as a student of epidemiology, he would say that the probabilities are that the typhoid fever in St. Louis was due to local causes rather than to any infection of the general water supply. His reason for this was the even distribution of the deaths throughout the months of each year, whereas, in his opinion, an infection of the general water supply would result in explosive outbreaks. (7320–7322.)

Considering the figures resulting from an addition of the deaths reported from typhoid and those reported as being due to malarial diseases, the witness stated that for 1890 to 1899, inclusive, there is a total of 3,708 deaths, equivalent to an average rate per year of 370. In the four years since 1899, or after the opening of the Chicago drainage canal, the total deaths were 1,261, or an average of 315 per year, showing that the rate was greater previous to the opening of the canal than subsequent thereto. He further stated that the situation would be reversed if the epidemic years of 1892 and 1893 were left out of the first total. Comparing the typhoid-fever rates in St. Louis with those in other cities, notably New York, Minneapolis, Philadelphia, Richmond, Buffalo, Albany, and Cleveland, he called attention to the fact that there had been an increase in all of these cities and that St. Louis had not occupied a different position in this respect from that of many other places. He attributed this to the fact that typhoid fever has been more widely disseminated over the country, having been, in his opinion, spread from the army camps in 1898. (7323–7326.)

That part of Table 1 showing the typhoid death rate per 100,000 in St. Louis was then presented to the witness, who stated that it did not indicate an epidemic of typhoid fever, inasmuch as in such an epidemic the increase ranges from 100 to 400 per cent and sometimes more. The increase shown was such as might be expected to be due to local conditions, especially if wells were getting more and more filthy and were not condemned. (7326–7328.)

The charts presented in the testimony of Professor Mason did not, according to the witness, show any causal relation between typhoid fever in Chicago and that in St. Louis. (7328.)

The witness then stated that he would look for the cause of increased typhoid in St. Louis in the local conditions. It is a wholly erroneous assumption that typhoid is carried altogether by means of drinking water, and in illustration of this he exhibited a chart based on the record of the Fifteenth Minnesota regiment, which was in camp on the fair grounds at St. Paul and at Fort Snelling, Minn. All of the men were supplied with water from a common source, yet some companies remained practically free from typhoid while others were largely affected. The transferrence of the infection was due, in the opinion of the witness, to direct contact from person to person, infection of tents, clothing, bedding, etc. The condition was comparable to that in crowded cities. (7328–7329.)

The witness could see no evidence from the typhoid statistics that the Chicago drainage canal had anything to do with typhoid fever in St. Louis. In the first place, the distribution of the disease in St. Louis is indicative of local contamination and spreading by contact rather than by any general infection of the water. Second, there are certain cities in which the increase in typhoid fever has been more marked than in St. Louis, notably, Buffalo, from which the Chicago drainage has been turned away. (7329.)

The cross-examination brought out no new facts.

WILLIAM S. THAYER.

William S. Thayer, called as a witness in behalf of the defendants, stated that he was a physician graduated from Harvard Medical School in 1889. After graduation he had spent a year as house physician at the Massachusetts General Hospital, had studied for a year in Berlin and Vienna, and then had taken the position of assistant resident physician in Johns Hopkins Hospital at Baltimore. He was later appointed assistant professor of medicine in the university, had pursued further studies in Europe, and was at the time of testimony one of the physicians in chief at Johns Hopkins Hospital Dispensary and visiting physician at the Union Protestant Infirmary.

The testimony of the witness was mainly corroborative of that given by Professors Dock, Vaughan, and Barker—namely, that the records of deaths from typhoid fever in St Louis do not constitute a satisfactory statement of the case, because the deaths recorded as being due to remittent, intermittent, typho-malarial, and other febrile diseases should be included in the typhoid column, and if such addition were made no increase in typhoid fever in St. Louis would be shown over and above that which might well be accounted for by natural causes and would be comparable with that in other cities; further, that no relation appeared between the fluctuations and typhoid deaths in Chicago and those in St. Louis. (7465–7501.)

JOHN W. HILL.

John W. Hill, a witness called on behalf of the defendants, stated that he was an hydraulic engineer, at that time engaged as chief engineer of the bureau of filtration of Philadelphia, which was conducting the improvement of the water supply of that city by filtration of the water from Delaware and Schuylkill rivers, the sources of public water supply. This work embraced the filtration of 320,000,000 gallons of water per day and a general reorganization of the distribution system, at a total cost of about $26,000,000. The witness stated that he first engaged in the planning and building of waterworks about thirty-two years previous to the date of testimony, and from that time on information concerning the hygienic quality of water supplies had always been an essential part of his work. He had been associated with about 60 such projects, looking either to the general construction or improvement of municipal waterworks. Wherever his engineering association with water-supply development had concerned the question of quality of water, investigations had been made to determine the desirability of available sources. Prior to his Philadelphia engagement his principal work of this kind had been for the city of Cincinnati, where he was chairman of the original board of engineers that made an investigation and furnished the plans on which the present improvements in that city are being constructed. He had also engaged in engineering along Ohio River at Parkersburg, W. Va., and Madisonville and Jeffersonville, Ind., the purpose being to determine the desirability of drawing water from Ohio River for drinking and other domestic purposes. He then gave an extended list of other cities in which he had made investigations concerning the desirability of streams as sources of public water supply. Aside from purely engineering investigations of drainage basins where rivers or ponds had been the sources of public supply, he had taken up the subject of bacteriology and attempted to qualify himself as an amateur in this line, not with a view of practicing the science as a profession, but to gain information as to the bacteriological condition of water supplies, with which, as an engineer, he would be required to deal. He had also studied the chemistry of water with the same purpose in view. (7502–7505.)

He had investigated typhoid-fever epidemics at Eaton, Ohio, and in the Cumberland Mountain region of Kentucky, both as a part of investigations looking to the improvement of the water supply of Cincinnati. He had also studied the records of all important typhoid epidemics that had been reported, as well as of certain cholera epidemics in Europe and in this country. (7505–7506.)

The witness professed to have examined and studied the analytical data concerning the waters of Lake Michigan, the Chicago drainage canal, and Desplaines, Illinois, Mississippi, and Missouri rivers, presented in evidence of behalf of the defendants by Professors Jordan, Palmer, Burrill, and Long. He also professed acquaintance with the natural features of the above-named bodies of water so far as they are represented in published documents and in hydrographic maps published by the United States Government and the city of Chicago. He had not made a personal examination of the drainage canal, nor of the Illinois River, except in the region of Peoria, where during 1882 he was employed on the Peoria waterworks. (7506–7507.)

With reference to *Bacillus prodigiosus* and its occurrence, the witness believed he had found it twice in investigations of Ohio River water during 1895 and 1896. He had also made experiments on the longevity of the typhoid bacillus in 1895, working with sterilized and unsterilized Ohio River water. These experiments indicated that the typhoid organism would grow in sterilized water without apparent reduction in virility for sixty days at least. The unsterilized water, however, gave negative results, as he was never able to find the germ after the first inoculation. He ascribed this not to the disappearance of the organism after such inoculation, but to his inability to isolate it in culture media. In connection with the work in Philadelphia he had caused experiments to be made with a view to determining what, if any, influence the amount of chlorine in Delaware River water might have on the longevity of the typhoid organism. Concentrations of chlorine in water varying from 25 to 300 parts per million were used, and the fact was revealed that the amount of salt in Delaware River water had little or no influence on the longevity of either the typhoid or the colon bacillus and that their life was limited to a period varying from five to eight days under the most favorable conditions. It was also revealed that the colon bacillus would live longer than the typhoid organism in unsterilized Delaware River water with varying degrees of salt concentration. These experiments were made because of the probability of an increase of chlorine content in the water of the Delaware to 50 parts per million at a time when the city of Philadelphia would be drawing 350,000,000 gallons per day for the city supply, the excess of chlorine being due to the influx of tidal water coming up the river from Delaware Bay. (7508–7510.)

Tables 88 and 89 were then introduced, giving the results of the above investigation. (7512–7513.)

In the opinion of the witness the above experiments afforded data on which to base an opinion concerning the longevity of the typhoid organism in polluted river water. In the absence of information to the contrary he would assume that the longevity of such organisms in lake or river water where sewage pollution was no less than in Delaware River above Philadelphia would be substantially the same as that found by him in these experiments. He gave this opinion mindful of the fact that the temperature of incubation doubtless would be the same for unsterilized as for sterilized water taken from any other suspected source of supply. In estimating the longevity of these organisms collected at some other point or from some other streams or source of water supply he would be governed by the results of the tests made on Delaware and Schuylkill river waters, and he would feel safe in expressing an opinion from such data that the organism would certainly not live longer in unsterilized than it did in sterilized water, and would probably have a shorter life history. He would expect that its life in unsterilized water would certainly be no longer and probably less than eight days. He regarded the conditions of the laboratory tests usually made as more favorable to the growth or the persistence of the typhoid organism than natural conditions, owing to the fact that a constant temperature is maintained in the flasks in which incubation is carried on and all other conditions conducive to the preservation of the life of the organism are generally observed. He would estimate the life of the typhoid organism in a sewage-polluted river water as from five to eight days. The degree of pollution would have an important effect. He assumed as a general proposition that rivers where they are used as sources of public supply, like the Delaware, Schuylkill, Merrimac, Hudson, Missouri, or Mississippi, do not differ widely with reference to sewage pollution, which is more intense in some cases and at some points than in others, but nevertheless there is a distinct pollution in all these streams that would have some modifying influence on the longevity of the organisms. (7514–7517.)

TABLE 88.—*Results of experiments to determine the longerity of Bacillus typhi abdominalis in sterilized raw water of Schuylkill and Delaware river under various conditions of chlorine content.*

Date of inoculation of test flasks.	Average temperature during experiment (° F.).		Estimated organic matter introduced into test flasks (parts per million).	Kind of water.	Chlorine added to water (parts per million).	Numbers of *B. typhi abdominalis* per cubic centimeter in test flasks after incubating at given temperatures for periods in days as follows:								Temperature of incubation of plates (° C.).	Number of days of incubation.	Kind of medium.
	Test flasks.	Schuylkill water at entrance to building.				0.	1.	2.	3.	5.	8.	12.	14.			
			0.25	Schuylkill River..	0	130	120	27	7	0	......	......	......			
			.25	Delaware River...	0	150	100	12	0	0	......	......	......			
			.25	.....do............	25	150	140	100	55	0	......	......	......			
Oct. 7, 1901....	73	64	.25	.....do............	50	150	65	12	0	0	......	......	......	39	1	Lactose agar.
			.25	.....do............	75	140	80	6	1	0	......	......	......			
			.25	.....do............	100	150	60	11	1	0	......	......	......			
			.25	.....do............	200	160	75	6	1	0	......	......	......			
			.25	.....do............	300	130	80	26	4	0	......	......	......			
			50	Schuylkill River..	0	110,000	43,000	25,000	4,200	1,000	3	......	0			
			50	Delaware River...	0	110,000	38,000	25,000	6,200	1,200	1	0	0			
			50	.....do............	25	110,000	41,000	28,000	8,100	1,800	1	0	0			
Oct. 16, 1901...	63	62	50	.....do............	50	80,000	34,000	22,000	4,900	1,000	1	......	0	39	1	Do.
			50	.....do............	75	85,000	35,000	26,000	7,500	1,700	0	......	0			
			50	.....do............	100	100,000	36,000	24,000	9,800	2,000	3	......	0			
			50	.....do............	200	74,000	63,000	27,000	12,000	2,500	4	......	0			
			50	.....do............	300	62,000	34,000	23,000	2,200	600	0	......	0			

TABLE 89.—*Results of experiments to determine the longevity of Bacillus coli communis in sterilized raw water of Schuylkill and Delaware rivers under various conditions of chlorine content.*

Date of inoculation of test flasks.	Average temperature during experiment (° F.).		Estimated organic matter introduced into test flasks (parts per million).	Kind of water.	Chlorine added to water (parts per million).	Numbers of *B. coli communis* per cubic centimeter in test flasks after incubating at given temperatures for period in days as follows:								Temperature of incubation of plates (° C.).	Number of days of incubation.	Kind of medium.
	Test flasks.	Schuylkill water at entrance to building.				0.	1.	2.	3.	5.	8.	12.	14.			
Oct. 7, 1901	73	64	0.25	Schuylkill River	0	180	230	1,700	(a)	(b)	(b)	......	......	39	1	Lactose agar.
			.25	Delaware River	0	180	140	61	49	....	15	......	......			
			.25	do	25	180	140	16	2	....	0	......	......			
			.25	do	50	160	100	9	4	....	1	......	......			
			.25	do	75	170	120	13	5	....	2	......	......			
			.25	do	100	160	130	22	6	....	2	......	......			
			.25	do	200	200	140	18	3	....	1	......	......			
			.25	do	300	190	180	33	7	....	2	......	......			
Oct. 16, 1901	63	62	50	Schuylkill River	0	41,000	18,000	2,500	2,000	1,400	800	400	400	39	1	Do.
			50	Delaware River	0	35,000	13,000	2,200	350	70	30	11	8			
			50	do	25	61,000	16,000	4,900	1,200	240	120	63	44			
			50	do	50	35,000	15,000	4,300	1,400	650	110	52	37			
			50	do	75	46,000	9,200	2,100	750	300	110	17	19			
			50	do	100	45,000	17,000	6,200	650	300	43	17	8			
			50	do	200	35,000	12,000	1,600	700	80	35	8	2			
			50	do	300	42,000	13,000	4,300	1,400	550	100	55	34			

a Too thick to count.

b Contaminated.

The witness stated that from such information as he had gathered concerning the bacteriological and chemical characteristics of the water of Illinois River, as disclosed by the data presented in evidence, and concerning the physical conditions with reference to slope and slack-water pools in the river at different points, he would not expect a greater longevity of the typhoid organism in Illinois River than he had found to be the case in Schuylkill and Delaware rivers. The dams erected across Illinois River create important opportunities for sedimentation. Each pool acts very much like a sedimentation basin operated on the so-called continuous plan. Flood conditions that take the river out of its channel in many places increase the opportunities for sedimentation, to the advantage of the purity of the water. The witness was certain that 800,000 cubic feet of Lake Michigan water per minute carried into Illinois River through the drainage canal would not so increase the rate of flow as to impede sedimentation to any marked extent. On the other hand, the dilution caused by such influx should mean a purer water in Illinois River, because, first, it would increase self-purification in a mechanical way by increasing the volume of flow and reducing the percentage of pollution; second, it would increase the rate of oxidation by adding to the polluted water a water containing large amounts of dissolved oxygen. The danger of infection to persons drinking polluted water is really diminished by dilution, because the percentage degree of pollution when referred to the total volume of water flowing is reduced. The dilution of the sewage-polluted water would act exactly in the same manner as the dilution of a poison, and if dilution is increased the pollution may finally be reduced to so small an amount as to eliminate all danger. Therefore, the purer water diverted from Lake Michigan into Illinois River should improve the quality of the latter in proportion to the relative volumes. (7517–7522.)

Being asked whether the addition of Lake Michigan water to the sewage of Chicago draining into Illinois River is a detriment or a benefit to the sanitary condition of the river water considered from the standpoint of chemical and bacterial changes, the witness stated that in general a comparison of the data for the four summer months of 1899 and 1900 indicated that the condition of the river below Peoria was better at the latter period. The nitrites decreased and the nitrates increased, showing that self-purification was progressing in greater degree. In giving this answer the witness stated that some account must be taken of the difference in stream flow for the two years, but that although the evidence of Jacob A. Harman shows that the flow was greater for 1900 than for 1899, nevertheless, some of the chemical conditions indicate better purification in 1900, and it does not appear that the addition of the Chicago sewage has injured the quality of the water below Peoria. Such addition would undoubtedly increase the current and to some extent the time required for sedimentation. Whenever the increased volume is sufficient to overflow the banks it might have the opposite effect, by reason of the large degree of sedimentation that would take place over the bottom lands. The chief factor governing the case is the mean velocity of flow before and after the opening of the canal. Sedimentation and oxidation of organic matter are favored by low surface slope of the channel, and the purification depends on the time and the distance; in two cases where the distances were the same and the time of flow greater for one than for the other, the self-purification would be most extensive in the stream having the slowest flow. (7522–7523.)

The witness then introduced a series of tables showing the variation in bacteria, suspended matter, total solids, oxygen consumed, nitrites, nitrates, and chlorine at various sampling points along the water course for the years 1899 and 1900 and interpreted the tables as showing the following results:

1. An increase in the bacterial content of the water in Illinois River from Havana to Grafton.

2. A decrease in the suspended matter from Wesley to Chain of Rocks at about one-fourth the distance from the Missouri shore.

3. An increase in total solids from Chicago to Grafton.

4. A reduction in total solids from Mississippi River at Grafton to Chain of Rocks at one-fourth the distance from the Missouri shore.

5. An increase in the total solids from the Missouri shore of Mississippi River at Alton to the Missouri shore at the St. Louis waterworks.

6. A reduction of total solids in Missouri River at Fort Bellefontaine.

7. With two exceptions a material reduction in the total oxygen consumed, which in the opinion of the witness is significant as indicating self-purification by natural processes during stream flow past the 32 sampling stations named.

8. An increase in the total oxygen consumed in Sangamon River, but a decrease at all other stations.

The nitrites and nitrates in the witness's opinion are always significant factors in showing changes taking place in the quality of polluted waters. The nitrites should diminish as the water is reduced in sewage pollution and the nitrates should increase. With the exception of four stations—namely, Desplaines River at Joliet, Kankakee River at Bloomington, Illinois River at Morris, and Sangamon River at Chandlerville—the nitrites are largely decreased. With the exception of nine stations—namely, the Illinois and Michigan Canal at Bridgeport, at Lockport, and at La Salle, Desplaines River at Lockport, Fox River at Ottawa, Illinois River at Ottawa, at La Salle, at

Henry, and at Averyville—there is everywhere a marked increase in the nitrates. Therefore, if the witness were applying the information to the work of filtration he would have no hesitation in claiming the same degree of purification by the filters as is here shown in the canal and river. In view of all the data, and particularly those relating to the total oxygen consumed and the nitrates and nitrites, the witness considered that the condition of the water flowing in the stream at Grafton had been improved. Basing his opinion on the technical data collected for the purposes of this investigation he did not think that the sewage of Chicago in its original condition is manifested in the water of Illinois River at Grafton, nor did he think that infected material from the sewers of Chicago would pass down to St. Louis, because of conditions of low water in Missouri River and high water in Illinois River. (7525–7530.)

In the light of the information presented by the experimental work in this case the witness would not expect a typhoid organism introduced into Illinois River through the Chicago drainage canal to pass the entire length of the stream. On the contrary, he would expect it to perish somewhere in transit before it reached Peoria, the evident reduction of organic matter in the river between the point of discharge into the canal and Peoria being the basis of this opinion. (7532.)

Referring to the statement made in the testimony on behalf of the plaintiff that in spite of the fact that the reservoir at Covington, Ky., was sufficiently large to furnish a thirty days' supply for the city, typhoid was prevalent there, the witness said that he did not believe that the conditions would justify such an assumption, because a large part of the people of Covington do business or are otherwise engaged daily in Cincinnati, and investigations of the typhoid-fever rates in Covington, Newport, and Cincinnati from 1890 to 1896 gave satisfactory evidence to his mind that the larger part of the typhoid fever in the Kentucky cities mentioned is chargeable to Cincinnati water. Notwithstanding this the rate in Covington was less than that in Cincinnati, as shown by the following statement of deaths per 100,000 of population:

TABLE 90.—*Typhoid deaths per 100,000 population in Cincinnati and Covington, 1890 to 1896.*

Year.	Cincinnati.	Covington.	Year.	Cincinnati.	Covington.
1890	67	43	1895	36	27
1891	62	45	1896	48	32
1892	40	40			
1893	43	27	Average	49.4	36.3
1894	50	42			

The witness did not believe that all the Covington typhoid was due to Cincinnati water, but asserted that a large part of it undoubtedly did arise from that cause. In Covington a considerable amount of water is obtained from old-fashioned dug wells, many of which are undoubtedly polluted. (7533–7536.)

In the interpretation of typhoid statistics the witness's preference was for the statement of cases based on the unit of 100,000 population rather than on the mortality percentage, the reasons being similar to those cited in connection with testimony previously reported herein (p. 254). (7537.)

The witness stated that the liability of infection of rivers is not so great from rural as from urban populations. In rural pollution the element of time is important, and it had been shown by the experience of numerous cities that such pollution may cause epidemics. (7537–7539.)

From a bacteriological point of view the water of Illinois River at Grafton is decidedly better than that of Missiouri River at Fort Bellefontaine. The same statement may be made if based on the amount of suspended matter, total solids, nitrates, nitrites, and chlorine. (7542.)

The witness then presented a table showing the relative areas of the drainage basins of Illinois River, of the Mississippi above the mouth of the Illinois, and of the Missouri above its confluence with the Mississippi. On the assumption that the mean rainfall would be the same over the combined drainage areas, and all consideration of the flow of the Chicago drainage canal being omitted, of each 100 gallons of water flowing in Mississippi River opposite Chain of Rocks, $75\frac{1}{4}$ gallons would come from Missouri River, $20\frac{1}{3}$ from Mississippi River, and $4\frac{2}{5}$ from Illinois River. As a matter of fact, however, the mean rainfall over the Missouri River drainage area is not so great as that over either of the other two basins, and this being considered it is probable that the total flow opposite St. Louis would be 70 per cent Missouri, 20 to 22 per cent Mississippi, and 6 to 7 per cent Illinois water. Carrying out these computations and considering the added flow from the Chicago drainage canal, the witness stated that on the basis of a uniform rainfall over the entire area of the three rivers 20 per cent of the water flowing opposite St. Louis would be from the upper Mississippi, $75\frac{1}{2}$ per cent from the Missouri, 2.96 per cent from the Illinois, and the remaining 1.54 per cent from the Chicago drainage canal. The witness then presented Table 91, including statistics concerning the drainage basins above mentioned and similar data for Delaware and Schuylkill rivers. (7542–7549.)

TABLE 91.—*Statistics concerning the drainage areas of Missouri, upper Mississippi, Illinois, Delaware, and Schuylkill rivers.*

MISSOURI RIVER DRAINAGE BASIN.

	Drainage basin.			Cities.	
	Area (square miles).	Population.	Distance of mouth from St. Louis (miles).	Population.	Distance from St. Louis (miles).
Missouri River (including all tributaries)	520,086	5,120,607			
Jefferson City, Mo				9,664	110
Kansas City, Mo				163,752	264
Leavenworth, Kans				20,735	290
Atchison, Kans				15,722	305
St. Joseph, Mo				102,979	322
Omaha, Nebr				102,555	440
Council Bluffs, Iowa				25,802	441
Sioux City, Iowa				33,111	530
Big Sioux River [a]	10,009	179,090	550		
Yellowstone River [a]	70,119	49,002	1,165		
Platte River	89,742	727,689	422		
Denver				133,859	980
Kansas River	60,436	1,014,772	265		
Kansas City, Kans				51,418	265
Topeka, Kans				33,608	398
Osage River [a]	16,254	531,765	107		

[a] No large cities on this river.

MISSISSIPPI RIVER DRAINAGE BASIN ABOVE ST. LOUIS.

Mississippi River (including all tributaries except Missouri River)	171,698	8,409,676			
Quincy, Ill				36,252	110
Burlington, Iowa				23,201	178
Rock Island, Ill				19,493	241
Davenport, Iowa				35,254	242
Clinton, Iowa				22,698	270
Dubuque, Iowa				36,297	325
La Crosse, Wis				28,895	423
St. Paul, Minn				163,065	545
Minneapolis, Minn				202,718	557
Illinois River	32,081	3,433,845	37		
Peoria, Ill				56,100	162
Ottawa, Ill				10,588	227
Chicago, Ill				1,608,575	357
Rock River	10,231	564,972	241		
Rockford, Ill				31,051	342
Beloit, Wis				10,436	360
Janesville, Wis				13,185	375
Wisconsin River [a]	12,823	326,197	380		
Chippewa River	8,818	167,098	490		
Eau Claire, Wis				17,517	530
Chippewa Falls, Wis				8,094	542
St. Croix River [a]	7,655	128,623	530		
Minnesota River	16,109	396,790	545		
Mankato, Minn				10,599	615
Cedar River [a]	12,657	470,205	200		
Des Moines River	14,025	513,516	140		
Des Moines, Iowa				62,139	283

[a] No large cities on this river.

DELAWARE RIVER DRAINAGE BASIN.

	Drainage basin.		Cities.	
	Area (square miles.)	Population.	Population.	Distance from Trenton (miles).
Delaware River (including all tributaries except Schuylkill River)	9,217	1,430,367		
Easton, Pa			25,238	42 5
Phillipsburg, N. J			10,052	42

TABLE 91.—*Statistics concerning the drainage areas of Missouri, upper Mississippi, Illinois, Delaware, and Schuylkill rivers*—Continued.

SCHUYLKILL RIVER DRAINAGE BASIN.

	Drainage basin.		Cities.	
	Area (square miles).	Population.	Population.	Distance from Philadelphia (miles).
Schuylkill River (including all tributaries)	2,008	382,192		
Norristown Borough, Pa			22,265	6
Reading, Pa			78,961	43
Pottsville, Pa			15,710	89

If typhoid-fever germs should be found in Mississippi River water at the Chain of Rocks intake, it would be wholly impossible to state from what source they were derived, because there are many large cities in the drainage basins of the three rivers above St. Louis which might contribute such germs to the river. Other things being equal it would be more likely that they would come from the nearest points of pollution. (7550–7551.)

With reference to the alleged increase of typhoid fever in St. Louis subsequent to the opening of the Chicago drainage canal the witness stated that if the typhoid statistics show an increase in the death rate per unit of population since the opening of the canal, and if the investigation clearly indicates that there is no other possible source of infection, and if the rate in St. Louis fluctuates synchronously with the rate in Chicago, it might be held that such increase could be charged to the flow of sewage in the drainage canal. In other words, unless the rate in St. Louis fluctuates with those in Chicago he would be of the opinion that such increase was caused by much nearer sources of infection, of which there are many above St. Louis. While it can not be positively stated that Chicago sewage might not contribute to this increase, it is equally out of the question to assert that a single city out of many discharging sewage into the rivers above St. Louis is the sole cause of it. The city of St. Charles, on Missouri River, being nearer the St. Louis intake, would constitute a greater menace to the water supply than Chicago or Peoria. The nearness of the place of local infection, rather than the size of the place, is the chief factor in determining the source of infection. (7554–7556.)

The witness then described his investigation to determine the population living on the three drainage basins above St. Louis. The first step was to divide the total population on the basin by its area, the result being the distribution per square mile. Then the population of each urban center was divided by the distance of the center from the St. Louis intake. The quotients thus obtained were averaged and the total population divided by the sum of the quotients, thus fixing the center of population. The effect of this was to give a numerical value showing the relative probable degree of pollution of the water flowing past St. Louis from each of the respective drainage basins. The next step was to take the mean of all the quotients obtained by dividing the population of the urban centers by the distance of each center from St. Louis, which gave a factor that fixed the probable center of pollution on each drainage basin. A further step along this line was made by adding together the total area of each of the three basins and dividing the area of each by the total to obtain a factor which would show the proportion contributed by each basin to the water flowing in Mississippi River below the confluence of all three streams. The rainfall was then considered. The amount on the Missouri basin as an entirety would be less than that on the Mississippi or the Illinois basin, and this fact would change the proportions obtained by the last-described computation. The results of these calculations were stated as follows:

The distribution of population per square mile is in the Missouri basin 9.94, in the Mississippi basin above Illinois River 43.21, and in the Illinois basin 107; the urban population per square mile of the Missouri basin 2, of the Mississippi basin 9, and of the Illinois basin 72. The result of dividing the population of urban centers containing 4,000 or more people by the distance of such centers from the St. Louis water intake is for the Illinois basin 209.2, for the Mississippi basin 122.47, and for the Missouri basin 106.56. The relation of these numbers to each other indicates inversely the relative value of each stream as a source of water supply with respect to sewage pollution from all sources. That is to say, the Missouri would have the highest value, the Mississippi next, and the Illinois lowest. In these calculations, however, no consideration is given to the flow of water in the stream. If, however, the flow was greatest in Missouri River, which normally would be the most valuable source of supply for St. Louis, and least in Illinois River, which was shown by the above computations to be the least desirable, the unfavorableness of Illinois River would be mitigated. For example, if the flow of Illinois River was 1 per cent of that of Mississippi River in front of St. Louis, then, notwithstanding the fact that the Illinois is the most objectionable drainage basin from which to draw the supply, the effect of this water when compared with the other 99 per cent of water derived from Missouri and upper Mississippi rivers would not be appreciable. (7556–7562.)

The witness stated that it would make no difference either in the cost of construction or the cost of operation of a filtration system at St. Louis whether the sewage of Chicago were turned into Illinois River or not, because from his experince he believed that sewage pollution is not a factor in the cost of filtering a polluted water, but rather that the suspended matter that such water carries would increase the cost of maintenance by reason of the frequent cleaning of the beds that such matter would make necessary. The cost of purification of Missouri River water would be greater than that of water from Illinois or upper Mississippi rivers, because the Missouri carries the largest amount of suspended matter. (7563–7566.)

No important new relevant facts were brought out on cross-examination.

TESTIMONY IN REBUTTAL FOR PLAINTIFF.

EDWARD W. SAUNDERS.

DIRECT EXAMINATION.

Edward W. Saunders, called as a witness on behalf of the complainant in rebuttal, stated that he had been a physician in general practice in St. Louis for twenty-six years, having graduated from the medical school of the University of Virginia in 1875. He testified concerning his acquaintance with typhoid fever, and stated that the Widal test was used by physicians for the purpose of making an early diagnosis of the disease. He considered that this test was in general use among the medical profession in St. Louis, and with reference to the effects thereof stated that many cases of disease that had been supposed on clinical diagnosis to be typhoid fever had not been supported by this test, the result of which was that they had been eliminated from the typhoid list, thereby having a tendency to reduce the numbers of fatal cases reported since the introduction of the method. On the other hand, he was of the opinion that the use of the test had resulted in correcting the diagnosis of malaria and placing it under the head of typhoid. On the whole, a lower rate of fatality from the disease had been the result of the adoption of this test. (7587–7593.)

In the witness's opinion the circular sent out by the St. Louis board of health urging all physicians to report their cases of typhoid fever had had no effect. (7593–7594.)

With reference to various medical terms, he stated, first, that he had no idea what the term "congestive fever" meant, but it would not necessarily be included among typhoid cases; second, that he understood the term "typho-malaria" as being a complication of typhoid fever and malaria; third, he would include "remittent fever" among the typhoid cases generally, because indigenous remittent fevers are not fatal; if, however, the case had been that of a very young or very old person and death had occurred at the onset of the disease he would believe it to be malaria, but not if death had occurred after a protracted illness, because quinine, usually administered in such cases, is as a rule a specific; fourth, he expressed the same opinion concerning "intermittent fever" as above noted with reference to remittent fever; fifth, he had no conception of what the term "bilious fever" meant; sixth, deaths referred to as caused by "simple continued fevers" he would place in the typhoid class, inasmuch as he believed in the dictum of Doctor Osler that any fever that continues a week and is not amenable to quinine must be typhoid. (7594–7596.)

CROSS-EXAMINATION.

On cross-examination the witness admitted that if it should appear in the health statistics of St. Louis during the last ten years that there was a group of deaths reported as remittent, intermittent, typho-malarial, congestive, and simple continued fevers and that these deaths amounted to something like 200 a year, it would be a reflection on the diagnostic ability and carefulness of the doctors making the reports. If the number of deaths from typhoid and the number reported to be caused by the other febrile diseases were about the same, it would be his opinion that the majority of these latter cases belonged in the typhoid column, and in the light of such evidence he would say that the physicians of St. Louis were not employing the Widal test. He admitted it to be the fact that practitioners wedded to old forms of treatment are obstinate in accepting new forms and that this would make itself manifest in the mortality statistics. Assuming that approximately the same number of deaths are recorded from typhoid fever as from the other febrile diseases mentioned, he would conclude that the typhoid report is as inaccurate as the other one, and he attributed these inaccuracies to failure in diagnosis. He further stated that physicians in general practice in St. Louis are not possessed of the degree of skill necessary to make the microscopic diagnosis either of malaria or typhoid. (7600–7605.)

With reference to the comparative fatality of typhoid and malaria, the witness stated that in his entire practice he had never written a death certificate from any form of malarial fever except in the very young, when convulsions carried off the patient in the onset of the disease, or in the aged, where malaria caused the death of a very weak person. (7608.)

WASHINGTON E. FISCHEL.

DIRECT EXAMINATION.

Washington E. Fischel, called as a witness on behalf of the complainant in rebuttal, stated that he had been practicing medicine in St. Louis since 1874. He graduated from the medical department of Washington University and had taken postgraduate studies in the universities of Berlin and Vienna. He had devoted himself entirely to internal medicine, which included the treatment of typhoid cases, and was at the time of testimony connected with St. Luke's Hospital and the city hospital, and lectured to classes in the latter. (7612–7613.)

The witness stated that, taking into consideration the value of the Widal test in early diagonsis of typhoid fever, and also the fact that typhoid is a disease which, if properly treated in its early stages, is less likely to become fatal than if diagnosed later, he believed that the introduction of this test would lessen the mortality in St. Louis. He further stated that he had observed more typhoid fever during the winter and spring months within the last few years than formerly, but did not recall any circular sent out by the city board of health with reference to reporting cases of typhoid and had heard no discussion of it among the profession. He stated that personally it had had no effect on his actions in connection with reporting cases. He believed, however, that many cases of deaths from typhoid fever had not been reported as such, for the reason that the physician, not having reported the case at its onset, would endeavor to avoid responsibility in the death certificate. With reference to the various terms for febrile diseases noted in the preceding testimony, he stated that he could not define the meaning of "congestive fever," but that he would suppose that it might mean typhoid or, on the other hand, it might mean something else. Similarly, deaths reported as caused by remittent or intermittent fevers would not necessarily be typhoid, but might be tuberculosis, pneumonia, meningitis, or diphtheria. (7614–7617.)

He then said that the effect of the opening of the drainage canal had been to make him extremely careful with reference to the diagnosis of typhoid, because naturally he felt that there was a great danger from the Chicago sewage and he wanted to make it clear to himself whether in his experience that danger existed, and therefore he never reported a case as typhoid when the Widal reaction was not positive. (7617–7618.)

CROSS-EXAMINATION.

On cross-examination the witness admitted that the converse of his statement concerning the effect of the use of the Widal reaction was true, namely, that many deaths from typhoid were reported as being due to other diseases. He was not of the opinion, however, that if the typhoid in St. Louis prior to the opening of the canal had been diagnosed with the same degree of care that had been used subsequent to the opening there would have been a larger number of deaths reported, because the rule is that the clinical picture of typhoid is no clearer and positive diagnosis would be made in a majority of cases without the Widal reaction. The deaths reported as being due to remittent, intermittent, and other febrile diseases may have been tuberculosis. He was of the opinion, however, that among these deaths typhoid fever should be reported more often than tuberculosis. He believed that the circular sent out by the board of health after the opening of the drainage canal, calling attention to the necessity for reporting typhoid, had, on the whole, made the physicians more careful. If the official statistics should disclose that the number of typhoid-fever deaths had increased since the opening of the canal and the number of deaths from the other febrile diseases mentioned had decreased, it would be an indication that the physicians had exercised more care in diagnosis. He would assign faulty diagnosis as a reason why many of the deaths were reported under the miscellaneous febrile diseases, and admitted that where it was found that the number of deaths attributed to these causes in a city of the size of St. Louis amounted to about 200 a year it was an indication that there were a great number of physicians who were not abreast with the profession. (7619–7623.)

LUDWIG BREMER, ALBERT E. TAUSSIG, AND C. H. GOODMAN.

Similar testimony in rebuttal was rendered by Drs. Ludwig Bremer, Albert E. Taussig, and C. H. Goodman. Doctor Goodman stated that although he had seen a number of cases of pernicious malaria in St. Louis, he would be greatly surprised if the fatality ran as high as 50 annually.

HERBERT E. SMITH.

DIRECT EXAMINATION.

Herbert E. Smith, a witness called on behalf of the complainant in rebuttal, stated that he was dean of the medical school at Yale University, had studied in the Sheffield Scientific School of Yale University in the chemical and bacteriological courses, and then in the medical department of the university. He received his degree of doctor of medicine at the University of Pennsylvania in 1882. Since graduation he had been connected with the Yale Medical School under various designations, and at the time of testimony held the title of professor of chemistry and dean of the medical faculty. In the eighties he was appointed one of the Connecticut State chemists; was later appointed chemist of the State board of health, and for a period of fourteen years had had immediate charge of all the work, chemical and bacteriological, which the board had done in the matter of river pollution. Since 1887 he had been a student of bacteriology and had imported one of the first sets of Koch's bacteriological apparatus into the United

States. His experience along all the lines of water supply, water pollution, and water and sewage purification had been continuous, and he had investigated epidemics of typhoid fever throughout the State of Connecticut. (7679–7683.)

Tables 86 and 87 (pp. 284,285), introduced into evidence by Professor Kinnicutt for the defense, were exhibited to the witness, also those of Professors Long, Palmer, and Jordan. He stated that they did not furnish sufficient data to permit him to form a positive opinion in regard to the value of the drainage canal as a septic tank in the purification of sewage. While the figures show that there is a considerable solution of suspended matter and decomposition of organic matter and a reduction taking place in various ingredients in the sewage while passing through the canal, no opinion could be formed from them concerning the destruction of pathogenic organisms, particularly those of typhoid fever. While a reduction might be apparent, there was nothing to show how efficient the canal was in this respect. The figures concerning the water at the various sampling points in Illinois River show the composition of the samples of water at the time and place at which they were collected. Those in the upper portion of the stream show a very high chemical and bacterial pollution, and there was a gradual diminution in the amount of the various constituents during the progress down the river to Averyville, an increase below Peoria, and a further reduction to Grafton, but the samples at Grafton show considerable evidence of sewage contamination still remaining. The results fail to show, however, the true conditions of the river at the several stations at all times, because a sample taken from a running stream from time to time can not show the composition of the river at that place at other times. The witness further stated that there was no evidence in the tables that the samples taken at the time were in amount proportional to the flow of the river, and obviously they would represent a different proportion of the constituents at times of flood from that which they would in times of low water, inasmuch as the samples were all of the same size. With reference to the individual results on which the averages were based, the witness stated that there were many which deviated widely from the average and that such averages do not show a true condition, because the general average can relate only to conditions at the times when and the places where the samples were taken. A sewage-contaminated stream varies greatly from time to time in its content of impurity, depending largely on the irregularities in the discharge of the sewage. At one time the sewage will be of a certain character and at another time it will differ widely, either because of the varying character of the material discharged from manufacturing plants or because of the differences that are found in the flow of sewage from houses at different parts of the day. Moreover, there is a very marked difference in the flow of streams, due to the variable rainfall at different seasons and times. This has the effect not only of increasing the volume of the flow, causing a consequent dilution, but also of bringing down accumulated polluting materials in the drainage area. Therefore an average result can not show the condition of the stream at all times. The witness asserted that the tables of averages introduced by Professor Kinnicutt do not form a competent basis in the present condition of sanitary science on which to form a definite opinion as to the sanitary condition of the stream to which they relate. He based this assertion on his belief that chemical analyses do not and can not show all the evidence of dangerous pollution that might exist in a stream. Such analyses are addressed to the detection and determination of certain elements that are useful in demonstrating the presence or absence of sewage in a stream, but in the present state of the science it is impossible to decide whether certain results are or are not evidence of sewage contamination. Furthermore, there are certain ingredients coming from sewage, which may be present in a stream and which are of material importance, that are not revealed by the chemical analysis. In the opinion of the witness neither do the bacterial analyses, in the present state of sanitary science, reveal in all cases the presence of constituents of sewage. (7683–7692.)

The witness had examined the figures relating to the extent of population residing on the drainage area of Illinois River, both urban and rural, the figures showing the amount of sewage discharged into Illinois River at various points along its course, and the data showing the flow of the river. Taking all these into consideration, he was of the opinion that the urban population on the several drainage areas tributary to the Illinois, exclusive of that of the Chicago sanitary district, gives, according to the analytical tables presented in evidence, a greater amount of sewage pollution than he would expect on a river of that size and population, and that such an excess of pollution must come from the Chicago drainage canal. Considering the sources of pollution and the natural and artificial conditions existing along Illinois River previous to the opening of the canal and comparing the same with those which were present subsequent to the opening, he stated that the earlier conditions were such as to afford greater facilities for the removal of pathogenic organisms than had existed later. (7692–7697.)

On the assumption that the sewage of Chicago passes through the drainage canal into Desplaines River, down the Illinois to the Mississippi, and past Chain of Rocks within ten to twenty days from its initial discharge into Chicago River, the witness stated that it was his belief that the water at Chain of Rocks is less valuable for sanitary use than it was before the opening of the drainage canal and that there is a very much greater liability to infection from typhoid fever of persons drinking the water from that point in the river. The increase of volume of Illinois River by the addition of water from the drainage canal at the rate of 250,000 cubic feet per minute would cause an increase in the flow of Illinois River, and would thereby largely increase the liability of typhoid-fever germs passing down into Mississippi River past Chain of Rocks in a virulent condition and thus becoming a serious menace to the health of persons living below the mouth of the Illinois. (7697–7701.)

A sanitarian in order to enable himself to pass intelligently on the character of a water should avail himself of all knowledge obtainable on the subject. A chemical examination may give such results as would indicate that the water is sewage polluted; but to decide how important the pollution is its condition and extent must be determined as far as possible by other means. There are cases, however, in which the chemical analysis will fail to give positive data as to the presence of pollution even when it is undoubtedly present, as shown by other data. The bacteriological analysis frequently aids in obtaining results indicating the presence of sewage contamination, but in other cases will not disclose the presence of anything of the kind. Such tests have often failed to show evidence of contamination even in streams which were known to have received sewage. In determining whether a water in use has been exposed to sewage pollution, the most positive way of obtaining evidence is by a careful study of the character of the effects which have been produced on the people using such water. Where a large community uses a water which has been sewage polluted and the injurious ingredients still persist, the fact is inevitably shown in its results upon the health of the people. The statistics of typhoid in a community are on the whole the best evidence of sewage pollution. (7701–7702.)

The witness stated it very positively as his opinion that typhoid bacilli living in the sediment of a polluted stream for a period of sixty days would be able to produce typhoid fever if taken into the human system. When typhoid bacilli are deposited on the bottom of Desplaines and Illinois rivers between Chicago and Peoria for a period of thirty or forty days they might retain their dangerous qualities if there is nothing which would make it certain that such organisms would meet with any material which would surely be destructive to them. Under such conditions the discharge of the drainage canal has unquestionably been, in the opinion of the witness, the cause of typhoid fever in St. Louis. (7703–7705.)

With reference to the location of the so-called zone of purification, mentioned in the testimony of several witnesses for the complainant, Professor Smith stated that the conditions affecting the purification of streams were so complex that it would be impossible by the ordinary methods to determine at what point in the river the purification was effected. The only entirely satisfactory way which could be suggested was by a study of the results of the use of such water by communities. If these fail to show any evidence of deleterious effects, it might reasonably be concluded that the point under consideration was outside of the zone of danger during the time of the experiments, but owing to the fact that the chief deleterious constituents of sewage are living organisms and that at certain times they may, by being embedded in solid materials, be protected from influences ordinarily adverse to them in streams it would be impossible to predict with certainty that at some other time than that of the experiments the water would be perfectly safe at that point. It is important to recognize in the matter of sewage pollution that the chief injurious ingredients are living organisms and that the question of dilution does not come into the discussion to anything like the extent that it would if the injurious ingredients were inert chemical substances. If the latter were the case, these ingredients could be diluted to such a point that the dose in any given amount of water in the stream would be without effect on living persons, but it is necessary to recognize that dilution does not affect the individual living organisms but only their dissemination through the water. It is possible, therefore, to find in one portion of the water something that will be deleterious, while in another adjacent portion there may not be any. There are no experiments which are entirely satisfactory in proving that typhoid bacilli are not able to survive in sewage for a period of three or four days or even for longer periods. In view of these facts and the further fact that the bacilli may be deposited in the bottom of a stream under conditions which would protect them from certain deleterious influences, it would be his opinion that typhoid bacilli may survive for a very much longer period than three or four days. (7705–7708.)

The experiments of Professors Russell, Jordan, and Zeit on the longevity of typhoid-fever bacilli, conducted by using parchment sacks, according to the witness, do not exemplify the true conditions found in a stream. The introduction of the typhoid bacilli in an artificial manner in such a quantity of sewage, inclosed in a parchment sack, does not simulate the condition that would exist in the case of typhoid bacilli discharged into sewage and coming from a patient suffering with typhoid fever, in which case the organisms might readily be inclosed in fecal matter. Further, the condition of the bacilli in the sack is quite different from that in which they would be if they were free in the stream, where they could be deposited in the sediment and become protected from the influence of sewage on them. Inclosed in the sacks, the bacilli would be subjected to the frequently changing condition of water in any one spot, while if not so retained they would pass farther down the river and be free from the deleterious effects of such changes. As they pass downstream, the conditions would become more and more favorable to them owing to the greater dilution and the proportionate decrease of unfavorable substances in the water. The results of the parchment-cell investigations do not agree with other experiments that have been made by sanitarians, and he did not know of anyone who had felt justified as a result of these experiments in limiting the period which typhoid bacilli may survive in sewage. No information was given concerning the organic matter in the parchment sack; it might have been so far decomposed as to afford no nutriment to the bacilli and they might have died as a result, but in general the conditions prevailing in the sack are so much at variance with the normal conditions and the results so much at variance with the ordinary experience of persons who have had to deal with epidemics of typhoid fever that the evidence is altogether too incomplete to form the basis of an opinion of so wide and far-reaching importance. (7708–7713.)

With reference to the increased amount of typhoid fever in St. Louis, the witness stated that the absence of any corresponding increase over the drainage area above Chain of Rocks, exclusive of the sanitary district of Chicago, is sufficient to demonstrate that such increase must have been due, in considerable part, at least, to infection from the Chicago sewage. In making comparisons of conditions before and after the opening of the canal the competent method of deciding whether or not there has been an increase is to compare the typhoid rates in St. Louis during the two periods 1896 to 1899, inclusive, and 1900 to 1903, inclusive. This affords the best method of testing whether or not the sewage of Chicago was deleterious to the health of the people of St. Louis. That there had been such an increase was shown by the mortality records in the office of the St. Louis health commissioner. The increase had been more noticeable during the winter and spring months than during the summer and autumn. (7716–7720.)

In the opinion of the witness the use of the Widal test had affected very materially the reports of deaths from typhoid fever, but had had a more marked influence in the matter of correct diagnosis of the milder cases. Boards of health in large cities usually have regulations concerning the reporting of certain diseases and among them typhoid fever is always included. Inasmuch as the circular sent out by the board of health of St. Louis shortly after the opening of the drainage canal related to the reporting of cases of typhoid fever and not at all to the reporting of deaths, there was no reason why there should be any special effect in the mortality reports. (7720–7721.)

The witness then testified to his experience in the oversight of water-filtration plants and the costs which they involved, and gave it as his opinion that the installation and operation of a filtration plant at St. Louis would be more expensive by reason of the discharge of Chicago sewage into Illinois River. (7722–7723.)

CROSS–EXAMINATION.

In reply to questions concerning the witness's contention that samples should be taken of an amount proportional to the flow of the river, he stated that if a stream is flowing 1,000 gallons per minute at one point and a gallon sample is taken therefrom the results of the analysis will not be comparable with those obtained with a sample taken from the stream where it is running 2,000 gallons per minute unless the latter sample is 2 gallons. While the results bear the same relation to the amounts taken, such results will have to be considered in making the average; that is, it will be necessary to give a value for the sample collected when the flow is 2,000 gallons per minute twice as large as for one taken when the flow is 1,000 gallons. Furthermore, in order to get thoroughly representative results the samples must necessarily be taken from weirs—that is, from some sort of a weir arrangement which will give a continuous flow, one portion going into the sample bottle and the other going on down the river. There is no substitute for this. The taking of a sample every week or hour or every five minutes will not truly represent the conditions. No one would, however, be likely to recommend the weir method described, because the value of the results obtained would not be comparable with the difficulties. (7723–7725.)

With reference to the character of Missouri River water as a source of supply, the witness stated that by reason of the numerous points of pollution in the drainage basin, he did not regard it an as ideal water for drinking purposes, but the typhoid-fever statistics in St. Louis from the time the water intake was located at Chain of Rocks to the date of the opening of the Chicago drainage canal compare very favorably with those of other cities in the United States having reasonably good supplies. He might recommend the continued use of the water with the sedimentation basin already installed, but it would be necessary to operate the plant with caution. He admitted that the water was not absolutely safe, but contended that there are very few absolutely safe waters, and even those which have been subjected to filtration could not be included among that class. Under such conditions, the expert is obliged to decide as to the reasonable safety of the water, and while he would hesitate to use it himself or to allow his family to use it, yet in giving an opinion concerning it he would have to recognize that it was reasonably safe and that the average community in the United States does not expect so high a standard for its requirements as he did in his own practice. This opinion he extended to the water of Mississippi River above Grafton and to that of Illinois River if all the sewage from Chicago were excluded. With regard to absolute safety, he stated that he could conceive of such an ideal condition existing in some drainage areas, but it is so difficult to find a large supply of water that is safe at all times that he would not expect to be able to recommend any such surface supply for a large community. (7736–7743.)

Referring to his testimony concerning the increased cost of filtering the water at Chain of Rocks after the opening of the drainage canal over that which would have been necessary had the canal not been constructed, the witness stated that the chief sanitary advantage of filtering water is to remove infection. The rapidity and the character of filtration and the scientific oversight of the operation of the filter all depend on the relative contamination of the water to be filtered. A water which has a certain amount of contamination would be satisfactorily filtered at a certain rate, but if it received a greater amount of pollution that rate would have to be reduced in order to accomplish the removal of the obnoxious matter with the same degree of thoroughness. Consequently, it would require a larger filter plant to purify the same amount of water. Furthermore, filters are liable to fail in their operation at times, and therefore a filter through which a highly contaminated water is being passed must be operated with greater care. It is not true that the chief cost of establishing and operating a filter from a sanitary standpoint depends on the amount of material in suspension. The question of infection is not, according to the witness, a matter of secondary importance. (7743–7747.)

The witness then repeated his opinion concerning the longevity experiments of Professors Jordan, Russell, and Zeit, namely, that the conditions were so different from those naturally prevailing in polluted water that he did not credit the experiments as being sufficient to permit a judgment concerning the longevity of the typhoid bacillus in polluted rivers. If the sacks had been allowed to float down the stream so protected that they would not have been subjected to the changing water conditions, the results might have been more accurate. Also, in the opinion of the witness it would have been a good plan to have tried sacks of such size as to admit the accumulation of considerable quantities of sediment. While the experiments were unquestionably very carefully performed, their weakness lay in the fact that they did not simulate natural conditions; and, in his opinion, the problem is so difficult and the variations in the conditions are so extreme that he could not conceive how laboratory methods of the character described could afford a satisfactory solution. (7747–7750.)

The witness stated that he had examined the typhoid-fever statistics of St. Louis by consulting two sets of data—those in the reports of the commissioner of health and the records in the mortuary office. There was a marked discrepancy in these data. The terms remittent and intermittent fevers are names applied to malarial infections and are used in statistical work as representing the different manifestations of malaria. The term typho-malaria is in variable usage. In the best usage it is confined to the condition which exists when the patient is suffering from a joint infection by the typhoid and malarial organisms; but it has been used to represent conditions that exhibit what is known as the typhoid state, referring rather to the symptomatology than to the case. The term congestive fever is undoubtedly restricted to the severe form of malarial infection that is manifested by the congestive chill. The term simple continued fever is no longer correctly used and does not represent any specific disorder, but grouped under it there have been unquestionably many low conditions which were characteristic of or characterized by continued fever. Many of them were simply bacterial infection, but not associated necessarily with typhoid or malaria. (7750–7751.)

Fatality from malaria differs greatly in different localities. In the temperate zones it is usually confined to feeble persons—either the extremely young or the extremely old, although of course persons of intermediate ages may succumb to malarial conditions if they are in feeble condition. Doctors undoubtedly confuse typhoid fever with other diseases at times, but this misinterpretation is probably much more frequent among cases that do not result in death than among fatal cases, because when a person dies from typhoid fever the condition is likely to display itself in such a manner that the diagnosis is generally corrected at some time before the death if there was a mistake in the original diagnosis. There are, however, some cases which are never correctly diagnosed. It is not uncommon for a physician after he has improperly treated a patient through faulty diagnosis to change his diagnosis on the occurrence of death when the symptoms become apparent and to record the death on the certificate in conformity to his later diagnosis. The witness had considered the typhoid deaths as reported and the data concerning each of the other febrile diseases. Even if all of the latter were included in the former, there was still an increase in the number of typhoid cases from 1900 to 1903, inclusive, over and above those occurring from 1896 to 1899, inclusive. He had also considered the compilations of deaths from the various febrile diseases with a view of forming an opinion as to whether any considerable portion of them were typhoid, but from the standpoint of the age of the person and the distribution of the cases by months he believed that comparatively few of them should be included in the typhoid class. The proportion of typhoid deaths due to local causes—such as wells, etc.—in St. Louis could not have been greater since the opening of the canal than previous thereto, and the rate which prevailed during the first period was about the same as that found in some of the cities of the better class in the United States. (7751–7755.)

JOHN W. ALVORD.

DIRECT EXAMINATION.

John W. Alvord, called as a witness on behalf of the complainant in rebuttal, stated that for twenty-four years he had been a practicing hydraulic and sanitary engineer in Chicago; that he had not graduated from any technical institution, but his engineering education had been confined to study and travel, coupled with practical experience. His first engineering work was in 1879, when he was connected with the construction of the Hyde Park pumping station of the Chicago waterworks. Subsequently he was in charge of the construction of the Lakeview station, and for four years was city engineer of Lakeview, which was at that time a separate municipality from Chicago. He had visited Europe in 1888 and 1894 and studied the question of water purification and sewage disposal. From 1890 to 1893 he had charge of a department in the construction of the World's Columbian Exposition. He resumed private practice in 1894 and had since been engaged in various capacities with about 35 different city waterworks and 45 municipal sewer systems, including the purification of water and the disposal sewage. In 1898 he made a report to the city of Columbus, Ohio, on the extension of its sewerage system and the purification of its sewage. From 1898 to 1902 he was consulting engineer to the Illinois State canal commission, advising as to the works of the sanitary district in and through Joliet and the litigation concerning the removal of dams and locks at Joliet. More recently he had been engaged in the development of water power at Petoskey, Mich., Big River, Mo., and Des Moines, Iowa. He had had some experience in typhoid epidemics, having studied them at Chicago in 1892 and 1893; at Hurley, Wis., Ironwood, Mich., Culver Academy, Ind., and Grand Forks, N. Dak., in 1894, and at Duluth in 1896. So far as he had studied these epidemics all of them had been caused by polluted water supplies. He was familiar with Chicago River, the Chicago drainage canal, and Desplaines and Illinois rivers, having in 1888 been engaged in litigation on behalf of the State of Illinois, and he had studied the progress of the construction of the drainage canal and related questions. He had observed Illinois River at Morris, where he designed a system of sewers; at Ottawa, where he was engaged in water-power litigation; at Marseilles, where he advised as to the enlargement of the water power; and at Seneca, La Salle, Peru, Hennepin, Peoria, Pekin, and Havana. He was also familiar with Mississippi River from Alton to St. Louis. He had given attention to the bacteriology and chemistry of water and had tried to keep himself posted on them in a general way ever since they had come into use among engineers. He had taken a partial course in chemistry at the University of Chicago in 1894, and in 1900 had studied bacterial quantitative analysis under the direction of Professor Novy, of the University of Michigan. He was employed in 1902 by the special commission to investigate the water supply of St. Louis, his part of the work being to study the financial history of the present works—their cost and the cost of operation. In the course of this work he had become familiar with the characteristics of the water-supply system and had visited the sedimentation basins at Chain of Rocks and Bissells Point. He had also made some study of the typhoid conditions on the drainage area above St. Louis, principally, however, from the data submitted in the present case by both complainant and respondents. (7761–7764.)

The witness then introduced a diagram and table showing the relation of typhoid deaths in St. Louis to those on the drainage area above that point. The results are contained in Table 92. (7766.)

TABLE 92.—*Relation of typhoid deaths in St. Louis to those on the drainage areas of Missouri, upper Mississippi, and Illinois rivers.*

Year.	Deaths in St. Louis.	Population in St. Louis.	Deaths in St. Louis per 500,000 population.	Deaths on drainage area.	Deaths in Chicago.	Deaths on drainage area, including Chicago.
1890	277	451,770	307			
1891	160	465,000	174			
1892	488	477,000	512			
1893	215	489,000	220	505		505
1894	178	500,000	178	474		474
1895	106	512,000	103	408		408
1896	106	524,000	101	354		354
1897	125	538,000	116	410		410
1898	95	550,000	86	411		411
1899	130	561,000	116	420		420
1900	168	572,238	147	503	339	842
1901	198	585,000	169	494	509	1,003
1902	222	600,000	185	431	801	1,232
1903	288	612,000	235			

This table was then explained by the witness, who made the following statement: In order to determine the causes of typhoid fever the deaths along the different rivers have been separated from each other, so as to determine the source of the most marked pollution. The figures show that the deaths from typhoid in the Illinois basin, exclusive of the sanitary district of Chicago, are fairly uniform up to 1899, but show an increase in 1900, the year in which the drainage canal was opened. The deaths on the Missouri basin appear to be reasonably uniform for the whole period under consideration, and those on the Mississippi basin above the mouth of Illinois River, while fluctuating somewhat more than the two above described, are generally uniform before and near the time of the increase in deaths in St. Louis. In summing up the total of typhoid deaths on the three drainage areas above St. Louis, it would appear that while there is some fluctuation and a low period about 1896, at no time since the increase in typhoid in St. Louis in 1900 had the number of deaths materially exceeded a fair average rate. The witness observed, however, that the addition of the deaths from the sanitary district almost doubles the total for typhoid in these drainage areas, influencing the pollution of the St. Louis water supply and increasing during 1901 and 1902, so that in the latter year the total typhoid deaths are nearly two and one-half times the deaths on the drainage areas above St. Louis exclusive of the sanitary district. After the opening of the drainage canal there appeared an increase in typhoid in St. Louis, caused undoubtedly by the added typhoid contamination from the sanitary district. (7769–7770.)

The witness stated that he had for some years past considered the longevity of the typhoid organism to be from sixty to ninety days in favorable environments. Although under unfavorable conditions large amounts of these bacilli might be removed from any given source of supply in a comparatively short time, it would not be safe to assume that a water once polluted could be recommended for public use under a period shorter than sixty to ninety days, unless the contamination were eliminated by a carefully designed and operated system of purification. (7771.)

The witness then stated that he was familiar with the experiments of Hiram F. Mills on the longevity of typhoid bacilli recorded in the reports of the Massachusetts State board of health, and also with those of Doctor Horrocks described in the Proceedings of the Sanitary Institute for 1899. He believed that the conditions under which typhoid bacilli are carried away from Chicago approximate those under which Messers. Mills and Horrocks carried on their experimental work. The sewerage system of Chicago has very flat gradients and requires frequent artificial flushing. During heavy rainfalls the entire contents of the sewers are discharged into the river, bringing into it a mass of pollution that has been accumulating for months. Before the opening of the drainage canal such periods of contamination were extremely dangerous to the water supply of Chicago, as shown by the increase in typhoid deaths following them. The heavy flushings of rainfall occur ordinarily in the early spring, after the breaking up of the winter, and at times when the temperature is most favorable to the longevity of the typhoid germs. Such flushing of the Chicago sewer system with its present large proportion of pure water and low temperature furnishes conditions which are more favorable to the longevity of the typhoid germ than those under which the experimental work of Mills and Horrocks was conducted. The discharge of this amount of pollution furnishes the necessary velocity for rapid conveyance through the sanitary canal and Desplaines and Illinois rivers to the intake of the St. Louis water supply. The increment of comparatively pure water from the tributary streams also increases the dilution and decreases the chances for toxic destruction of the total number of typhoid germs present. As another factor in increasing this rapid conveyance of the pollution the witness stated that in the case of heavy rainfall on the drainage area of Chicago River it is often necessary, in order to prevent outflow into Lake Michigan, to lower the Bear Trap dam at Lockport, so as to produce greater velocity at all stations on the drainage area. This undoubtedly aids in the rate with which the pollution is conveyed away from Chicago and down Illinois River. (7771–7773.)

Referring to the float measurements given in the testimony of Isham Randolph, the witness stated that he was unable to find anything that gives a clue to the amount of discharge in Desplaines and Illinois rivers either at Joliet or Peoria and was therefore unable to determine the stage of the river at the time of these measurements. The experiments were performed in July, 1903, and this time is not covered by the table of discharges in Mr. Randolph's testimony, nor are there any gage readings given at Peoria, although the testimony includes a rating table for this place. The testimony consists of the bare statements that the float passed over the distance in fifteen days, which is raised to eighteen and one-half days by dividing it by eight-tenths. The witness failed to see the pertinency of Mr. Randolph's conclusion that a correction should be made, tending to reduce the maximum surface velocity to the mean velocity of flow. The use of the correction by eight-tenths in the manner described in Mr. Randolph's testimony is a very rough approximation, used by hydraulic engineers when surface floats are run in the most rapid part of the channel of the river in order to determine the average flow for the whole cross section and thus get at the quantity passing a given point at a given time. In the case under consideration, the endeavor is not to determine the quantity of water so passing, but to determine what length of time any given pollution, flowing in mid-channel, will take to pass over the distance from Chicago River to Chain of Rocks at St. Louis. This required, in the opinion of the witness, a determination of the mean velocity of the central section of the stream. The floats described in the testimony were not surface floats but were partly submerged, and gave the mean velocity of the central portion of the stream with a fair degree of accuracy. Therefore the correction, in his opinion, was not necessary and the actual time of fifteen days would fairly represent the total time required for polluted materials to pass over the distance. With reference to the respective velocities shown by the float experiments of Professor Van Ornum for the complainant and Mr. Randolph for the defendants, the witness stated that in July, 1903, when the work of Mr. Randolph was performed, the water was at a very much lower stage than during Professor Van Ornum's experiments. The latter commenced in a low-stage period between two March rises in the river, when 289,000 cubic feet per minute was flowing over the Bear Trap dam, which gives a very low velocity in the drainage canal. At the same time about 394,000 cubic feet per minute were passing over Dam No. 1 at Joliet. Five days after the operations of Professor Van Ornum were commenced, nearly double this amount was passing over Dam No. 1. It would seem, therefore, that the work was done during a comparatively high stage, but not by any means the highest stage of the river. The observations show that Peoria was passed when the flow of Illinois River was about 50,000 cubic feet per second, which would correspond to a stage of the river somewhat overflowing the banks in the lower courses. As Professor Van Ornum used submerged floats, the witness believed that the actual time traveled represents the mean velocity of the pollution vehicle. He had had occasion to make very careful velocity studies in that part of Desplaines River immediately below the Bear Trap dam and had verified the results of Professor Van Ornum. Summing up the two investigations, the witness stated that nine and eight-tenths days were consumed between Bridgeport and Chain of Rocks, this being based on the mean velocity to Joliet and Professor Van Ornum's results for the rest of the distance. The witness did not consider that this was the shortest time in which pollution could travel the distance. He believed that such high flood stages as occurred in 1892 would reduce the time at least to eight days and possibly to less. He then stated that nine and eight-tenths days represented in his opinion a velocity which could be counted on as occurring during a number of periods each year. (7775–7780.)

The chart introduced into evidence by Rudolph Hering, representing the self-purification of Missouri, Mississippi, and Illinois rivers, based on the longevity of life of the typhoid bacillus as fixed by the experiments made under the direction of Hiram F. Mills, represented, according to the witness, an attempt to derive the possible amount of contamination in the water at Chain of Rocks from the sanitary district of Chicago, by assuming that the original pollution is proportional to the population and that the longevity of the typhoid bacillus is that found by the experiments of Mr. Mills. The chart also makes the same deductions for Mississippi and Missouri rivers. In the case of Illinois River, the length of time of flow from Chicago to Chain of Rocks is taken at eighteen and one-half days, corresponding with the results of Mr. Randolph's experiments. It seemed to the witness that Mr. Hering had not given due weight to the effectiveness of different populations in the production of pollution. The sanitary district of Chicago has been afflicted for years with an abnormal number of typhoid deaths. The other cities in the Illinois drainage area, deriving their water from artesian wells, have very low typhoid rates. Therefore, it would appear to the witness that to make the chart more exact some method should be introduced by which the disparity in the typhoid data could be allowed for in representing the effect on the St. Louis water supply. The time used by Mr. Hering in the diagram and table (7001–7003) gives the rate of travel of polluting material at low stages of the river, and, therefore, does not fairly indicate the greater danger to the St. Louis supply at medium or high stages. It would seem that the diagram should be so constructed that these modifications would be clearly apparent. The witness then introduced a diagram which he called a schematic representation of the reduction of typhoid bacterial pollution in Illinois River, based on the data and methods proposed by Rudolph Hering in his diagram submitted in the case, but with suggestions for correction, first, by using Professor Van Ornum's float experiments; second, by valuing the effect of contributory population on the basis of a standard typhoid death rate of 20 per 100,000 living; third, by using velocity of pollution vehicle rather than average velocity of cross section of the river. In explaining the diagram the witness stated that the figures cover only the reduction of typhoid bacterial pollution in Illinois River, and are prepared as nearly as possible in the manner introduced by Mr. Hering, based on the experiments of Hiram F. Mills as to the longevity of typhoid germs. The ordinates of the diagram represent the tributary population calculated in its relation to typhoid death production. As a basis for this a standard of 20 deaths per 100,000 living had been assumed, this being the death rate of an ordinarily well regulated city in the situation of Chicago, having due regard to the protection of its water supply. On this basis the witness had determined for the year 1902 the typhoid death rate of Chicago and other places along Illinois River, which are given in the table and accompanying diagram. The population of the sanitary district is taken from Mr. Mills's chart and not from the Federal census. The abscissas of the diagram indicate the number of days consumed in the flow of the pollution from the sewers of Chicago, up to the fifteenth day, based on the float experiments of Professor Van Ornum from Lake Joliet to Chain of Rocks, and on the witness's estimates of the velocity in the drainage canal and Desplaines River down to Peoria. With these data a curve had been plotted, due consideration being given to percentage of reduction in the typhoid contamination from the population center through the proper increments of time, to agree with the experiments of Mr. Mills. This curve indicates the relative typhoid bacterial pollution so far as it can be predicated on the population. The witness further observed that the chart represented comparative pollution contributed by fatal cases alone. It should be remembered that in fatal cases infection ceases to be contributed to the stream on and after the date of death, while in cases not fatal infecting matter may be and is contributed to the stream for days, weeks, and even months. The diagram fails to take into account this extra pollution and therefore must be considered as conservative. On the assumption that the active typhoid contamination is proportional to the population and that the diminution in the number of typhoid germs day by day is as shown in the experiments of Mr. Mills, the modifications introduced into the diagram by the witness would show a considerably increased amount of typhoid pollution entering the intake at St. Louis. Whereas Mr. Hering's diagram shows that the typhoid pollution entering the intake at the end of a low-river flow of eighteen and one-half days is equivalent to an infection from a tributary population immediately above the intake of a city of 13,000 people, the conclusions of the diagram would seem to indicate that the normal flow of fifteen days would be equivalent to an infection from a city with a population of 90,000 located above the intake, having a fatal typhoid rate of 20 per 100,000; while on the basis of ordinary spring floods such as were gaged by Professor Van Ornum, the infection similarly arising at Chain of Rocks would be equivalent to that derived from the population of a city of 415,000, with a death rate of 20 per 100,000. With a maximum flood such as occurs only at infrequent intervals, it would appear that the comparative pollution reaching the St. Louis intake would be equivalent to the infection from a population of 960,000 with a similar typhoid death rate. The witness stated that he used the rate of 20 per 100,000 because there are a very considerable number of cities which have so exercised care and discretion in the protection of their water supplies that they have reduced the typhoid rate to a point lower than that. It would therefore seem to be fairly reasonable to assume that all cities having regard for the purity of their supplies would be able in the light of present science, to reduce their typhoid death rates to this figure, or even materially lower. (7780–7787.)

In the opinion of the witness, the chemical data introduced by the defendants with reference to the character of the contents of the drainage canal do not indicate that any septic action has taken place. The amount of improvement in the sewage in its travel through the canal he believed to be largely due to aerobic action, although possibly there might be anaerobic action to a very limited extent, but not enough to influence the results perceptibly. The dilution of the sewage of Chicago by the richly oxygenated water of Lake Michigan is not a useful preliminary to septic action, but, on the contrary, is distinctly opposed to the inception of such action. In good practice, it is the endeavor to design a septic tank so as to bring the sewage in as quietly as possible, undiluted with surface or underground waters containing dissolved oxygen. The absence of marked current, the presence in certain places of more foul products and considerable surface scum, the absence of undissolved oxygen as shown by chemical examinations, and the physical production of gases bubbling up through the depths characterize the action of the septic tank in the active reduction of its organic matter. It was the belief of the witness that typhoid germs could survive materially longer under the present conditions of dilution in the Chicago drainage canal than under those which formerly prevailed in the Illinois and Michigan Canal and South Branch of Chicago River. (7787–7791.)

The witness thought that the discharge of sewage from the canal would make more costly the construction and operation of a water-purification system for St. Louis, because such a plant dealing with a seriously polluted water, especially one of known high typhoid pollution, should be more complete and delicately adjusted to its work than one dealing only with a water of rare infection and presenting less dangerous difficulties, such as turbidity and color. The added protection necessary should be in the form of double filtration or complete sedimentation followed by careful filtration. Such double filtration had been resorted to in several places in Germany and had been recommended for Springfield, Mass., and introduced into the filtration system at Philadelphia. (7791–7792.)

The witness was then asked whether in his opinion there was any practical modification of the existing system of sewage disposal in Chicago by which the drainage canal could still be employed for keeping the Chicago River in an inoffensive condition and yet the pouring of unpurified sewage into Desplaines and Illinois rivers could be avoided. In reply he stated that such a scheme would be entirely practicable, and he would suggest, as the proper remedy, the construction of suitable intercepting sewers along Chicago River and its branches, by means of which the sewage flow of the city may be kept out of the river and led along its banks to the upper end of the drainage canal below Bridgeport, and then raised by pumping to a suitable purification plant constructed in accordance with the latest bacteriological principles, and capable of effectually removing from the sewage practically all of its wastes and pathogenic bacteria. The effluent from such a plant could be emptied into the drainage canal near Bridgeport. He had considered the expense in a general way and was of the opinion that such intercepting sewers and purification plant could be constructed at a cost no greater than that necessary to widen South Branch of Chicago River, as had been done, and he was further of the opinion that the operating expense of such a plant would be no greater than that of the present system of pumping sewage and the necessary dilution water for the northern and southern portions of the sanitary district.

CROSS-EXAMINATION.

The witness had estimated that the cost of such an intercepting sewerage system, the construction of pumps, and the installation of pumping machinery as described by him would be between $12,000,00 and $15,000,000. The plans contemplated the purification of the sewage of the entire sanitary district. He had given detailed consideration to the proper method of sewage purification. He believed that land might be secured at some suitable point for a reasonable sum. At the time the original recommendation was made by the engineering commission for the construction of the canal, sewage purification was not so well developed as at the present time, and there was little to justify the commission in considering such a plan. (7796–7802.)

The witness said he had not compared the typhoid conditions in Chicago and St. Louis by months, in the manner indicated by the charts of Professor Mason, because he believed that it would throw no light on the main question, owing to the many fluctuations and variable elements involved; he would prefer to take the averages for a year, which would show in a more marked manner any main distinguishing characteristics. (7805.)

While the city of St. Charles, on Missouri River, undoubtedly had some effect on the typhoid death rate of St. Louis, there was, in his opinion, no reason to believe that the effect had been greater since the opening of the drainage canal, and therefore the increase that had occurred in the St. Louis death rate could not be accounted for in that way. The witness stated that he did not regard the water from Missouri River at its mouth, from Mississippi River above Grafton, or from Illinois River, even though the sewage of Chicago were excluded, as fit for domestic consumption in the raw state. (7806–7809.)

The greatest item of expense in constructing a filter depends on the kind of water and its amount of pollution. With a turbid water free from typhoid pollution the turbidity will undoubtedly be the cause of the greatest expense, whereas with a water comparatively clear but subject to typhoid infection the infection will be the cause of the greatest expense. In providing filtration for Illinois River at Grafton the purification of the water from typhoid infection would be at least equal in cost to the removal of turbidity, while for the Mississippi the cost would be greater for turbidity and less for typhoid infection.

The witness stated that he disagreed with John W. Hill in his assertion that in the construction of the Philadelphia plant the infection of the water was no element of cost in the operation and installation. (7814–7816.)

E. E. LOCHRIDGE.

DIRECT EXAMINATION.

E. E. Lochridge, called as a witness on behalf of the complainant in rebuttal, stated that he had graduated from Beloit College with the degree of bachelor of science in 1898, having given particular attention to the study of chemistry. During his senior year he had acted as private assistant to Prof. E. G. Smith and had studied questions of water supply. Immediately after graduation he had served as instructor in chemistry for two terms at Drury College, Springfield, Mo. He then returned to Beloit as regular instructor in chemistry, and in 1900 took the regular and some special courses in bacteriology under Prof. E. O. Jordan, of the University of Chicago. He then resumed his studies as private assistant with Professor Smith, and in the course of this work had had occasion to visit many public and private water supplies and to study and investigate several epidemics of typhoid fever, among which were those at Rock Island, Ill., and Baraboo and Ashland, Wis. He had studied the operation of filters for municipalities in a practical way in nine different places. During 1902 and 1904 he attended the Massachusetts Institute of Technology as a graduate student, taking the regular courses in sanitary engineering. In June, 1903, he was appointed by a commission, consisting of George W. Fuller and Samuel M. Gray, to make special studies on the problem of the purification of the water supply of Springfield, Mass. This work involved experimental investigation of various means of double filtration. (7821–7823.)

The witness asserted that he had examined the tables of typhoid statistics introduced into the record and testimony of Doctor Barker and stated that these statistics differ only slightly from the results obtained by compiling the deaths attributable to typhoid fever in the record books of the mortuary office. He did not believe that a comparison of the typhoid-fever deaths previous to 1896 with those subsequent to that year would be practical as a means of determining whether or not typhoid fever had increased in St. Louis after the opening of the Chicago drainage canal, because previous to 1896 the intake of the St. Louis waterworks was so located as to expose the supply to infection from the city sewers, and for that reason it was removed farther up the Mississippi, above such contamination. In order to show the great change in the typhoid-fever mortality of St. Louis at the time the intake was removed, the witness presented a diagram, which appears on page 7825 of the record. In the interpretation of this diagram the witness pointed out that the death rate from typhoid fever in St. Louis was uniformly high up to the time of the change of the intake from Bissell's Point to Chain of Rocks. Following this change there was a period of five years in which the rate was much lower. In 1900 there was a considerable increase, which had continued through subsequent years to the end of 1903. (7823–7826.)

The subsequent testimony of the witness was addressed to several series of charts showing the occurrence of typhoid fever, malaria, and the other febrile diseases already noted in connection with the testimony of various medical experts of the defense, together with the distribution of those cases according to the sanitary districts of the city. These charts will not be introduced in this digest, but will be explained and discussed so far as practicable. (The reader is referred to the record, pages 7827–7928, for the illustrations.)

The witness introduced six charts showing the occurrence and monthly distribution during 1896 to 1903, inclusive, of deaths in St. Louis from typhoid, remittent, intermittent, typho-malarial, congestive, and the continued fevers. The totals by years from these diseases are shown in Table 93.

TABLE 93.—*Deaths from typhoid and other fevers in St. Louis, 1896–1903.*

	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903
Typhoid fever	102	114	90	121	154	181	216	281
Remittent fever	40	29	26	15	15	23	17	17
Intermittent fever	12	12	16	25	10	12	9	11
Typho-malarial fever	50	42	30	31	36	23	34	36
Congestive fever	26	22	13	15	15	4	15	7
Continued fever	1	1	0	0	1	0	1	2
Malarial fever	27	34	23	35	40	28	38	53
Bilious fever	11	8	3	6	3	5	7	7
Enteric fever	0	1	3	2	2	2	2	0
Typhoid pneumonia	13	18	17	14	9	18	15	26
Typhoid complications[a]	0	1	1	1	0	2	3	8

[a] Not included under other tables.

In discussing the above results the witness stated that the figures did not correspond with the results introduced into testimony by Professors Barker and Jordan. Adding together the figures given in the records of the St. Louis mortuary office for deaths from remittent, intermittent, typho-malarial, congestive, and continued fevers he found that for 1896 to 1899, inclusive, there were respectively 129, 106, 85, and 86 deaths, and if the number of deaths from malaria are added to these the totals for 1896 to 1899, inclusive, would be 156, 140, 108, and 121 deaths, respectively, while Professor Jordan's data give for the corresponding years 177, 172, 134, and 148 deaths—a somewhat greater rate than appeared from the witness's investigations. In contrast to this, he stated that during the period 1900 to 1903, inclusive, he had found for the diseases above-mentioned records showing a somewhat higher rate than that given by Professor Jordan; or, in a summary of both periods, in view of the fact that malarial fevers were probably recorded in Professor Jordan's list, as they did not occur under another caption so far as the witness could discover, the Jordan list differed from the Lochridge list as follows: Twenty-one more deaths in 1896, 32 more in 1897, 26 more in 1898, 27 more in 1899, 25 less in 1900, 10 less in 1901, 12 less in 1902, and 35 less in 1903, making it apparent, according to the witness, that the reduction in the recorded number of deaths from these diseases during the successive years in the period had not been so great as it had been made to appear by the mortality tables of Professors Jordan and Barker. The witness then presented a series of charts designated as charts 15 to 22, inclusive, showing the deaths from typhoid fever distributed according to sanitary districts and according to whether the deaths occurred in residences or hospitals; if in hospitals and the residence was known, the deaths were referred to the district from which the patient was transferred. (These charts appear on pages 7845–7852 of the record.) With reference to the evidence shown by them the witness stated that there were 40 typhoid deaths in the hospitals of St. Louis during 1896, 21 of which it was impossible to transfer to the proper residence districts; in 1897 20 of the 35 hospital deaths could not be so referred, in 1898 16 of the 26 deaths, and in 1899 11 of the 21 deaths; while in 1900 but 4 of the 35 deaths could not be so referred, in 1901 5 of the 55, in 1902 6 of the 67, and in 1903 3 of the 75 deaths. The charts showed that since 1900 the distribution throughout the seven sanitary districts had been very uniform and that in no district was there an unusual number of deaths when compared to those in the other districts. Such uniformity indicated that the cause of typhoid fever was one equally applicable to all the citizens who use a polluted water supply.

Similar charts were introduced by the witness showing the deaths from malaria for the period 1896 to 1903, inclusive. (See pages 7856–7863 of the record.) The witness stated that these charts indicate the distribution throughout the year and the increase in malaria between 1896 and 1903. The distribution is not so uniform in the city as was shown by the charts for typhoid fever. Similar charts concerning the deaths from typho-malaria elicited the same comment with reference to distribution.

The witness then introduced a series of charts numbered 39 to 46, inclusive, showing the typhoid-fever deaths in St. Louis for 1896 to 1903, inclusive, classified by ages of decedents and month of the year in which the deaths occurred. (See pages 7874–7881 of the record.) From a study of the charts the witness stated that a large proportion of the deaths occurred between the ages of 11 and 50 and that the ages between 6 and 60 will include practically all of them. The number of children under six months of age dying from typhoid is the same during the first four years as during the last four. The charts showed not only the increase in the number of typhoid cases since the opening of the drainage canal, but also the increase under each age and by the season of the year. He pointed out that there was considerable increase in the winter months, as well as a somewhat less, though marked increase, in the summer months. Previous to the opening of the canal the number of deaths during the period from January to May and the month of December is low, while since the opening of the canal there had been a very marked increase in the number of deaths for this period—much greater in proportion than during the other six months.

The witness then introduced a series of charts similar to the last, giving the distribution of deaths from remittent fever during the period 1896 to 1903, inclusive, also similar charts for intermittent fever. (These appear on pages 7884–7901 of the record.) With reference to the monthly distribution of deaths from intermittent fever the witness pointed out that in 1899 there were 5 deaths from this disease of children under six months of age and 5 more between the age of six months and one year. With this exception the distribution is practically the same in all the charts. There were 17 deaths during 1899 from intermittent fever of persons either below the age of 3 years or above the age of 61, the very young or advanced ages during which persons are not susceptible to typhoid, and only 8 of the age during which typhoid fever is most prevalent. There was not a single death from intermittent fever during 1899 of a patient between the ages of 11 and 30 years, the most fatal typhoid period.

The witness then introduced charts numbered 63 to 70, inclusive, showing by months and ages the distribution of deaths in St. Louis from typho-malarial diseases for 1896 to 1903, inclusive, also similar charts for malaria and malarial fever. These charts appear in the record, pages 7904–7920. The witness stated that they show a decided increase in these diseases since the year 1900 in the ages from about 20 to 40. Similar charts showing the number of deaths from congestive, billious, and enteric fevers appear on pages 7922–7928 of the record.

In connection with the results shown by the charts above described the witness stated that in the earlier years, notably the first four years, 1896 to 1899, inclusive, a much larger proportion of deaths occurred between the months of July and November, but during the years 1901 to 1903, inclusive, there is a decided increase in the number of deaths occurring from December to May and this is greater than the proportional increase throughout the year, so that during the latter period the typhoid-fever deaths are scattered fairly uniformly throughout the year, there being but a few more deaths in the summer and fall than in the winter months. Two charts were introduced to show this relation, the salient results of which are given in Table 94.

TABLE 94.—*Typhoid rates per 100,000 inhabitants in St. Louis, 1896–1903.*

	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.
Winter typhoid	9.2	13.9	13.1	15.7	18.8	19.0	28.8	35.2
Summer typhoid	29.5	28.8	19.7	27.8	34.8	42.4	42.8	55.6

The above results were summed up by the witness in another diagram showing an increase in the number of typhoid deaths during the cold months of 1900 to 1903, inclusive, of 118.2 per cent over the period from 1896 to 1899, inclusive; expressed as deaths per 100,000 the increase is 94.8 per cent. Similar calculations with reference to the typhoid deaths during the warm months showed an increase in the number of deaths 84 per cent and in the deaths per 100,000 of 65.7 per cent, making, according to the witness, a total increase after the opening of the drainage canal of 95 per cent in the number of deaths and 77.7 per cent in the rate per 100,000. The data for these results were taken from the records of the mortuary office of St. Louis, and the estimates of population used were the same as those computed by Professors Barker and Jordan and used in their testimony. (7930–7938.)

The witness then took up the consideration of the ages of decedents from the various febrile diseases noted, for the purpose of showing that in the majority of cases these ages were either below or above the periods at which typhoid is generally fatal. He stated that in 1896, for example, the typhoid deaths lie well between the ages of 6 and 60, while over 50 per cent of the remittent-fever deaths in the same year involved either younger or older persons than these age limits. In 1897 there were 11 less deaths from remittent fever than in 1896, but that loss might be considered as entirely among the very young children and it can be seen by referring to the typhoid deaths for that year that not one of these had been added to the column for typhoid fever; in other words, no transfer could have been made to typhoid fever by reason of better diagnosis. If a change in the annual number of remittent-fever deaths had been due to better diagnosis, such deaths had been referred to some other disease than typhoid fever. The study of the table through all the following years for remittent fever will show, according to the witness, this same variation, confined to the number dying under the age of 6 years, the number of deaths during the ages in which the mass of typhoid fever deaths occur remaining practically the same. (7942–7943.)

With reference to deaths from intermittent fever the witness stated that in each of the years 1896 and 1897 there were 12 deaths, but these were in different ages, the same variation in the number of deaths in children under the age of 1 and, in some cases, under the age of 6 being very apparent. He also stated that this might be noticed effectively in the increase of the number of deaths from intermittent fever in 1899 to 25, such increase being entirely in the younger ages. In 1900 the deaths of persons of 20 years of age and under from intermittent fever numbered only 3, while in the deaths from typhoid fever there is no marked increase in this age and no deaths from typhoid were recorded in that year under the age of 1, so that the decrease in the number of intermittent-fever deaths in the year 1899 had not been brought about by the transfer of these deaths to the typhoid group. In the other age periods the intermittent and typhoid fever deaths are practically the same. (7943.)

The witness then stated that the number of deaths recorded as being due to typho-malaria was practically the same during the four years before and the four years after the opening of the Chicago drainage canal. In malaria there had been a marked increase during the past few years, and he noted that there were about the same number of deaths in the younger ages from malaria and malarial fever during these years, but the number among the older people is proportionately higher than the mortality in these ages from typhoid fever. (7944.)

Referring to the relation between the deaths from congestive fever and those from typhoid, the witness noted a large variation occurring among those under the ages of 6 months and 1, 2, and 3 years, the variation being about the same as in the case of remittent and intermittent fevers. In 1896, 13 of the congestive-fever deaths were under the age of 5 years and 10 of these were under 1 year. With the exception of two years when the congestive-fever list was low the variation was due to deaths at these early periods of life and among the aged, the periods during which typhoid fever is not likely to attack. The reports for bilious fever showed that in all cases there was no variation in the number. The deaths were at the younger or the older age period and there had been no increase in the typhoid-fever deaths in these ages to correspond with the decline in bilious fever. (7945.)

In reply to a question as to the effect of the Louisiana Purchase Exposition on the typhoid rate in St. Louis, the witness stated that the highest fatality from typhoid fever per 100,000 population in any of the four years prior to January 1, 1900, was in 1899, when the rate was 21.6. This includes the localized epidemic of that year. On the assumption that the influx of those connected with the construction of the exposition or the attendance thereon would increase the typhoid rate of the city, the witness had calculated the population that would be required to make 21.6 the death rate per 100,000 for each of the six years since that time. In 1900 there were 154 deaths from typhoid fever in the city. This would indicate a population of 714,000, or an increase of 139,000 over the population of the city in 1899. Under the same death rate the total of 216 deaths from this cause in 1902 would indicate a population of 1,000,000, and the 281 deaths in 1903 would require a population of 1,300,000, or an increase of more than the entire population of the city. Therefore, on the basis of Professor Jordan's estimate of the population of the city, which was 618,500 in 1903, or something less than 60,000 increase over that in 1899, it will be seen that the increase in typhoid fever has been much more rapid and can not be ascribed, to any considerable extent, to the addition of cases brought in by visitors during the fair. The witness then discussed the relation of typhoid to population in another way. Considering the figures given by Professor Jordan for the population of St. Louis, and supposing that the typhoid rate had remained 21.6, he stated that this population would have indicated about 130 deaths from typhoid in 1903, while the actual number was 281. Thus it can be seen that the typhoid rate was in 1903 more than double what it was in 1899, while the population increased but a little over 10 per cent. (7945–7947.)

It was the witness's opinion that the conditions under which the experiments of Professors Zeit, Jordan, and Russell with reference to the longevity of the typhoid germ in polluted water were performed did not simulate natural conditions for the following reasons: Any sack lodged at one place will, if the osmotic conditions are as perfect as is supposed, receive the influence of sewage which is constantly fresher than that which would be in contact with the sack should the same be passing downstream. The results, to some extent, vary from earlier results obtained by various bacteriologists. In but three of Professor Jordan's experiments in the drainage canal was the typhoid organism found at all after ten minutes had elapsed. Of these three, one is a recorded instance of its occurrence on the tenth day, which was attributed by Professor Jordan to the fact that bacteria, and especially the typhoid bacteria, may be dried against the neck or some part of the sack, and thus be subject to conditions favoring greater longevity. This the witness accepted as a possible explanation, but suggested another. It is a fact that if several forms of micro-organisms are in the water one of these forms will apparently mask others, as in the case of experiments with *Bacillus coli* and streptococci. In the earlier periods the former mask the latter so well that but few or none are seen, while later the streptococci develop much more abundantly and to an extent overgrow the coli. Later, however, the coli may again appear. In view of this principle, it may have been impossible in any of the earlier determinations of Professor Jordan to have detected the typhoid organism, although there is no conclusive proof that they were of necessity absent up to the time of this appearance on the tenth day, and the three typhoid colonies found may be ascribed to the fact that their presence was masked before that date. The other determinations of Professor Jordan, showing that the typhoid was certainly alive in two cases after the second day, indicated that this germ will live at least this long; but the witness did not believe that they necessarily showed that it will not live longer. It seemed to him quite probable that the typhoid bacteria may have been incased in particles of fecal matter which were placed in the sack and thus have been preserved for a long period. The witness made the additional points that the experiments maintained in the canal and the waters of Illinois River did not apply to all seasons of the year and the results might have been quite different had the work continued throughout the year or been repeated at some other season than that which was selected. (7947–7949.)

The evidence presented by Professors Jordan and Burrill on the colon tests, according to the witness, did not by any means show a total elimination of the *B. coli* in the waters of Illinois River. He granted that there was a reduction, but no point was reached at which there was an elimination. These colon determinations are always subject to a great many conditions that frequently mask the bacilli, so that no reaction of them is given. In a river water it frequently happens that of two samples of equal volume taken from the same source at the same time one will give the positive and the other the negative reaction for coli, so that a negative reaction is by no means an indication of the absence of the germ. (7949–7950.)

The witness testified to his familiarity with the Widal test, and stated that he had frequently made it in the laboratory and on several occasions in the office of the city board of health. He did not believe that the introduction of the Widal test had made any material change in the reports of typhoid mortality. There are some reasons for believing that it has reduced the number of deaths, because it results in an early diagnosis, which eliminates many cases of other fevers with similar symptoms. (7950.)

CROSS-EXAMINATION.

No new facts were brought out under cross-examination, but counsel for the defense made an argument in support of the rejection of all the evidence of the witness in regard to the record of the mortuary office on the ground that the testimony of the witness was not proper and competent evidence to impeach the official published reports of the health commissioner of St. Louis, for the reason that the published records of the mortuary office, if competent to impeach the published reports of the health officer, can not be proved in the manner testified to by the witness, but the records themselves should be presented in evidence; and further, that it was improper at that time to attempt to impeach the final reports of the health commissioner of St. Louis, which were relied on and testified from in the evidence in chief of the complainant's witnesses and made a part of that evidence, and that it was not proper rebuttal, as the defendants had the right to rely on the official reports of the health commissioner of St. Louis, and if such reports were incorrect and unreliable it was the duty of the complainant to make such proof in chief and not wait until the defendants had rested their case to introduce testimony of impeachment.

WILLIAM THOMPSON SEDGWICK.

William Thompson Sedgwick, recalled as a witness in rebuttal by the complainant, presented evidence concerning the correctness of deductions drawn from the statements of typhoid-fever deaths as percentages of total deaths. The percentage mortality method eliminates altogether from the problem the question of population, and inasmuch as the population in many communities, especially between census years, is a most uncertain matter the value of the method is apparent. On the other hand, there is no doubt that under certain circumstances the method of stating the number of deaths as the rate per 100,000 furnishes more instructive and more accurate results. This is particularly true when the population is accurately known. In order to show that in the case of St. Louis it was immaterial whether the typhoid-fatality rate was stated according to the one method or the other, the witness presented two charts, the first showing the typhoid fatality in that city according to the number of deaths per 100,000, and the second according to the percentage method. The marked similarity in the two curves led the witness to state that no misleading conclusion could be drawn from his original testimony, because either method would show the same essential facts. (7955–7959.)

With reference to the statement in the testimony of Professor Jordan that the witness had incorrectly quoted the report of the rivers, pollution commission of Great Britain, he read from the original report as follows: "There is no river in the United Kingdom long enough to secure the oxidation and destruction of any sewage which may be discharged into it, even at its source." The witness said that the popular version of this statement is that "there is no river in the United Kingdom long enough to purify itself," and he believed that this statement would substantially represent the doctrine of sanitary science at the time of testimony. (7959–7960.)

The parchment and colloidin sack experiments of Professors Jordan, Russell, and Zeit on the longevity of typhoid bacteria when immersed in sewage-polluted water were then discussed by the witness, who stated that he would not be able either to form or to formulate a comprehensive opinion from them. They show that the germs survive for certain lengths of time, but he would be unable to conclude that under different conditions they might not survive for longer periods. In other words, the experiments were by no means conclusive on the longevity of typhoid-fever germs. He stated that he did not see how it is possible in the present state of bacteriology to devise any series of experiments that would accurately imitate the infinitely varying conditions of running streams. The experiments were carried on in cold weather, but even if they had been continued over an entire year under all actual variations, they would still, in his judgment, have been incomplete for the reason that in other years under other conditions organisms as sensitive as the typhoid-fever germs might have encountered environments that would have materially altered the results. Besides this, the experiments, to speak broadly, indicate a considerably shorter period of life than has been found by the majority of previous investigators. A greater number of experiments conducted for a longer period of time and under different conditions would not, in his opinion, fail to show that typhoid-fever germs live for a very much longer time than was indicated by the experiments under discussion. They were undoubtedly well planned and executed, but it was easy to suggest a great number of points in which they had failed. The fact that the cells were anchored instead of being allowed to float down the stream was important. It can readily be seen that this is an unnatural condition, especially in the case of the Chicago drainage canal and Illinois River, for the reason that the chemical composition of these bodies of sewage and water is subject to frequent changes. If, for example, the waste from a large industrial plant should be turned into Chicago River at any particular moment, the water which received it would vary materially in chemical composition from that just preceding or just following. Again, the seasonal variations must be taken into consideration. The floods in the tributaries bring in new materials and new bacterial flora. The principal trouble was, in the opinion of the witness, that in trying to fix the longevity of typhoid-fever or any other microbes it is necessary to deal with extremely sensitive and almost infinitesimal organisms which have been known at all only within the last few years and which are not yet by any means thoroughly known. (7960–7963.)

He then referred to the testimony and charts introduced by Professor Mason in which it was asserted that there was no relation between the number of deaths from typhoid in Chicago and the number in St. Louis, and stated that, taking into consideration the distance between the two cities and the time required for the passage from Chicago to St. Louis and taking into consideration also the character of the drainage canal and Illinois River and the fact that the water drawn from the intake at Chain of Rocks for public supply is subjected to extensive sedimentation, he would not expect to find any close correspondence between the typhoid-fever curves of the two cities. Consideration must also be given to the fact referred to by Professor Zeit in his testimony, namely, that typhoid germs arriving at St. Louis might act through the formation of local foci of infection, the time required for which must always be of uncertain duration. He would expect to find a correspondence between the prevalence of the disease in the two cities only when considerable periods were compared. It is, of course, probable that a very severe epidemic of typhoid in Chicago would make itself felt in St. Louis in such a way that cause and effect would be obvious, but here again much would depend on the season of the year, the rate of flow, local conditions of sewage, and the efficiency of sedimentation in the St. Louis basins. He did believe, however, that by taking long periods and averages definite relations were apparent, for example, as when comparing the rate of typhoid-fever deaths previous to 1900 with the rate for the years following. (7963–7964.)

The witness also expressed doubts concerning the significance of the colon-bacillus tests made with the water of Illinois River by Professors Jordan and Burrill. While these do show a very great decline in the number of organisms present in the lower reaches of the river at the time when the experiments were performed and in those particular samples, they do not in any sense enable one to form a correct idea as to the presence or absence of typhoid germs in the water at those points. Only a comparatively small number of specimens were examined, and from the nature of the case such specimens only imperfectly represent the true and complete character of the stream at all times and seasons; moreover, the colon test is by no means a sure and perfect measure of the presence or absence of either the colon or the typhoid bacillus. He was of the opinion, therefore, that while the work of Professors Jordan and Burrill throws great light on the process of bacterial purification going on in Illinois River, it does not by any means establish the fact that typhoid infection is completely or effectively removed from the water of the river before it empties into the Mississippi at Grafton. (7965–7966.)

The witness stated that he was thoroughly familiar with the tables introduced by E. E. Lochridge, because they had been prepared at his request and under his constant advice and supervision. He discussed these tables and agreed with Mr. Lochridge concerning their significance. (7966–7969.)

He then discussed the effect on the typhoid rate of the large number of visitors to expositions in cities. He cited his investigations with reference to the effect of the World's Columbian Exposition and the Centennial Exposition of 1876 in Philadelphia, and expressed the opinion that no important portion of the increase in typhoid in St. Louis since January, 1900, can reasonably be attributed to the influx of workmen and visitors to the Louisiana Purchase Exposition. (7969–7970.)

The witness then stated that circulars sent by boards of health to physicians urging them to report cases of typhoid fever could have no influence on the reporting of deaths from the disease for the reason that physicians are legally bound to report deaths in any event before a burial permit can be obtained. (7970–7971.)

The testimony of Professor Zeit in which he attributed extensive destructive effects on typhoid-fever germs to the toxic products of saprophytes in sewage was presented to the witness. He stated that while many authorities agree with Doctor Zeit, others do not accept that view, and he quoted an experiment made by himself and D. D. Jackson in 1893 in which the very point under consideration was studied. A portion of sewage was very carefully freed from all microbes present, saprophytic or parasitic, by filtration. In this condition the sewage was free from all the living organisms, but contained their toxic products. A portion of this filtrate was then seeded with typhoid-fever microbes to the number of 329 per cubic centimeter. If the toxic products of the saprophytes had been capable of destroying typhoid germs, these would have gradually declined in number. The facts were, however, that one hour after inoculation there were 333 per cubic centimeter, twenty-four hours later there were 63,198 per cubic centimeter, and two days later they were innumerable. This specimen was kept at blood heat. The germs were carefully examined to make certain that they were true typhoid bacilli, and the culture was then placed in the ice chest. Six days later the number of typhoid germs had fallen to 888,000 per cubic centimeter; twelve days after the seeding the number present was 832,100; twenty days after, 375,000, and thirty-six days after, 56,500. These experiments had satisfied the witness that whether or not typhoid germs ultimately disappear in sewage they are not readily destroyed by the toxic products of saprophytes, but rather multiply and live long in their presence. The witness also cited a similar experiment of Doctor Horrocks in which abundant typhoid-fever germs were found in sewage filtered in the same way after forty-two days. (7971–7972.)

The witness stated that he had examined all the chemical and bacteriological data introduced into evidence by the defendants, and while he had thereby obtained a much better knowledge of the processes of chemical and bacterial purification going on at certain times and seasons in Illinois River, he had failed to discover any reason for changing his original opinion that the principal part of the increase of typhoid fever in St. Louis since January, 1900, has been due to the presence of deleterious elements contained in the public water supply derived from the unpurified sewage of the city of Chicago. (7973.)

DECISION OF THE SUPREME COURT.

The report of the testimony of which the above is a digest was presented to the Supreme Court of the United States, with voluminous briefs and arguments by the parties to the suit, in the October term of 1905. The following is the full text of the opinion of the court, as rendered by Mr. Justice Holmes February 19, 1906:

This is a suit brought by the State of Missouri to restrain the discharge of the sewage of Chicago through an artificial channel into the Desplaines River, in the State of Illinois. That river empties into the Illinois River, and the latter empties into the Mississippi at a point about forty-three miles above the city of St. Louis. It was alleged in the bill that the result of the threatened discharge would be to send fifteen hundred tons of poisonous filth daily into the Mississippi, to deposit great quantities of the same upon the part of the bed of the last-named river belonging to the plaintiff. and so to poison the water of that river, upon which various of the plaintiff's cities, towns and inhabitants depended, as to make it unfit for drinking, agricultural, or manufacturing purposes. It was alleged that the defendant sanitary district was acting in pursuance of a statute of the State of Illinois and as an agency of that State The case is stated at length in 180 U. S. 208, where a demurrer to the bill was overruled. A supplemental bill alleges that since the filing of the original bill the drainage canal has been opened and put into operation and has produced and is producing all the evils which were apprehended when the injunction first was asked. The answers deny the plaintiff's case, allege that the new plan sends the water of the Illinois River into the Mississippi much purer than it was before, that many towns and cities of the plaintiff along the Missouri and Mississippi discharge their sewage into those rivers, and that if there is any trouble the plaintiff must look nearer home for the cause.

The decision upon the demurrer discussed mainly the jurisdiction of the Court, and, as leave to answer was given when the demurrer was overruled, naturally there was no very precise consideration of the principles of law to be applied if the plaintiff should prove its case. That was left to the future with the general intimation that the nuisance must be made out upon determinate and satisfactory evidence, that it must not be doubtful and that the danger must be shown to be real and immediate. The nuisance set forth in the bill was one which would be of international importance—a visible change of a great river from a pure stream into a polluted and poisoned ditch. The only question presented was whether as between the States of the Union this Court was competent to deal with a situation which, if it arose between independent sovereignties, might lead to war. Whatever differences of opinion there might be upon matters of detail, the jurisdiction and authority of this Court to deal with such a case as that is not open to doubt. But the evidence now is in, the actual facts have required for their establishment the most ingenious experiments, and for their interpretation the most subtle speculations, of modern science, and therefore it becomes necessary at the present stage to consider somewhat more nicely than heretofore how the evidence it is to be approached.

The first question to be answered was put in the well-known case of the Wheeling bridge. *Pennsylvania* v. *Wheeling & Belmont Bridge Co.*, 13 How. 518. In that case, also, there was a bill brought by a State to restrain a public nuisance, the erection of a bridge alleged to obstruct navigation, and a supplemental bill to abate it after it was erected. The question was put most explicitly by the dissenting judges but it was accepted by all as fundamental. The Chief Justice observed that if the bridge was a nuisance it was an offence against the sovereignty whose laws had been violated, and he asked what sovereignty that was. 13 How. 561. Daniel, J., 13 How. 599. (See also *Kansas* v. *Colorado*, 185 U. S. 125.) It could not be Virginia, because that State had purported to authorize it by statute. The Chief Justice found no prohibition by the United States. 13 How. 580. No third source of law was suggested by any one. The majority accepted the Chief Justice's postulate, and found an answer in what Congress had done.

It hardly was disputed that Congress could deal with the matter under its power to regulate commerce. The majority observed that although Congress had not declared in terms that a State should not obstruct the navigation of the Ohio, by bridges, yet it had regulated navigation upon that river in various ways and had sanctioned the compact between Virginia and Kentucky when Kentucky was let into the Union. By that compact the use and navigation of the Ohio, so far as the territory of either State lay thereon, was to be free and common to the citizens of the United States. The compact, by the sanction of Congress, had become a law of the Union. A State law which violated it was unconstitutional. Obstructing the navigation of the river was said to violate it, and it was added that more was not necessary to give a civil remedy for an injury done by the obstruction. 13 How. 565, 566. At a later stage of the case, after Congress had authorized the bridge, it was stated again in so many words that the ground of the former decision was that "the act of the legislature of Virginia afforded no authority or justification. It was in conflict with the acts of Congress, which were the paramount law." 18 How. 421, 429.

In the case at bar, whether Congress could act or not, there is no suggestion that it has forbidden the action of Illinois. The only ground on which that State's conduct can be called in question is one which must be implied from the words of the Constitution. The Constitution extends the judicial power of the United States to controversies between two or more States and between a State and citizens of another State, and gives this Court original jurisdiction in cases in which a State shall be a party. Therefore, if one State raises a controversy with another, this Court must determine whether there is any principle of law and, if any, what, on which the plaintiff can recover. But the fact that this Court must decide does not mean, of course, that it takes the place of a legislature. Some principles it must have power to declare. For instance, when a dispute arises about boundaries, this Court must determine the line, and in doing so must be governed by rules explicitly or implicitly recognized. *Rhode Island* v. *Massachusetts*, 12 Pet. 657, 737. It must follow and apply those rules, even if legislation of one or both of the States seems to stand in the way. But the words of the Constitution would be a narrow ground upon which to construct and apply to the relations between States the same system of municipal law in all its details which would be applied between individuals. If we suppose a case which did not fall within the power of Congress to regulate, the result of a declaration of rights by this Court would be the establishment of a rule which would be irrevocable by any power except that of this Court to reverse its own decision, an amendment of the Constitution, or possibly an agreement between the States sanctioned by the legislature of the United States.

The difficulties in the way of establishing such a system of law might not be insuperable, but they would be great and new. Take the question of prescription in a case like the present. The reasons on which prescription for a public nuisance is denied or may be granted to an individual as against the sovereign power to which he is subject have no application to an independent State. See 1 Oppenheim, International Law, 293, §§ 242, 243. It would be contradicting a fundamental principle of human nature to allow no effect to the lapse of time, however long, *Davis* v. *Mills*, 194 U. S. 451, 457, yet the fixing of a definite time usually belongs to the legislature rather than the courts. The courts did fix a time in the rule against perpetuities, but the usual course, as in the instances of statutes of limitation, the duration of patents, the age of majority, etc., is to depend upon the lawmaking power.

It is decided that a case such as is made by the bill may be a ground for relief. The purpose of the foregoing observations is not to lay a foundation for departing from that decision, but simply to illustrate the great and serious caution with which it is necessary to approach the question whether a case is proved. It may be imagined that a nuisance might be created by a State upon a navigable river like the Danube, which would amount to a *casus belli* for a State lower down, unless removed. If such a nuisance were created by a State upon the Mississippi the controversy would be resolved by the more peaceful means of a suit in this Court. But it does not follow that every matter which would warrant a resort to equity by one citizen against another in the same jurisdiction equally would warrant an interference by this Court with the action of a State. It hardly can be that we should be warranted in declaring statutes ordaining such action void in every instance where the circuit court might intervene in a private suit, upon no other ground than analogy to some selected system of municipal law, and the fact that we have jurisdiction over controversies between States.

The nearest analogy would be found in those cases in which an easement has been declared in favor of land in one State over land in another. But there the right is recognized on the assumption of a concurrence between the two States, the one, so to speak, offering the right, the other permitting it to be accepted. *Mannville Co.* v. *Worcester*, 138 Mass. 89. But when the State itself is concerned and by its legislation expressly repudiates the right set up, an entirely different question is presented.

Before this Court ought to intervene the case should be of serious magnitude, clearly and fully proved, and the principle to be applied should be one which the Court is prepared deliberately to maintain against all considerations on the other side. See *Kansas* v. *Colorado*, 185 U. S. 125.

As to the principle to be laid down the caution necessary is manifest. It is a question of the first magnitude whether the destiny of the great rivers is to be the sewers of the cities along their banks or to be protected against everything which threatens their purity. To decide the whole matter at one blow by an irrevocable fiat would be at least premature. If we are to judge by what the plaintiff itself permits, the discharge of sewage into the Mississippi by cities and towns is to be expected. We believe that the practice of discharging into the river is general along its banks, except where the levees of Louisiana have led to a different course. The argument for the plaintiff asserts it to be proper within certain limits. These are facts to be considered. Even in cases between individuals some consideration is given to the practical course of events. In the black country of England parties would not be expected to stand upon extreme rights. *St. Helen's Smelting Co.* v. *Tipping*, 11 H. L. C. 642. See *Boston Ferrule Co.* v. *Hills*, 159 Mass. 147, 150. Where, as here, the plaintiff has sovereign powers and deliberately permits discharges similar to those of which it complains, it not only offers a standard to which the defendant has the right to appeal, but, as some of those discharges are above the intake of St. Louis, it warrants the defendant in demanding the strictest proof that the plaintiff's own conduct does not produce the result, or at least so conduce to it that courts should not be curious to apportion the blame.

We have studied the plaintiff's statement of the facts in detail and have perused the evidence, but it is unnecessary for the purposes of decision to do more than give the general result in a very simple way. At the outset we can not but be struck by the consideration that if this suit had been brought fifty years ago it almost necessarily would have failed. There is no pretense that there is a nuisance of the simple kind that was known to the older common law. There is nothing which can be detected by the unassisted senses—no visible increase of filth, no new smell. On the contrary, it is proved that the great volume of pure water from Lake Michigan which is mixed with the sewage at the start has improved the Illinois River in these respects to a noticeable extent. Formerly it was sluggish and ill smelling. Now it is a comparatively clear stream to which edible fish have returned. Its water is drunk by the fishermen, it is said without evil results. The plaintiff's case depends upon an inference of the unseen.

It draws the inference from two propositions. First, that typhoid fever has increased considerably since the change and that other explanations have been disproved, and second, that the bacillus of typhoid can and does survive the journey and reach the intake of St. Louis in the Mississippi.

We assume the now prevailing scientific explanation of typhoid fever to be correct. But when we go beyond that assumption everything is involved in doubt. The data upon which an increase in the deaths from typhoid fever in St. Louis is alleged are disputed. The elimination of other causes is denied. The experts differ as to the time and distance within which a stream would purify itself. No case of an epidemic caused by infection at so remote a source is brought forward and the cases which are produced are controverted. The plaintiff obviously must be cautious upon this point, for if this suit should succeed many others would follow, and it not improbably would find itself a defendant to a bill by one or more of the States lower down upon the Mississippi. The distance which the sewage has to travel (357 miles) is not open to debate, but the time of transit to be inferred from experiments with floats is estimated at varying from eight to eighteen and a half days, with forty-eight hours more from intake to distribution, and when corrected by observations of bacteria is greatly prolonged by the defendants. The experiments of the defendants' experts lead them to the opinion that a typhoid bacillus could not survive the journey, while those on the other side maintain that it might live and keep its power for twenty-five days or more, and arrive at St. Louis. Upon the question at issue, whether the new discharge from Chicago hurts St. Louis, there is a categorical contradiction between the experts on the two sides.

The Chicago drainage canal was opened on January 17, 1900. The deaths from typhoid fever in St. Louis, before and after that date, are stated somewhat differently in different places. We give them mainly from the plaintiff's brief: 1890, 140; 1891, 165; 1892, 441; 1893, 215; 1894, 171; 1895, 106; 1896, 106; 1897, 125; 1898, 95; 1899, 131; 1900, 154; 1901, 181; 1902, 216; 1903, 281. It is argued for the defendants that the numbers for the later years have been enlarged by carrying over cases which in earlier years would have been put into a miscellaneous column (intermittent, remittent, typho-malaria, etc., etc.), but we assume that the increase is real. Nevertheless, comparing the last four years with the earlier ones, it is obvious that the ground for a specific inference is very narrow, if we stopped at this point. The plaintiff argues that the increase must be due to Chicago, since there is nothing corresponding to it in the watersheds of the Missouri or Mississippi. On the other hand, the defendants point out that there has been no such enhanced rate of typhoid on the banks of the Illinois as would have been found if the opening of the drainage canal were the true cause.

Both sides agree that the detection of the typhoid bacillus in the water is not to be expected. But the plaintiff relies upon proof that such bacilli are discharged into the Chicago sewage in considerable quantities; that the number of bacilli in the water of the Illinois is much increased, including the *Bacillus coli communis*, which is admitted to be an index of contamination, and that the chemical analyses lead to the same inference. To prove that the typhoid bacillus could make the journey an experiment was tried with the *Bacillus prodigiosus*, which seems to have been unknown, or nearly unknown, in these waters. After preliminary trials, in which these bacilli emptied into the Mississippi near the mouth of the Illinois were found near the St. Louis intake and in St. Louis in times varying from three days to a month, 107 barrels of the same, said to contain 1,000,000,000 bacilli to the cubic centimeter, were put into the drainage canal near the starting point on November 6, and on December 4 an example was found at the St. Louis intake tower. Four others were found on the three following days, two at the tower and two at the mouth of the Illinois. As this bacillus is asserted to have about the same length of life in sunlight in living waters as the *Bacillus typhosus*, although it is a little more hardy, the experiment is thought to prove one element of the plaintiff's case, although the very small number found in many samples of water is thought by the other side to indicate that practically no typhoid germs would get through. It seems to be conceded that the purification of the Illinois by the large dilution from Lake Michigan (nine parts or more in ten) would increase the danger, as it now generally is believed that the bacteria of decay, the saprophytes, which flourish in stagnant pools, destroy the pathogenic germs. Of course the addition of so much water to the Illinois also increases its speed.

On the other hand, the defendants' evidence shows a reduction in the chemical and bacterial accompaniments of pollution in a given quantity of water, which would be natural in view of the mixture of nine parts to one from Lake Michigan. It affirms that the Illinois is better or no worse at its mouth than it was before, and makes it at least uncertain how much of the present pollution is due to Chicago and how much to sources further down, not complained of in the bill. It contends that if any bacilli should get through they would be scattered and enfeebled and would do no harm. The defendants also set against the experiment with the *Bacillus prodigiosus* a no less striking experiment with typhoid germs suspended in the Illinois River in permeable sacks. According to this the duration of the life of these germs has been much exaggerated, and in that water would not be more than three or four days. It is suggested, by way of criticism, that the germs may not have been of normal strength, that the conditions were less favorable than if they had floated down in a comparatively unchanging body of water, and that the germs may have escaped, but the experiment raises at least a serious doubt. Further, it hardly is denied that there is no parallelism in detail between the increase and decrease of typhoid fever in Chicago and St. Louis. The defendants' experts maintain that the water of the Missouri is worse than that of the Illinois, while it contributes a much larger proportion to the intake. The evidence is very strong that it is necessary for St. Louis to take preventive measures, by filtration or otherwise, against the dangers of the plaintiff's own creation or from other sources than Illinois. What will protect against one will protect against another. The presence of causes of infection from the plaintiff's action makes the case weaker in principle as well as harder to prove than one in which all came from a single source.

Some stress was laid on the proposition that Chicago is not on the natural watershed of the Mississippi, because of a rise of a few feet between the Desplaines and the Chicago rivers. We perceive no reason for a distinction on this ground. The natural features relied upon are of the smallest. And if under any circumstances they could affect the case, it is enough to say that Illinois brought Chicago into the Mississippi watershed in pursuance not only of its own statutes, but also of the acts of Congress of March 30, 1822, c. 14, 3 St. 659, and March 2, 1827, c. 51, 4 St. 234, the validity of which is not disputed. *Wisconsin* v. *Duluth*, 96 U. S. 379. Of course these acts do not grant the right to discharge sewage, but the case stands no differently in point of law from a suit because of the discharge from Peoria into the Illinois, or from any other or all the other cities on the banks of that stream.

We might go more into detail, but we believe that we have said enough to explain our point of view and our opinion of the evidence as it stands. What the future may develop of course we can not tell. But our conclusion upon the present evidence is that the case proved falls so far below the allegations of the bill that it is not brought within the principles heretofore established in the cause.

Bill dismissed without prejudice.

True copy.

Test:

Clerk Supreme Court, U. S.

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E.

F.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 194.]

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April, 1907.

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