ILLINOIS STATE WATER SURVEY

BULLETIN NO. 23

DISPOSAL OF THE SEWAGE OF THE SANITARY DISTRICT OF CHICAGO

A Report to the District Engineer,
U. S. Engineer Office, Chicago

By

ALVORD, BURDICK & HOWSON
Consulting Engineers

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THE DISPOSAL OF THE
SEWAGE OF THE
SANITARY DISTRICT OF
CHICAGO.

STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE WATER SURVEY
A. M. BUSWELL, Chief

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WATER SURVEY DIVISION

A. M. BUSWELL, *Chief*

LETTER OF TRANSMITTAL.

State Water Survey Division

ARTHUR M. BUSWELL, CHIEF

Urbana, Ill.

February 18, 1927.

A. M. Shelton, Chairman, and Members of the Board of Natural Resources and Conservation Advisors:

Gentlemen: Herewith I submit a report on the disposal of the sewage of the Sanitary District of Chicago and recommend that it be published as Bulletin No. 23 of the State Water Survey Division.

This report was prepared by Alvord, Burdick & Howson, consulting engineers, of Chicago, by order of the Secretary of War pursuant to a resolution of the Committee on Rivers and Harbors of the House of Representatives, U. S., April 14th, 1924, and submitted to the District Engineer, U. S. Engineer Office, Chicago.

The printing of this report as a Water Survey Division Bulletin has been authorized by the Secretary of War. The letter granting this authorization is included herewith.

The material presented in this manuscript contains so much data on the cause and remedy of the most serious stream pollution problem in the State that it seems highly advisable to make it available to the citizens of the State in published form.

Respectfully submitted,

A. M. Buswell, *Chief.*

LETTER OF AUTHORIZATION.

WAR DEPARTMENT
UNITED STATES ENGINEER OFFICE
537 SOUTH DEARBORN STREET
CHICAGO, ILLINOIS

October 25, 1926.

Dr. A. M. Buswell, Chief, State Water Survey Division, Board of Natural Resources and Conservation, Urbana, Illinois.

DEAR SIR: Your request for permission for the State Department of Registration and Education to print the report of Alvord, Burdick & Howson, Engineers, to the U. S. District Engineer on the Disposal of the Sewage of the Sanitary District of Chicago, has been approved by the Chief of Engineers, with the condition that Chapter XII be also published, and that credit and acknowledgment be made to the Chief of Engineers and the War Department, for whom and under whom the report was prepared.

Yours very truly,
EDWARD H. SCHULZ,
Colonel, Corps of Engineers,
District Engineer.

PART I.

INTRODUCTION, SUMMARY, AND CONCLUSIONS.

District Engineer,
U. S. Engineer Office,
337 S. Dearborn St.,
Chicago, Ill.

Dear Sir:

Proceeding under our instructions of January 16, 1925, we have studied the problem of sewage disposal for the City of Chicago and vicinity, including more particularly that territory embraced within the Sanitary District of Chicago.

Our study has been particularly directed to answers for the following questions:

(a) Determination of a pollution standard for the Chicago Drainage Canal for each of the following average diversions from Lake Michigan; —2,000, 4,167, 6,000, 7,500, 8,500 and 10,000 cubic feet per second; this standard to be the lowest that will prevent the occurrence of nuisance in the Des Plaines and the Illinois River, and will permit a thriving fish life therein.

These diversions include the sewage flow of the Sanitary District; and they therefore represent the dry weather flow of the Drainage Canal at Lockport, approximately.

(b) Determination of the extent to which purification measures must be taken by the Sanitary District of Chicago for each of the flows specified above, in order that the pollution standard be maintained unimpaired.

(c) Determination of the most feasible method of treating the surplus pollution, and, for each flow specified, the cost of the necessary works and the operating costs thereof.

(d) The determination of the time that reasonably would be required to build the necessary works and place them in operation for each of the flows specified.

In the study of this matter the time at our disposal has not permitted original investigations. It has been possible only to view the present situation by inspection, and to study the large amount of data that has been accumulated by the Sanitary District of Chicago and other agencies, bearing directly upon the answers to the above questions.

We have further brought to bear upon the study of the problem the experience of other cities regarding sewage disposal, insofar as information has been gained that would throw light upon the Chicago situation.

Upon the pages which follow we have stated the local problem in some detail, and we have discussed the various phases of it insofar as we believe is required for a general understanding of the problem, and our answers to the questions previously stated. For the benefit of those already somewhat familiar with this problem we will first briefly state our summarized findings and conclusions. We will follow this statement by a more detailed consideration of the problem, and a further statement of the conditions and the reasons leading to the conclusions stated.

SUMMARIZED CONCLUSIONS.

1st. *Present Disposal:*

The diversion of the Chicago sewage from Lake Michigan, resulting from the Drainage Canal and other causes, has effected a remarkable improvement in the death rate from water borne diseases. The sewage nuisance in the streams of the Chicago district has been reduced to a large extent.

This result has been accomplished, however, by transferring the bad conditions in Chicago to the Des Plaines and Illinois Rivers in which a crying nuisance has been created for more than one hundred miles; and by diverting large amounts of water from the Great Lakes, over strenuous objections from property owners claiming a right to the water diverted.

It is generally conceded that the present conditions should not be allowed to continue. The Sanitary District is already engaged upon remedial measures through which a large part of the sewage will be treated before discharge into the Drainage Canal.

2nd. *Population and Growth:*

In planning works for sewage disposal, it is necessary to consider the future population of the locality. It is not financially practicable to make expenditures now for a problematical future. It is necessary, however, to determine the future populations approximately and to adopt works capable of construction in units that may be increased in capacity from time to time as occasion requires, without destroying previous expenditures. Thus each dollar expended will provide a link in a complete chain of sewage disposal works.

We have examined the forecast of population as estimated by the Sanitary District of Chicago, and we believe it represents future probabilities as accurately as required for the above purpose. This estimate covering the population of the Sanitary District is as follows:

1920 census,	2,978,635
1930	3,710,000
1940	4,425,000
1950	5,140,000
1960	5,850,000
1970	6,580,000

In addition to the population in the Sanitary District, there is now (1925) a population of 180,000 in the northern Indiana cities bordering the lake and draining through the Calumet River. Under ordinary low flow conditions this drainage passes through the Sag Channel to the Main Drainage Channel and thus into the Illinois River.

The Sanitary District includes about eighty-five per cent of the total population in the greater Chicago region which includes Cook, Kane, DuPage, Lake and Will Counties in Illinois, and Lake County in Indiana. The greater part of the outlying population has more or less effect upon the pollution of the lake and the nearby streams.

3rd. *Amount and Character of Sewage:*

The present discharge of the sewers within the Sanitary District is about 800 million gallons per day. This is equivalent to a river 100 feet wide and five feet deep flowing one and one-half miles per hour.

This sewage carries an organic load per capita greater than any other large city for which accurate figures have been available to us. This excessive load is partly due to a few great industries which produce an amount of pollution estimated by the Sanitary District to be the equivalent of about 1,500,000 people (1920).

4th. *Standard for Pollution:*

In the consideration of sewage treatment works that will be required under various drafts of dilution water from Lake Michigan, it has been necessary to fix a standard of maximum pollution for the Chicago Drainage Canal in order that reasonable sanitary conditions may be maintained in the Des Plaines and Illinois Rivers. We suggest the following as a reasonable standard:

> The liquid discharged by the Drainage Canal, as evidenced by the average of representative samples taken for any thirty consecutive days shall,
>
> (a) Be practically free from settleable solids deposited in two hours, and,
>
> (b) Shall contain dissolved oxygen equal to or exceeding the biochemical oxygen demand of said liquid for five days when incubated at 20 degrees C.

(c) Shall contain not less than three parts per million of dissolved oxygen.

The treatment works hereinafter outlined in connection with specified dilutions from the lake will meet this standard in our opinion.

5th. *Protection of the Water Supply:*

Even under the heavy diversions from Lake Michigan in recent years and the generally favorable typhoid death rate, the quality of the water supply for Chicago has been far from satisfactory. This is due to the incidental pollution of the lake, periodic discharges from the Chicago and Calumet Rivers and other causes. Occasionally sporadic typhoid outbreaks have occurred attributable to the water. Safety is only secured by heavy dosages of liquid chlorine which are extremely objectionable to many people and which the Chicago authorities regard as closely approaching the maximum dosage tolerable.

Compared to the usual standards applicable to clean water, the water is dirty most of the time, and it is quite turbid more than ten per cent of the time. Even when comparatively clear it often contains miscroscopic animal organisms no doubt harmless, but very objectionable to many people.

The filtration of drinking water has been extensively practiced for more than twenty years. More than twenty million people are thus supplied in the United States. Many filtration plants handle a water polluted to a greater degree than Lake Michigan water would be under any diversions for dilution purposes considered in this report.

Chicago can secure pure clean water at all times by the filtration of its present supply. We regard this as the only means by which a satisfactory supply of water may be obtained, regardless of any practicable measures for sewage treatment or lake water diversions for dilution.

Filtration is considered as a pre-requisite to the adequate disposal of sewage in all projects considered in this report.

6th. *Metering of the Water Supply:*

At the present time ninety per cent of all water services in Chicago are served through so-called "flat rates." The pumpage of water is excessive, pressures are deficient, fire protection service is jeopardized and the costs of water supply, intercepting sewers and sewage disposal are greatly increased over what would be necessary if water waste were restricted.

Universal metering of the water services is urgent. Metering alone will

(a) Double the average pressure within the City of Chicago.

(b) Furnish *all* adequate water service where but twenty-five percent now enjoy it.

(c) Enable the present water works with but minor extensions to serve the City for the next generation.

(d) Through the immense savings effected in deferred construction costs enable the City to install filtration works.

If universal metering of the Chicago Water Works is accomplished within the next ten years savings of from $200,000,000 to $225,000,000 will be effected prior to 1945. This amount is so great that in addition to financing the installation of meters and filtration works for the entire city, it would cover the cost of constructing the entire intercepting sewer and sewage disposal works required in the Chicago Sanitary District up to 1945 and leave a large surplus in addition.

The costs of sewage disposal are also influenced by the waste of water. If universal metering of the water works services is not undertaken, the estimated costs of the interceptors and sewage treatment works outlined in this report must be increased by an amount of from $42,000,000 to $53,000,000 depending upon the flow available for dilution and the types of plants required thereby.

7th. *Volume of Sewage:*

The total quantity of sewage to be treated in the Chicago District may be taken as approximately equal to the total water supply. This assumes that infiltration into the sewers will be offset by that part of the water supply used for sprinkling and other purposes which do not contribute to the sewage flow.

At the present time, due to water waste, the pumpage of water in the Chicago District is excessive. The dry weather flow of sewage is correspondingly much larger than it would be if the waste of water were curtailed.

The total volume of sewage under metered and unmetered conditions has been estimated based upon the assumption that a ten year period beginning in 1925 and terminating in 1935 will be required to install meters on all water services in the City of Chicago, and that when all services are metered the sewage per capita, including industrial and all other uses, will be approximately 160 gallons per day.

Under these assumptions the following table shows the estimated quantities for each five year period from 1925 to 1945.

Million Gallons Sewage Daily.

Year	Present Conditicns of Metering	Universal Metering
1925	877	...
1930	1,054	777 (50% metered)
1935	1,243	662
1940	1,437	711
1945	1,629	769

The installation of meters on all services will cause the sewage flow of 1945 under complete metering to be less than at the present time, when but ten percent of the services are metered.

8th. *Intercepting Sewers:*

The Sanitary District has adopted tunnels for its intercepting sewers. This appears to be a logical conclusion in view of congestion on the ground surface.

Intercepting sewers have been built or are under construction for all areas except the West Side and the Southwest Side. The intercepting sewers to serve these two areas will in general extend along both sides of the main channel and the north and south branches of the Chicago River beginning with Fullerton Avenue on the North Side and extending in a southwesterly direction to the site proposed for the West and Southwest Side plants along the Drainage Canal near Summit.

It is believed that with universal metering these intercepting sewers should be designed of such capacity that they will carry a flow equivalent to 375 gallons per capita per day. This is approximately two and one-third times the average flow as it is estimated to be after the installation of meters.

It is believed that a 35-year period (i. e. to 1960) is that for which the design of interceptors should be economically and practically made for sewers constructed in tunnel, capable of duplication in the future without excessive costs.

The 20 miles of intercepting sewers required for the West Side system have been estimated to cost $7,890,000.

The 15 miles of sewers required for the Southwest Side plant have been estimated to cost $4,495,700.

9th. *Sewage Disposal Costs in Other Cities:*

Construction and operating costs of sewage pumping stations and treatment works in other cities were compared with similar costs incurred by the Sanitary District of Chicago in certain works already built.

In making this comparison consideration has been given to the price basis when the work was done and the unit costs for labor and materials in the cities compared. We deduce the following conclusions from the comparison:

(a) Recent intercepting sewer contract costs in Chicago have been substantially double those secured in other cities under like construction conditions.

(b) The Calumet Imhoff tank plant, constructed by the Sanitary District of Chicago (after being credited with the reasonable cost of an experimental sprinkling filter and activated sludge plant), cost approximately three times the average of tank plants of similar type in other cities.

(c) The Des Plaines activated sludge plant of the Sanitary District of Chicago cost approximately three times the average cost of similar plants in Milwaukee and Indianapolis.

(d) The cost of operating the Calumet Imhoff tank plant (after being credited with the reasonable cost of operating a small sprinkling filter and a small activated sludge plant), is approximately four times that of operating similar plants in other cities when compared on the basis of cost per million gallons treated or ten times the average based on cost per capita served.

(e) The cost of operating the Des Plaines activated sludge plant of the Sanitary District of Chicago is from eight to ten times that estimated to be necessary for the operation of the activated sludge plant at Milwaukee.

(f) The cost of operating the 39th St., Lawrence Avenue and Calumet pumping stations of the Sanitary District of Chicago is approximately three times as great per unit of work performed as that of other stations of similar size and type in other cities.

10th. *Basis of Cost Estimates:*

All estimates of cost of construction and operation used herein are predicated upon labor and material prices prevailing in the Chicago District in the early part of 1925. The estimates are further based upon the average efficiency which it is practicable to secure in public enterprises of similar nature; no better and no worse than conditions recently prevailing in Detroit, Cleveland and Milwaukee.

11th. *Types of Treatment Works:*

At the present time the Des Plaines activated sludge plant and the Calumet Imhoff tank plant are in operation. The Sanitary District is also definitely committed to the construction of an activated sludge plant at the North Side plant, the construction of which is about one-third completed.

All of the estimates herein made for all amounts of flow considered are based upon the Sanitary District's program of adding sprinkling filters at the Calumet plant, and of building a sprinkling filter plant at the Corn Products Plant and an activated sludge plant at the Stockyards. The variations in degree of treatment required with the several flows considered, are all secured herein by applying different treatment processes to the West and Southwest Side plants.

All estimates of cost herein are in addition to contracts now let and under construction on the North Side intercepting sewers and that part of the North Side disposal plant for which contracts have thus far been let.

In our opinion the sites for proposed sewage disposal works are well chosen.

12th. *Additional Works Required with 10,000 Cubic Feet Per Second Flow:*

A flow in the channel of 10,000 cubic feet per second will necessitate in addition to the sewage disposal works now constructed or under contract, preliminary or tank treatment of the sewage at the West Side plant and complete tank and sprinkling filter treatment for the Southwest Side.

The cost of additional purification works including intercepting sewers required with a total flow of 10,000 cubic feet per second is estimated at $57,415,240 to 1935 and $64,692,700 to 1945.

The cost of operation of all pumping stations and sewage disposal plants with a flow of 10,000 cubic feet per second is estimated at $4,364,000 in 1935 and $5,004,800 in 1945.

13th. *Required Works with 4,167 Cubic Feet Per Second Flow:*

With a smaller amount of diluting water, complete secondary treatment of the sewages at both the West and Southwest Side plants would be necessary. Tanks and sprinkling filter treatment would not be sufficient by 1945. Activated sludge treatment is required to meet the 1945 conditions with but 4,167 c. f. s. flow available.

The estimated cost of all interceptors and disposal plants required with the flow of 4,167 cubic feet per second is $69,213,500 for 1935 conditions, and $76,583,300 for 1945 conditions.

We estimate the cost of operating all sewage pumping stations and sewage disposal plants necessary with the flow of 4,167 cubic feet per second at $5,163,100 in 1935 and $5,817,600 in 1945.

14th. *Required Works with 2,000 Cubic Feet Per Second Flow:*

With a flow as small as 2,000 cubic feet per second there is no practicable way of meeting the pollution standard herein suggested.

15th. *Required Works with 7,500 Cubic Feet Per Second Flow:*

The 7,500 cubic feet per second flow requires that a complete sprinkling filter plant be built at the West Side and tanks at the Southwest Side. This will suffice up to as late as 1947 after which filters will be required at the Southwest plant also. The estimated cost of constructing all plants under this flow is $61,477,920 in 1935, and $67,-926,100 in 1945.

The annual cost of operating all pumping stations and disposal plants is estimated at $4,530,400 in 1935 and $5,137,000 in 1945.

16th. *Required Works with 8,500 Cubic Feet Per Second Flow:*

The required works with 8,500 cubic feet per second flow would be the same as those required for 10,000 cubic feet per second flow. The construction and operating cost would be the same as those outlined under the project in paragraph above.

17th. *Review of Expenditures Under Various Diversions:*

The expenditures for construction and operation of the treatment works required for 1935 and 1945 conditions with flows varying from 2,000 to 10,000 cubic feet per second are shown in Table 1.

Increasing the flow from 4,167 to 10,000 cubic feet per second saves but sixteen and one-half percent in the expenditures required for sewage treatment, and but fourteen and one-half percent in the annual operating costs.

18th. *Suggestion for Stockyards Wastes:*

The Sanitary District program contemplates a separate sprinkling filter plant at Argo and a separate activated sludge plant for the Stockyards wastes. Other cities in which the packinghouse waste per capita contributing sewage is as great as that at Chicago have found it practicable to treat this waste, mixed with the domestic sewage, at either sprinkling filter or activated sludge plants. At Chicago the Southwest Side intercepter passes almost directly by the Stockyards, which suggests the further practicability of combining this concentrated waste, after the removal of the coarse solids, with the domestic sewage before treatment.

If treatment of the Stockyards waste, mixed with the sewage of the West and Southwest Side, is practicable on stone filters, there will result a saving in construction cost of from $2,300,000 to $3,500,000. There will also result a saving in annual cost of operation of $350,000 per year, even after crediting an income of $360,000 per year from the sale of the sludge from the activated sludge plant. This annual saving capitalized at four percent adds a further sum of $8,500,000, making the total capitalized saving between $10,800,000 and $12,000,000.

The rates of flow for dilution purposes, as stated in this report, are the estimated rates required under warm weather conditions at which

TABLE 1.

EXPENDITURES REQUIRED FOR SEWAGE DISPOSAL WORKS, IN ADDITION TO WORKS NOW BUILT OR UNDER CONSTRUCTION, WITH VARIOUS FLOWS IN THE DRAINAGE CANAL.

	Flow in Cubic Feet per Second.				
1935 Conditions	4167	6000	7500	8500	10,000
Cost of Construction	$69,213,520	$68,726,620	$61,477,920	$57,415,240	$57,415,240
Cost of Operation	5,163,100	5,432,400	4,530,400	4,364,000	4,364,000
1945 Conditions					
Cost of Construction	$76,583,300	76,740,100	67,926,100	64,692,700	64,692,700
Cost of Operation	5,817,600	6,194,000	5,137,000	5,004,800	5,004,800
(excl. fixed chgs.)					
Adequate until	1950	1970	1945	1945	1960

Notes:

1. All of above costs include full costs of Stock Yards and Argo plants.
2. All of above costs are based upon separate plant for Stock Yards.
3. Stock Yards plant operating costs are credited with revenue from dewatered sludge at $10.00 per ton.
4. Flow of 2000 c. f. s. inadequate for practicable treatment of Chicago wastes.

time the rate of diversion would necessarily be greatest. It is a fact that considerably smaller rates of diversion will be required in the cooler months of the year. Riparian owners on the Great Lakes and other parties interested are chiefly concerned with the average yearly diversion. It is believed to be proper therefore in the operation of the Drainage Canal to vary the draft of diversion water from month to month dependent upon conditions. The ability to do this will provide a large factor of safety for maintaining good conditions in the effluent channels and down-stream rivers.

We have made no allowance for the fact that more or less sewage from the Indiana-Calumet region now containing 180,000 people, now reaches the Sag Canal in a more or less unpurified state. This situation must ultimately be solved by adequate purification works for this region, and a specific allowance for dilution water if the sewage continues to flow via the Illinois River.

The conclusions in this report are predicated on keeping the Drainage Canal reasonably clean of organic settlings by dredging. Very little will be required in this regard after purification works are built, and after the present deposits are removed. Several years may be required before existing sludge deposits in the Illinois River are completely eliminated.

We have given no consideration to the development of water power. We have neither included the costs thereof, nor credited benefits. Where power is required in the operations of pumping and sewage disposal we have estimated the cost thereof on the basis of electric power purchased from the Commonwealth Edison Company at their published rates.

Upon the pages which follow we have discussed the matters above treated in further detail.

PART II.

PRESENT DISPOSAL OF SEWAGE AND DEFICIENCIES

Chicago, and the industrial region surrounding it, occupies the Southwestern shore of Lake Michigan. The ground is comparatively low. The greater part of it lies less than 20 feet above Lake Michigan. This entire region formerly drained naturally into the lake through the Chicago and Calumet Rivers. That locality now constituting the western suburban area, however, is tributary to the Des Plaines River, which parallels the lake shore about ten miles inland, the waters of which are tributary to the Mississippi river system through the Illinois river.

More than three million people now occupy this territory. It is conservatively estimated that the population will double within the next thirty years. The present flow of sewage is about 800 million gallons per day. This is equivalent to a river 100 feet wide and five feet deep flowing one and one-half miles per hour.

The shore line of Lake Michigan from Gary on the south to Waukegan upon the north is about seventy-five (75) miles in length. More than half of it is densely populated. Much of it is occupied by industries. The northern one-third of it is residential in character.

Development of Sewers.

Sewers were built as required, draining immediately to the nearest water outlet. The earliest settlement of considerable size, was located at the mouth of the Chicago river. In this locality all sewers drain directly into the river or into its north or south branch. As the population extended northward and southward, sewers were built discharging directly into the Lake. When sewers became necessary in the region adjoining the Calumet River, sewers were built discharging directly into this stream.

The construction of sewers in Chicago was begun in 1856. At this time the population was about 80,000. Thereafter the growth of the city was very rapid. The mileage of sewers kept pace with the population for in many localities the habitation was not practicable until sewers had been built.

Early Disposal of Sewage.

Sewers discharging into the Chicago River and branches ultimately reached the lake except for a small amount, which from the earliest use of sewers, reached the old Illinois and Michigan canal by pumping, and thus passed to the Des Plaines and Illinois Rivers.

Illinois and Michigan Canal.

The Illinois and Michigan canal was completed in 1848. It parallels the Drainage Canal a few hundred feet to the south. Its water supply was obtained partly by gravity from the Calumet River and partly by water pumped from the south branch of the Chicago River. From time to time the pumping works were increased in capacity, which temporarily tended to improve the foul conditions in the Chicago River, and to divert some of the sewage from the lake.

Water Supply.

The water supply for the City of Chicago and for all its suburbs bordering the lake is taken from Lake Michigan. Public Water Works for Chicago began operation in 1856. Water was taken from the lake at the foot of Chicago Avenue, about one mile north of the mouth of the Chicago River. As the occupied area of the city grew it became necessary to construct additional Water Works' intakes, and as the pollution from the sewers was constantly increasing, the intake cribs were progressively located farther from the shore.

At the present time the city is supplied through six cribs varying from two to four miles distant from the shore line.

In the years of rapid municipal growth up to 1890, the sanitary conditions in the outlet streams, particularly the Chicago River and its branches, became progressively worse. Comparatively great accumulations of filth were washed into the lake, and occasionally reached the Water Works' intakes. This resulted in the general prevalence of typhoid fever, and occasional epidemics.

Drainage Canal.

We will not recite here all the steps that were taken to bring about an improvement in the sanitary conditions. These matters, while of general interest, are recited elsewhere, and bear only indirectly upon this problem. The most important step taken toward improving conditions was the passage of the State law creating the Sanitary District of Chicago and empowering it to construct the Chicago Sanitary Ship Canal, May 29th, 1889.

The Drainage Canal is twenty-eight miles long from the Chicago River at Robey Street to the Controlling Works at Lockport. It creates a reversal of the flow of the Chicago River, and in addition it draws in certain quantities of water from Lake Michigan, depending upon its controlled rate of flow. The flow is controlled at the foot of the Canal.

This work was started in 1892 and completed January 2, 1900. The flow capacity of the main channel is approximately 10,000 cubic feet per second.

In 1907 the canal was extended beyond Lockport, a distance of about four miles to concentrate an available fall of about thirty-four feet, and utilize the same in the development of a water power in dropping the canal flow down to the level of the Des Plaines River. Since the completion of this power plant it has generally formed the means for regulating the flow of the Drainage Canal, although the flow can also be regulated at the Controlling Works, four miles upstream.

In connection with the utilization of the main drainage canal it was necessary to improve the Chicago River in order to permit the desired flow without interfering with navigation. The river was widened and deepened at various places between the years 1897 and 1920. In 1910 the north shore channel was completed connecting the north branch of the Chicago River with Lake Michigan at Wilmette. At this place a pumping station was built operating at about three feet head. This canal and pumping station serves the purpose of pumping fresh water into the head of the north branch of the Chicago River, thus improving the sanitary conditions therein, resulting from the large amount of sewage received. This channel is eight miles in length and has a capacity of 1,000 cubic feet per second.

The Calumet Sag channel taps the little Calumet River at Blue Island diverting the water thereof westerly and joining the main drainage canal at Sag. This canal was completed in 1922. It has a length of sixteen miles and a capacity of 2,000 second feet.

Intercepting Sewers.

With the opening of the Drainage Canal January 2, 1900, all sewage discharging into the Chicago River and branches was diverted to the Illinois River. There remained, however, a considerable amount of sewage which reached the lake, through the sewers discharging directly therein. To stop this pollution a system of intercepting sewers along the lake shore was planned and built by the City of Chicago.

All sewage entering the lake, between the Chicago River on the north and 87th St. on the south, is now intercepted by a main sewer on Stony Island Avenue running north from 83rd St. and thence following Cornell Avenue and the shore of Lake Michigan to 39th St. At this place the 39th St. pumping station lifts the sewage to the twenty feet sewer running west on 39th St., entering the south branch of the Chicago River. This station is also equipped with pumps to take dilution water directly from the lake for the purpose of keeping the south fork of the river clean. Plans are now under way to extend the 39th St.

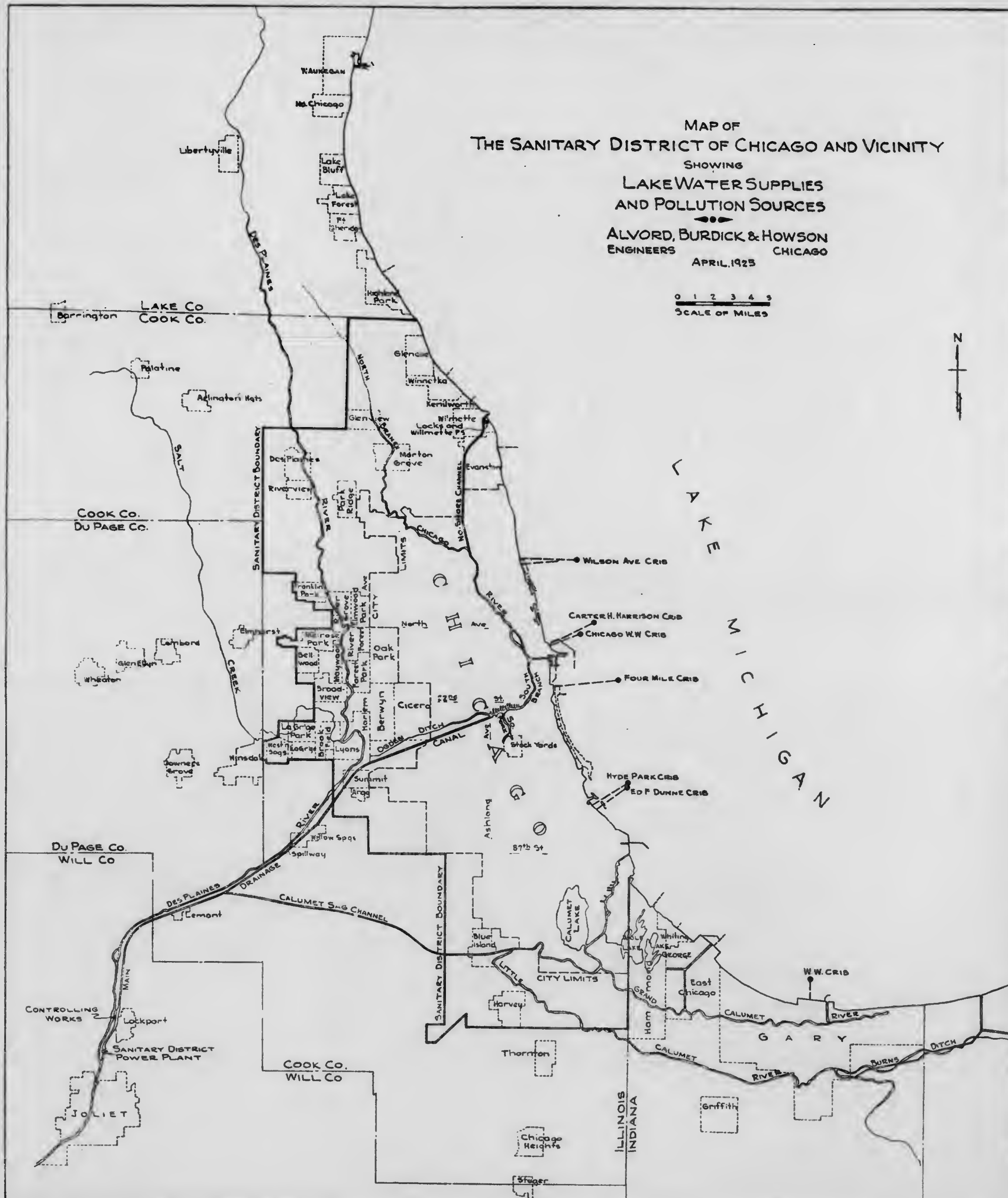


Figure 1.—Map of the Sanitary District of Chicago and vicinity.

sewer so that it will enter the drainage canal at Western Avenue near 31st St. This will obviate the necessity for dilution water in the south branch of the river. The southern part of the Stony Island Avenue district is pumped into the Stony Island Avenue sewer by pumping station constructed and operated by the City of Chicago at 73rd St. and Stony Island Avenue.

The South Side intercepting sewer was completed in 1907.

The North Side sewers entering the lake were intercepted by the construction of sewers paralleling the lake shore running north to Lawrence Avenue, and from Howard Avenue running south to Lawrence Avenue. At Lawrence and Racine Avenue a pumping station was constructed, discharging the sewage westward into the north branch of the Chicago River. This station is also equipped with pumps to draw dilution water from Lake Michigan for the purpose of improving the character of the water in the north branch of the Chicago River.

A similar system of intercepting sewers north of Howard Avenue lead to the Evanston pumping station at Orrington Avenue and Lake Street, which intercepts the remainder of the lakeward flowing sewers south of Wilmette and discharges the sewage into the north shore channel.

All sewage originating in the Sanitary District north of Wilmette is intercepted by a system of sewers terminating at the north shore channel and Sheridan Road. The Wilmette pumping station, located at this point, is equipped with pumps to draw dilution water from the lake for the purpose of maintaining cleanly conditions in the north shore channel and the north branch of the Chicago River.

The North Side intercepters, within the City of Chicago, became effective in 1908. The intercepting sewer system north of Wilmette became fully effective in 1916. The Evanston sewer and pumping station was completed in 1921.

Calumet Region.

Sewage within the City of Chicago, south of 87th Street, has heretofore been discharged directly into the Calumet River, and considerable of it still reaches the river. This will very shortly be corrected by the completion of the Calumet intercepting sewer and the pumping station at 95th Street and the Calumet pumping station at Indiana Avenue and 125th St. With the completion of these sewers all sewage south of 87th St. will be pumped into the Calumet Sag Channel after treatment, and delivered to the Chicago Drainage Canal at Sag.

The Sag Canal does not reverse the Calumet River system at all times, the flood flow of this stream greatly exceeding the capacity of the Sag Canal. Periodic discharges from the Calumet River have been a serious menace to the water supplies, particularly those near the mouth of the Calumet. This menace will continue to a greater or less extent.

TABLE 2.

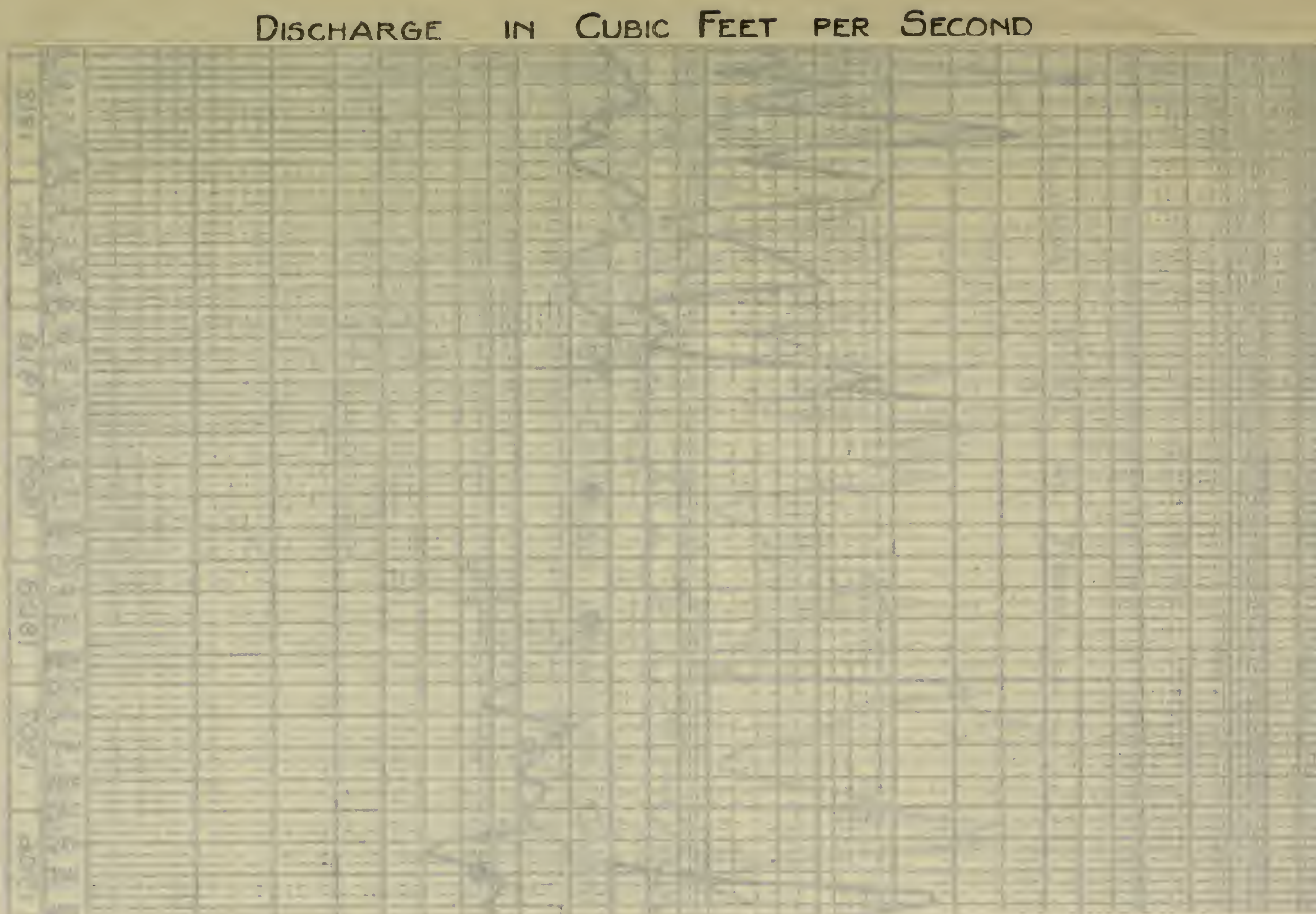
FLOW IN MAIN CHANNEL.

Year	Population	Authorized Flow by State Law Cu. Ft. per Sec.	*Actual Flow Cu. Ft. per Sec. as Corrected.
1900	1,640,000	5,467	2,990
1901	1,688,000	5,627	4,046
1902	1,736,000	5,787	4,302
1903	1,934,000	6,447	4,971
1904	1,985,000	6,617	4,793
1905	2,035,000	6,783	4,480
1906	2,090,000	6,967	4,473
1907	2,144,000	7,147	5,116
1908	2,195,000	7,317	6,443
1909	2,250,000	7,500	6,495
1910	2,308,000	7,693	6,833
1911	2,370,000	7,900	6,896
1912	2,432,000	8,107	6,938
1913	2,509,000	8,363	7,839
1914	2,589,000	8,630	7,815
1915	2,652,000	8,840	7,738
1916	2,716,000	9,053	8,200
1917	2,782,000	9,273	8,726
1918	2,846,000	9,487	8,826
1919	2,916,000	9,720	8,595
1920	2,986,000	9,953	8,346
1921	3,063,000	10,210	8,355
1922	3,143,000	10,477	8,858
1923	3,214,000	10,713	8,348
1924	3,284,000	10,947	9,465

*These quantities have been computed from the latest available data.
Note—From Report of Engineering Board of Review.

Diluting Water.

It was the original idea in the construction of the Drainage Canal that the sewage of the Sanitary District would be diluted by mixing with a sufficient amount of fresh water from Lake Michigan to render the mixture innocuous, and to assist in the natural purification of the sewage in its transit through the Drainage Canal and the river system


DISCHARGE IN CUBIC FEET PER SECOND

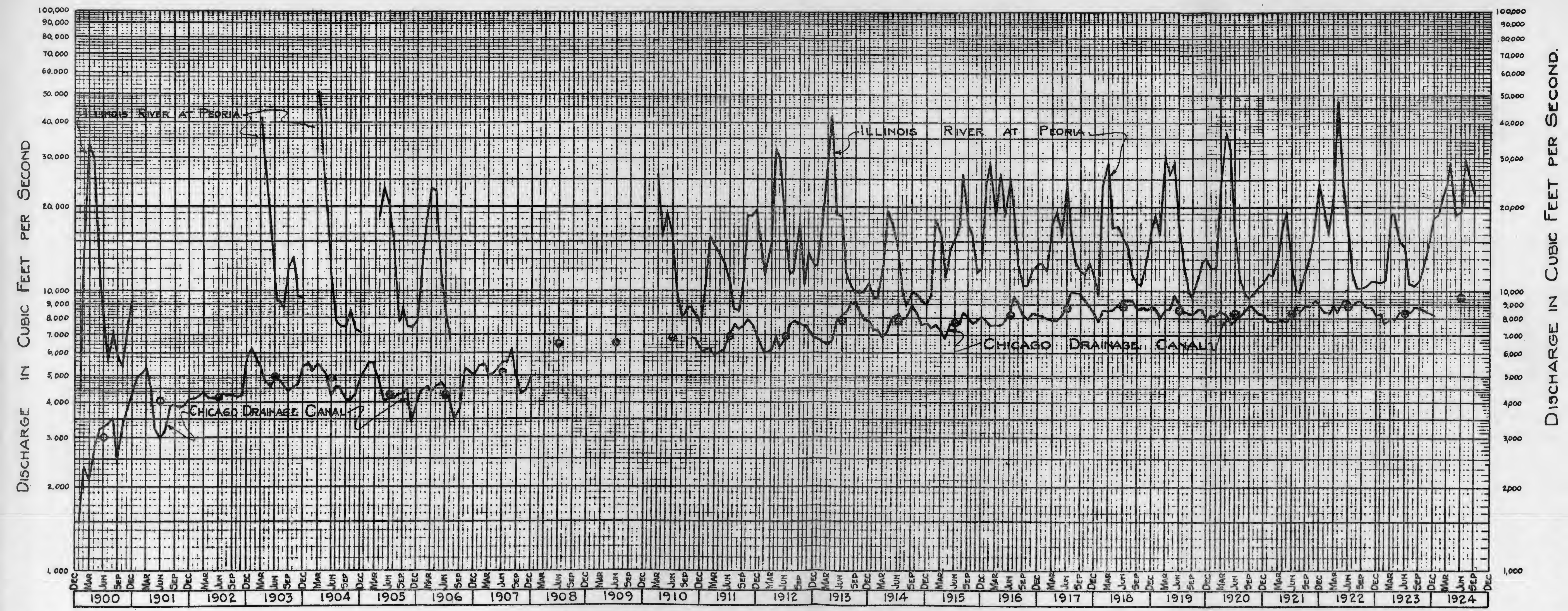


Figure 2.—Hydrograph for Chicago Drainage Canal and Illinois River at Peoria, 1900-1924.

References: Flow of Illinois River as reported by U. S. G. S. except year 1900, which is estimate by J. A. Harman.
Line marked "Chicago Drainage Canal" is average monthly flow as reported by Sanitary District of Chicago.
Dots within circles indicate average yearly flow as reported by Eng. Board of Review, Jan. 23, 1925.

below same.

Table 2 shows the average flow at the outlet of the Drainage Canal for each year since the canal was opened in 1900. This flow was limited in the early years by the ability to get the water through the Chicago River. Within the past ten years the flows have been more nearly up to the pollution requirements of the population served, but they have never been adequate to properly care for the sewage and trade wastes. The table also shows the estimated amounts of flow required by the State law creating the Sanitary District, under which a minimum dilution of three and one-third second feet per thousand people was required.

The above flows include the sewage, as well as the diversion, for dilution purposes. Water for both purposes is taken from the lake. The present liquid volume of the Chicago sewage is approximately 1200 second feet or about twelve percent of a total diversion of 10,000 second feet.

Additional Dilution.

Immediately after passing the controlling works at Lockport the Drainage Canal water joins the natural flow of the Des Plaines River. The flow of this stream during the late summer and fall is usually negligible. Large flows of fresh water are, however, brought in during the flood seasons.

Below Joliet the principal tributary is the Kankakee River, which joins the Des Plaines forming the Illinois River. The next principal tributary is the Fox.

The net effect of all these streams and other minor tributaries coming in above Peoria is indicated on Figure 2, which shows graphically the flow of the Illinois River at Peoria, and the flow of the Chicago Drainage Canal since the latter was opened in 1900. During the past ten years the flow of the Drainage Canal at Lockport has generally ranged between 8,000 and 9,000 second feet. During the two dryest months in the year the additional flow coming in above Peoria has usually ranged between ten and twenty per cent of the Drainage Canal flow. During the remainder of the typical year this additional inflow has been considerably more, possibly averaging as much as a fifty percent addition of fresh water. During several months of nearly every year the additional water coming in has been fully equal to the flow of the Drainage Canal. In certain months of heavy flow it has been four to five times as great as the Drainage Canal flow. During the year 1924, which was a year of sustained natural flow in the Illinois river, the tributaries above Peoria brought in a flow of fresh water fully equal to the Drainage Canal flow throughout the year up to and including September.

Sewage Treatment Works.

Realizing the inadequacy of dilution as a permanent solution for the Chicago sewage problem, the Sanitary District some years ago began experimentation and the preparation of plans for sewage disposal works to supplement the dilution project. Up to the present time treatment works have been built as follows:

Des Plaines River Treatment Plant.

The Des Plaines plant is located at Roosevelt Road and S. 1st Avenue, Maywood.

At this place a system of intercepting sewers terminates, draining an area of 18.5 square miles between North Avenue and 22d St., and west of Harlem Avenue. The present population served is approximately 39,000. This plant serves the towns of Maywood, Melrose Park, Forest Park, River Forest, the north part of Oak Park, and the U. S. Government Speedway Hospital.

This plant began operation in August, 1922. It consists of a pumping plant, an electric driven power plant and treatment works by the activated sludge process, including a dewatering plant for sludge. The capacity of the plant is four million gallons per day; slightly less than this amount of sewage is being treated at present.

This plant has been designed with the view to experimentation in order more effectively to plan the larger plants subsequently to be built.

Calumet Treatment Works.

The Calumet Treatment Works is located near E. 125th St. adjoining the west shore of Lake Calumet. It is intended to serve all the territory south of 87th St. Sewage will be delivered by the Calumet pumping station. Purified effluent will be discharged into the Calumet Sag Channel. The area to be served is approximately 42.5 square miles. It has a present population of 179,000 of which approximately 100,000 reaches the plant at present.

The plant consists of a system of Imhoff tanks having an estimated daily capacity of 55 M. G. D. The plant was put in operation in September, 1922. A small activated sludge plant and a small trickling filter are also in operation at this site for experimental purposes.

Other Works.

The Sanitary District includes forty-nine incorporated cities and villages, many of which are so located as to make it economical to solve their problems separately.

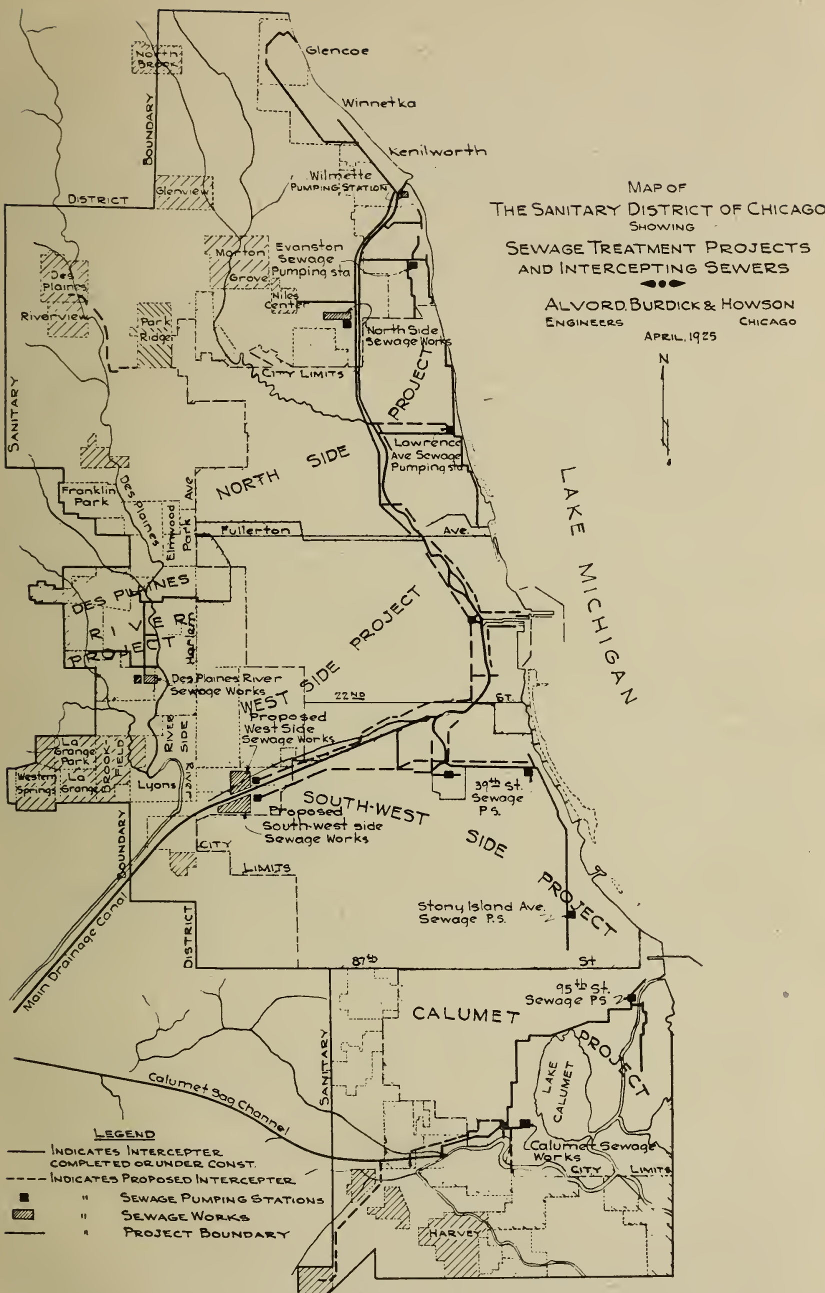


Figure 3.—Map of the Sanitary District of Chicago showing sewage treatment projects and intercepting sewers.
(Scale appox. 1 inch = 6 miles.)

The District has built, and is operating a small settling tank and trickling filter plant at Morton Grove, completed in 1914, serving 1200 people. A small plant has also been completed at Glenn View.

Minor treatment projects are proposed for the towns of LaGrange, Brookfield, LaGrange Park, North Brook, Oak Forest, Posen Robins, Upper Des Plaines Towns, Harvey and Schiller Park. Other miscellaneous plants will ultimately be required for outlying towns.

North Side Plant.

Work is now well under way covering the North side sewage treatment project located at Howard Avenue, immediately west of the North Shore Channel. This plant will consist of a pumping station, an electric driven power plant and an activated sludge plant. As now being built it will have a capacity of 175 M. G. D., and it will be subject to indefinite enlargement by the addition of units. Sludge will be pumped to lagooning beds southwest of the city.

The disposal tract covers 188 acres. The project serves all territory in the Sanitary District lying north of Fullerton Avenue. Area sixty-two square miles. Present population (1927) is approximately 737,000. The plant is scheduled for completion in 1928.

West Side Sewage Treatment Project.

This treatment project is proposed to serve an area of 57.5 square miles, embracing the heart of Chicago, and lying between Fullerton Avenue on the north and 31st St. on the south, and extending from Lake Michigan westward, including the loop district of the city. The population at the present time is about 1,340,000. The plant will be located adjoining the north bank of the drainage canal somewhere in the vicinity of South Harlem Avenue. Plans for this plant have not been made. It is tentatively proposed to use sedimentation tanks, supplemented by sprinkling filters when necessary.

Southwest Side Treatment Works.

A similar plan is proposed for the Southwest side embracing all remaining territory in the City of Chicago north of 87th St. and south of 31st St., lying south of the drainage canal. This comprises an area of 59 square miles. The population at present is about 910,000. Some parts of the district are sparsely settled.

Industrial Wastes Treatment Projects.

A very important part of the organic load contained in the Chicago sewage is contributed by certain industries, particularly the packing industries located near the head of the Drainage Canal. Also the Corn

Products Company located at Argo on the Drainage Canal and near the western city limits.

The Packing Town wastes and the Corn Products wastes are derived from comparatively small areas respectively. The wastes are highly concentrated and require special treatment. Thorough studies have been made in cooperation with the industries.

Plans have been made to treat Packing Town wastes by the activated sludge process.

Further experimentation at the Corn Products plant is now underway. The experiments to date indicate that the wastes can best be treated by sprinkling filters.

Effectiveness of Disposal Operations.

The diversion of the sewage from Lake Michigan has been followed by a remarkable reduction in typhoid fever in the City of Chicago. A number of other matters have contributed to this improvement, including the chlorination of the water supply which was begun in 1912, the pasteurization of milk begun in 1910, and also no doubt other important causes outside of the Chicago district, which have been instrumental in very greatly reducing the typhoid death rates throughout the United States. Table 3 shows these facts in tabular form.

Condition of the Lake.

Lake Michigan is still badly polluted in the Indiana Calumet region, from the Indiana cities and the periodic discharge of sewage from the southern part of Chicago, a part of which still reaches the Lake. There have also been periodic, but relatively infrequent sewage discharges from the Chicago river due to flow reversals caused by floods. Minor pollution still reaches the lake from the suburban towns north of the Sanitary District. This pollution is comparatively small, and will probably become less with improved conditions in the North Shore Sanitary District, embracing certain suburban towns north of the Cook County line.

Particularly at times of great storms the sanitary condition of the water at the Chicago intakes is very bad. This subject will be discussed hereinafter.

River Conditions.

During recent years the main channel of the Chicago River through the heart of the city, while not seriously objectionable, nearly always contains evidence of floating sewage. Conditions in the north branch of the Chicago River generally range from bad to fair, depending upon the extent of operation of the dilution pumps. The south branch of the river to the head of the Drainage Canal increases in foulness as the additional sewers join the stream. The Drainage Canal throughout its length, as would be expected, always bears evidence of the heavy sewage load carried. Odors on the banks are usually noticeable, but conditions only become very foul during the summer and early fall months.

At Lockport dissolved oxygen is normally exhausted during the warm weather season. A similar condition prevails generally throughout the Illinois River to the head of Peoria lake about ninety-six miles

TABLE 3.

ANNUAL TYPHOID FEVER MORTALITIES IN CHICAGO PER 100,000 POPULATION.

From Report of Engineering Board of Review, and Supplemented.

Years	Typhoid Fever Mortality	Percent of Total Mortality	Remarks
1867	73.3	3.45	
1868	79.3	3.34	
1869	65.3	2.82	
1870	87.4	3.66	
1871	61.0	2.92	
1872	142.6	5.16	
1873	71.6	2.85	
1874	53.4	2.63	
1875	51.7	2.62	
1876	41.2	1.96	
1877	37.0	1.98	
1878	33.4	1.97	
1879	42.3	2.41	
1880	34.0	1.63	
1881	105.2	4.03	
1882	82.4	3.49	
1883	62.2	3.12	
1884	56.2	2.84	
1885	74.6	3.98	
1886	68.6	3.53	
1887	50.3	2.48	
1888	46.7	2.38	
1889	48.4	2.67	
1890	91.6	4.61	
1891	173.8	7.20	
1892	124.1	5.68	
1893	53.5	2.47	
1894	37.5	2.06	
1895	37.9	2.14	
1896	52.6	3.23	
1897	29.3	2.00	

TABLE NO. 3—Continued.

Years	Typhoid Fever Mortality	Percent of Total Mortality	Remarks
1898	40.8	2.79	
1899	27.2	1.73	
1900	19.8	1.35	Opening of Drainage Canal
1901	29.1	2.09	
1902	44.5	3.03	
1903	31.8	2.03	
1904	19.6	1.42	
1905	16.9	1.21	
1906	18.5	1.27	Opening South Side Intercepters
1907	18.2	1.16	Completion South Side Intercepters
1908	15.8	1.09	Opening North Side Intercepters
1909	12.6	0.87	
1910	13.7	0.90	Pasteurization of Milk
1911	10.7	0.74	Completion North Shore Intercepters
1912	7.6	0.51	Chlorination of Water Started
1913	10.6	0.71	
1914	6.9	0.49	
1915	5.3	0.37	
1916	5.1	0.35	
1917	1.6	0.11	Complete Chlorination of Water
1918	1.4	0.08	
1919	1.2	0.09	Completion Evanston Intercepters
1920	1.1	0.09	
1921	1.1	0.09	Completion Calumet Intercepters
1922	1.1	0.10	
1923	1.9	0.16	
1924	1.5	0.13	

TABLE 4.

TYPHOID FEVER DEATH RATE IN FIVE-YEAR PERIOD AVERAGES, PER 100,000 POPULATION

For Cities of over 100,000 Population in Great Lakes Region.

	Chicago	Milwaukee	Detroit	Cleveland	Buffalo	Rochester	Hamilton	Toronto
1880-1884	67.8	34.4	*53.0	67.2	**53.0	34.0		65.0
1885-1889	57.8	31.8	46.0	52.6	28.8	33.0	39.4	52.8
1890-1894	96.4	32.8	43.4	51.8	44.2	34.6	24.6	62.2
1895-1899	37.6	18.0	19.4	33.4	23.4	20.2	18.2	21.6
1900-1904	29.2	17.4	22.0	56.8	29.4	15.2	15.4	19.6
1905-1909	16.6	23.0	21.6	15.2	24.4	12.4	19.4	23.0
1910-1914	10.1	22.0	18.2	12.1	17.0	10.6	14.08	21.4
1915-1919	2.9	7.48	11.3	5.6	9.0	3.76	4.52	3.7
1920-1923	1.32	1.88	5.02	2.6	4.23	2.15	3.7	2.2

*Years 1880 and 1881 not included.

**Year 1880 not included.

Note—From Report of Engineering Board of Review.

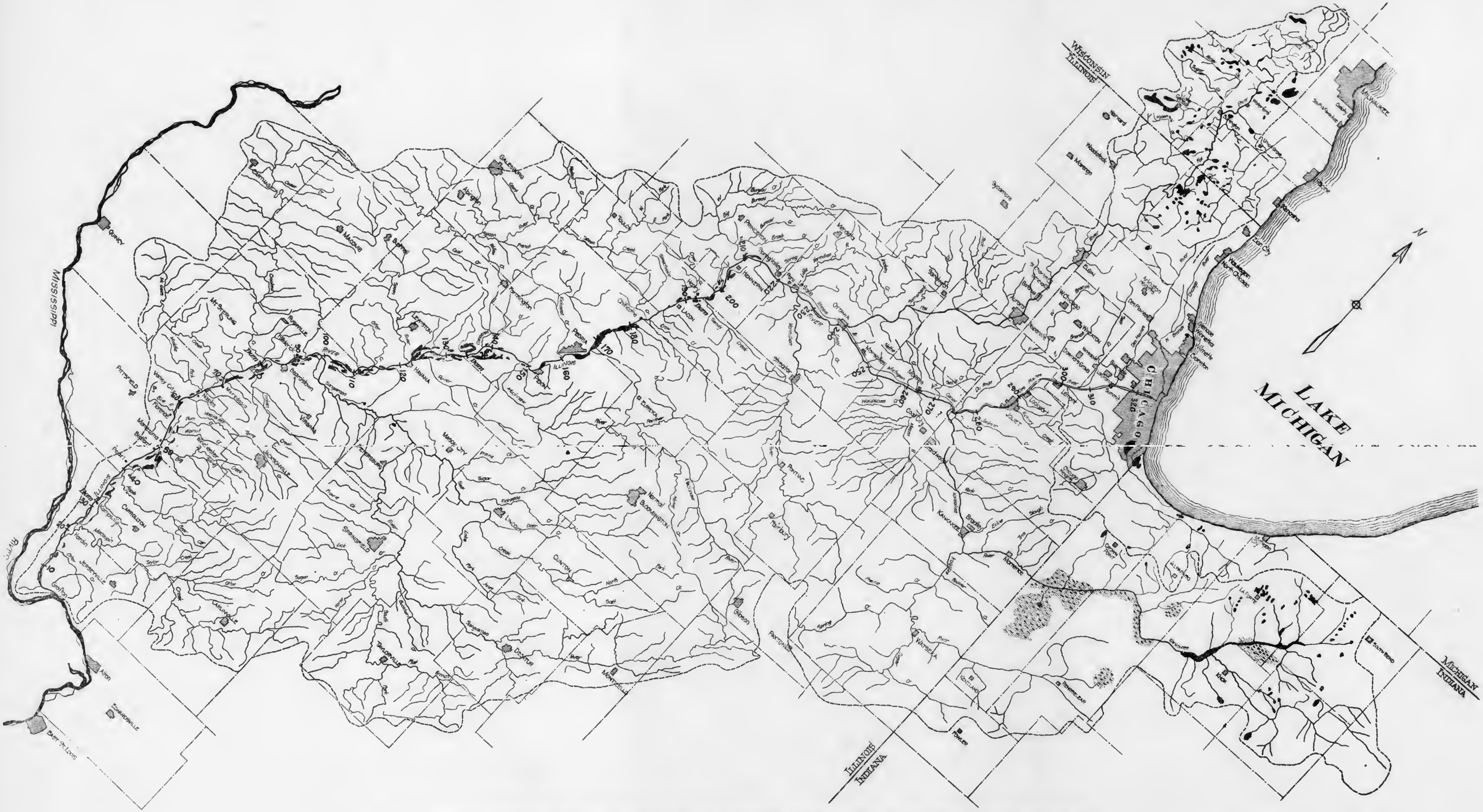


Figure 4.—Watershed of the Illinois River showing drainage areas of main stream and principal tributaries.

below Lockport. Within this reach of the streams conditions vary, as to the presence or absence of oxygen and the prevalence of putrefactive odors. For ten years or more the natural life of the river, animal and vegetable, has been destroyed. No life is present except sewage organisms. The water is not suitable for bathing and is disagreeable for users of pleasure craft.

During certain seasons objectionable conditions and the destruction of the natural water life of the stream has occurred as far south as Peoria. The wet season of 1924 has materially improved the conditions in Peoria Lake.

Conditions in the Des Plaines and Illinois Rivers, below Lockport, have been aggravated by large quantities of sewage sludge which passes down the river during the colder months of the year, comparatively in an undecomposed state, which tends to add materially to the demand on the oxygen contained in the water during the summer months, when decomposition reaches a maximum. This sewage sludge has accumulated to great depths behind dams and in other places where the current is slack during the twenty-five years that the Drainage Canal has been operating. Conditions are becoming worse with the increasing organic load discharged by the Chicago sewage and the Chicago industrial wastes.

Incidentally the river receives additional pollution although comparatively of small amount from the cities between Joliet and Peoria. At Peoria and Pekin important additional industrial wastes are added to the river. Up to the present time this pollution has been small as compared to the Chicago load.

It has been recognized, by all concerned, that the existing conditions on the Illinois River should not be permanently tolerated. For sometime it has been realized that unless corrective measures are applied promptly, these conditions will become materially worse with the further growth of the Chicago region.

The Chicago sewage problem will not be solved until the water supply of the Chicago district is adequately protected, and the streams receiving sewage are restored to a condition of reasonable cleanliness.

Analytical Studies.

The most accurate picture of the sanitary conditions in the Des Plaines and Illinois Rivers, below the outlet of the Chicago Drainage Canal, is furnished by the comprehensive study of the U. S. Public Health Service, covering fourteen months beginning July 1, 1921, and ending August 31, 1922. A complete report of this investigation has not yet been printed. There has been furnished to us, however, a series of tabulations, summarizing the principal results.

It was the purpose of this investigation to determine the extent of pollution, the character of the water at various places within the streams and the factors that particularly affect the decomposition of the organic matters discharged therein. Twenty-seven sampling stations were established between Lockport and the mouth of the Illinois River. Samples were collected daily, or, at certain points tri-weekly, from mid-depth of the stream. At the stations between Lockport and Shanahan, the latter place just above the mouth of the Kankakee, samples were collected from the center of the stream. At all stations below Shanahan samples were taken at three points from the cross section. Samples were carefully taken, iced and promptly transported to the nearest laboratory. Examination of samples was made in all cases in less than three hours. The average time was much shorter. The report of the preliminary examination states: "Due to fluctuations in the sewage strength from night to day at the outlet of the Sanitary canal, and to the variation in flow caused by opening and closing of the gates at the power plant above Joliet, it is probable that the results of analyses recorded in the tables which follow do not represent exactly the average condition throughout the day of the water at the sampling point."

The tabular data, accompanying the preliminary report, is too bulky to present in full. We summarize the principal features of it on Figures 5 to 8 inclusive. We show upon these diagrams the average dissolved oxygen for each month during the investigation at each of the sampling points. Also the five day bio-chemical oxygen demand for the same places and times. These determinations represent the character of the water from the pollution and nuisance standpoints. The bio-chemical oxygen demand is representative of the amount of organic pollution carried. The dissolved oxygen represents the possibility of local nuisance and the practicability of existence of the natural water life of the stream. Both determinations considered progressively down-stream indicate the degree of improvement in the sanitary character of the water flowing.

Winter Conditions.

We show separate diagrams intended to indicate typical conditions in the four seasons of the year. In the winter time the dissolved oxygen is high in the water taken from the lake on account of its low temperature. It will be observed that at no point between Lockport and the mouth of the Illinois does the dissolved oxygen fall below 7.5 p. p. m.; further there is very little reduction in the dissolved oxygen throughout the travel of the water from Lockport to the Mississippi. The net total effect is an increase.

The organic matter (as represented by 5 day b. o. d.) is very high at Lockport, averaging generally from twenty to twenty-four p. p. m. Near LaSalle it has been reduced about two-thirds in p. p. m. and about one-third in the total load carried by the stream, allowing for the additional dilution water coming in from the tributary streams above LaSalle. The improvement is probably due largely to sedimentation supplemented by a small amount of oxidation. Between LaSalle and

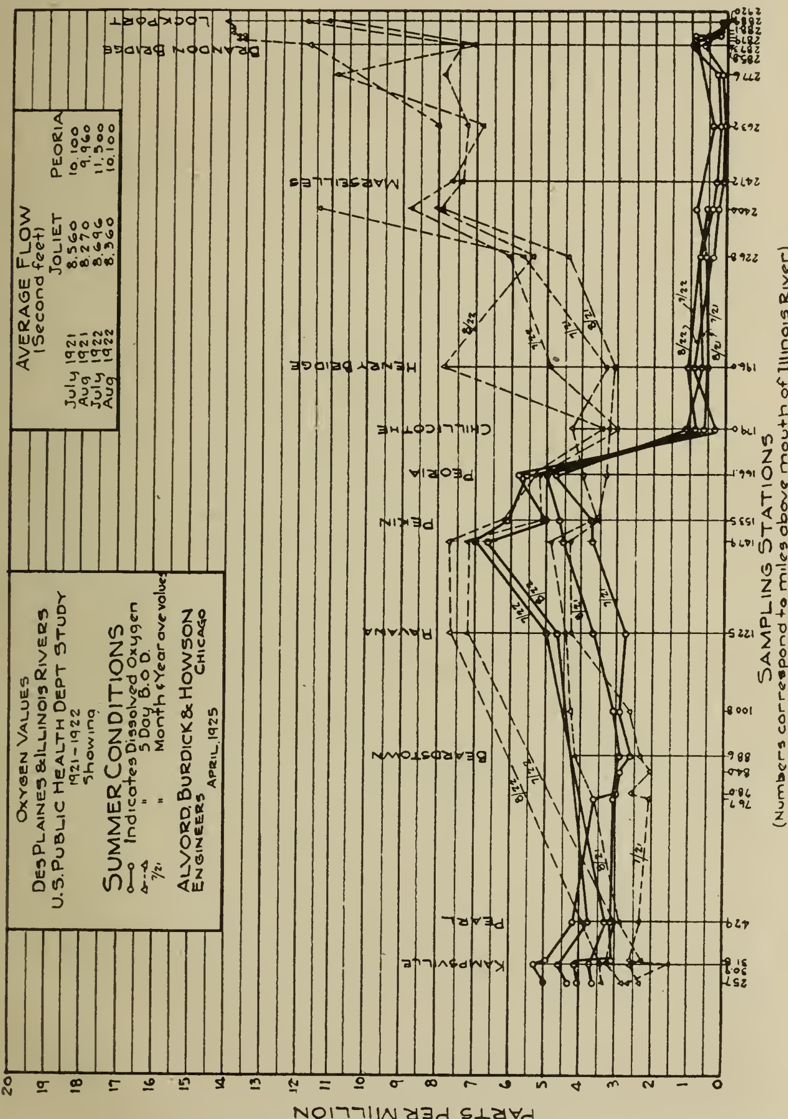


Figure 5.—Oxygen values, Des Plaines and Illinois Rivers, summer 1921-1922.

Peoria the improvement is much greater by reason of further sedimentation in the wider and deeper river between LaSalle and Peoria. The diagrams plainly show the additional pollution reaching the Illinois River at Peoria and Pekin, and the improvement of the stream below Havana. In the winter season there is apparently practically no improvement in the quality of the sewage and dilution water between Chicago and Lockport. At this season of the year each sewer drops its

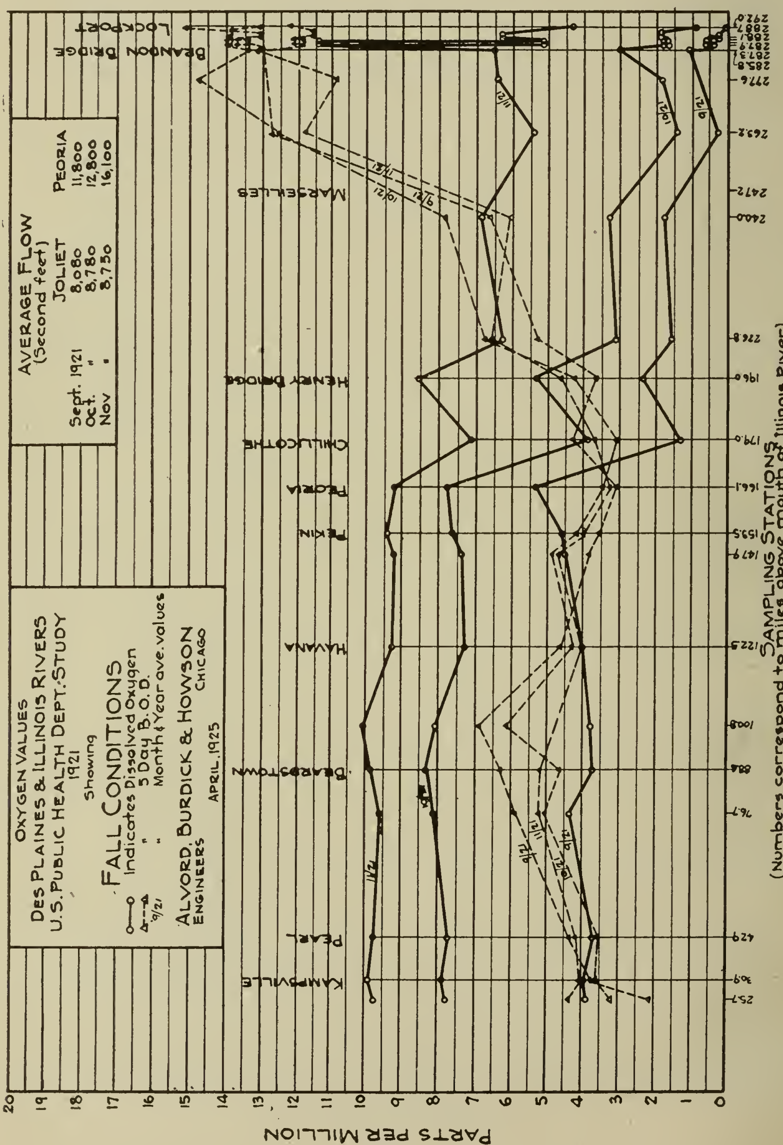


Figure 6.—Oxygen values, Des Plaines and Illinois Rivers, fall 1921.

load into a stream of ice cold lake water. Practically speaking, the sewage travels in cold storage to Lockport and throughout its course to the Mississippi River. Apparently the principal improvement in the character of the stream is due to sedimentation.

Summer Conditions.

The summer conditions present a very different picture. At this season of the year organic decomposition reaches its maximum, producing a heavy demand on the oxygen in the stream with a tendency to produce putrefactive conditions with attendant odors and a reduction in the oxygen to the point where the natural water life of the stream may be suffocating.

At this season the mixture of sewage and lake water, as delivered at Lockport, has an organic load slightly more than half that contained in the winter season (5 day b. o. d.). This probably results from oxidation and septic action in the Drainage Canal above Lockport, the

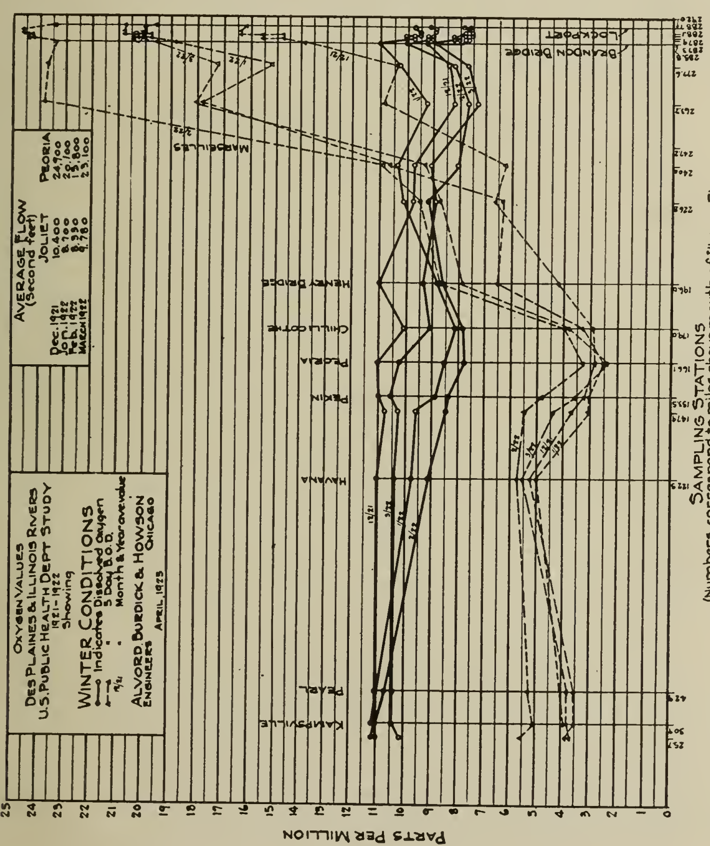


Figure 7.—Oxygen values, Des Plaines and Illinois Rivers, winter 1921-1922.

result of the decomposition being carried away partly in gases and partly in inert matter carried along with the water in suspension. At this season oxygen is practically exhausted in the Drainage Canal between Chicago city limits and Lockport. It does not exceed 1 p. p. m. at any place above Chillicothe, 110 miles below Lockport. Between Chillicothe and Peoria the stream rapidly recovers its oxygen in its traverse through Peoria Lake. This is due to the reduction in organic

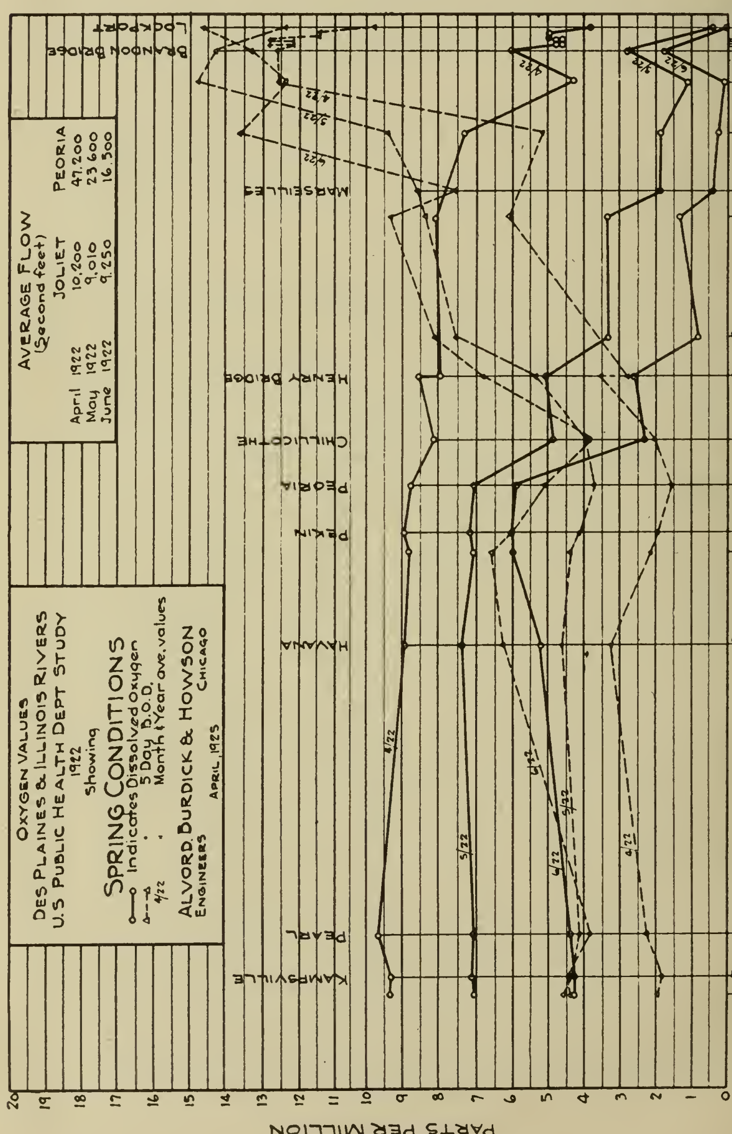


Figure 8.—Oxygen values, Des Plaines and Illinois Rivers, spring 1922.

matter that has taken place up-stream, oxygen absorption from the atmosphere on the large surface of Peoria lake, and the product of oxygen-producing aquatic vegetation. Below Peoria and Pekin there is a further draft upon the oxygen resulting from added pollution. It is considerably reduced at the mouth of the Illinois. From Peoria to the mouth, however, the Illinois River contains sufficient oxygen to permit a thriving natural water life. The reduction in the organic matter (5 day b. o. d.) is somewhat greater than in the winter time, taking into consideration the comparatively small amount of diluting water coming in from the natural streams below Joliet. The organic load has been reduced nearly two-thirds from Lockport to Peoria. It suffers a large increase at Peoria and Pekin and is again reduced in traveling to the mouth of the stream.

As would be expected, from the absence of oxygen, between Lockport and Chillicothe the river is in a very foul condition. It is entirely devoid of natural stream life. It is possible for sewage organisms only to live in this water. Below Chillicothe the rapid increase in the dissolved oxygen creates a very different condition. Below Peoria in 1921-22 conditions probably permitted the presence of fishes of all kinds naturally inhabiting the stream.

Spring and Fall Conditions.

The spring and fall conditions typify the transition from the winter conditions to the summer conditions, and from the conditions of summer to the conditions of winter. This is due to the gradually warming water in spring as summer is approached, and the gradual chilling of the water between September and November. This effect is plainly evident on Figures 6 and 8. Each diagram carries a tabular statement of flow from Joliet to Peoria. Attention is invited to the month of April, 1922, in which the flow at Peoria was nearly five times the flow at Joliet.

The effect of this additional dilution water is evident in the reduced organic content (5 day b. o. d.) at Peoria. Allowing for this dilution the total organic load of the stream at Peoria is apparently reduced to fifty percent as compared to the vicinity of Lockport, indicating that the agencies of oxidation and possibly sedimentation persist in floods.

Past Conditions—Illinois and Des Plaines Rivers.

What has been said above typifies as accurately as possible conditions which prevail at present. These conditions have been progressively growing worse since the Drainage Canal began to operate in 1900.

The following is quoted from a recent statement of Dr. Stephen A. Forbes, Chief, State Natural History Survey Division, Illinois Department of Registration and Education:

"A serious and practically continuous study of the system of the plant and animal life of the Illinois River was begun by the State Natural History Survey of Illinois in 1894 and has been continued with only one important interruption to the present year. The actual periods of active field operations on the river were as follows: 1894-1899 inclusive, 1901-1903, 1909-1912, 1913-1915, 1918, 1920, and 1922-1924. The interval of five years after 1903 was given mainly to the preparation and publication of a final report on the fishes of the State.

"We have had from the very beginning until now the continuous co-operation of the Water Survey of the State, upon which we have depended for chemical tests and analyses, and for bacterial data.

"Our reason for so prolonged attention to a single subject is found in the progressive changes in the stream itself, its content, and its environment, which have worked corresponding changes in the aspect and internal order of its biology, requiring frequent repetition of our studies and a consequent revision of our conclusions. The most important of these changes have been the introduction of the European carp in 1885 and its enormous multiplication until it has become more abundant than all the other fishes of the stream taken together; a general diking and reclamation of the very extensive bottomlands of the river and the draining of their numerous lakes; and a rapidly increasing pollution of the stream by sewage wastes from towns on its banks, and especially from the Sanitary District of Chicago. It is a very difficult matter to disentangle these several causes of change in a way to distinguish clearly their separate biological aspects. There was, for example, a large and rapid increase in the fisheries yield of the river at about the time of the opening of the sanitary canal in 1900, sometimes attributed to the canal itself, but largely due to a rapid multiplication of the carp before 1900; and there has been of recent years a general falling off in the fisheries yield coincident with increasing pollution of the stream, but this is in great measure consequent upon a restriction of the overflow of levees and the draining of the lakes.

"In this confusion of causes and effects, it is quite impossible to show clearly and fully just how and to what extent the remarkable fisheries yield of the river, amounting in 1908 in prices paid to fishermen, to a dollar for every two feet of its length, has been affected by sewage pollution, but I must do what I can to this end in the brief time alloted.

"The injurious biological effects of pollution of the Illinois River by raw sewage from Chicago have, of course, varied widely according to a number of local and temporary conditions. Being greatest at the upper end of the river at mid-summer temperatures, and at low water, and increasing with the population of the Sanitary District and with the activity of operations at the Chicago Stock Yards, they have diminished downstream, with lower temperatures of the advancing season, and with the rise of the river levels. At their worst they have destroyed or driven from the upper Illinois all its clean-water plants and animals, including, of course, its fishes, substituting for them those normal to septic or pollutional conditions. In the mid-summer of 1911 the upper ten miles of the river were practically a septic tank, the gases of the bottom sludges being 79% methane; 19% carbon dioxide; 1.02% nitrogen; 0.56% carbon monoxide; 0.03% oxygen. There were no fishes in that part of the stream, or for many miles below, and no mollusks or crawfishes on the bottom, the only animals there being sludge worms, certain midge larvae, and other foul water forms able to live without oxygen on the crude sewage precipitates. From this extreme condition there was a gradual shading off downstream until at a distance of sixty to seventy miles from the point of entrance of Chicago sewage the plant and animal life of the stream was virtually normal. Seven years later, however, that is, in 1918, pollutional conditions had moved downward some 60 miles farther, the river being at this time nearly deserted by fishes as far as the Peoria lakes, 93 miles down the stream, characteristic sewage organisms having extended their range in thrifty condition to 77 miles from its origin, and the areas of offensive pollution, distinguished by a stinking sludge containing an abundance of sewage worms and no clean water organisms, had moved downstream from Ottawa to Lacon, a distance of 51 miles.

"An expansion of the river 17 miles long and up to a mile in width, known as Peoria Lake, (although really a chain of three lakes connected by so-called narrows) served as a partial barrier to a further extension of the conditions of the upper river until the period of the world war when, coincident with an enormous increase in the organic wastes of the Chicago stockyards, these pollutional conditions were still further extended and intensified, culminating in 1920 in a virtual extermination of the original life of the river bottom as far down as Peoria Lake and in the lake itself and in the substitution for it of plants and animals usually to be found only in heavily polluted water.

"With the close of the war and a diminished outpouring of stockyards sewage, there has been a noticeable improvement of conditions in Peoria Lake, although in 1922 they were still far below their pre-war status; but in this year 1924, which has been characterized by an extraordinary high water level of unexampled long continuance, Chicago sewage has been so far diluted that fishes have ascended the stream to LaSalle, 60 miles above Peoria and only 50 miles from the river head.

"There seemed at one time to be good general ground for believing that the addition of household sewage to a stream might increase its fisheries yield, especially where, as in the Illinois River, this addition was made far enough above the more productive fishing grounds to permit the oxidation of nitrogenous materials and their conversion into forms available as food for fishes young or old, but our more recent computations show that there has always been an abundance of food in the Illinois River for a much larger stock of fishes than it carried—that the food supply, in other words, has not been the limiting factor in the river fishes, and that an increase of it consequently could not be a benefit.

"The product of this present season's operations on the river has not yet been sufficiently worked up to give us more than fragments of the biological picture, but one feature may be of special interest to sanitary engineers. We found in the summer of 1911 that heavy rains at a given point, followed by a rise in the river, increased the organic contents of the water and diminished the ratios of dissolved oxygen, the latter effect being continued downstream as putrefaction increased, so that oxygen ratios were actually diminished downwards instead of increasing as they usually do; and this effect of local contamination by washing rains was still more clearly shown this summer by bacterial data contributed by the State Water Survey. Taking, for example, two points below Peoria which were six miles apart with a tributary stream between them; on July 31 the water at the uppermost of these points averaged 8000 bacteria to the c. c. and that at the lower point 32,000, while on August 8, soon after a very heavy rain, when the upper count was 4,000 instead of the former 8,000, the lower count was 120,000 instead of the former 32,000, this jump in numbers being evidently due to the muds swept in from the tributary after the storm.

"Time fails me to attempt to follow the effect of Chicago pollution beyond the wide water of Peoria Lake, where the situation becomes complicated, indeed, by a heavy addition of fresh sewage from Peoria itself and from the city of Pekin, 9 miles below, and it is certain that in 1920 this lake barrier was being forced and that the life of even the lowest of the chain of three was far from normal—that the lakes were delivering to the river beyond a considerable part of the load of trouble which they had received from above."

It is impracticable definitely to show the progressive deterioration in the quality of the water in the Illinois River throughout the entire period during which the Drainage Canal has been contributing flow, for the reason that during this period of twenty-five years the technique of water analysis has changed so that results cannot be compared numerically. No such comprehensive studies as that undertaken by the U. S. Public Health Service have been made. More or less fragmentary studies, however, indicate the increasing pollution with the growth of the population and industries in Chicago.

We show on Figure 9 a series of dissolved oxygen readings made by the State Water Survey covering six round trips between July 22nd and September 11th, 1911, a single trip between July 11th and July 13th, 1912, a single trip between August 28th and September 3rd, 1918, and four round trips between July 15th and September 17th, 1920. This diagram indicates that in 1911 the summer oxygen content was fairly satisfactory up-stream as far as Marseilles. In 1918 and 1920 the conditions were very similar to those typified by the Public Health studies as far south as Chillicothe.

Ice Conditions.

Although the conditions on the Illinois River during the winter are generally favorable as regards nuisance, and not particularly detrimental to the natural life of the stream, yet occasionally protracted cold weather and an unusually extensive covering of ice brings about unfavorable conditions During the winter of 1924 and 1925 this unfavorable condition prevailed.

An investigation under the direction of Dr. Forbes brought out the following facts. In Clear Lake, below Pekin, the dissolved oxygen content of the water varied from 0.4 to 1.8 p. p. m. All kinds of fish were found to be dead in set nets and also under the ice outside of the nets. At Quiver Lake, just above Havana, where the water contained 2.5 p. p. m. a river seine hauled under the ice gave carp, buffalo and gars;

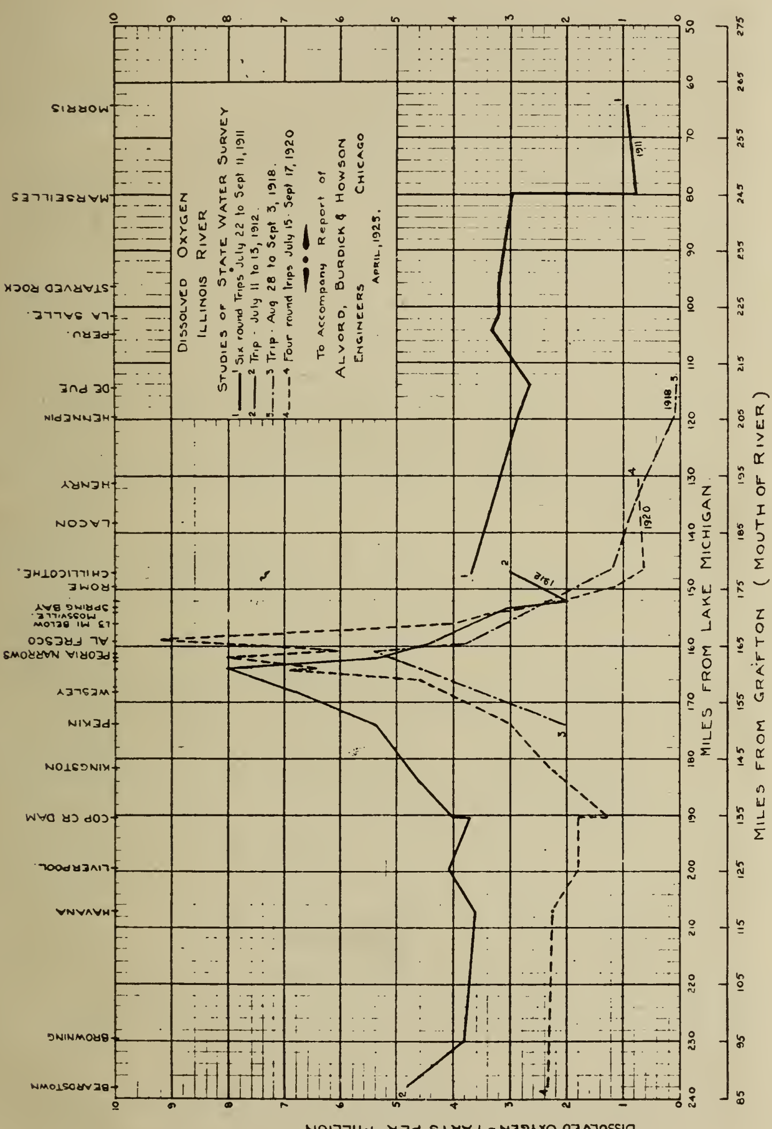


Figure 9.—Dissolved oxygen, Illinois River, 1911-1920.

all stupid, pallid in color and of a disagreeable odor called "gassy" by fishermen, characteristic of fish taken from polluted water. At Treadway Lake, near Meredosia, where the oxygen content was 5.4 to 5.8, practically the entire variety of river fish were being taken in hoop nets, all in good condition.

Similar conditions were noted by the State Natural History Survey in 1912. This condition unfavorable to fishes is brought about through organic pollution in the water, coupled with the inability of the stream to replenish its oxygen supply from the air. That these conditions are due to sewage pollution is shown by recent observations of Dr. Forbes' department, referring to Clear Lake, Quiver Lake, Coleman and Treadway Lakes. Also in Quiver Creek. Clear Lake is the farthest upstream and contains only river water which begins to enter into it when the river is three and one-half or four feet above low water mark at Peoria. Conditions there were as previously described. Quiver Lake receives water continually from the river, but also from Quiver Creek, an unpolluted stream. Its condition is consequently not so deadly as that of Clear Lake, although the mass of its water comes from the river.

Treadway and Coleman Lakes are 8 or 9 miles above Beardstown, on the same side of the river and a little distance below the mouth of the Sangamon, an unpolluted stream, from which they receive a large part of their water.

Investigations in the above lakes show a gradation from practical complete destruction of fish under the ice at Clear Lake, most open to pollution, to normal conditions at Coleman and Treadway Lakes, also frozen over but filled mainly with Sangamon River water. The Quiver Creek, tributary of Quiver Lake, is reported to have shown 11.9 to 12.3 of oxygen, and to have yielded in hoop nets put down over night vigorous and active European carp, native carp, or quill-back, buffalo, gars, channel cat, bullheads, black bass, striped bass and sheepshead, a good variety of ordinary fish in good condition.

Thus it will be noted that the fish which were in distress were occupying polluted waters, and were apparently not affected by the unpolluted streams, even although the same were ice bound.

In this connection it should be noted, however, that in natural lakes and rivers, unpolluted by sewage, the exhaustion of oxygen and the distress of fishes may occur under the ice due to the decomposition of vegetable organisms. The distress of fish in the ice bound condition of the stream was observed upon the Illinois River prior to 1900. This situation may or may not have been brought about by sewage contamination. While the stream did not receive a large pollution from Chicago it was rather heavily polluted at Peoria, which may have contributed to the un-

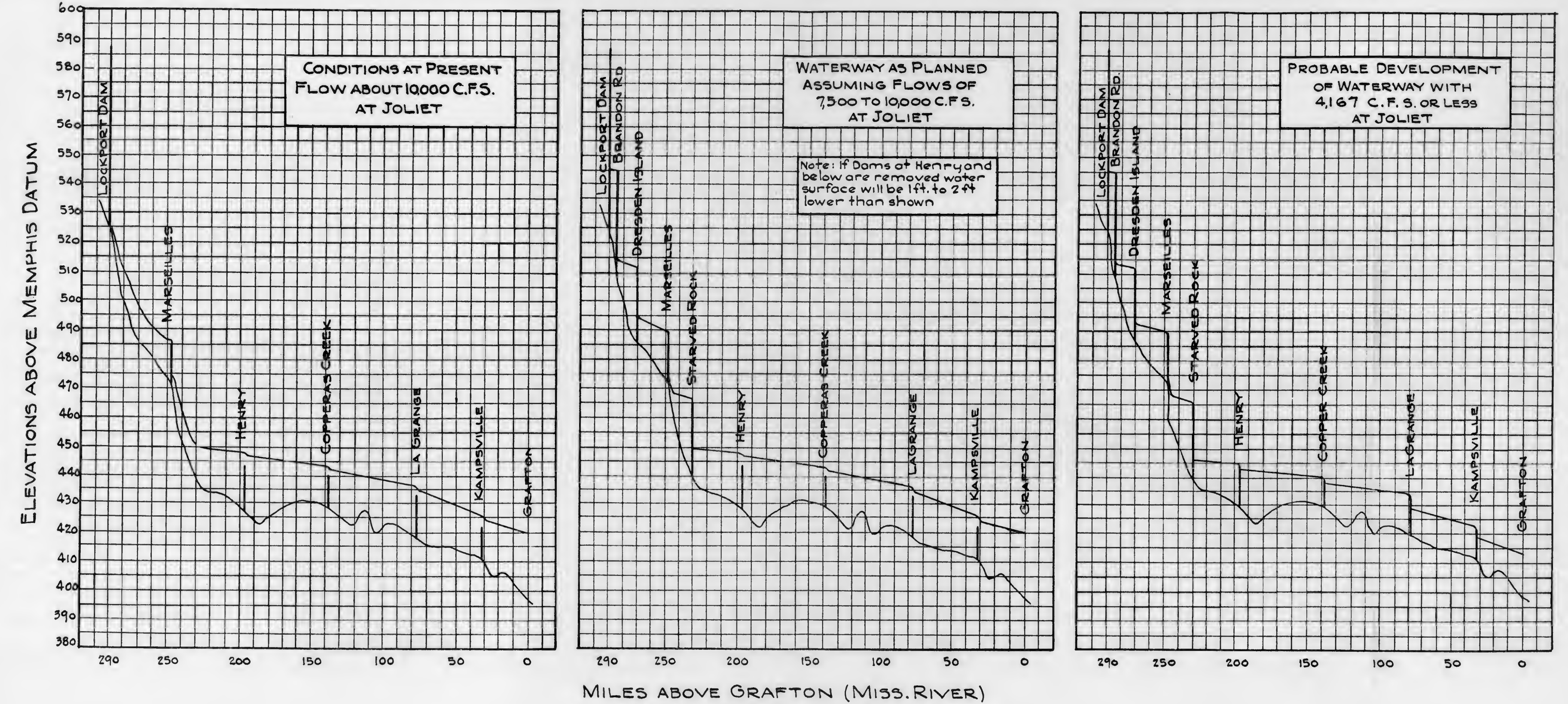


Figure 10.—Profile of Illinois and Des Plaines Rivers.

favorable conditions noted. Relatively speaking the river as a whole was an unpolluted stream at that time.

Future Effect of Water-Way Improvement.

When the Illinois water-way is built some changes will be brought about in the river conditions, principally between Lockport and LaSalle. In this reach of the Des Plaines and Illinois Rivers it is proposed to improve the same on the basis of slack water navigation. To accomplish this purpose dams will be constructed at Brandon Road, Dresden Island, Marseilles and Starved Rock. The pond created by each of these dams will extend to the foot of the next dam up-stream.

At the present time the water occupies a period of about thirty-seven hours in its passage from Brandon bridge to LaSalle. Except for the pond created by the present Marseilles dam the current is rapid and conditions are favorable for the absorption of atmospheric oxygen.

After the construction of the water-way based on present plans, contemplating a flow of about 10,000 second feet, the time of travel between Joliet and LaSalle will be increased to about 66 hours. The water surface area in this reach of the stream is about 10.5 square miles at the present time. The dams will increase it to about thirteen square miles.

Below LaSalle the flow of water is much less rapid. Six and one-half days is at present required for it to flow from LaSalle to Peoria. The total time of flow from Joliet to the mouth of the Illinois River is about thirteen days at summer stages with present flows.

With the improved water-way assuming a flow of 10,000 second feet conditions below LaSalle will not be greatly changed. Proposed plans contemplate water surface elevations which differ not greatly from those prevailing at present. With this flow, however, the existing dams will probably be taken out.

Thus the net result of the construction of the water-way will be practically to double the time of travel from Joliet to LaSalle, and to increase the area of water surface about twenty-five percent. Below LaSalle conditions will remain about as at present.

Conditions with Smaller Diversions.

If the diversion of water from Lake Michigan is very much below 10,000 second feet the plan for the Illinois water-way will probably require the retention of the present dams below LaSalle. Above LaSalle the dams contemplated under a 10,000 second foot flow would probably be unchanged, and the existing areas would not be greatly altered as compared to the larger flow. The time of travel, however, would be increased approximately in an average ratio to the quantity of water flowing.

Rough approximations of the time of travel, assuming various quantities flowing in the stream would be as follows:

TIME OF TRAVEL IN DAYS.

	Joliet to LaSalle	LaSalle to mouth of Illinois River
10,000 feet per second	2.7	14.5
8,500 " " "	3.2	17
7,500 " " "	3.6	19
4,167 " " "	6.4	35
2,000 " " "	13	73

It is believed that the net effect of the construction of the waterway will be to introduce into the Illinois River a series of four ponds above LaSalle, which may be expected to have a similar effect to that now produced in Lake Peoria. It is believed that the net effect upon the stream under present pollution and diversion conditions would be to throw the "dead line" now existing near Peoria Lake much further upstream.

PART III

POPULATION AND GROWTH.

Chicago has grown from a frontier trading post to the third city of the world within a period of ninety years. It is the commercial and transportation center of the largest and richest agricultural community on this continent. Its position is such, as regards lines of communication, that it will continue to be the hub of interior America. Its future development must inevitably follow the development of a vast interior region, the limits of growth for which cannot be predicted.

In planning sewage disposal works for this great industrial center, it obviously will be wise to plan for a larger future growth. It is not financially practicable, however, nor is it wise to build very far in advance of immediate requirements. It is practicable, however, to plan for future growth, and to build upon a unit system so that units may be built a little in advance of need. If the plan is wisely made each unit so built will be permanently useful. It will constitute a link in a future chain of sewage disposal works. Thus each dollar invested will be a permanent investment. If the growth is more rapid than anticipated, units can be added more rapidly, and assessed valuations will be available to meet the necessary charges. If growth is less rapid than is anticipated, works constructed from year to year will be useful for a longer time.

Population—Sanitary District:

The Sanitary District of Chicago includes fifty-two towns and villages lying within Cook County, Illinois. The population by 1920 census was 2,978,635, of which 2,701,705 or ninety-one percent was resident within the corporate limits of the City of Chicago. Table 5 is a statement of the population within the present boundaries of the Sanitary District in the census 1900 to 1920 inclusive. Within this period the population of the district increased sixty-seven percent. The outlying towns and villages practically trebled in population during the two decades.

Greater Chicago Region:

Since 1900 municipal growth has extended beyond the Illinois border line into Northern Indiana, in which a great industrial region is developing, served by numerous main lines of railroad and new lake harbors, which have been built at Gary and East Chicago. Improved labor conditions in the outlying localities, adjacent to Chicago, have favored the location of certain industries, on the borders of the city limits, and in certain cities outside of Cook County. The greater Chicago region, as defined by U. S. census, includes Cook, Kane, DuPage, Lake and Will Counties in Illinois and Lake County in Indiana. The total population of this region was 3,521,789 in 1920. It had increased seventy-five percent in the two decades following 1900. Table 6 shows the population within this region for each county for the last three census years. As will be noted the Sanitary District of Chicago includes approximately eighty-five percent of the total population of the greater Chicago region.

TABLE 5

POPULATION OF CITIES AND VILLAGES IN THE SANITARY DISTRICT OF CHICAGO

Name	Population 1900	1910	1920
Bellwood (village)	....	943	1,881
Berwyn (city)	....	5,841	14,150
Blue Island (city)	6.114	8,043	11,424
Broadview (village)	....	....	430
Brookfield (village)	1,111	2,186	3,589
Burnham (village)	....	328	795
Burr Oak (village)	....	....	1,237
Chicago (city)	1,698,575	2,185,283	2,701,705
Cicero (town)	16,310	14,557	44,995
DesPlaines (village)	1,666	2,348	3,451
Dolton (village)	1,229	1,869	2,076
Elmwood Park (village)	....	....	1,380
Evanston (city)	18,721	25,668	37,234
Evergreen Park (village)	445	424	705
Forest Park (village)	4,085	6,594	10,768
Franklin Park (village)	483	683	914
Glencoe (village)	1,020	1,899	3,381
Glenview (village)	....	652	760
Harvey (city)	5,395	7,227	9,216
Cook County	....	....	127
Hinsdale (village) (DuPage County)	2,578	2,451	3,975
Kenilworth (village)	336	881	1,188
LaGrange (village)	3,969	5,282	6,526
LaGrange Park (village)	730	1,131	1,684
Lyons (village)	951	1,483	2,564
Maywood (village)	4,532	8,033	12,072
Melrose Park (village)	2,592	4,806	7,147
Morton Grove (village)	564	836	1,079
Mount Greenwood (village)	190	276	1,441
Niles (village)	514	569	1,258

Niles Center (village)	529	568	763
Northbrook (Schermerville) (village)	....	....	554
North Riverside (village)	....	....	....
Norwood Park (township)	3,447	5,251	6,897
Oak Park (village)	....	19,444	39,858
Park Ridge (city)	1,340	2,009	3,383
Phoenix (village)	....	679	1,933
Posen (village)	....	343	947
Riverdale (village)	558	917	1,166
River Forest (village)	1,539	2,456	4,358
River Grove (village)	333	418	484
Riverside (inc. N. Riverside) (village)	1,551	1,702	2,532
Riverview (village)	406	312	334
Robbins (village)	....	....	431
Schiller Park (village)	....	....	390
South Holland (portion village)	766	1,065	1,247
Stickney (village)	....	....	550
Summit (village)	547	949	4,019
Tessville (village)	....	359	355
Western Springs (village)	662	905	1,258
West Hammond (Calumet City) (city)	2,935	4,948	7,492
Wilmette (village)	2,300	4,943	7,814
Winnetka (village)	1,833	3,168	6,694
Total population	1,788,278	2,338,278	2,978,635
Total population, excluding Chicago	89,703	152,995	276,930

TABLE 6

POPULATION OF THE CHICAGO METROPOLITAN DISTRICT

County	1900 Census	1910 Census	1920 Census
Cook	1,838,735	2,405,233	3,053,017
Kane	78,792	91,862	99,499
DuPage	28,196	33,432	42,120
Lake	34,504	55,058	74,285
Will	74,764	84,371	92,911
Lake (Ind.)	37,892	82,864	159,957
Total	2,092,883	2,752,820	3,521,789

Chicago Growth Compared to Other Cities:

We show on Figure 11 a diagrammatic representation of the growth of Chicago with a comparison of the growth of London and New York, the only cities which exceed it in population; also several other cities. It will be observed that the rate of growth of Chicago has been exceeded only by that of New York, which has been largely influenced by annexations. Figure 12 is a similar diagram showing a little more clearly the growth of the Chicago region, as compared to

London and New York, the population of these two cities being platted for the several decades immediately before and after the time when they passed the three million mark, without regard to the year.

Within the past ten years there have been several comprehensive studies of the future growth of Chicago and vicinity; more particularly the studies for the Chicago Traction Commission, the Commission on Smoke Abatement and also several studies concerning the improvement of the Chicago Water Works. The Chicago Telephone Company necessarily keeps itself quite accurately informed as to the probable requirements for the extension of its service. It has recently made a study of the growth of the Chicago region.

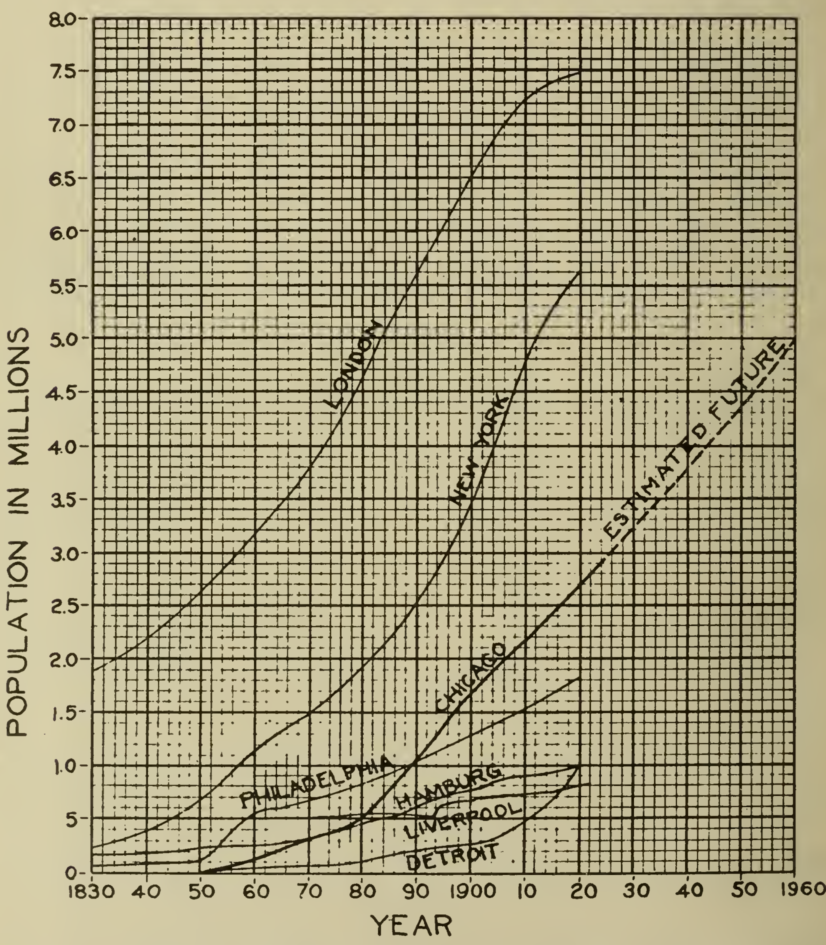


Figure 11.—Population growth of Chicago and other large cities, with city engineer's forecast for the city of Chicago.

All these investigations substantiate, with reasonable accuracy, the figures which have been prepared by the Sanitary District of Chicago, as representing the most probable future population of the Sanitary District so far as it can be determined in the light of past growth and recent development in this region.

Forecast of the Sanitary District:

We show diagrammatically on Figure 12 the forecast of the Sanitary District for the population within the Sanitary District up to the year 1970. In designing sewage purification works it will be important

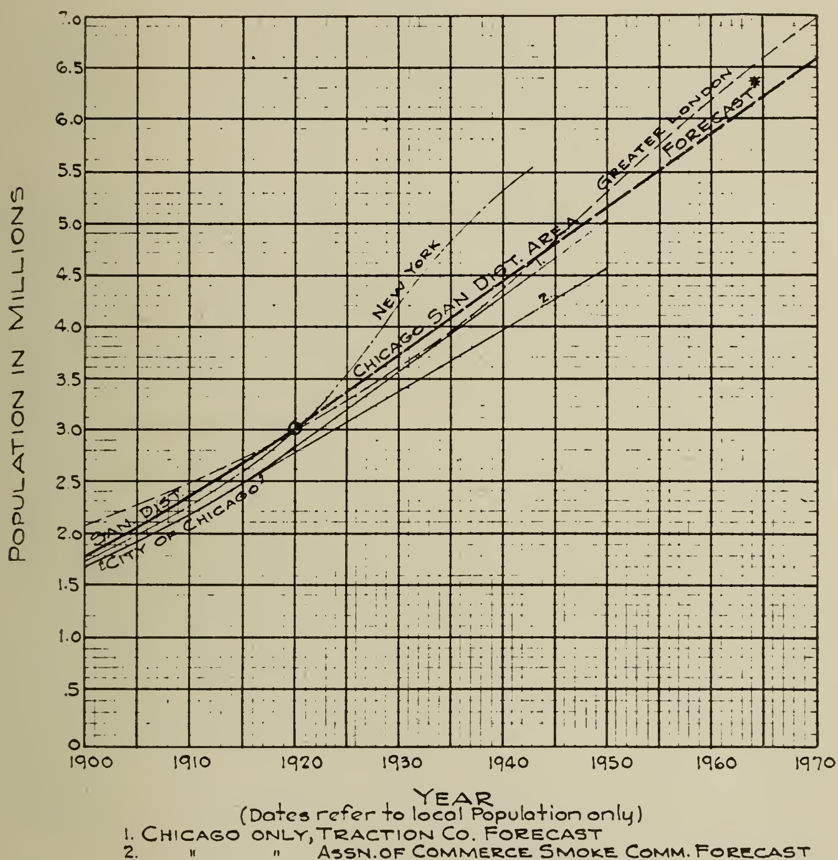


Figure 12.—Population growth and forecast for the Sanitary District of Chicago and City of Chicago in comparison with growth of other large cities. (Dates refer to local population only).

1. Chicago only, Traction Co. forecast.
2. Chicago only, Assn. of Commerce Smoke Comm. forecast.

*Note—Estimate of the Sanitary District of Chicago.
Greater London population 3,000,000 in 1857.
Greater New York population 3,000,000 in 1895.

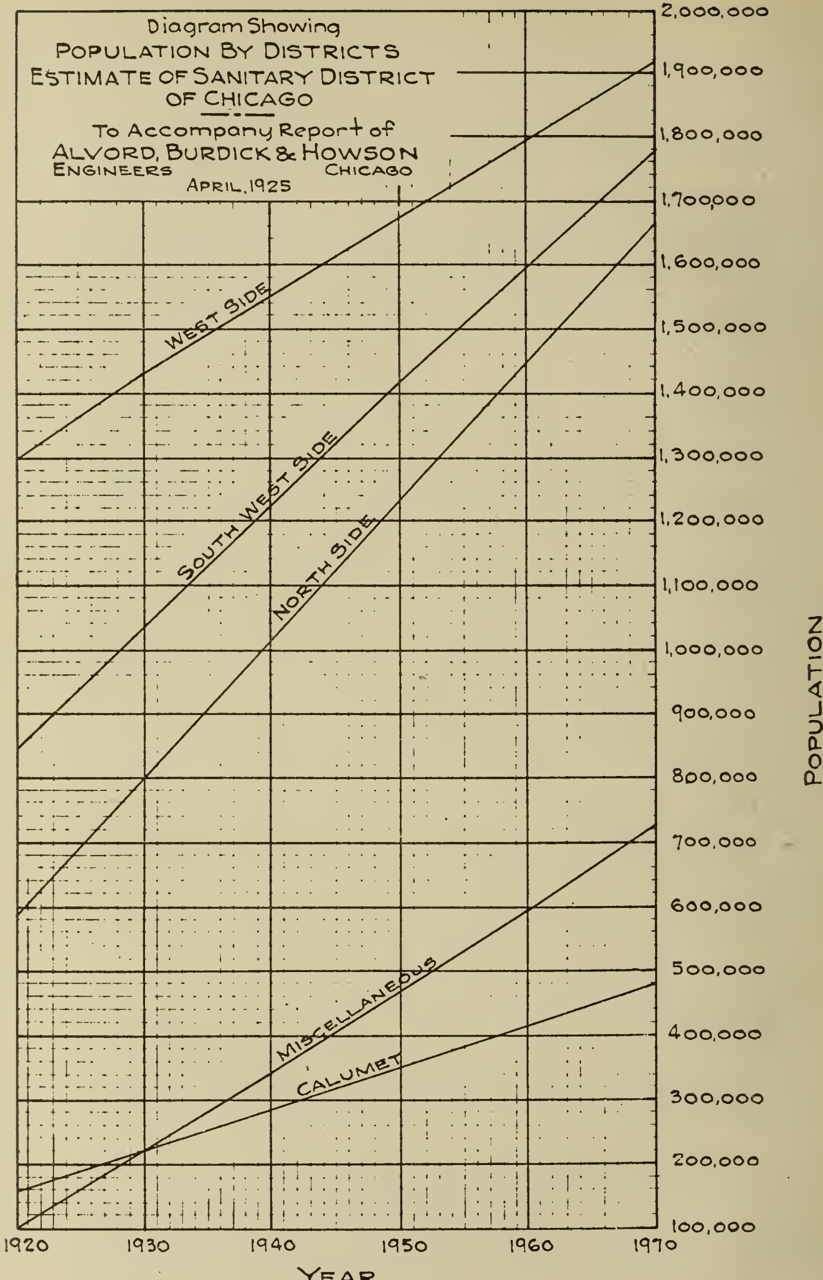


Figure 13.—Population by districts. Estimate of Sanitary District of Chicago.

to determine present and prospective populations by locality, as a basis for determining the amount of sewage delivered to each plant. Table 7 shows the estimate of the Sanitary District for each future decade, divided as between five localities in which purification works will probably be required. Figure 13 shows the same facts diagrammatically. This diagram is chiefly useful in illustrating the comparative rates of growth in the different parts of the district, and in preparing approximate estimates of population for the years intermediate between the census years.

TABLE 7

PRESENT AND FUTURE POPULATION OF AREAS TRIBUTARY TO TREATMENT PLANTS, AS ESTIMATED BY THE SANITARY DISTRICT OF CHICAGO

Year	North Side	West Side	Calumet	S. W. Side	Misc.	Total all Plants
1920	590,000	1,300,000	160,000	850,000	100,000	3,000,000
1930	800,000	1,430,000	225,000	1,040,000	215,000	3,710,000
1935	915,000	1,490,000	255,000	1,135,000	275,000	4,070,000
1940	1,015,000	1,550,000	290,000	1,230,000	340,000	4,425,000
1950	1,230,000	1,680,000	350,000	1,415,000	465,000	5,140,000
1960	1,450,000	1,800,000	415,000	1,600,000	595,000	5,850,000
1970	1,670,000	1,920,000	480,000	1,780,000	730,000	6,580,000

Distribution of Population:

We present herewith Figures 14 and 15 which show a diagrammatic representation of the distribution of the population of Chicago and vicinity for the census year 1920, and the population distribution as it will probably be in 1940. These diagrams were prepared by the Illinois Bell Telephone Company; each spot on the diagrams represents 100 families. These diagrams serve to indicate the most favorable locations for sewage purification works. As will be pointed out later the Sanitary District has apparently selected the most favorable sites possible for purification works, in that localities have been chosen as remote as possible from present and future habitation, with due regard to proximity to the districts contributing sewage.

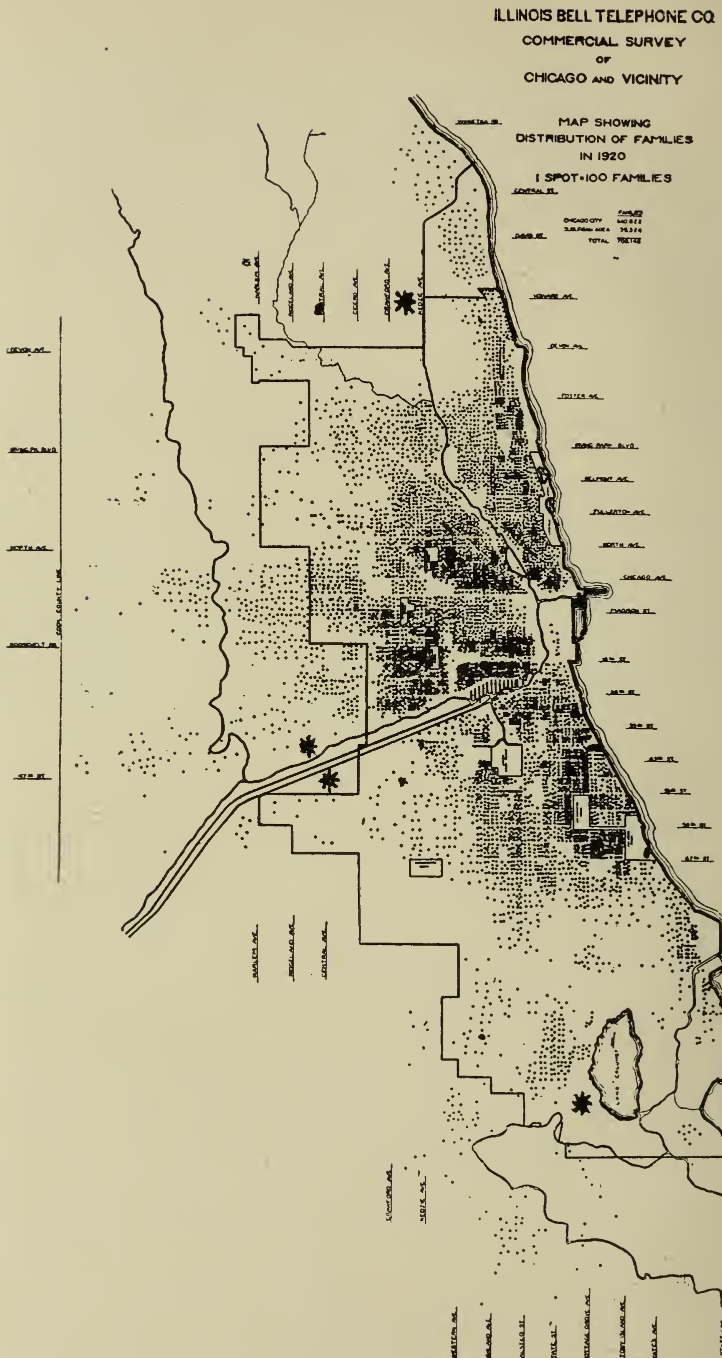


Figure 14.—Map of Chicago showing distribution of population in 1920.

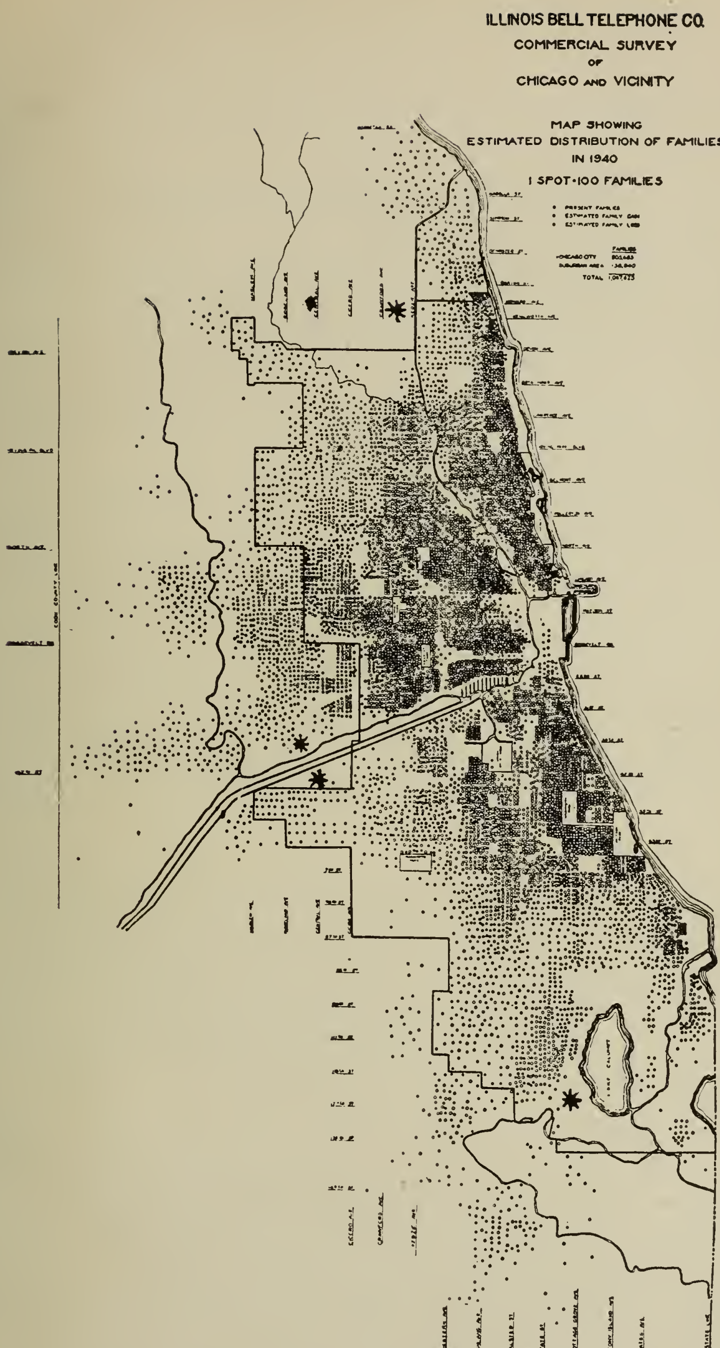


Figure 15.—Map of Chicago showing distribution of population in 1940.

PART IV

AMOUNT AND QUALITY OF SEWAGE.

In a study of the sewage problem of any community, a knowledge of the volume and quality of the sewage is of primary importance.

With respect to quality, sewages are often classified as domestic and industrial, and the use of these terms is generally intended to convey the idea that domestic sewage is that resulting from strictly domestic or household operations, while industrial sewage is that resulting from manufacturing or industrial operations.

A strictly domestic sewage consists of the water-borne wastes resulting from household operations in the laundry, kitchen, bathroom, and toilet and the qualitative character of such wastes is substantially the same in any community where the habits of life of the people do not differ materially. Sewage of a strictly domestic character is rarely encountered in large cities, as most, if not all, of our large cities have more or less varied industries, which produce waterborne wastes differing in quality from strictly domestic sewage. The character and extent of industrial operations consequently are largely responsible for any wide differences in quality which may be found in the sewages of various cities.

Measurement of Load:

Various analytical determinations are made today to give expression to the quality or composition of sewage, such as total nitrogen, free ammonia, suspended solids, settleable solids, oxygen absorbed from permanganate, stability value, biochemical oxygen demand, etc., and in the discussion of the quality of sewage, the only analytical value which will be used for the present will be that secured by the biochemical oxygen demand test.

The biochemical oxygen demand test consists of incubating a known volume of sewage with known volumes of pure water containing a known supply of oxygen in solution, and observing the rate at which the oxygen is exhausted, also, the total amount of oxygen required to effect a complete combustion of the putrescible matter in the sewage. The incubation is carried out at a constant temperature, usually twenty degrees C., and for a sufficient number of days to accomplish a practically complete destruction of the readily oxidizable material in the sewage. This test attempts to show what happens in the way of oxygen depletion in a stream of pure water when it is polluted with sewage.

It has long been known that streams are able to affect a destruction of putrescible matter and after doing so to recover their original purity. When sewage is discharged into a stream of water there begins a drama with three actors, namely putrescible matter, bacteria and oxygen. Bacteria and oxygen combine to destroy putrescible matter, and if the bacteria have an ample supply of oxygen, putrescible matter is destroyed in a quiet and orderly manner, but if the supply of oxygen is inadequate, the drama may develop into a tragedy, and although the bacteria will eventually triumph, the stream will suffer considerably from the experience.

The problem then is one of oxygen supply, if sewage destruction is to be accomplished without offense, and there are a number of factors which govern the supply of and demand for oxygen in a polluted stream of water. One second foot of pure water at a temperature of 32° F. is saturated when it carries 79 pounds of oxygen in solution in a twenty-four hour period, whereas at a temperature of 86° F., it is saturated when it carries 41 pounds of oxygen in solution. On the other hand, the activity of the bacteria which destroy the putrescible matter, is almost nil at 32 degrees F., whereas at 86 degrees F., they are exceedingly active. It is thus apparent that in cold weather there is a large oxygen content in the water and a low rate of demand, whereas in warm weather there is a low oxygen content in the water and a high rate of demand.

Reaeration:

An additional factor in the recovery of a stream from pollution is that of reaeration, which is more rapid in warm weather than in cold, and also increases with the degree of depletion; i. e., if the water is saturated, there will be no reaeration, if it has a zero saturation, the reaeration will be at a maximum for any given condition, and the rate of reaeration will decrease as the oxygen deficit decreases. Other factors affecting reaeration are turbulence and depth, the replenishment increasing with the turbulence and decreasing with the depth.

Example of Oxygen Requirement:

As a concrete example of the relation of the oxygen demand of a sewage and the oxygen supply of a stream, it will be assumed that one second foot of sewage per day, or a total of 646,000 gallons has, by the biochemical oxygen demand test, been shown to require 820 pounds of oxygen to destroy its putrescible matter, and, that it is desired to mix this second foot of sewage with enough second feet of saturated water at 86 degrees F. to supply all the oxygen required. The one second foot of sewage per day requires 820 pounds of oxygen and one second foot of water per day at 86 degrees F. will supply 41 pounds of oxygen, consequently twenty second feet of water will be required, neglecting, of course, reaeration.

Reaeration is no doubt a big contributor to the total oxygen required to destroy putrescible matter in a stream, but, as it has a value which is a resultant of depth of water, turbulence, temperature, and degree of depletion, it is difficult to give it quantitative expression. The efficacy of reaeration in preventing complete depletion of oxygen in a stream is probably closely related to the excessive demand for oxygen which occurs during the early stages of the incubation of the sewage and stream water.

The results of many studies of the oxygen demand of mixtures of pure water and sewage when incubated in closed containers, which prevent reaeration, have indicated that on the basis of the total amount of oxygen absorbed in twenty days at twenty degrees C., twenty-one percent will be required the first day, sixteen percent the second day, thirteen percent the third day, eleven percent the fourt day and seven percent the fifth day, making a total of sixty-eight percent for the first five days. The second five days will require twenty-two percent of the total and the next ten days, ten percent of the total of which, however, but three percent is required in the last five days.

These rates are indicative of a general average result rather than absolutely specific, and are given to show the need for a good supply of oxygen during the first few days of contact between sewage and stream water. In converting a given oxygen demand value secured by a given period of incubation, to an oxygen demand value for a longer or shorter period of incubation, the above rates of satisfaction have been used, as the results of experimental studies in many places have shown them to be reasonably reliable.

If the supply of oxygen, which the diluting water carries in solution, is insufficient to meet the needs of the wet combustion process which takes place in a polluted stream, reaeration conditions may be such that the oxygen supplied in that way will be used up as fast as it is absorbed and distributed and the water of the stream will be left in a condition of zero saturation.

With these considerations in mind, a study of daily oxygen requirements of the sewage of the Sanitary District of Chicago has been made, and the results of this study are herewith presented.

Load of Sanitary District:

There are two ways of expressing the daily oxygen requirements, namely, as a definite number of pounds of oxygen per person per day, or, as a total number of pounds of oxygen per day for the entire district.

The determination of the total daily oxygen load from a representative district divided by the population contributing to this load, will give a per capita daily load which may be applied to the whole district. In the event that there are large industrial loads that have a marked effect on the total load, such industrial loads should be determined separately and added to the total load as estimated from the representative district, in which event, the human population per capita load will be increased, or, the industrial loads may be converted into an industrial equivalent population load, in which case the human population plus the industrial equivalent population times the human population per capita load will give the total load.

A common way of expressing an industrial load is to convert it into an equivalent human population, but in order to avoid confusion, no use has been made of the industrial equivalent population.

The sewage of the entire Sanitary District of Chicago is discharged by approximately 150 sewers, varying in diameter from two feet to sixteen feet, into the north and south branches of the Chicago River, the Des Plaines River, the Calumet River, and the Drainage Canal, making it very difficult to get an accurate determination of the sewage flow of the entire district.

Thirty-Ninth St. Studies 1914:

During the year 1914, hourly samples of sewage were taken at the 39th St. sewage pumping station, and dosed with nitrate solution of known concentration, then allowed to incubate for ten days. At the end of the ten-day period of incubation, the twenty-four hourly samples were composited without correction for flow fluctuations and the residual nitrite and nitrate determined on the composite sample. The oxygen demand value secured in this way was taken as the mean value for the day. The incubation was not carried out at a constant temperature, but at whatever temperature happened to exist where the incubating samples were stored.

The average oxygen demand as determined in this manner after a ten-day incubation was found to be 121 parts per million, which means that 121 pounds of oxygen would be required to destroy the putrescible matter in one million pounds of sewage, or 1008 pounds of oxygen would be required for one million gallons of sewage. The average rate of pumpage was found to be 71 million gallons per day (or *219 gals.

*Note—Total City pumpage year 1914, 254 gals. per capita.

per capita), and this was secured by taking the daily records of the speed of the pumps and determining the discharge by using the manufacturer's speed, capacity, and head curves. There is some doubt as to the accuracy of this method in determining the discharge of the pumps.

The population of the district contributing sewage to this station was estimated at 324,000. On the basis of the above data the daily per capita oxygen load was 1008 pounds times 71 M. G., divided by 324,000 or 0.22 pounds of oxygen, on a ten-day oxygen demand basis.

Thirty-Ninth St. Studies, 1920:

Between November 8th, 1920, and December 11th, 1920, a similar investigation was made at the 39th St. sewage pumping station. The oxygen demand was determined by the dilution method after a ten-day incubation at a constant temperature of twenty degrees centigrade. Samples were taken hourly, with four consecutive hourly samples composited for a single oxygen demand test. Six composited samples per day were subjected to the oxygen demand test, and the mean of the six values was taken as the daily mean value. No attempt was made to weight samples to conform with hourly flow fluctuations.

The average oxygen demand after a ten-day incubation at 20 degrees C., was found to be 140 parts per million, which means that 1166 pounds of oxygen would be required to destroy the putrescible matter in one million gallons of sewage. The average rate of pumpage was found to be 86.17 million gallons per day (or *207 gals. per capita), the same being estimated as in the previous test. The population was estimated to be 417600 and on the basis of the above data the daily per capita oxygen load was 1166 pounds times 86.17 M. G. divided by 417600 or 0.24 pounds of oxygen on a ten-day oxygen demand basis.

Des Plaines Studies:

The operating results for the Des Plaines treatment works for the year 1924 show an average daily sewage flow of four million gallons, an average ten-day oxygen demand of 153 and a tributary population of 40000 and on the basis of the above data the daily per capita oxygen load was 153 pounds times 8.33 times 4 M. G. divided by 40000 or 0.127 pounds of oxygen on a ten day oxygen demand basis.

Calumet Studies:

The operating results for the Calumet treatment works for the year 1924, show an average daily sewage flow of thirty million gallons, an average ten-day oxygen demand of eighty and a tributary population

*Note—Total city pumpage year 1920, 276 gals. per capita.

of 107,000, and on the basis of this data, the daily per capita oxygen load was 80 pounds times 8.33 times 30 M. G. divided by 107000 or 0.187 pounds of oxygen.

Comparison with Other Cities:

In Table 8, a comparison may be made between Chicago sewage and that of other American and English cities. It is quite apparent from the data contained in this table that Chicago sewage is considerably stronger than the average strength of sewages listed in the table.

Industrial Load:

The Chicago industrial load is quite large in the aggregate, the principal elements of which, in the order of their magnitude, are as

TABLE 8

TABLE SHOWING THE STRENGTH OF MUNICIPAL SEWAGES ON THE BASIS OF THE OXYGEN REQUIREMENT IN POUNDS PER CAPITA PER DAY

Ref.	City	Gallons sewage per capita per day by contributing population	5-Day oxygen demand in P. P. M.	Pounds oxygen required per capita per day
A	Alliance, Ohio	131	92	0.100
	Baltimore, Md.	106	120	0.106
	Canton, Ohio	64	213	0.113
	Columbus, Ohio	94	190	0.148
	Fitchburg, Mass.	88	155	0.114
	Lexington, Ky.	89	144	0.107
	Reading, Pa.	101	118	0.099
	Rochester, N. Y.	137	104	0.119
B	Malton, Eng.	40	467	0.155
C	Huntingdon, Eng.	27	475	0.107
D	Brooklyn, N. Y.	102	223	0.189
	Min. value			0.099
	Max. value			0.189
E	Average Eng. Sewage	35	350	0.102
	Strong Eng. Sewage	35	500	0.146
F	Chicago	206	106	0.182
G	Chicago	219	91	0.167
H	Chicago	100	122	0.102
I	Chicago	280	64	0.149

References:
A. U. S. Public Health Service Bull., No. 132, p. 115.
B. Eighth Report Roy. Com. Sew. Disp. Vol. 2, Appendix, pages 27, 68, 81.
C. Eighth Report Roy. Com. Sew. Disp. Vol. 2, Appendix, page 20.
D. Brooklyn, N. Y. Sewage Treatment Experiments by George T. Hammond, Reprinted from 1919 Proc. Am. Soc. Mun. Improvements, p. 20 and 22 of Reprint.
E. Eighth Rept. Roy. Com. Sew. Disp. Vol. 1, page 9.
F. Operation data, 39th St. Sew. Pump. Sta. Year 1920.
G. Operation data, 39th St. Sew. Pump. Sta. Year 1914.
H. Operation data Des Plaines Sewage Treatment Works, Year 1924.
I. Operation data Calumet Sewage Treatment Works Year 1924.

follows: Stockyards and Packingtown wastes, corn products wastes, tannery wastes, wool pulling and washing wastes, and numerous other smaller industrial wastes, many of which are common to all large cities. The Stockyards and Packingtown wastes and the corn products wastes have been and are now being extensively studied by the sanitary engineering division of the Sanitary District and the conclusions which they have arrived at may be summarized as follows:

	Estimated average daily sewage flow in million gallons for year 1925	Average 10-day oxygen demand value	Pounds oxygen required per day
Stockyards wastes	33.5	900	250,000
Corn Products wastes	15.5	600	77,000
Total	49.0		327,000

The sewage flow from the packing industries is based on numerous sewer gagings and the oxygen demand is an average value of numerous determinations made between the years 1911 and 1918, all of which data is reported in detail in the Reports on Industrial Wastes from the Stockyards and Packingtown, Vol. 1 having been issued in October, 1914, and Vol. 2 in January, 1921.

The tannery and other miscellaneous wastes of the Sanitary District of Chicago have been estimated by officials of the Sanitary District to have a daily oxygen requirement of 40,000 pounds.

The total industrial load of the district has been estimated by officials of the Sanitary District to have a daily oxygen requirement of 367,000 pounds.

Canal Studies:

An entirely separate study of the Chicago load has been made by investigations conducted at several points along the canal between Brandon Bridge below Joliet, and Summit. In these studies the load was estimated by determining the oxygen lost from the mixture of lake water and sewage to a given station or observation point, and adding this load to the unsatisfied demand at the station. The sewage flow was an assumed value, the dissolved oxygen content of the sewage was assumed, the dissolved oxygen content of the diluting water was determined by analysis, the total flow of the canal was taken from a rating curve for a U. S. G. S. gaging station, and all other values were determined by analysis. The results of these studies as well as all other studies of the Chicago load, which have been investigated, are recorded in Table 10.

An inspection of the data in Table 10 shows that the daily oxygen load as estimated from the results of canal studies varies as follows:

1. On basis of 5 day oxygen demand— 886000 to 1195000 pounds
2. On basis of 10 day oxygen demand—1117000 to 1580000 pounds
3. On basis of 20 day oxygen demand—1266000 to 1760000 pounds

TABLE 9.

SHOWING INDICATED TOTAL OXYGEN LOAD BASED ON LOCKPORT DATA.

	July 1922	August 1922	Febr'y 1922
Temp. lake water, degrees C.* (temp.)........	22.4	23.8	1.0
Oxygen in lake water, P.P.M.* (ave.).........	8.45	7.88	12.37
Oxygen found at Lockport in P.P.M............	0.01	0.01	9.11
Oxygen loss in P.P.M.........................	8.44	7.87	3.26
Total flow in second feet....................	8696	8360	8330
Assumed sewage flow in sec. ft...............	1220	1220	1220
Dilution factor at Lockport..................	7.1	6.85	6.8
B.O.D. value reduction to Lockport (in 1220 sec. ft.)	60	54	22
B.O.D. value at Lockport—5 day value........	11.20	11.88	23.46
B.O.D. value at Lockport, corrected to 1220 sec. ft.—5 day value.......................	80	81	160
Total B.O.D. value at sewer outlets–5 day value	140	135	182
Total daily oxygen load in pounds...........	919,000	886,000	1,195,000

*Averages found to prevail in these calendar months.

A further inspection of this table will show that the average daily oxygen load of studies Nos. 7, 8, 9, and 10 (warm weather period) based on the 20-day demand values, is 1,300,000 pounds and that the average daily load of studies Nos. 5 and 6 (cold weather period) based on the 20-day demand values, is 1,600,000 pounds. In view of the fact that there was a marked oxygen depletion at the points of observation during the warm weather tests, and probably a considerable amount of replenished oxygen used in satisfying the demand up to the observation station, and that this condition did not obtain to such a marked degree in the cold weather tests, it seems probable that the total indicated load of 1,600,000 pounds of oxygen is more nearly correct for the year 1922. The average daily oxygen load based on the 10 day oxygen demand values and the cold weather tests is 1,450,000 pounds and the average daily oxygen load based on the 5-day oxygen demand values and the cold

TABLE 10.

SHOWING RESULTS OF STUDIES OF THE OXYGEN LOAD OF THE SEWAGE OF THE SANITARY DISTRICT OF CHICAGO.

Study No.	Source of Data	Year	Human Population Contributing	Sewage Flow in M. G. D.	Oxygen Demand P. P. M. Based on 20°C. Incubation for			Total Pounds Oxygen Required Per Day Based on 20°C. Incubation For			Pounds Oxygen Required Per Capita Per Day Based on 20°C. Incubation For		
					5 Days	10 Days	20 Days	5 Days	10 Days	20 Days	5 Days	10 Days	20 Days
1	39th St. Sewer	1914	324,000	71.06	91	121	133	53,800	71,600	78,700	0.167	0.220	0.243
2	39th St. Sewer	1920	417,600	86.17	106	140	156	76,100	100,500	112,000	0.182	0.240	0.267
3	Calumet Sewage Treatment Works	1924	107,000	30.00	64	85	94	16,000	21,250	23,500	0.149	0.200	0.220
4	Des Plaines Sewage Treatment Works	1924	40,000	4.00	122	162	180	4,065	5,400	6,000	0.102	0.135	0.150
5	Brandon Bridge Joliet U. S. P. H. Ser. Average for Jan., Feb. and March	1922	3,100,000	788	151	200	222	990,000	1,320,000	1,460,000	0.320	0.425	0.470
6	Lockport at 16th St. Br. U.S.P.H.S., Feb.	1922	3,100,000	788	182	241	268	1,195,000	1,580,000	1,760,000	0.385	0.510	0.570
7	Lockport at 16th St. Br. U.S.P.H.S., July	1922	3,100,000	788	140	185	205	919,000	1,200,000	1,350,000	0.295	0.387	0.435
8	Lockport at 16th St. Br. U.S.P.H.S., Aug.	1922	3,100,000	788	135	180	200	886,000	1,117,000	1,300,000	0.285	0.360	0.420
9	Lockport at 16th St. Br. U.S.P.H.S., July and August	1922	3,100,000	788	154	189	203	1,012,000	1,234,000	1,335,000	0.326	0.398	0.430
10	Summit, San. Dist. of Chicago, July & Aug.	1922	3,100,000	788	144	176	191	946,000	1,166,000	1,266,000	0.305	0.376	0.408

weather tests is 1,092,000 pounds. Taking human population for 1922 as 3,100,000, the oxygen load per capita per day was as follows:

On basis of 20-day demand value............0.516
On basis of 10-day demand value............0.468
On basis of 5-day demand value............0.352

Taking the human population for 1925 as 3,355,000, the total oxygen load per day for the year 1925, would be as follows:

On basis of 20-day demand value....1,730,000 pounds
On basis of 10-day demand value....1,570,000 pounds
On basis of 5-day demand value....1,180,000 pounds

Resume of Studies:

In Table 11 are shown comparative data on the oxygen requirements of the sewage of the Sanitary District of Chicago, as determined from three separate sources.

In the studies conducted by the U. S. Public Health Service during the year 1922, samples were taken from the canal at Lockport between 6 a. m. and 8 a. m., and the oxygen demand determined after a 5-day period of incubation at a constant temperature of twenty degrees C. These studies were completed in August, 1922, and some doubt existed as to the single samples being representative. The Sanitary District of Chicago was asked to make a study which would show whether there was a fluctuation in strength during a twenty-four hour period.

A study to determine this was made by the Sanitary District during September, October, and November, 1922, samples being taken at the same sampling point at Lockport as that from which the U. S. P. H. S. samples were taken, and at 4 a. m., 8 a. m., noon, 4 p. m., 8 p. m., and 12 p. m. daily. The oxygen demand was determined on each sample by a 5-day incubation at a constant temperature of 20 degrees C

A curve was plotted showing the daily fluctuations at four hour intervals and another curve was plotted to show the fluctuations of the flow during this period. From these two curves a correction factor of 1.27 was evolved to apply to the single daily sample taken from 6 a. m. to 8 a. m. to make the oxygen demand representative.

An hourly fluctuation curve for oxygen demand resulting from the temperatures obtaining in the canal water in September, October, and November will probably be different from a similarly plotted curve for warmer or colder weather; consequently it is believed that this particular oxygen demand curve is not suitable or reliable for full year application. The load value secured in this way is less convincing than it would be had the results been based on weighted daily composites, and it is impossible to say whether the indicated load is too high or too low.

TABLE 11.

SHOWING COMPARATIVE DATA ON OXYGEN REQUIREMENTS OF SEWAGE OF SANITARY DISTRICT OF CHICAGO. (Based on Population Contributing.)

Oxygen Demand Basis	Average of Cold Weather Results Brandon Bridge and Lockport, Year 1922			Results on Sewage from 39th St. Sewer, Year 1920			Results from Calumet and Des Plaines Sewage Treatment Works for year 1924 (mean value weighted according to population)		
	Pounds oxygen per capita per day	Pounds oxygen per 1,000 pop. per day	Second feet req. per 1,000 pop. in July and August @ 40 lbs. oxygen per sec. ft.	Pounds oxygen per capita per day	Pounds oxygen per 1000 pop. per day	Second feet req. per 1000 pop. in July & August @ 40 lbs. oxygen per sec. ft.	Pounds oxygen per capita per day	Pounds oxygen per 1,000 pop. per day	Sec. ft. req. per 1,000 pop. in July and Aug. @ 40 lbs. oxygen per sec. ft.
20 days	0.516	516	12.9	0.267	267	6.68	0.200	200	5.00
15 days	0.500	500	12.50	0.260	260	6.50	0.194	194	4.85
10 days	0.468	468	11.7	0.240	240	6.00	0.180	180	4.50
5 days	0.352	352	8.8	0.182	182	4.55	0.136	136	3.40
2 days	0.191	191	4.78	0.099	99	2.47	0.074	74	1.85
1 day	0.108	108	2.70	0.056	56	1.40	0.042	42	1.05

The determination of the daily load from the results of the operation of the Calumet and Des Plaines sewage treatment works for the year 1924, would be open to criticism because the use of a per capita value secured from these results would result in adopting a load value from about three percent of the population of the district and calling it representative.

Best Criterion for Domestic Load:

The determination of the daily domestic load from the results of the 1920 studies of the 39th Street sewer seems at this time to be the most logical course to pursue for the following reasons:

1st. The district contributing to this sewer is considered to be reasonably representative.

2nd. The study was made during a census year and for this reason a reasonably accurate estimate of the contributing population could be made.

3rd. The analytical data is complete and satisfactory for use in determining the load.

4th. The pumpage record is not thought to be very accurate and the average daily flow, if in error, is believed to be too high, and if this is true the indicated load is too high and the error is on the side of safety.

5th. The population contributing to this sewer is approximately ten percent of the total population of the district.

From the data which has been reviewed, it is thought that the load values as shown in Table 11 for the 39th Street sewer are the most dependable. Furthermore, it is thought that a carefully planned study of the canal at Lockport or at some other location or locations would result in a *more* reliable determination of the daily load, and these studies would also provide a check on the previous studies of the Stockyards and Corn Products wastes.

Summarized Conclusions on 1925 and Projected Daily Loads:

In estimating the total daily load of the entire Sanitary District for the year 1925, and projecting these loads at five year intervals to 1945, the following basic data have been accepted and used:

1. The 1920 results at the 39th St. sewer which show the daily domestic load to be 0.24 pounds of oxygen per capita per day on a ten-day oxygen demand basis.

2. The human population estimates of the Sanitary District for five-year intervals from 1925 to 1945.

3. A value of 900 for ten-day oxygen demand for the packing and stockyards industrial wastes, and the assumption that the strength

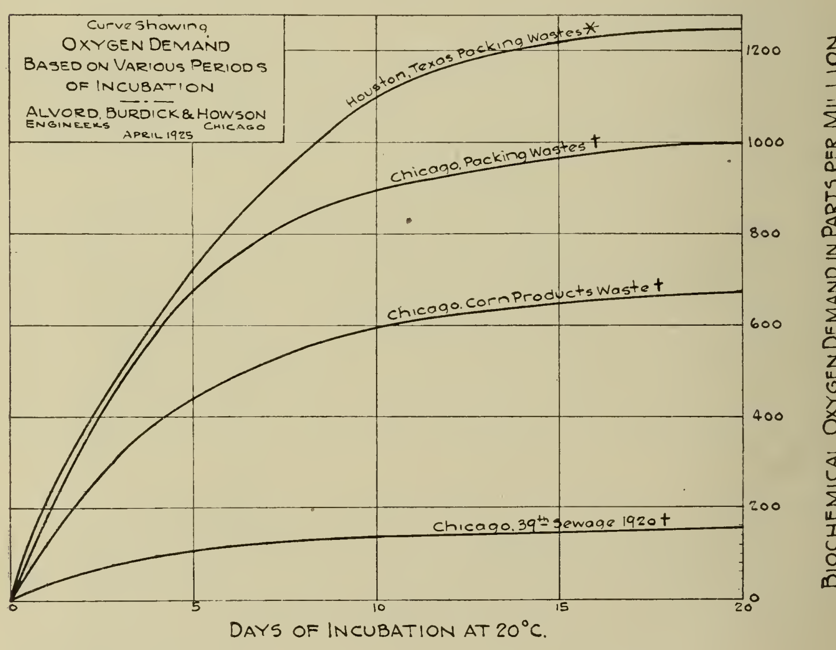
of this waste will not change materially during the period of time involved.

4. The estimate of the Sanitary District relative to the present daily volume of the Packingtown and Stockyards wastes for the years 1925 and 1945, which volumes are respectively thirty-three and one-half and 40 million gallons per day.

5. A value of 600 for the ten-day oxygen demand for the corn products wastes and the assumption that the strength of this waste will not change materially during the period of time involved.

6. The estimate of the Sanitary District relative to the present daily volume of the corn products wastes for the years 1925 and 1945 which volumes are respectively 15 and 19 million gallons per day.

The oxygen demand values for the Packingtown and corn products wastes are accepted after a study of the many analyses, which have been made over a period of years. The actually determined value for the



* G. L. Fugate, Eng. News-Record 94, No. 11.

† Data by Sanitary District of Chicago.

Figure 16—Biochemical oxygen demand based on various periods of incubation.

packing wastes is 900 parts per million for ten-days at 20 degrees C The value of 680 for the five-day demand at 20 degrees C. is a calculated value which was furnished from the laboratory of the Sanitary District. The twenty-day value was secured by dividing the ten-day value by 0.90.

The basis for determining the load from the corn products plant was a determined five-day oxygen demand value of 450 and a calculated ten-day value of 600, both values being furnished from the laboratory of the Sanitary District. The twenty-day value was secured by dividing the ten-day value by 0.90.

The basis for determining the domestic load was the determined ten-day oxygen demand value of 140 for the 39th St. sewer in 1920. The five day and twenty-day values were calculated by using a rate of satisfaction as follows:

5-day value	68%	of 20-day value
10-day value	90%	of 20-day value
20-day value	100%	of 20-day value

A curve of oxygen demand for packing wastes of Chicago and Houston, Texas, corn products wastes of Chicago, and 39th St. sewage of Chicago accompanies this report.

Table 12 contains a summary of the estimated daily oxygen loads of the domestic sewage, stockyards waste, and corn products waste, the sum of which is taken as the total daily load of the entire district.

It will be noted in this table that the total daily load is shown on the basis of 5, 10, and 20 day demand values, the 20-day value indicating what might be termed a substantially complete oxygen requirement, although it is not strictly an absolute value.

Although the total load as indicated by the 20-day value must be disposed of finally, it is not required that this amount of oxygen must be supplied as an initial content in lake water, as reaeration may be expected to contribute a substantial portion of the total oxygen required.

The rate of oxygen satisfaction occurring from the beginning to the completion of a 20-day period of incubation in closed containers, which has been referred to previously in this discussion, has been found by a number of investigators to be reasonably reliable on a general average basis. These rates of oxygen satisfaction grouped for five-day intervals indicate the following period rates:

1st.	5 days—68%	of 20-day requirement
2nd.	5 days—22%	of 20-day requirement
3rd.	5 days— 7%	of 20-day requirement
4th.	5 days— 3%	of 20-day requirement

TABLE 12

SHOWING ESTIMATED DAILY OXYGEN LOAD OF SEWAGE OF SANITARY DISTRICT OF CHICAGO

Year	Polluting Element	Daily Polluting Units	Pounds of Oxygen Required Per Day Per Polluting Unit on Basis of Oxygen Demand Value for			Pounds of Oxygen Required Per Day for Polluting Element on Basis of Oxygen Demand Value for		
			5 Days	10 Days	20 Days	5 Days	10 Days	20 Days
1925	Human Population*	3,355,000	0.182	0.240	0.267	611,000	805,000	896,000
	Stock Yards Waste	33.5 M. G.	5650	7500	8330	189,000	251,000	279,000
	Corn Products Waste	15.0 M. G.	3750	5000	5670	56,000	75,000	85,000
	Totals	....	....	....	....	856,000	1,131,000	1,260,000
1930	Human Population*	3,710,000	0.182	0.240	0.267	675,000	890,000	990,000
	Stock Yards Waste	35 M. G.	5650	7500	8330	198,000	262,000	292,000
	Corn Products Waste	16 M. G.	3750	5000	5670	60,000	80,000	91,000
	Totals	....	....	....	....	933,000	1,232,000	1,373,000
1935	Human Population*	4,070,000	0.182	0.240	0.267	741,000	977,000	1,087,000
	Stock Yards Waste	36.5 M. G.	5650	7500	8330	206,000	274,000	354,000
	Corn Products Waste	17.5 M. G.	3750	5000	5670	66,000	87,000	99,000
	Totals	....	....	....	....	1,013,000	1,338,000	1,540,000
1940	Human Population*	4,425,000	0.182	0.240	0.267	805,000	1,062,000	1,181,000
	Stock Yards Waste	38.2 M. G.	5650	7500	8330	216,000	286,000	318,000
	Corn Products Waste	18.2 M. G.	3750	5000	5670	68,000	91,000	103,000
	Totals	....	....	....	....	1,089,000	1,439,000	1,602,000
1945	Human Population*	4,785,000	0.182	0.240	0.267	871,000	1,148,000	1,278,000
	Stock Yards Waste	40 M. G.	5650	7500	8330	226,000	300,000	333,000
	Corn Products Waste	19 M. G.	3750	5000	5670	71,000	95,000	108,000
	Totals	....	....	....	....	1,168,000	1,543,000	1,719,000

*Includes Minor Industrial Wastes.

The above rates indicate that the demand for oxygen during the first quarter of the 20-day period is quite high and a substantial percentage of the total required for a reasonably complete destruction of the polluting material.

The first 5-day period is also one in which poor reaeration conditions would be most apt to cause serious conditions in a stream through oxygen depletion resulting from a rapid rate of demand and a slow rate of replenishment.

A study of the daily rates within the first 5 days shows that approximately fifty-five per cent of the total 5-day requirement must be met during the first two days.

Quite a number of laboratory studies of mixtures of sewage and clean water incubated in open containers have shown invariably that where a proper dilution was used and in which enough initial oxygen was present to supply the needs for the first two days, an increase in dissolved oxygen content began after the first two days of incubation.

Criterion for Load:

In view of such evidence as has been available and on the basis of the observed behavior of mixtures of sewage and clean water which have been shown to have reasonably definite general average rates of demand for oxygen, it is considered that a supply of dilution water having an initial oxygen content equal to the total 5-day oxygen demand load of the Sanitary District will be sufficient and satisfactory.

For the above reasons, and for the reasons more fully stated in Part V and Part VI, we conclude that the 5-day biochemical oxygen demand of the sewage, and purification plant effluents, will furnish the most useful criterion of organic load.

PART V.

STANDARD OF MAXIMUM POLLUTION

It is desirable that a standard should be fixed to measure the effectiveness of means to be taken to prevent excessive pollution of the rivers below Joliet. This standard should be applicable whether the protective measures consist of dilution from Lake Michigan, sewage treatment works, or both. It will be most desirably and conveniently applied at the foot of the Drainage Canal. A test must cover a period sufficiently long to represent conditions which might create a nuisance, to eliminate unavoidable errors in sampling, and to average up ordinary variations that might be caused by excessive discharge from the storm sewers.

It is regarded as essential that the standard should exclude settleable suspended matters of an organic character; otherwise deposits in the stream below Lockport, in the colder weather, will tend to rob the stream of oxygen in summer, thus producing undesirable conditions, the magnitude of which is not subject to prediction.

Subject to the above requirement, it is believed to be practicable to prescribe an oxygen content and an organic load, which, aided by reaeration and added dilution from streams below Lockport, will permit of satisfactory stream conditions at all places on the Illinois and Des Plaines Rivers, including freedom from nuisance, conditions tolerable for fishes in the Des Plaines and Upper Illinois, and such as to permit a thriving fish life in the lower Illinois.

Limitations of Standard:

In fixing a standard to be used as a governing basis for the pollution of the Illinois River, both now and hereafter, there are two considerations that should be set forth clearly in the beginning:

1st. It is economically impractical to expect that the Illinois River should be returned to a condition such as exists in streams which receive no pollution at all; i. e., to a condition of pristine purity.

2nd. The existence of any appreciable amount of settleable putrescible material in the drainage course is apt to upset all efforts which are aimed at the maintenance of proper stream conditions through sewage treatment and regulated diversion.

During the year 1922, the U. S. Public Health Service made a careful and systematic study of the condition of the waters of the Illinois River and its tributaries.

Condition of Illinois River:

The condition of the Illinois River was studied by taking daily samples of the water at a number of stations between Lockport and Kampsville and determining the dissolved oxygen and the five-day oxygen demand at twenty degrees C., in addition to other determinations the results of which will not be considered in this connection. The average monthly oxygen values for each sampling station are plotted on Figures 5, 6, 7 and 8 to show winter, spring, summer and fall conditions in the Illinois River.

An inspection of Figure 7 shows that during the winter months of the year 1922, there was a marked preponderance of oxygen demand over the dissolved oxygen supply at Lockport, and that a balance of oxygen supply and demand was not reached for a distance of approximately 50 miles below Lockport. The dissolved oxygen content of the water was, however, at no time or place below 7 parts per million, indicating that a low rate of oxygen depletion was taking place and that an absence of a smell nuisance existed.

An inspection of Figure 8 will show that during the spring months of the year, the same disparity between oxygen demand and supply existed at Lockport, and that the balance was reached in April 29 miles below, in May 100 miles below, and in June 120 miles below Lockport. The dissolved oxygen in April was not below three and three-fourths parts per million, in May it reached a low value of one-half of a part, and in June it was zero at Lockport.

Figure 5 shows the summer conditions in the river and the oxygen values indicate that the Illinois River was practically dead for a distance of 113 miles below Lockport, from which point its condition began to improve until an oxygen balance existed at a distance of 125 miles below Lockport.

An inspection of Figure 6 shows conditions quite similar to those which existed during the spring months with a progressive improvement from September to November. The oxygen balance was established within the following distances below Lockport; in September, 122 miles; in October, 92 miles, and in November, 52 miles, the improvement in the last month resulting both from an increase in dilution and a reduction in temperature.

Condition of Tributaries to Illinois River:

The condition of the waters of the tributaries of the Illinois is reflected by their dissolved oxygen content and the demand for oxygen when incubated in closed containers for 5 days at 20 degrees C., and these values are recorded in Table 13.

The values recorded in Table 13 are the mean values for the months indicated, and are based on from ten to fifteen samples per month for each stream so that the information thus secured gives a very satisfactory index of the sanitary quality of the water.

It will be noted from these monthly averages that in only three instances did the 5-day oxygen demand exceed the dissolved oxygen content, and the average relation for all the streams was: dissolved oxygen, 2.9, oxygen demand 1.0, indicating a very safe relation between the oxygen supply and demand.

The best condition found among the several tributaries of the Illinois was the average result for the Kankakee River, where the relation was 4.7 dissolved oxygen to 1.0 of oxygen demand.

A relationship for the Illinois River such as the average relationship for its tributaries, we consider to be too severe and one which it would be impractical to impose because the cost involved would probably be out of proportion to the advantages which would accrue therefrom.

Seasonable Dilutions:

It is a well known fact that a given dilution will be more potent in preventing a nuisance in a polluted stream in cold weather than the same dilution will be in warm weather, and this is due to the inhibiting effect of low temperatures on bacterial activity, and this in turn reduces quite materially the rate at which oxygen must be supplied.

The danger of oxygen depletion in a polluted stream where a given dilution prevails, is very materially reduced with the coming of freezing temperatures, consequently quite a material reduction in diversion water can be made during periods of low temperatures. Sufficiently reliable information is not available at this time upon which to base a schedule of diversions which might be applied to take advantage of the changing rates of oxygen satisfaction which accompany marked changes in temperature.

An indication of the effect of temperature on the rate of oxygen depletion is shown by the results of some laboratory studies conducted at the sewage treatment works of Columbus, Ohio, some years ago, in which mixtures of sewage and clean water were incubated in closed containers for a period of twenty-four hours at various temperatures.

TABLE 13.

SHOWING DISSOLVED OXYGEN AND 5 DAY OXYGEN DEMAND IN PARTS PER MILLION OF WATERS OF TRIBUTARIES TO THE ILLINOIS RIVER.

	Des Plaines		Kankakee		Fox		Vermilion		Mackinaw		Spoon		Sangamon		Crooked Creek		Macoupin Creek		Mississippi	
Month and Year	D. O.	5 Day B.O.D.	D. O.	5 Day B.O.D.	D. O.	5 Day B.O.D.	D. O.	5 Day B.O.D.	D. O.	5 Day B.O.D.	D. O.	5 Day B.O.D.	D. O.	5 Day B.O.D.	D. O.	5 Day B.O.D	D. O.	5 Day B.O.D	D. O.	5 Day B.O.D
1921																				
July	……	……	……	……	7.69	1.93	5.44	2.28	7.94	3.31	4.70	2.15	4.23	2.48	5.56	1.52	3.61	2.16	……	……
August	8.55	2.79	7.60	1.37	7.86	1.57	5.70	3.30	7.73	2.44	5.52	2.35	3.23	3.71	4.70	2.48	4.34	2.92	7.25	2.25
September	9.21	4.59	7.65	1.87	7.35	2.01	7.01	2.29	7.50	1.83	5.71	2.01	4.39	6.45	5.47	4.24	5.16	2.88	6.59	2.43
October	6.89	3.53	10.09	2.34	9.02	1.77	8.75	1.53	9.21	1.48	7.39	2.39	9.41	5.05	8.12	4.02	6.80	2.49	9.18	2.58
November	10.05	3.08	11.65	2.73	11.23	2.83	10.39	2.40	10.55	2.76	10.59	3.02	11.48	5.86	10.04	4.16	7.86	3.39	11.58	3.24
December	11.36	3.27	11.93	2.20	12.46	3.13	12.03	2.36	11.53	2.82	11.80	4.23	……	……	……	……	11.05	3.20	12.74	3.97
1922																				
January	8.63	3.29	12.93	2.48	12.28	2.89	12.75	2.69	11.54	2.07	10.32	4.72	……	……	……	……	……	……	13.31	4.06
February	6.18	4.22	11.59	3.49	11.51	3.40	11.72	3.09	12.01	3.41	9.68	5.65	……	……	……	……	11.71	3.46	13.66	4.53
March	8.82	4.58	10.93	2.70	11.05	5.55	11.28	2.17	10.40	2.51	10.38	4.50	……	……	……	……	10.36	2.92	11.08	4.90
April	8.93	2.32	8.90	2.55	9.59	3.05	9.52	1.66	8.74	2.26	8.86	2.22	……	……	……	……	8.86	2.22	10.86	2.62
May	8.36	5.65	7.68	1.4	7.84	1.97	8.13	1.04	7.47	2.17	6.28	2.76	……	……	……	……	5.59	7.21	7.58	3.24
June	5.90	6.34	7.30	1.15	7.04	0.98	6.22	1.18	7.90	1.58	6.67	3.21	……	……	……	……	6.30	4.73	6.68	2.35
July	6.34	7.34	7.09	1.00	7.05	1.14	5.84	1.54	7.79	2.08	6.70	5.36	……	……	……	……	5.75	3.99	6.54	2.35
August	4.13	5.29	6.50	0.91	6.11	1.42	6.11	2.89	8.28	2.76	5.70	5.16	……	……	……	……	5.28	4.57	7.09	2.77
Totals	103.35	56.29	121.84	26.24	128.08	33.64	120.89	30.42	128.59	33.48	110.30	49.73	32.74	23.55	33.26	16.42	92.67	46.14	124.14	41.29
Means	8.0	4.3	9.4	2.0	9.2	2.4	8.6	2.2	9.2	2.4	7.9	3.6	6.5	4.7	6.7	3.3	6.6	3.5	9.6	3.2
Max	……	7.34	……	3.49	……	5.55	……	3.30	……	3.41	……	5.65	……	……	……	……	……	7.21	……	4.90
Max. Max.	……	7.34	……	……	……	……	……	……	……											

Average values for all Tributaries { Dissolved Oxygen in parts per million = 8.61. Day oxygen demand in parts per million = 2.94.

Worst relation for one Tributary for any single month (July, 1922) Des Plaines { Dissolved oxygen in parts per million = 6.34. 5 Day oxygen demand in parts per million = 7.34.

The results of these studies showed the following rates of depletion, taking the rate at the highest temperature used (90 degrees F.) as 100 percent; 90 degrees F. 100 percent; 80 degrees F. 76 percent; 70 degrees F. 55 percent; 60 degrees F. 38 percent; 50 degrees F. 22 percent; and 40 degrees F., 9 percent.

If the above rates of oxygen depletion are typical of what occurs in the drainage course, it is evident that a very marked reduction in diversion water could be made during freezing weather; also a schedule of seasonal diversions might be worked out which would materially reduce the total annual diversion required to meet the necessary sanitary considerations.

Oxygen in Lake Water:

In connection with the possibilities of regulated diversion to conform to temperature conditions and also to take advantage of the greater amounts of dissolved oxygen which are present in cold water, the following table of typical average monthly temperatures and dissolved oxygen content of lake water is of interest. The values given are mean monthly averages based on daily analyses of lake water at the 39th St. Pumping Station from September, 1921, through August, 1923.

Month	Temp. Degs. C.	Dissolved Oxygen Content Parts per Million
January	2.5	13.48
February	2.5	13.17
March	3.7	12.98
April	8.6	11.72
May	12.4	10.59
June	17.4	9.28
July	20.2	8.10
August	21.5	7.80
September	19.2	9.08
October	14.2	9.55
November	8.6	10.97
December	4.3	12.31
Annual Mean	11.3	10.75

Stability Studies:

The results of many years of river inspection studies at Columbus, Ohio, have shown certain relationships which exist between oxygen demand, dissolved oxygen, and stability as determined by the methylene blue test. Some of these relations are indicated in the following data:

Range in oxygen demand values, 37 deg. C. 24 hrs.	Ave. Oxy. demand value within the range	Average dissolved oxygen in water in situ	Per cent dissolved oxygen is of oxygen demand	Stability value of water as taken in situ
25-30	27.5	0.00	0.00	3
20-25	22.0	0.00	0.00	3
15-20	17.0	0.34	2.00	5
10-15	12.1	2.16	18.00	36
7-9	8.0	2.07	26.00	62
Below 7	4.4	3.92	89.00	84

A study of individual samples having oxygen demand values between 6 and 12 and showing complete stability by the methylene blue test, has indicated that the dissolved oxygen does not have to equal the oxygen demand value to insure complete stability, and a few instances have been noted where the dissolved oxygen in the river water was only forty percent of the oxygen demand yet the samples showed complete stability, indicating that some other source of oxygen was available, probably in the form of nitrites or nitrates.

Five-Day Value:

As the relationship between the rapidity of oxidation in sewage at constant temperature is subject to prediction, approximately from day to day, it would be possible to use any reasonable period of incubation as a test citerion. The period of five days has been frequently used in determining the quality of sewage and sewage polluted waters. It has the advantage over other periods of incubation in that if a mixture of sewage and water contains sufficient oxygen to meet the five day oxygen demand of the organic matter content, then the liquid under ordinary conditions in streams will not become entirely devoid of oxygen, and thus no nuisance will be created. If a shorter period of incubation should be used as a criterion, the oxygen content for equal freedom from nuisance would necessarily exceed the biochemical oxygen demand. If a period of incubation longer than five days should be taken, an oxyben content less than the biochemical oxygen demand would be justified. Therefore, the use of the period five days as an index is a convenient period for use. It has been used by the U. S. Public Health Service in its stream studies in the United States, and it was adopted by the Royal Commission on Sewage Disposal in its very comprehensive report upon "The Sewage Pollution of Streams" in England.

Laboratory Experiments:

Certain laboratory experiments at Columbus, Ohio, in connection with the sewage disposal problem, bear upon this point. Table 14 shows certain data regarding the rapidity of oxygen depletion and the recovery thereof with sewage in open containers.

In the first two columns of this table it is apparent that all of the oxygen absorbed from the air was used up at once and this continued for six days in both the first and second tests. In the third test it was five days before the original content of oxygen was restored, and in the fourth test it was four days before this condition obtained. The last three tests were made on diluted samples, and the results indicate that the maximum depletion occurred during the first two days, and that thereafter reaeration and demand were balanced. The last three tests also show that the dissolved oxygen is drawn upon rather heavily before reaeration becomes a marked factor, indicating that if a marked depletion of dissolved oxygen is to be prevented the initial oxygen must be considerably in excess of the two-day demand.

Reference in again made to the rates of satisfaction (page 50 of this report) which is as follows:

In 1 day—21% of total 20-day requirement
In 2 days—37% of total 20-day requirement
In 3 days—50% of total 20-day requirement
In 4 days—61% of total 20-day requirement
In 5 days—68% of total 20-day requirement

TABLE 14.

RESULTS OF OPEN INCUBATION TESTS OF RAW SEWAGE AND TANK EFFLUENTS AT THE SEWAGE TREATMENT WORKS AT COLUMBUS, OHIO.

Dissolved Oxygen Content in Parts per Million of 10 Gallon Mixtures After Incubation in Open Containers at Room Temperature.

	Undiluted Raw Sewage	Undiluted Raw Sewage	Undiluted Tank Effluent	Undiluted Tank Effluent	Raw Sewage diluted 4 times. (1)	Raw Sewage diluted 8 times. (2)	Raw Sewage diluted 12 times (3)
At Start	1.0	0.0	1.2	1.2	5.3	6.8	6.9
After 1 day.....	0.0	0.0	0.6	0.6	0.8	2.4	3.2
After 2 days....	0.0	0.0	0.3	0.7	0.7	3.2	3.2
After 3 days....	0.0	0.0	0.4	1.0	1.1	3.6	4.0
After 4 days....	0.0	0.0	0.7	1.6	0.8	4.0	4.0
After 5 days....	0.0	0.0	1.5	2.8	1.0	4.0	4.3
After 6 days....	0.4	0.4	2.6	3.0	1.0	3.9	4.0
After 7 days....		0.9		3.5			
After 8 days....		1.0		3.8			
After 9 days....		1.2		4.0			
After 10 days...		1.4		4.0			

1. Raw sewage one volume, clean water 3 volumes.
2. Raw sewage one volume, clean water 7 volumes.
3. Raw sewage one volume, clean water 11 volumes.

If the 5-day demand is taken as the total oxygen which must be supplied by the dilution water, the relation is as follows:

	Per cent of 20 day demand	Per cent of 5 day demand
One day	21	30.9
Two days	37	54.4
Three days	50	73.5
Four days	61	89.7
Five days	68	100.0

Reaeration Absent:

The standard hereinafter proposed in this report is that the residual dissolved oxygen and 5-day demand must be equivalent at Lockport, and the worst condition that might result is shown in the following table, and is based on the entire absence of reaeration:

	Dissolved Oxygen in P.P.M.		
	Initial	Consumed	Residual
Start	8.0		
After 1 day		2.47	5.53
After 2 days		4.35	3.65
After 3 days		5.88	2.12
After 4 days		6.18	1.82
After 5 days		8.00	0.00

In the above table it is assumed that the dissolved oxygen content of the water is 8.0 parts per million, and complying with the standard proposed in this report, the 5-day demand would be 8.0 parts per million.

Reaeration:

It is our belief that there will be enough reaeration to prevent a serious depletion of oxygen in the Drainage Canal if the recommended standard of pollution is adhered to.

When the mixed lake water and sewage reaches Lockport, in summer, the purifying action of the lake water is finished. The oxygen content of the liquid is practically zero. Nevertheless in its further flow to Chillicothe, the total organic units, passing that point in a given time, are greatly reduced through agencies other than Lake Michigan water. This, notwithstanding the fact that the normal load in the summer season is greatly augmented by river bottom deposits which have remained in refrigeration during the colder months.

An analysis of the studies of the U. S. P. H. Service for the month of August, 1922, indicate that the purifying agencies acting below Lockport and above Chillicothe, from sources other than Lake Michigan, are more potent in total than the total diluting water from Lake Michigan. These purifying agencies may include sedimentation, putrefaction, and oxidation. In our opinion oxidation is the chief factor. This opinion is reinforced by the fact that between Chillicothe and Peoria (in Peoria Lake) a distance of sixteen miles, the recovery of oxygen units in the water is nearly as great as was obtained in total diversion from Lake Michigan.

In addition to the natural agencies there are artificial agencies that may be called into action if needed to increase reaeration; namely, the fall at Lockport, and the available fall at the several state dams when the Illinois waterway is built. Several studies of the river indicate a marked recovery in oxygen at the Marseilles dam where much of the water is wasted over the dam. At Lockport it nearly all passes through the water wheels of the Sanitary District, with practically no oxygen gain at present.

Thus in our opinion reaeration even of still water is a most important agency of purification.

Dilution in Other Cities:

Attention is further invited to Table 15 which shows the dilution water available for several American cities which discharge untreated sewage into the streams along which they are located. The data contained in this table simply shows what has been allowed to exist as a permissible pollution and probably the conditions created therefrom in the several streams have varied from satisfactory to doubtful.

The recommended standard contained in this report (eliminating for the moment the matter of settleable solids) is that 5.9 cubic feet per second per 1000 human population will be required to properly dispose of the entire untreated sewage of the Sanitary District of Chicago during the warm weather season of the year.

Dilution After Purification:

We show in Table 16 a list of cities in which more or less complete purification has been adopted, together with the amount of diluting water that is available in dry weather to mix with the purified effluent in the stream below the purification works. The dilution is expressed in cubic feet per second per thousand of population based on the 1920 census.

It will be observed that in several instances the stream goes dry.

TABLE 15.

DILUTION WATER AVAILABLE FOR SOME AMERICAN CITIES THAT HAVE NO SEWAGE TREATMENT.

	City	Name of River	Population Tributary 1920	Drainage Area Sq. Miles	Estimated Dry Weather Flow in C.F.S.		
					Total	Per Sq. Mi. Drainage Area	Per 1000 Pop. Tributary
1	Cincinnati	Ohio	681,000	76,320	6,490	0.085	9.50
2	Grand Rapids	Grand	171,000	4,900	1,433	0.292	8.25
3	Iowa City	Iowa	17,000	3,140	128	0.041	7.42
4	Lansing	Grand	57,000		265		4.62
5	Washington	Potomac	541,000	12,555	2,300	0.183	4.25
6	Minneapolis & St. Paul	Mississippi	680,000	35,700	1,600	0.045	2.36
7	Dayton	Gt. Miami	210,000	2,598	342	0.131	1.62
8	Pittsburgh	Ohio	1,216,000	19,020	1,670	0.088	1.37
9	Des Moines	Des Moines	126,000		164		1.30
10	Youngstown	Mahoning	287,000	958	167	0.175	0.58
	Sums		3,986,000	154,233	15,150		
	Means					*0.095	3.80
	Mean, No. 10 Omitted						4.05

* Nos. 4 and 9 omitted.

The numerical average dilution is .58 second feet per thousand people. The weighted average is .42 second feet per thousand people. Attention is called to the fact that as these cities grow the dilution ratio must become less, for in all cases, so far as known, there is no practicable means by which the dry weather flow of the stream will be increased.

As compared to the above figures the standard recommended in this report and the recommended purification works contemplate dilutions as follows: These dilutions are expressed in second feet of diluting water per thousand people as of the year 1935, when recommended sewage works have been completed, and ten years thereafter.

With total diversion including dilution water and sewage of	In Year 1935	In Year 1945
4,167 second feet	.65	.5
6,000 second feet	1.1	.9
7,500 second feet	1.5	1.2
8,500 second feet	1.7	1.4
10,000 second feet	2.1	1.7

These figures when compared with the data shown in Table 16 tend to indicate that a liberal amount of dilution is provided by the recommended standard for pollution and the recommended works for purification. It would appear that if this dilution is not sufficient, then the satisfactory disposal of sewage in many of our inland cities is impossible.

Pollution and Fishes:

It is evidently desirable that our streams insofar as possible should be sufficiently pure to permit the continuance of the natural water life thereof, including the fishes. This matter is particularly important in Illinois River which has been the best fish stream in the Middle West. For many years it has supported a commercial fishery with a catch ranging from ten million to twenty-three million pounds per year. About seventy-five percent of the catch has been the so-called coarser fishes such as Carp and Buffalo. The so-called game fishes have been present in large numbers, and the Illinois River has been the playground of the game fisherman, and is so at present in its lower reaches. Of recent years the commercial catch has materially declined due in part to causes other than sewage pollution.

Inorganic Wastes:

In certain parts of the country inorganic wastes are produced by industries that have poisoned the fishes and entirely destroyed them throughout long stretches of streams. Numerous industrial wastes are poisonous to fishes when present in certain amounts.

TABLE 16.

DILUTION OF TREATED SEWAGE IN VARIOUS CITIES OF THE UNITED STATES.

City	Population 1920	Stream	Drainage Area Sq. Mi.	Estimated Dry Weather Flow C. F. S.	Estimated Dry Weather Flow C. F. S. Per 1000 Pop.	Method of Treatment
1. Akron, Ohio	208,435	Little Cuyahoga	....	76	0.36	Imhoff Tanks and Sprinkling Filters.
2. Calvert, Texas	2,099	Tidwell Creek	....	0	0.0	Separation Tanks, Sprinkling, Final Settling.
3. Fitchburg, Mass. ..	41,029	N. Br. Nashua	62	25	0.61	Imhoff Tanks, Sprinkling Filters, Secondary Tanks.
4. Lincoln, Neb.	54,948	Salt Creek	....	64	1.16	Separate Sludge Digestion, Sprinkling Filters.
5. Madison, Wis.	38,378	Yahara	235	35	0.92	Separate Sludge Digestion Sprinkling Filters.
6. Sherman, Texas ...	15,031	Town, Br.	....	0	0	Activated Sludge.
7. Champaign & Urbana	33,780	Salt Fork	75	0-2.6	0-.08	Imhoff Tanks and Sprinkling Filters.
8. Columbus, Ohio ..	260,338*	Scioto	1,666	30-50	0.12-0.19	Imhoff Tanks and Trickling Filters.
9. Decatur, Ill.	43,818	Sangamon	862	0	0	Imhoff Tanks, Sprinkling Filters, Secondary Settling Tanks.
10. Oklahoma City	91,295	N. Canadian	....	0	0	Tanks and Trickling Filters.
11. Dallas, Texas	184,515*	Trinity	5,950	130	0.71	Imhoff Tanks.
12. Austin, Texas	34,876	Colorado	37,000	130	3.72	Imhoff Tanks.
13. Ashland, Ohio	9,249	Jerome Fork	....	3	0.33	Tanks and Sand Filters.
14. Delaware, Ohio ...	8,756	Olentangy	....	4	0.46	Tanks and Contact Filters.
15. Fostoria, Ohio	9,987	Portage Creek	35	3	0.30	Screens, Storage Reservoirs, Sand Filters.
16. London, Ohio	4,080	Oak Run	....	3	0.73	Tanks, Contact Filters.
17. Mansfield, Ohio ...	27,824	Rocky Fork	32	5	0.18	Tanks, Contact Filters.
18. Plain City, Ohio..	1,330	Big Darby Creek	268	3	2.28	Tanks, Contact Filters.
19. Shelby, Ohio	5,578	Black Fork Creek	40	2	0.36	Tanks, Intermittent Filters.
20. Westerville, Ohio ..	2,480	Alum Creek	150	2	0.81	Tanks, Contact Filters.
21. Crystal Lake, Ill..	2,249	(Creek)	4	0	0.0	Tanks and Sand Filters.
22. Lexington, Ky. ...	41,524	Town Br.	....	1.5	0.037	Imhoff Tanks, Trickling Filter.
23. Houston, Texas ..	138,276	Brays Bayou	155	5	0.036	Activated Sludge.
Numerical Ave.	....	....	....	....	0.58	
Weighted Ave.	....	....	....	....	0.423	

*Population of City and adjoining territory U. S. Census of 1920.

Upon the Illinois River, so far as we know, the inorganic pollution has not reached amounts to be seriously detrimental to fishes.

Organic Pollution:

Certain of the coarser fishes may live and possibly thrive in waters more or less heavily sewage polluted. There is, however, a limit to the suspended organic matters present in waters in which fishes may maintain healthy conditions. All the fishes and the attendant train of water life necessary for their existence are killed, if the air supply in the water is reduced to zero for a sufficient period. This exhaustion of air may result from the decomposition of organic matters.

With a reduction in the dissolved oxygen carried by a stream, the more sensitive fishes, and ultimately all the fishes endeavor to get away. If escape is impossible they die. Some of the so-called coarser fishes may tolerate for a time, conditions in which oxygen is practically exhausted from the water, due to their power to take, store, and use a certain amount of atmospheric oxygen. Other fishes do not have this ability.

During the winter of 1924-5, ice conditions on the Illinois River reduced the dissolved oxygen to figures as low as from .4 to 1.8 parts per million. Under conditions such as this all kinds of fish taken from nets under the ice were found to be dead. At another place where the water contained 2.5 parts per million of dissolved oxygen, only Carp, Buffalo, and Gars were taken alive, all in a stupid condition. In another part of the stream where the oxygen content was 5.4 to 5.8, all fish were found in good condition under the ice.

It is believed that the above figures typify minimum conditions under which the fishes may survive. They probably require more favorable conditions than this throughout most of the year, in order to propagate and thrive.

A study of the graphs and tables of pollution on the Des Plaines and Illinois Rivers herein-elsewhere shown, coupled with a knowledge of the places where fishes may now be found, throw some light upon limits of pollution.

Fishing conditions below Peoria in general are good. Above Peoria fishes are practically extinct except as follows: In seasons of low flow from the tributary streams, the dead line has moved downstream to Peoria and unfavorable conditions have been noted as far south as Havana. In seasons of maximum flow from the tributaries, the dead line moved upstream. It is understood that the 1925 season finds fishes in Peoria Lake, from which they have been largely or entirely absent for several years. This is probably due to the heavy summer flows in 1924.

The study of the river seems to indicate that where the dissolved oxygen exceeds the five-day demand of the organic matter in summer, and considerably exceeds it throughout the remainder of the year that fish may thrive providing that the minimum dissolved oxygen at any time is three parts per million or more.

In the works which we have suggested for sewage treatment at Chicago under various rates of dilution, and the standard herein-elsewhere set down for the liquid discharged by the Drainage Canal at Lockport, we believe that satisfactory fish conditions will be maintained throughout the greater part of the Illinois River. We believe that conditions will permit the coarser fishes to live at all places from Joliet to the Mississippi.

Recommended Standard:

After reviewing all the data which has been available relative to the past conditions which have prevailed in the Illinois River below Lockport, in addition to the studies which have been made and which indicate the sanitary quality of the waters of the streams which are tributary to the Illinois; and, with the purpose in view of seeking a reasonable degree of cleanness in the Illinois River below the terminus of the drainage canal; and, in the belief that the maintenance of such condition is not prohibitive in cost or unduly difficult of attainment; the following standards of maximum pollution are proposed:

The liquid discharged by the Drainage Canal, as evidenced by the average of representative samples taken for any thirty consecutive days shall:

(a) Be practically free from settleable solids deposited in two hours and

(b) Shall contain dissolved oxygen equal to, or exceeding, the biochemical oxygen demand of said liquid for five days when incubated at twenty degrees Centigrade.

(c) Shall contain not less than three parts per million of dissolved oxygen.

In connection with the second standard relating to the oxygen balance, it is expected that there will be times when a condition of extreme refrigeration will exist in the waters of the canal which may result in a five-day oxygen demand value in excess of the dissolved oxygen content, but it is considered that, with an absence of settleable, putrescible solids in the water and the probability of the presence also of an ample supply of dissolved oxygen, a violation of this standard under these conditions will not be detrimental to the maintenance of proper stream conditions in the Illinois River below the terminus of the Drainage Canal.

It is also suggested in connection with the application of these standards of permissible pollution that sewage treatment devices should not be expected to register maximum efficiency at all times, and that occasionally conditions will arise which will temporarily reduce their efficiency until proper corrective measures can be applied. Fallibility is characteristic of all things human, so that these standards are to be considered, as a rule, with occasional justifiable and unavoidable exceptions.

PART VI.

REQUIRED DEGREE OF PURIFICATION WITH VARIOUS DILUTIONS.

Our instructions require that we should report upon the purification works necessary under each of several diversions from Lake Michigan; namely 2,000, 4,167, 6,000, 7,500, 8,500, and 10,000 cubic feet per second.

We have been instructed to consider these quantities as stated to be total diversions from the lake, including the water contained in the sewage plus the water used for diluting purposes. Thus practically speaking, the total diversion is equivalent to the dry weather flow discharged at the mouth of the Drainage Canal near Lockport.

Water for Dilution:

For the purpose of this study the amount of water available for dilution in the critical period of the year, July and August, is considered to be the total diversion less the liquid volume of sewage of the Sanitary District. In this computation it will be assumed that the sewage liquid is substantially the same as that which was analyzed in determining the total organic load of the Sanitary District as summarized in Part IV of this report.

In the estimates for purification works hereinafter made, the above total diversions from the lake are considered as constant from year to year. The organic load of the city as shown in Table 12 of Part IV must grow from year to year. Experience indicates that during the hot weather months the sewage has been delivered at the sewer outlets in a condition practically devoid of oxygen. Within ordinary variations in the supply of water per capita, this will probably continue to be the fact. Therefore, with a constant total diversion from the lake and an increase in organic load which is delivered at the sewer mouths devoid of oxygen, the available diluting water will progressively decrease with the growth of the city, and the effectiveness of works for purification must progressively increase as time goes on.

Organic Load and Dilution:

The organic content of sewage for practical purposes must be determined at the point of delivery of the sewers. At this point in warm weather more or less oxidation has already taken place. The analysis represents the organic content of that particular sewage which has passed through a certain history as regards amount of dilution and in other respects. If the water supply per capita has been less, the analysis would have shown a sewage somewhat stronger in organic load per capita, for less oxidation would have taken place enroute to the sewer outlet. If the water supply per capita had been greater, the analysis would have shown less organic matter per capita, or more dissolved oxygen in the sewage, possibly both.

It is believed that when considering such variations in the use of water per capita as may occur in Chicago, it will be immaterial whether the organic wastes of the city are diluted by water taken into the sewers through the faucet or by water mixed with the sewage at the sewer outlet. It is our opinion, therefore, that it will be logical and proper to take the organic load of the District at the time when the analyses were made; to take the liquid volume of the sewage existing at the time when the analyses were made; to assume that all sewage is delivered to the stream devoid of oxygen; to assume that the liquid volume of the sewage will increase in proportion to the increase in the organic load, namely, that the consumption of water per capita remains constant; and that the available diluting water will be the total diversion less the liquid sewage computed upon the basis as above.

The Sanitary District has made a careful estimate of the total liquid load as of the year 1920 at 758 million gallons. This is equivalent to 253 gallons per capita. We have used the round number 250 gallons per capita in computing Table 17, which shows the total net dilution water available between 1925 and 1945 under the various specified total diversions from 2,000 to 10,000 second feet. The table also shows the available oxygen in the dilution water. These figures are used in Parts XIII, XIV, and XV of this report.

Necessary Purification Plant Efficiencies:

In selecting the type of treatment best adapted to supplement various rates of dilution, it is useful to estimate the average rate of purification that would be required to produce a satisfactory effluent. Upon the following pages we describe the method of calculation, and tabulate the principal results.

The degree of purification of the combined wastes of the Sanitary District of Chicago which must be accomplished in order to make certain specified diversions effective in maintaining proper conditions in the rivers which receive the discharge of the Drainage Canal, is determined on the basis of the daily oxygen required by the entire liquid-borne wastes of the District, and the supply of oxygen furnished daily by any given diversion of lake water.

TABLE 17.

ESTIMATED "NET DILUTION WATER" WITH VARIOUS "TOTAL DIVERSIONS" AND OXYGEN AVAILABLE FOR DILUTION IN JULY AND AUGUST.

Year	1925	1930	1935	1940	1945
Estimated volume of sewage delivered to stream devoid of oxygen—sec. ft.	1280	1410	1530	1650	1770
With 2000 sec. ft. Constant Diversion					
Net water for dilution sec. ft.	720	590	470	350	230
Available oxygen lbs. per day	31000	25400	20200	15000	9900
With 4167 sec. ft. Constant Diversion					
Net water for dilution sec. ft.	2887	2757	2637	2517	2397
Available oxygen lbs. per day	124000	118400	113200	108000	103000
With 6000 sec. ft. Constant Diversion					
Net water for dilution sec. ft.	4720	4590	4470	4350	4230
Available oxygen lbs. per day	203000	197000	192000	187000	182000
With 7500 sec. ft. Constant Diversion					
Net water for dilution sec. ft.	6220	6090	5970	5850	5730
Available oxygen lbs. per day	268000	262000	257000	252000	246000
With 8500 sec. ft. Constant Diversion					
Net water for dilution sec. ft.	7220	7090	6970	6850	6730
Available oxygen lbs. per day	310000	305000	300000	294500	289000
With 10000 sec. ft. Constant Diversion					
Net water for dilution sec. ft.	8720	8590	8470	8350	8230
Available oxygen lbs. per day	375000	370000	365000	360000	354000

The basic data for the first part of this computation is recorded in Part IV, Table 12, in which is shown the total oxygen required per day, separately and collectively, by the three polluting elements contributing to the load. This same table also shows the total daily oxygen loads of the entire district for the year 1925, and for five-year intervals to 1945.

One second foot of lake water per day during the warm months of the year (July and August) will supply forty-three pounds of oxygen, and the second feet of lake water required per day during July and August will be as shown in the first portion of Table 18.

Taking, for instance, the second feet per day required for the year 1925, Table 12 of Part IV shows the total daily oxygen requiremnt on the five-day demand basis to be 856,000 pounds, consequently, 856-000 pounds divided by forty-three pounds gives 19,900 as the second feet required per day for untreated sewage.

Table 18 shows the daily oxygen loads for the polluting unit of each polluting element; also the second feet of water required per day during July and August for each polluting unit. These months were selected for use because they represent the critical period of the year both as regards oxygen supply and demand.

TABLE 18.

SHOWING DAILY OXYGEN LOADS AND DILUTION WATER REQUIREMENTS FOR POLLUTING UNITS.

Polluting Element	Polluting Unit	Pounds Oxygen Supplied During July and August Per Sec. Ft. Per Day by Diluting Water	Pounds Oxygen Required Per Day Per Polluting Unit on Basis of Oxygen Demand For			Second Feet Required Per Day During July and August Per Polluting Unit on Basis of Oxygen Demand For		
			5 Days	10 Days	20 Days	5 Days	10 Days	20 Days
Human Population	1000 Pop.	43	182	240	267	4.23	5.58	6.21
Stock Yards Waste	1 Mil. Gals.	43	5650	7500	8330	131	174	194
Corn Products Waste	1 Mil. Gals.	43	3750	5000	5670	87	116	132

TABLE 19.

SHOWING TOTAL DAILY DILUTION REQUIREMENTS AND PURIFICATION REQUIRED FOR SPECIFIED DIVERSIONS.

Year	Second Feet Required Per Day During July and August on Basis of Oxygen Demand For			Purification Required on Basis of Following Daily Diversions in Second Feet and For Oxygen Demand Values of 5 Days, 10 Days and 20 Days. (Expressed in Per Cent)																	
	5 Days	10 Days	20 Days	5 Days						10 Days						20 Days					
				2000	4167	6000	7500	8500	10000	2000	4167	6000	7500	8500	10000	2000	4167	6000	7500	8500	10000
1925	19,900	26,300	29,300	96.4	85.5	76.3	68.7	63.7	56.2	97.3	89.0	82.0	76.3	72.6	66.8	97.5	90.1	83.9	78.8	75.4	70.2
1930	21,700	28,600	31,900	97.3	87.2	78.8	70.5	67.3	60.4	97.9	90.3	83.9	78.7	75.2	70.0	98.1	91.3	85.6	80.9	77.8	73.1
1935	23,600	31,100	35,800	98.0	88.8	76.8	74.7	70.5	64.0	98.5	91.5	85.6	80.8	77.6	72.8	98.7	92.6	87.5	83.3	80.5	76.3
1940	25,300	33,400	37,200	98.6	90.0	83.2	76.9	72.9	67.0	98.9	92.5	87.0	82.5	79.5	75.0	99.1	93.2	88.3	84.3	81.6	77.6
1945	27,100	35,900	40,000	99.1	91.1	84.4	78.9	75.2	69.6	99.6	93.3	88.5	84.0	78.5	77.1	99.4	94.0	89.4	85.7	83.2	79.4

If it is desired to determine the pounds of oxygen available in one second foot of lake water per day, the result is secured by multiplying as follows:

Parts per million of dissolved oxygen in water × 0.646 M. G. in one second foot per day × 8.33 pounds per gallon, or parts per million of dissolved oxygen in water × 5.4.

The factor 5.4 is the product of 0.646 X 8.33 and is a constant.

Table 19 shows the second feet required per day during July and August for five-year periods from 1925 to 1945, and for five, ten and twenty-day oxygen demand values. The five-day demand is sixty-eight percent of the twenty-day demand and the ten-day demand is ninety percent of the twenty-day value. It is assumed in this computation that the strength of the polluting unit of each polluting element will remain the same during the period of time involved.

The second section of Table 19 shows the purification, expressed in percent, required for gross diversions of 2,000, 4,167, 7,500, 8,500 and 10,000 second feet per day and for oxygen demand values of five, ten and twenty days.

The computation showing the percentage of purification required, is simply one of subtraction and division, and may be illustrated by taking the first value in the table; viz., 96.4 which is arrived at as follows:

19,900 second feet — (2,000 second feet —1,280 second feet) divided by 19,900 or 96.4%.

The percentage values in this table are carried to the first place beyond the decimal; however, this is not intended to imply that this degree of refinement should be followed in the use of these values as they constitute simply a record of a mathematical computation.

With these data in hand and a knowledge of practicable plant efficiencies, it is possible to select the types of treatment works that would produce required results.

Seasonal Variations:

All the computations hereinabove made refer to the critical season of the year, namely, the warm months of July and August. In the winter time each unit of lake water will carry about double the amount of oxygen available during the critical period. Furthermore, oxidation takes place at a slower rate during the cooler months of the year, and the sewage is thus afforded the opportunity to travel further downstream, to be subjected to additional aeration and to be mixed with additional tributary waters.

For all these reasons, it is undoubtedly practicable to regulate the diversion from the lake in accordance with the needs of the situation existing from month to month. All the interests affected by diversion of water from the lake are concerned only with an average diversion. There appears to be no reason why it will not be entirely practicable to materially increase the flows herein estimated for the warm months of the year should occasion arise, and to save the water thus taken during other months of the year, thus staying within a stipulated average diversion.

Factor of Safety:

It must be admitted that it is not practicable to compute exactly the amount of diluting water that necessarily must be added to the sewage in order to obviate nuisance and to permit a thriving fish life. It is desirable that there should be a factor of safety to provide against error. In our opinion, it will be wise to adopt as the average diversion with various degrees of purification the amounts herein set down as required in the months of July and August, and to use the additional water available in the cooler months of the year as a factor of safety, thus permitting some increase of the dilution in the hot months to cover,

(a) The possibility of less reaeration in the lower river than herein contemplated.

(b) Washings from the sewers in storm that may be necessarily by-passed from the sewage purification plants.

(c) The accidental depletion in the oxygen in the lower river through the sudden death of green plant growths.

(d) Some degree of inferiority in the diluting water entering through the Sag Canal and other minor drafts on the oxygen supply not specifically considered herein.

Additional Oxygen:

No specific consideration has been given to additional oxygen that may be furnished by the effluent from the sprinkling filter plants and the activated sludge plants. This oxygen will be in addition to that obtained from the lake and from the other sources mentioned.

At the present time practically no aeration is obtained at Lockport in dropping the water from the Drainage Canal into the Des Plaines River in passing through the water wheels. It would probably be possible to add from one to two parts per million to the sewage by an overfall especially designed for aeration. This possibility will occur at all of the dams hereinafter constructed for navigation purposes on the Illinois River except where the water may be used for power purposes.

PART VII.

PROTECTION OF THE WATER SUPPLY

It must be a part of any scheme for sewage disposal that the water supply should be protected against any possibility of sewage contamination. Unless this is accomplished sewage disposal fails in its principal requirement.

This matter is particularly important to municipalities located on the shores of the Great Lakes. In all of these cities the lakes constitute the only practicable means for municipal water supply. In many instances the lakes are the only practicable means for sewage discharge.

In the Chicago region the means has been provided through the drainage canal, by which the great majority of all impurities are diverted from Lake Michigan. As will be pointed out, certain sources of pollution still remain, and will continue to exist, regardless of any improvements in the Sanitary canal. These sources of pollution are sufficiently great to seriously menace the water supply, unless adequate precautions are taken to guard against them.

Lake Shore Line:

The south end of Lake Michigan is relatively shallow. On the Chicago water front the distance outward for twenty-five feet depth varies generally from half a mile to a mile. The four-mile crib at Chicago stands in thirty-six feet of water. The depth of water is five to eight feet less at the other intake cribs, located at lesser distances from shore. Opposite the mouth of the Chicago River a depth of fifty feet is attained only at seven miles from the shore. Opposite the mouth of the Calumet River the same depth is only attained nine miles out. Opposite Gary the lake is deeper; fifty feet is attained at a distance of four miles from shore.

At the shore line there is a fringe of sand generally varying from ten feet more or less, at Chicago, to about fifty feet in the vicinity of Gary. This sand is a superficial deposit upon a bed of blue clay. The sand layer generally disappears within a mile or two from shore, and the coating is scattering and thin at this distance out.

Intakes and Pollution Sources:

The accompanying map, Figure 1, shows the Lake Michigan shore line, the location of the Water Works intakes, and the location of the streams forming potential sources of pollution.

The distance of the Chicago Water Works' cribs from the mouth of the Chicago River, and Calumet River respectively are as follows:

	Miles from Chicago River Mouth	Miles from Calumet River Mouth
Wilson Ave. Crib	5.2	16
Carter Harrison Crib	2.3	12.7
Chicago Ave. Crib	1.3	12.2
Four Mile Crib	3	9.3
Hyde Park & E. F. Dunn Cribs	8	3.7

About six miles southeast of the Calumet River mouth, the Indiana Harbor canal is located, which taps the Grand Calumet River and discharges more or less sewage into the lake. Between these two points lie the Water Works' intakes of Whiting and Hammond, Indiana. The East Chicago intake is close to the shore, and only a short distance from the Indiana Harbor canal. The Gary intake is one and one-half miles from shore, six miles east of the Indiana Harbor canal and twelve miles from the Calumet River, measured in a direct line.

Sources of Pollution:.

From the mouth of the Calumet River, north to the Cook County line, the sewers are now diverted from the lake. North of the Cook County line the towns between Highland Park and Waukegan sewer into the lake, except a small population in Highland Park which sewers inland toward the Skokie Marsh. Most of this sewage reaches the lake in a raw state at present. A portion of it is partially purified. These cities are members of the North Shore Sanitary District, intended to prevent excessive pollution of the lake. Conditions in this locality will probably be somewhat improved hereafter.

Indiana Towns:

The Indiana towns from the State line eastward, including Gary, now contain a population of 180,000. These towns are growing very rapidly. They are the sites of some of the largest industries in the Chicago region. Grand Calumet River is the main sewer of this region. Considerable sewage from the shore population in Hammond and Whiting, and from several industries, discharges directly to the lake. The entire City of Gary, and the greater part of the sewage in East Chicago and Hammond drains inland and only reaches the lake through the outlets of the Calumet.

Calumet River:

Attention is invited to the Grand Calumet and Little Calumet Rivers, and their relation to Lake Calumet, the outlet of the two streams into Lake Michigan, and the location of the Calumet Sag Channel. The

Sag Channel is now designed for 2,000 second feet. At certain seasons of the year this is sufficient to take the sewage of the Chicago Sanitary District reaching it and the entire flows of the Grand and Little Calumet Rivers. In seasons of flood the Sag Channel is very insufficient to take the flow of these streams.

Figure 17 is a watershed map of the Grand Calumet and Little Calumet Rivers. The total drainage area of these streams is 770 square miles.

The maximum measured flood in this district occurred in February, 1887. It was measured at Riverdale on the Little Calumet River and amounted to 13,300 second feet. The Sanitary District of Chicago has estimated the maximum flood to be expected from the combined Grand and Little Calumet Rivers at 16,000 second feet. The estimate of the International Waterways Commission is substantially the same.

Continuous gaugings are not available showing the frequency and duration of floods. In a report of Mr. Wisner, Chief Engineer, of the Chicago Sanitary District, June 9, 1909, it is estimated that with 2,000 second feet flowing in the canal, there would be 22.4 days per year when the flood flow from the Calumet Rivers would exceed the flow of the Sag canal. The source of the information upon which this estimate is based is not stated. Judging by the experience of the nearest adjoining streams upon which flow records are available, it appears that the above figure may be approximately true. Flow records on the Kalamazoo River, draining somewhat similar territory in Michigan, applied to the Calumet Rivers with drainage area correction, indicate a probability of eighteen days per year when the flow of these sereams might be expected to exceed 2,000 second feet. A similar comparison based on daily gaugings on the Des Plaines River, corrected for drainage area, indicate about twenty-five days flow in excess of 2,000 second feet.

A large flood on these streams will undoubtedly wash great quantities of filth into Lake Michigan. The Calumet cities are beginning to study the question of sewage purification. Conditions in the future will no doubt be improved. No practicable means for sewage purification will place these streams in condition where their waters may be periodically flushed into the water supply of the region even occasionally, with safety to the water supplies.

Water Level Changes:

The lower Calumet River, between Calumet Lake and Lake Michigan, is dredged 200 feet wide and twenty-one feet deep. It requires a slope of only a small fraction of an inch from Lake Calumet to Lake Michigan to discharge 1,000 second feet. A difference in level of slightly over two inches will discharge 5,000 second feet. A recording guage at

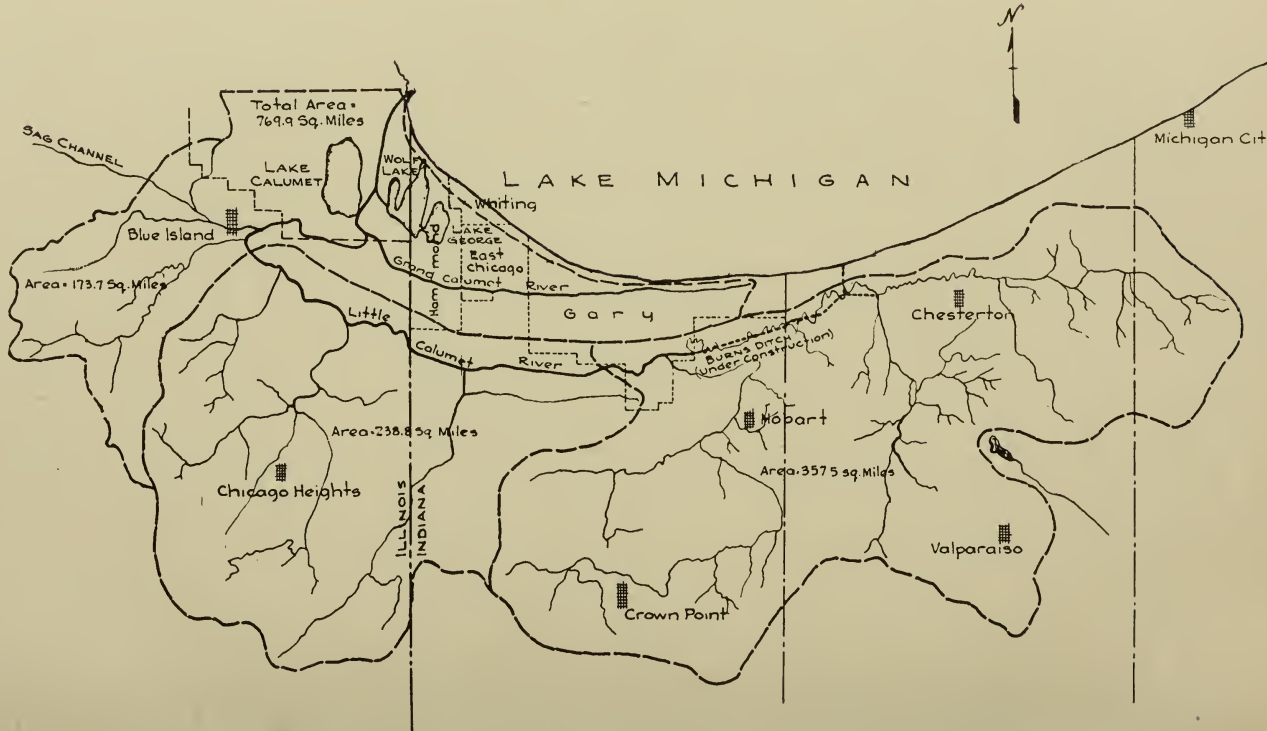


Figure 17.—Drainage area of Grand Calumet and Little Calumet Rivers. (Scale approx. 1 inch = 8.4 miles)

the mouth of the Calumet River shows that the surface of the lake is constantly rising and falling, due principally to changes in direction and velocity of the wind. Changes of six inches in less than an hour are very common. It is an exceptional day in which the total variation is less than six inches at different times during the day. Upon moderately windy days the variation is frequently more than one foot.

Some years ago we conducted a systematic watch of the currents in the lower Calumet River, estimating the current velocities by rod floats This study confirmed what would be expected by the water level variations in Lake Michigan, and the comparatively large volume of stagnant water in the Calumet Rivers and Lake Calumet. Whenever the lake surface dropped a few inches a rapid current was set up toward Lake Michigan, which continued until a change in the wind caused the lake surface to rise, in which case if the rise was great enough the outflow was stopped, the current reversed, and often a rapid current ran inland for several hours, to return again with a subsequent fall in the lake level. Thus on February 20, 1920, with a variation in lake level of about three tenths of a foot and a brisk northwest wind gradually decreasing after 3 p. m., the flow of the river varied from 1,000 second feet from the lake at 2 p. m. to 3,000 second feet toward the lake at 5 p. m.

On February 11th, with a brisk northeast wind, the flow from 1 to 5 p. m. varied from 1,000 to 1,500 second feet landward. For short periods it became nearly stagnant. On February 12th with a mild southwest wind the flow averaged about 2,000 second feet toward Lake Michigan from 1 to 3 p. m., but stopped entirely as the wind died down about 4 p. m.

Thus the Calumet Rivers and Lake are constantly "breathing" in and out, toward and from Lake Michigan, depending principally upon the direction and velocity of the winds. In severe storms there are also very important barometric changes causing lake level fluctuations of several feet, bringing out heavy discharges for periods of many hours.

No doubt a similar condition exists where the Indiana Harbor canal taps the Grand Calumet River. This is a wide and deep harbor; only a small difference in head, an inch or less, is required for the interchange of water between the river and Lake Michigan. The sewage of Gary is supplemented by a large amount of condensing water from the steel mills. A rapid flow is produced in the upper Grand Calumet. The final disposition of this sewage laden water depends upon the stream cross-sections, and the relative elevations of the moment as between the Calumet Rivers and Lake Michigan.

Chance Pollution from Chicago River:

Prior to the construction of the drainage canal, conditions at the mouth of the Chicago River were somewhat similar to those previously described as prevailing in the Calumet region. The floods of the Chicago River have not been accurately measured. It has been estimated that the discharge capacity of the storm water sewers in Chicago makes it possible to produce a flood of about 11,000 second feet. Possibly it may be questioned whether this is so at the present time. If it is not true today it probably will be true as the city becomes improved to a greater extent than at present. With the drainage canal in operation at the rates of flow, which have prevailed during the past ten years, there is little danger of a material amount of flood water reaching Lake Michigan. There have been a few occasions, however, for a short time when a lakeward flow has been noticed following great rain storms. With lesser flows in the drainage canal these occasions would become more frequent and of longer duration.

At the present time lakeward flows of water would be very detrimental to the Chicago water supply. With the general adoption of sewage purification works, and the consequent cleaning up of the Chicago River, the dangers resulting from a lakeward flow of water would be diminished but there would still be a potential danger to the water supply. The purification of the sewage would not be a determining factor in the matter further than to diminish the quantity of filth that might be washed into the lake by flow reversal.

Travel of Pollution in the Lake:

The question as to the travel of pollution in the waters of Lake Michigan has been studied very thoroughly upon several occasions covering the Chicago water front, the water front opposite the Chicago north shore suburban towns and further north along the lake at Racine and Milwaukee. The results of these studies indicate similar conditions wherever sewage contamination reaches the lake and variable winds and waves are available for dispersion. The net results from these studies are well summed up by Major W. V. Judson in his paper on currents in Lake Michigan, (first report Lake Michigan Water Commission, page 67).

"In my opinion the currents of Lake Michigan are so irregular in character that nothing would be gained worth the cost if attempt were made to obtain classified further data of a general nature. If it is a question of protecting the water supply of any particular locality, in any event, special study would have to be made inasmuch as the lake currents, available as they are, are much influenced by local conditions.

We do know, and perhaps it is enough for the purposes of this commission, that occasional currents of considerable velocity, say several miles per hour, may be expected to arrive from almost any direction at any point reasonably near either shore of the lake. It is, therefore, apparent that in a general case if the waters of the lake are polluted by the discharge into it of large quantities of sewage, then, practical localities in the lake, even twenty or thirty miles distant from the point of entrance to the sewage, are not safe places in which to derive water for domestic use."

Numerous special investigations of lake water condition, and the practical experience in the operation of the water works intakes, all indicate that in any particular place reasonably adjacent to the lake shore the quality of the water varies between extremely wide limits, including water almost sterile for considerable periods of time, the usual prevalence of moderately heavy pollution, depending upon the locality, with occasional gross pollutions, regardless of locality within practicable reach of a water works inlet.

Turbidity:

In drawing a continuous supply for the water works, it is necessary to locate the intake not closer than two or three thousand feet from the shore, in order to prevent ingress of sand and stoppages from anchor ice. A large supply must necessarily be taken further from the shore. The Chicago intakes are located from two to four miles outward.

Upon the west shore of Lake Michigan there are long periods of the summer season when the prevailing winds are from the west and southwest. At such times the surface water is blown out into the lake and is replaced by a return current along the lake bottom. At such times as this an exceptionally clear and pure water may be drawn from an intake located at or below mid depth, in twenty-five to forty feet depth.

Severe storms usually occur with an east or northeast wind, The surface water is blown in toward the shore, breakers are formed in the shallow water, the dirty sand and accumulated sludge adjoining the shore are stirred up and the water is returned lakeward as an undertow. The filth is, however, more or less intermixed, from bottom to top of water, in depths under fifty feet. At such times as this no clean or pure water can be obtained; the degree of the turbidity and extent of pollution depends principally upon the severity of the storm and somewhat upon its direction.

Wind conditions varying between the two extremes, which have been mentioned above, produce water conditions varying between the extremes of quality previously mentioned. There are certain conditions in storms when pollution may travel with great rapidity to a Water

Works intake. The situation is much like the dissipation of smoke from a tall chimney. In relatively calm weather it may disappear within a short distance from the chimney. Under a current of wind it may stream out in one direction, traveling for miles. Pollution in a lake may travel in similar manner.

Present Condition of the Water Supply:

About two-thirds of the time the water drawn from the Chicago cribs is clear. It is often quite pure for short periods. However, its sanitary character cannot be depended upon from hour to hour. For a considerable portion of time at all the intake cribs it is distinctly bad. It can only be safely used after heavy doses of liquid chlorine. The required dosage has increased of recent years. Occasionally the Health Department has advocated boiling. The water as delivered to consumers is often decidely turbid for weeks at a time.

The net result from a sanitary standpoint from the water as chlorinated has been very good, although there have been times when it has been suspected of producing typhoid fever in local instances, apparently due to chance pollution. To a large number of people the taste imparted to the water through the chlorine dosage is extremely objectionable. The demand is becoming stronger from year to year for a water free from the chlorine taste.

Records of Turbidity:

The two mile crib supplying the Chicago Avenue pumping station and a part of the water of the 22nd St. Station furnishes about one-fifth of the total water supply of the city, including the downtown district. Table 20 shows the prevailing turbidity of the water drawn from this crib during the past ten years.

In the consideration of turbidity, which represents the apparent cleanliness of the water, it should be stated that a clean water, such as produced by water filtration plants, has a turbidity of about five. A turbidity of ten is noticeable by people accustomed to clear water. A turbidity of fifteen would cause serious complaint where people are accustomed to clear water. A turbidity of fifty represents a very dirty water that would desirably be treated by sedimentation before application to a mechanical filter.

The records for the two mile crib shows that the water has a turbidity more than ten practically at all times. It has a turbidity above fifty for periods totaling from two to seven weeks per year, excepting one year. This crib being the nearest to shore generally has the highest turbidity as compared to other Chicago cribs.

TABLE 20.

TURBIDITY OF WATER AT TWO MILE CRIB
Showing Number of Days of Various Degrees of Turbidity.

	1915			1916			1919			1920			1921			1922			1923			1924		
	Above 50	Above 10	Below 10	Above 50	Above 10	Below 10	Above 50	Above 10	Below 10	Above 50	Above 10	Below 10	Above 50	Above 10	Below 10	Above 50	Above 10	Below 10	Above 50	Above 10	Below 10	Above 50	Above 10	Below 10
Jan.	0	31	0	0	31	0	4	31	0	0	31	0	0	31	0	0	25	6	0	31	0	0	31	0
Feb.	0	28	0	0	29	0	1	28	0	0	4	25	0	28	0	0	18	10	0	28	0	0	29	0
March	16	31	0	5	31	0	9	31	0	2	19	12	1	31	0	0	31	0	3	31	0	0	31	0
April	2	30	0	4	30	0	22	30	0	10	29	1	6	30	0	2	30	0	6	30	0	0	30	0
May	2	31	0	0	31	0	4	31	0	3	31	0	9	31	0	0	22	9	6	31	0	0	31	0
June	0	30	0	0	30	0	0	30	0	2	26	4	1	19	11	0	28	2	0	30	0	0	30	0
July	1	31	0	0	31	0	0	31	0	0	29	2	0	24	7	0	31	0	0	31	0	0	31	0
Aug.	4	31	0	0	31	0	0	31	0	1	31	0	0	31	0	0	31	0	0	31	0	0	31	0
Sept.	7	30	0	1	30	0	0	30	0	0	28	2	0	30	0	0	30	0	0	30	0	0	30	0
Oct.	16	31	0	14	31	0	0	31	0	1	31	0	1	31	0	0	31	0	0	31	0	...	....	....
Nov.	0	30	0	12	30	0	6	30	0	0	30	0	17	30	0	0	30	0	0	30	0	...	....	....
Dec.	0	31	0	3	31	0	2	31	0	0	31	0	1	31	0	0	31	0	0	31	0	...	....	....
Totals	48	365	0	39	366	0	48	365	0	19	320	46	36	347	18	2	338	27	15	365	0	...	....	....

Data from Chicago Department of Public Works, Bureau of Engineering.

TABLE 21.

FREQUENCY OF TURBIDITY IN CHICAGO PUBLIC WATER SUPPLY—FEBRUARY TO DECEMBER (inclusive) 1924 SAMPLING STATIONS IN LAND TUNNEL SHAFTS.

Station	WILSON AVE. CRIB							
Turbidity Range	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100
January	....	....	....	....	...	...	...	...
February	0	3	6	7	5	5	0	1
March	1	9	11	7	3	0	0	0
April	7	12	9	2	0	0	0	0
May	7	14	10	0	0	0	0	0
June	16	10	2	1	0	0	0	0
July	24	5	2	0	0	0	0	0
August	19	10	2	0	0	0	0	0
September	7	21	2	0	0	0	0	0
October	10	20	1	0	0	0	0	0
November	11	17	2	0	0	0	0	0
December	8	13	9	1	0	0	0	0
Year — Days	110	134	56	18	8	5	0	1
Year — %	33.1	40.4	16.9	5.4	2.4	1.5	...	0.3
Year — Total Samples	332							

Station	CARTER HARRISON CRIB							
Turbidity Range	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100
January	....	....	....	....	...	...	...	...
February	0	1	3	5	10	4	3	1
March	0	6	17	3	4	0	1	0
April	8	16	5	1	0	0	0	0
May	15	6	7	2	1	0	0	0
June	26	2	1	0	1	0	0	0
July	25	4	1	1	0	0	0	0
August	21	7	2	0	1	0	0	0
September	4	17	6	3	0	0	0	0
October	8	20	3	0	0	0	0	0
November	4	24	2	0	0	0	0	0
December	8	14	5	4	0	0	0	0
Year — Days	119	117	52	19	17	4	4	1
Year — %	35.8	35.1	15.6	5.7	5.1	1.2	1.2	0.3
Year — Total Samples	333							

Station	TWO MILE CRIB							
Turbidity Range	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100
January	No Samples Collected During January							
February	0	0	5	4	5	1	4	4
March	0	1	9	10	7	1	2	1
April	0	8	7	10	4	0	1	0
May	2	14	13	2	0	0	0	0
June	14	9	6	1	0	0	0	0
July	1	26	4	0	0	0	0	0
August	13	17	0	0	0	0	0	0
September	5	12	9	3	1	0	0	0
October	2	22	7	0	0	0	0	0
November	3	16	11	0	0	0	0	0
December	5	5	11	6	2	2	0	0
Year — Days	45	130	82	36	19	4	7	5
Year — %	13.7	39.7	25.0	11.0	5.8	1.2	2.1	1.5
Year — Total Samples	328							

Station	FOUR MILE CRIB							
Turbidity Range	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100
January	....	....	....	....	...	...	...	...
February	0	2	8	2	5	1	4	3
March	1	15	7	5	3	0	0	0
April	9	13	4	1	3	0	0	0
May	10	6	9	3	2	1	0	0
June	22	8	0	0	0	0	0	0
July	29	1	1	0	0	0	0	0
August	30	1	0	0	0	0	0	0
September	19	7	4	0	0	0	0	0
October	21	9	1	0	0	0	0	0
November	22	8	0	0	0	0	0	0
December	14	10	6	1	0	0	0	0
Year — Days	177	80	40	12	13	2	4	3
Year — %	53.5	24.2	12.1	3.6	3.9	0.6	1.2	0.9
Year — Total Samples	331							

TABLE 21 (Concluded).

Station	68th ST. CRIB								DUNNE CRIB							
Turbidity Range	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100
January	....	....	....	....	...	...	...	...	....	....	....	....	...	...	...	...
February	0	0	0	8	8	2	7	0	2	1	0	6	9	1	8	0
March	0	6	9	10	4	0	1	1	0	7	12	7	4	1	0	0
April	9	14	3	2	2	0	0	0	9	15	4	0	1	0	0	0
May	21	10	0	0	0	0	0	0	21	10	0	0	0	0	0	0
June	[illegible]	2	0	0	0	0	0	0	28	2	0	0	0	0	0	0
July	26	4	0	0	0	0	0	0	25	3	3	0	0	0	0	0
August	31	0	0	0	0	0	0	0	30	1	0	0	0	0	0	0
September	20	6	4	0	0	0	0	0	13	12	3	2	0	0	0	0
October	23	7	1	0	0	0	0	0	19	11	1	0	0	0	0	0
November	28	2	0	0	0	0	0	0	22	8	0	0	0	0	0	0
December	6	8	3	1	2	0	0	0	10	11	5	5	0	0	0	0
Year — Days	92	59	20	21	16	2	8	1	179	81	28	20	14	2	8	0
Year — %	60.2	18.5	6.3	6.6	5.0	0.6	2.5	0.3	53.9	24.5	8.4	6.0	4.2	0.6	2.4	...
Year — Total Samples	319								332							

Station	ALL CRIBS—DAYS								ALL CRIBS—PERCENT							
Turbidity Range	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100	0 5	6 10	11 15	16 20	21 30	31 40	41 50	51 100
January	No Samples Collected During January								....	....	....	....	....	..	....	...
February	2	7	22	32	42	14	26	9	1.3	4.5	14.3	20.8	27.3	9.1	16.9	5.8
March	2	44	65	42	25	2	4	2	1.1	23.7	34.9	22.6	13.4	1.1	2.1	1.1
April	42	78	32	16	10	0	1	0	23.5	43.6	17.9	8.9	5.6	...	0.5	...
May	76	60	39	7	3	1	0	0	40.9	32.3	21.0	3.7	1.6	0.5	....	...
June	134	33	9	2	1	0	0	0	74.9	18.4	5.0	1.1	0.6	...	....	...
July	130	43	11	1	0	0	0	0	70.3	23.2	6.0	0.5	....	...	....	...
August	144	36	4	0	1	0	0	0	77.8	19.5	2.2	....	0.5	...	....	...
September	68	75	28	8	1	0	0	0	37.8	41.7	15.6	4.4	0.5	...	....	...
October	83	89	14	0	0	0	0	0	44.6	47.9	7.5	....	....	...	....	...
November	90	75	15	0	0	0	0	0	50.0	41.7	8.3	....	....	...	....	...
December	51	61	39	18	4	2	0	0	29.1	34.9	22.3	10.3	2.3	1.1	....	...
Year — Days	822	601	278	126	87	19	31	11	....	....	....	....	....	..	....	...
Year — %	41.6	30.4	14.1	6.4	4.4	1.0	1.5	0.6	41.0	30.1	14.1	6.6	4.7	1.1	1.8	0.6
Year — Total Samples	1975															

Table 21 shows the maximum and average turbidities at each of the Chicago cribs. The average turbidity was less than ten a little more than half the time during the year 1924, up to October. The average turbidity at all the cribs ranged between twenty and thirty-five during February, thirteen to twenty-five during March, and ten to fifteen during April. The maximum turbidity was above ten at most of the cribs during the months of February to October inclusive. It was above fifty at all the cribs during February, from 30 to 55 during March, from eighteen to fifty during April, and ten to forty in May.

Filtration:

All objection to the present water supply can be eliminated by mechanical filtration, which it is practical to apply to the Chicago water supply at a comparatively moderate expense. Filtration will give the citizens of Chicago pure clean water all the time, eliminating all possibility of danger from the chance pollutions of the lake. A number of cities upon the Great Lakes have already installed filtration works, including several of the smaller cities in the Chicago region, also including the cities of Detroit, Cleveland, Lorain, Erie and Niagara Falls. In several cases highly polluted waters are rendered entirely satisfactory for domestic consumption.

Polluted Waters Treated:

At several places on the Great Lakes, lake water is safely filtered after receiving the sewage of the city supplied through intakes removed only a comparatively short distance from the sewage outlets. Cleveland is an example of this type. At Cleveland the water is taken within 19,000 feet from sewer inlets receiving only partially purified sewage.

Upon the Ohio River, city after city, from Pittsburgh to Cairo, takes its water supply from the river, returning the sewage again to the stream, the water being again and again used by the cities downstream after filtration. Table 22 shows a list of these cities with approximate distances measured by river, from sewage outlet to water works intake.

Although it has been felt desirable, and is proper in all cases in the water supply of cities, to select as pure a source as possible even when filtration is resorted to, it has been necessary in some cases to filter more or less grossly polluted water. The results from the sanitary standpoint can safely be said to have exceeded expectations wherever filtration has been resorted to.

TABLE 22.

SUCCESSIVE POLLUTION AND USE FOR WATER SUPPLY OF THE OHIO RIVER FROM PITTSBURGH TO CAIRO.

City Using Filtered River Water			Nearest Principal Source of Pollution		
Miles Below Pittsburgh	City	Population 1920	Miles Upstream	City	Population 1920
0	Pittsburgh	588,343			
50	E. Liverpool	21,411	20	Beaver Monaca	7,900
66	Toronto	4,684	20	Wellsville	8,849
80	Steubenville	28,508	8	Toronto	4,864
105	Wheeling	56,208	25	Steubenville	28,508
110	Bellaire	15,061	5	Wheeling	56,208
190	Marietta	15,140	73	Moundsville	10,669
202	Parkersburg	20,050	12	Marietta	15,140
322	Huntington	50,177	37	Gallipolis	6,070
340	Ashland	14,729	4	Catlettsburg	4,183
344	Ironton	14,007	4	Ashland	14,729
372	Portsmouth	33,011	28	Ironton	14,007
498	Cincinnati	401,247	126	Portsmouth	33,011
499	Newport	29,317	126	Portsmouth	33,011
520	Aurora	4,299	22	Cincinnati	594,000*
634	Louisville	234,891	136	Cincinnati	594,000*
639	New Albany	22,992	5	Jeffersonville	10,098
804	Evansville	85,264	35	Owensboro	17,424
815	Henderson	12,169	11	Evansville	85,264
837	Mt. Vernon	5,284	25	Henderson	12,169
934	Paducah	24,735	105	Henderson	12,169
			130	Evansville	85,264
979	Cairo	15,203	45	Paducah	24,735

*Including adjoining river towns.

Niagara Falls:

A typical example as to what filtration can accomplish with a freshly polluted water is instanced by the experience at Niagara Falls, New York. For many years prior to 1913 this city was one of the most important typhoid centers in the United States. The city water supply is taken from Niagara River a few hours after the water receives the sewage from more than 500,000 people at Buffalo, and from other smaller cities downstream. The accompanying Table 23 shows the typhoid history of Niagara Falls prior to and following the installation of filter plants in the year 1913. Two plants were installed. The municipal plant went into service in February and the New York Water Company's plant went into service in June, 1913. For a period of eighteen months shortly following the installation of the filters no typhoid deaths occurred in the city, although shortly prior thereto and for many years previous the typhoid death rate had commonly exceeded 100 per hundred thousand per annum. Within the past ten (10) years there have been only a few cases reported, a careful tally of them has been kept, and it is stated they have not been traced to water supply.

Cost of Filtration for Chicago:

It is believed that the most feasible plan for filtering the Chicago water supply will consist of plants located on the lines of the intake channels at or close to the Lake Shore line. The city could be served by four (4) plants, namely at Wilson Avenue, Chicago Avenue, Roosevelt Road and 67th St. It would be practicable to install bulkheads and

TABLE 23.

TYPHOID DEATH RATE AT CITY OF NIAGARA FALLS, N. Y.

Year	Typhoid Deaths	Estimated Population	Typhoid Death Rate per 100,000	Remarks
1899	24	17,261	139	
1900	24	19,457*	123	
1901	29	20,362	143	
1902	22	21,267	103	
1903	29	22,172	131	
1904	34	25,037	135	
1905	49	26,432	185	
1906	43	27,827	154	
1907	37	28,000	132	
1908	28	29,000	97	
1909	24	29,793	80	
1910	32	30,445*	105	
1911	55	32,800	168	
1912	23	35,000	66	
1913	10	37,000	27	Began water filtration**
1914	3	39,000	7.7	
1915	0	41,000	0	
1916	5	43,000	11.6	
1917	5	44,800	11.1	
1918	2	46,600	4.3	
1919	2	48,500	4.1	
1920	5	50,760*	9.8	
1921	5	52,600	9.5	
1922	2	54,800	3.6	
1923	1	57,000	1.8	
1924	3	59,000	5.1	

*U. S. Census.
**Municipal Water Filtration Plant put in operation in February.
**Western New York Co. Filtration Plant put in operation in June.

gates in the tunnels, pump the water to the surface, pass it through sedimentation basins and filters, store it in clear water reservoirs of moderate size, and return the water again to the tunnel system beyond the shore gates where it could pass as at present to the pumping stations.

It is stated that the water in the tunnel system now receives some pollution from unknown sources after entering the tunnels. The City Engineer states that his investigations indicate that this pollution is probably confined to pollution at certain shafts. It seems hardly possible that pollution could enter the tunnels proper, after passing landward from the shore line. It is feasible to stop the surface pollution at the shafts, if it exists. It is further possible in the design of the filter works to eliminate any possibility of pollution by adopting an hydraulic grade line in the tunnel system above the ground water plane. This would be possible by extending the shafts at the pumping stations to a higher elevation and pumping water to a corresponding height at the shore line. This could be done without increased cost of pumping. It is practicable to purchase low lift pumps in large units that will have an efficiency substantially equal to the pumps used in delivering water to the city, and there would be no net loss of head.

In several instances the filtration plants could be located in existing city parks, or in connection with the lake shore park improvements now under way. It is possible to design the plants so that they would add materially to the beauty and interest of the parks. Where the lake shore is not proposed to be used for park purposes, it is possible to construct the plants upon made ground closely adjoining the shore line. Much ground of this character has already been made adjacent to the city, and is in process of making in connection with Chicago's lake front improvements.

Tentative estimates made by City Engineer, John Ericson, on the filtration of Chicago water are as follows:

	Mil. Gals. per Day	Investment	Annual Operating Expenses	Total annual expense including 5% interest and 2% depreciation
Wilson Ave. Plant.......	200	$ 4,000,000	$ 234,335	$ 514,335
Chicago Ave. Plant......	500	10,000,000	676,705	1,376,705
Roosevelt Rd. Plant.....	155	3,100,000	188,120	405,120
68th St. Plant...........	445	8,900,000	651,000	1,274,000
Totals	1,300	$26,000,000	$ 1,750,160	$ 3,570,160

The above estimate covers an installation that would be sufficient to filter the present water supply. If the water supply of the city is metered, the above plant would serve all requirements of the city until after the year 1960, making due allowance for the seasonal and hourly variations in pumping.

The above total cost is approximately $8.65 per capita on the present population of Chicago. The average annual cost, including operating and fixed charges, is approximately $1.20 per capita on the present population, and would be materially less under the increased population of Chicago during the next thirty years during which the investment would be effective.

Conclusion Regarding Filtration:

Chicago is entitled to a clean water, safe from a Sanitary standpoint 365 days per year. This standard is generally demanded throughout the United States. It is only a question of time when it will be demanded in Chicago.

In our opinion filtration will insure a pure clean water for Chicago at all times, under any diversion through the drainage canal exceeding 2,000 second feet. It is our belief that no amount of diversion up to the present capacity of the Chicago drainage canal will insure safe water for Chicago without filtration. We believe this is true regardless of any practicable measures that may be taken for sewage purification. We believe it is the only adequate safeguard for the Chicago water supply.

PART VIII.

SAVINGS EFFECTED BY METERING.

The quantity of municipal sewage is largely dependent upon the water supply. In Chicago where the population for which sewage treatment is to be provided is large, the industrial load is great, and the amount of water pumped is extravagant, the problem of keeping expenditures for sewage treatment works reasonably low, is difficult. The first two factors, i. e., population and industrial wastes, are fixed as of any particular time; the last factor, water pumpage, is capable of regulation. The question of water waste restriction is acordingly a sewage disposal problem as well as a water supply problem. With this in mind a study of the effect of metering on the costs of sewers and sewage disposal has been made herein and incidental thereto certain observations as to the effect upon the water works and water service are included.

At the present time ninety percent of all of the consumers furnished water by the Chicago Water Works are served through socalled "flat rates" under which there is no incentive to keep plumbing in repair, nor to curtail other wastes. As a result the pumpage of water is excessive. the water service is deficient as to quantity, quality and pressures, and the Water Department is confronted with the continual necessity of making large expenditures in its hopeless effort to keep pace with the open faucet.

In 1923, the last year for which published records are available, but 9.65 percent of all services were metered. The water passed through these meters was 30.4 percent of the total pumpage. The revenue derived from the sale of metered water was 57.96 percent of the total revenue of the Water Works.

The metered water consumers paid an average of approximately six and one-fourth cents per thousand gallons for the water consumed. Approximately seventy percent of the gross pumpage which is unmetered yielded a revenue equivalent to approximately two cents per 1,000 gallons, or less than the actual cost of pumping.

Water waste is directly reflected in the costs of construction, and the cost of operating the Water Works plant. In the past thirty years, during which the population and the mileage of mains have increased approximately 150 percent, the cost of improvements to the Water Works and the average daily pumpage have increased approximately

400 percent, or at a rate two and a half times as fast as the population.

Pumpage and construction costs increase at approximately parallel rates.

Water waste results in deficient water pressures throughout the greater part of the city. At the present time approximately seventy-five percent of the area of the city of Chicago suffers from inadequate pressure during periods of peak consumption.

Water waste decreases the effectiveness of fire protection service.

Water waste is directly reflected in the dry weather sewage flow. It therefore increases the costs of constructing intercepting sewers, sewage pumping stations and sewage disposal plants; it is also directly reflected in the operating costs of sewage pumping stations and sewage disposal plants.

Curtailment of Waste:

Ample precedent and experience are available from which it is practicable to determine, within reasonable limits of accuracy, the possibilities of waste restriction for Chicago, and its effect upon costs of water service and sewage disposal. Table 24 presents the data relative to results accomplished by metering in eleven American cities. Figure 18 shows diagrammatically what has been accomplished by meters in these and other cities. Numerous studies have been made of the particular problem of restricting waste of water in this city. All in-

TABLE 24.

EFFECT OF METERING UPON THE CONSUMPTION OF WATER.

	Use of Water in Gallons per Service	
City	Before Extensive Metering	After Extensive Metering
Evansville, Ind.	1048	396
Cincinnati, O.	1108	734
Cleveland, O.	1258	688
Milwaukee, Wis.	1314	656
Lowell, Mass.	630	427
Peoria, Ill.	838	396
Ironwood, Mich.	853	383
East Chicago, Ind.	2240	1165
Terre Haute, Ind.	1560	508
Hartford, Conn.	1035	635
Fall River, Mass.	755	599
Averages	1149	599
Average per cent metered	6.7	95.0

Average reduction by increasing meters from 6.7% to 95.0% was from 1149 to 599 gallons per service or 48%.

vestigators have been in substantial accord as to the immense savings in cost and benefits in service which would result therefrom.

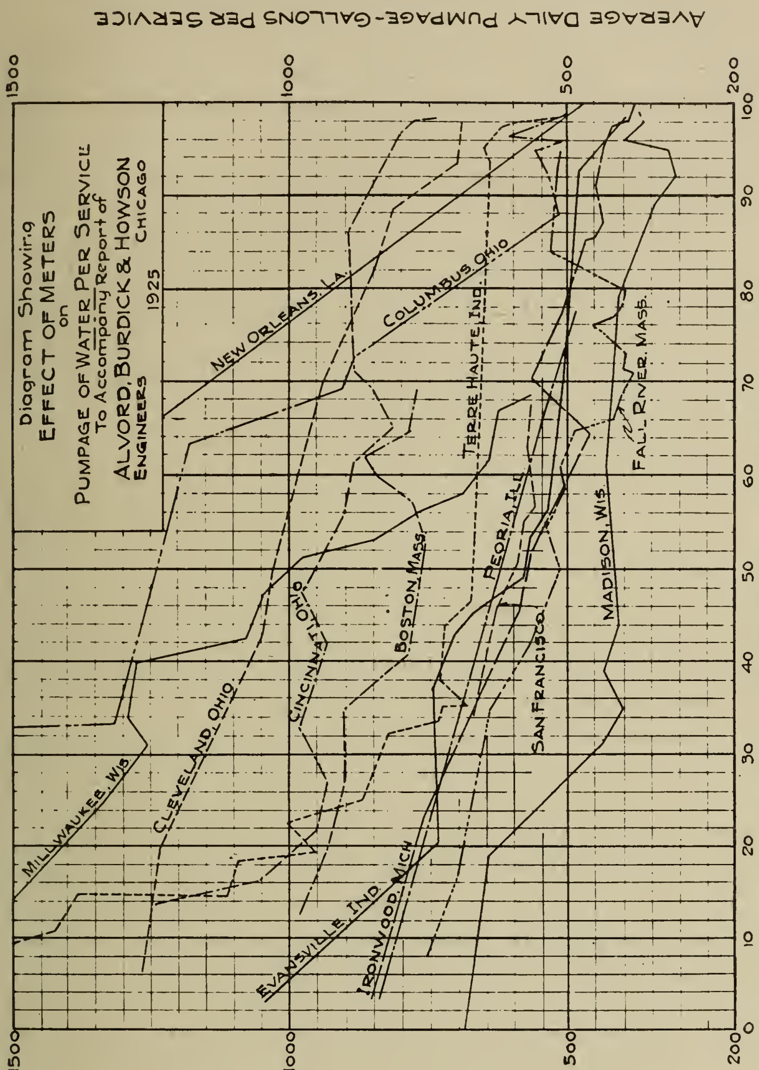


Figure 18.—Effect of meters on pumpage of water per service.

Quite recently, at the mid-winter convocation of the Western Society of Engineers, held in February, 1925, Mr. John Ericson, for nearly thirty years city engineer of Chicago, presented a paper on "THE WATER SUPPLY PROBLEM IN RELATION TO THE FUTURE CHICAGO." In this paper Mr. Ericson effectively showed the need of metering and the results which might be accomplished thereby.

Mr. Ericson estimated the pumpage requirements which the Chicago water supply would be called upon to meet if the present system of metering were to continue, and also what these requirements would be if all water consumers were to be metered within the next ten-year period.

The results of this analysis are shown in diagrammatic form on Figure 19. It is estimated that the total pumpage in 1924, of approximately 800,000,000 gallons per day will increase to 2,200,000,000 gallons per day by 1960, if the present system of metering is continued. If, however, all water services are metered within the next ten years the total pumpage of approximately 800,000,000 gallons per day at the present can be reduced to approximately 520,000,000 gallons per day in 1935, increasing to 800,000,000 gallons per day by 1960. In other words, the pumpage with universal metering, thirty-five years hence will be less than the pumpage at the present time with but ten percent of the services metered. We have carefully investigated this matter and we believe that Mr. Ericson's estimates of reduced pumpage are approximately correct.

This fact has an important bearing upon water works construction costs. No additional crib intake or pumping station capacity and no expenditures for feeder mains would be required for the next thirty-five years if universal metering were to be adopted.

The savings to the Chicago Water Works, due to metering, have been estimated at from $225,000,000 to $425,000,000 in the next twenty-five to thirty-five years. Mr. Ericson, based upon a population of 5,000,000 people in 1960, figures that the saving in operation up to that time will be $117,000,000, the saving in repairs and renewals $43,000,000, and the saving in additions and extensions $143,000,000. Total saving $303,000,000. This saving does not take into consideration fixed charges on the savings in new construction, which if taken at a rate of five percent and based upon the construction expenditures being made at a uniform rate from the present time to 1960, would add an additional $125,000,000, making the total saving to the Chicago Water Works amount to $428,000,000 by 1960.

In a paper "What metering would do for the Chicago Water Works" presented before the Western Society of Engineers by L. R. Howson on February 1, 1923, it was estimated that the savings prior to 1950, due to universal metering would be $88,000,000 in construction expenditures, $145,000,000 in operation, including saving in fixed

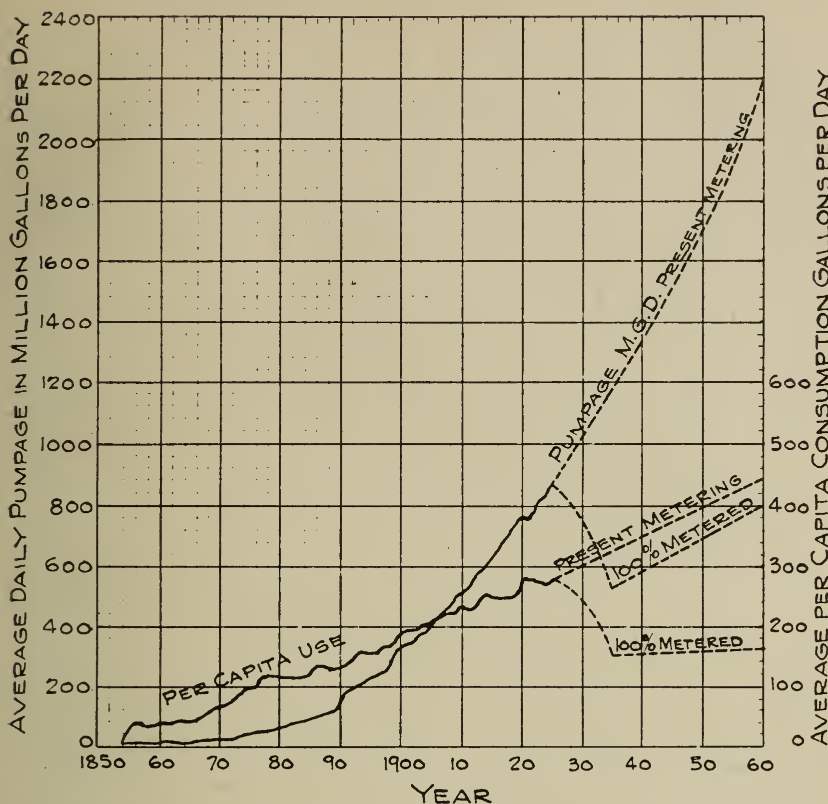


Figure 19.—Effect of metering the Chicago water supply upon total daily pumpage and per capita use.

From paper by John Ericson read before Western Society of Engineers.

charges, total saving $233,000,000, or approximately eight and one-half million dollars per year.

Other estimates have been made, all of which show the enormous savings which can be effected by metering. The exact amount is not of so much importance when the lowest estimates that have been made by competent engineers investigating this matter show a saving in the next generation of over $200,000,000.

Effect of Metering on Intercepting Sewers and Sewage Disposal Costs:

The amount of water reaching the sewers is important in the design of intercepters and sewage disposal works. The costs of a large part of this type of construction are directly proportional to the quantity of sewage to be treated.

Intercepting Sewers:

The capacity of intercepters is directly affected by the amount of the water supply, practically all of which reaches the sewers. If the water pumpage is excessive and can be reduced to the extent of thirty-five percent the intercepting sewer sizes can be reduced about twenty percent and the cost a somewhat smaller percentage. In view of the large mileage of intercepting sewers yet to be built the question of the water supply and its effect upon intercepter sizes is important.

At the present time the intercepting sewers for the Des Plaines and Calumet plants have been completed. The intercepters leading to the North Side plant are all under contract, and construction is well on toward completion. The intercepting sewers leading to the West and Southwest plants have not yet been started. Intercepting sewers for the West Side plant, as tentatively designed by the Sanitary District, include an approximate length of twenty miles of large size, the maximum being twenty-one and one-half feet in diameter. The tentative design of the intercepting sewers for the Southwest plant includes some fifteen miles of sewers, varying in size from five to eighteen feet. In view of the status of the intercepting sewers for these two plants yet to be built, it is pertinent to inquire into the affect of metering upon the design and costs of these sewers.

We have been furnished by the Sanitary District with the basis of design for the West and Southwest sewers. They have furnished us with the drainage areas tributary at points of interception, the population estimated as being located on each drainage area in 1960, the industrial use as estimated by the Sanitary District in cooperation with the City Water Department, and figures as to infiltration. The total sewer capacity average over the entire district amounts to 600 gallons per capita per day.

Based upon figures as furnished by the Sanitary District, the tentative design made by the District's engineers contemplates that the sewers will flow three-fourths full under peak flow conditions. However, under the use of water estimated by Mr. Ericson and others under present conditions of metering, the sewers would be flowing full instead of three-fourths full if universal metering is not adopted. The average use of water if unmetered will be 440 gallons per capita per day. If thirty-five additional is added for the peak flow excess over average the entire sewer capacity is required.

With the entire water supply metered the average use of water would be but 160 gallons per capita per day or 280 gallons per capita per day less than if the present system is continued. Deducting this amount from the capacity allowed in the Sanitary District's estimates an equivalent capacity of 320 G. P. D. per capita would be indicated. This is a lower figure than we would however care to adopt and we have arbitrarily raised it to 375 gallons per capita per day. The effect of metering upon sewer costs is therefore made on this basis.

The sizes of sewers required under both the metered and unmetered bases have been determined for each reach of the intercepters serving the West and Southwest areas in which construction for sewage disposal has not already started. Comparable grades and velocities were assumed.

The costs of the intercepters were estimated using the unit prices developed as described in Part X. It was found that metering will effect a saving of $3,105,500 in the cost of the intercepters to the West Side plant, and $2,043,800 in the cost of the intercepters to the Southwest Side plant; a total of $5,149,300. This saving results from metering alone. It is a saving perfectly practicable of realization. Metering must eventually come.

Had the actual costs of sewers built under contracts let by the Chicago Sanitary District been used as a basis of the comparison the indicated savings would have been much greater.

Metering cannot be retroactive in saving expenditures on sewers already built; it will , however, greatly extend the period of adequacy of such sewers.

In view of the ultimate necessity for metering the Chicago Water Supply, as agreed by all engineers who have given it thorough study, it would seem a wise procedure to give due consideration to this question in the design of sewers by the Sanitary District. Sewers built for the present without meters will be adequate for 1960 with meters.

Effect of Metering on Sewage Disposal Plant Costs:

The cost of certain parts of sewage disposal plants varies directly with the quantity of sewage to be handled. These parts include pumping stations, grit chambers, screens and aeration tanks; other parts vary directly with the solid or organic load of the sewage. These parts include sludge chambers of Imhoff tanks, sludge beds, and sludge pressing and drying equipment, for activated sludge plants.

Other parts of the plants vary in a ratio which is neither directly in proportion to organic load nor to the quantity coming to the plant. This refers particularly to air compressor equipment and to sprinkling filters. It has been found practicable to load sprinkling filters handling domestic sewage with 2,000 to 4,000 people per acre foot depth of sprinkling filters. It has also been found practicable to put sewage through these filters at rates as high as 2,500,000 to 3,000,000 gallons per acre per day without operating difficulties.

The following table shows the operating rates on several plants operating satisfactorily under reasonably heavy loadings.

Sprinkling Filter Loads.

City	Pop. Served	Acre Fact of Stone Filters	Pop. per Acre foot	Sewage per capita (gal.)
Lincoln, Neb.	50,000+	6×2.8=16.8	3,000+	80
Madison, Wis.	51,500	6×2.5=15	(a)3400	(a)102
Columbus, O.	270,000(1920)	5⅓×10=53.3	5060	100
Atlanta, Ga.				
Intrenchment	30,000	5¾×2=11.5	2730	167
Lexington, Ky.	28,000	6×2=12	2330	90
Baltimore, Md.	600,000(1924)	8½×30=255	(a)2360	86
As operated for best results			(a)3500	
Average			3200	104

(a) Exclusive of packing house waste.

At Baltimore where there is a total of thirty acres of stone beds the units are operated so as to maintain as nearly as possible from two and one-half to three million gallons per acre per day rate (average is from 2.79 to 2.91, C. E. Keefer, Engineering News Record, 2-7-24), the equivalent under Balitmore conditions of approximately 3500 people per acre foot of stone beds.

Included in this optimum loading of 3500 people per acre foot of stone filters is a packing house waste, which, based upon weight of animals slaughtered per capita contributing sewage to the plant, is about thirty-five percent as great as that of the Chicago stockyards wastes.

The Madison stone filters, aperating satisfactorily at a rate of 3400 people per acre foot have in addition a packing house waste practically the same as the Chicago stockyards waste, compared on a slaughter weight per capita basis.

A study of the effectiveness of sprinkling filters in reducing the biochemical oxygen demand shows that the Baltimore and Columbus filters reduce the demand sixty-seven and fifty-five percent respectively as compared to thirty-one, thirty-one and forty-nine percent respectively for the two Atlanta and Fitchburg plants with population loads per acre foot, but about half of those at Baltimore and Columbus.

It is our opinion that good operation may be secured within the upper limits of at least 3,000 people per acre foot, and three million gallons per acre per day for six foot stone beds.

As with a per capita use of 160 gallons per day the population served by a six and one-half foot filter operating at a three M. G. D. per acre rate would be about 2850 per acre foot the rate of liquid dosage rather than the population load is considered the limiting factor in comparing the cost of sprinkling filters at Chicago under metered and unmetered conditions.

In the estimated savings on the item of sprinkling filters, effected by metering, we have therefore assumed that the more dilute sewage, under unmetered conditions, would have a direct effect on area and cost of beds. In other words, if the quantity of sewage is doubled due to water waste the area and cost of stone beds would likewise be doubled compared to areas and costs under fully metered conditions.

The effect of metering upon plants already built is to prolong their period of usefulness and defer the time at which additions will be required. Each plant has been analyzed in its component parts, its capacities studied with reference to future needs under metered and unmetered water supply conditions, and the savings effected by universal metering ascertained.

The following is a summarization of the savings which universal metering will effect in the future construction costs of intercepters and sewage disposal works.

Savings in intercepter costs are computed for 1960 quantities; disposal plants for 1945 conditions.

The total savings of approximately $50,000,000 do not include any savings in the construction cost of sewage disposal works to the Chicago Sanitary District after 1945. The savings cover the cost of construction only, operating cost not having been taken into consideration in this part of the study.

The small estimated saving with a flow of 4167 c. f. s. results from the fact that a larger part of the cost of an activated sludge plant is independent of liquid volume than is the case with a sprinkling filter plant. The sludge drying and pressing equipment varies only with the solid content which is in turn independent of the dilution of the sewage.

The 4167 c. f. s. project is the only one contemplating activated sludge treatment at the West and Southwest Side plants.

Savings in Operating Costs:

The restriction of water waste will also have a marked effect upon operating costs of pumping stations and disposal works. Practically all the costs of sewage treatment in plants such as herein considered vary nearly in proportion to liquid quantities, except costs incident to sludge handling and sludge drying, which are practically independent of liquid volume. In estimating the savings in operating cost due to metering, the following bases have been assumed:

(a) The cost of power varies directly with the liquid volume.

(b) Pumping station labor costs vary at a rate of fifty percent as

TABLE 25.

SAVINGS IN CONSTRUCTION COSTS (1945)
OF SEWAGE DISPOSAL WORKS—EFFECTED BY METERING THE WATER SUPPLY.

	Cubic Feet per Second Flow in Channel				
Item	4167	6000	7500	8500	10000
West Side Intercepter	$ 3,105,500	$ 3,105,500	$ 3,105,500	$ 3,105,500	$ 3,105,500
Southwest Intercepter	2,043,800	2,043,800	2,043,800	2,043,800	2,043,800
Calumet Disposal Plant	3,538,800	3,538,800	3,538,800	3,538,800	3,538,800
West Side Disposal Plant	16,092,900	21,192,600	21,188,000	14,683,000	14,683,000
Southwest Side Disposal Plant	10,813,600	17,420,000	13,037,000	13,037,000	13,037,000
North Side Disposal Plant	5,589,500	5,589,500	5,589,000	5,589,000	5,589,000
Totals	$41,184,100	$52,890,200	$48,502,100	$41,997,100	$41,997,100

great as the variation in liquid volume, i. e. if the liquid volume is doubled the station labor is increased fifty percent.

(c) Labor for sewage treatment plant operation varies as above for station labor as the costs are approximately fifty percent determined by liquid volume and fifty percent by total solids or sludge.

The estimated savings in disposal plant operating expenses resulting from metering of the water supply have been estimated as above outlined for the year 1945. The savings vary from $3,000,000 to $4,000,000 per year depending upon the treatment processes necessary with the flows in the channel varying from 10,000 c. f. s. to 4167 c. f. s.

TABLE 26.

SAVINGS IN OPERATING COSTS (1945) OF SEWAGE DISPOSAL WORKS (EXCLUSIVE OF FIXED CHARGES)—EFFECTED BY METERING THE WATER SUPPLY.

	Cubic Feet per Second Flow in Channel.				
Plant	4167	6000	7500	8500	10000
Calumet	$ 174,750	$ 174,750	$ 174,750	$ 174,750	$ 174,750
North Side	947,000	947,000	947,000	947,000	947,000
West Side	1,869,500	1,288,500	1,288,500	968,000	968,000
Southwest Side	1,239,500	850,800	636,800	850,800	850,800
Total Annual	$4,230,750	$3,261,050	$3,047,050	$2,940,550	$2,940,550

Basis.

Sta. labor varies 50% with liquid volume—50% not affected by volume.
Power varies directly with liquid volume.

Treatment plant operating cost varies 50% with liquid volume and 50% with solids.

These savings in operating cost do not include savings in fixed charges which at four percent for interest and two percent for depreciation reserve would amount to from $2,500,000 to $3,000,000 per year in 1945.

The estimated saving in operating cost resulting from metering for each flow is shown in the table included herewith.

Summarization of Savings by Metering:

A study of the estimated savings to the Chicago Water Department during the thirty-five year period to 1960 and other estimated savings for other periods would lead us to believe that not less than $200,000,000 to $225,000,000 would represent a fair measure of the total savings (including interest) to the Chicago Water Works prior to 1945 if meters were adopted and universally installed within ten years. Add to this $200,000,000 saving in the water works, an additional saving of $40,000,000 to $53,000,000 in sewers and sewage disposal and the amount becomes $240,000,000 to $253,000,000 saved in twenty years, an average of over $12,500,000 per year, through the introduction of universal metering, and without crediting any savings after 1945.

An additional amount reaching $3,000,000 to $4,000,000 per year in 1945 will be saved in operating costs of pumping stations and treatment works.

Magnitude of Savings:

The estimated saving of approximately $250,000,000 in twenty years is so great that it will in addition to installing meters at a cost of approximately $10,000,000 build complete filtration works for the Chicago water supply at an estimated cost of $26,000,000 (Mr. Ericson's W. S. E. paper) finance complete sewage disposal for the entire city and still leave over $100,000,000 net, which would be more than enough to acquire the elevated lines and make a good start toward the subway system.

Effect of Metering on Water Service:

In addition to the financial advantages, metering alone will double the average pressure in the water mains of the city, and will enable the water works to furnish all consumers adequate service, where but twenty-five percent now have it.

Water metering will make filtration possible. Without it Chicago must continue to drink unfiltered and at times turbid lake water, highly chlorinated with resulting tastes and odors.

Effect of Metering Upon Protection of Health:

Few sanitary engineers will dispute the assertion that $36,000,000 spent for meters and filtration plants will do more to protect the people of Chicago from water-borne disease than will an equal or larger amount spent for sewage disposal works.

It has been estimated that with a diversion of but 4167 c. f. s. there would be from seven to eight reversals of flow with discharge of sewage into the lake each year (see memorandum concerning drainage and sewage conditions at Chicago, Sanitary District, December, 1923). It is believed to be a safe assertion that seven or eight reversals with filtration would be much less hazardous than the one to four reversals now occurring.

Filtration is the first line of defense against water borne disease. Its results are positive, continuous and effectual. It has repeatedly demonstrated its ability to safeguard the public health.

Filtration is only practicable at Chicago if universal metering is adopted. Its cost, together with large additional savings, can be recovered by metering. Metering is, therefore urgent to:

(a) Protect health against water borne disease.

(b) Enable the water plant to furnish adequate service and pressure

(c) Prevent wasteful expenditures for the waterworks.

(d) Prevent wasteful expenditures for intercepting sewers and sewage disposal works.

PART IX.

VOLUME OF SEWAGE.

The volume of sewage liquid to be treated is dependent upon:

1st. Tributary population.

2nd. The total water use, and

3rd. Infiltration.

So far as the sewage contributed by the domestic population of the Chicago Sanitary District is concerned, practically the entire amount will be collected in the five major sewage disposal plants; viz. The Des Plaines, Calumet, North Side, West Side and Southwest side. The distribution of the population for the present and for each five year period up to 1945, is shown on Table 27.

It will be noted that the total population tributary to these five major plants is somewhat less than the total population of the district as estimated in Part III, and as shown in this table. It is estimated that approximately 105,000 people residing in the district are not tributary to any one of these five plants at the present time, and that it is probable, due to the rapid expansion of the suburban area, that this number will gradually increase and reach approximately 300,000 people by 1945. The sewage originating from this population must either be treated by outlying plants or by pumping to one of the major plants.

TABLE 27.

POPULATION TRIBUTARY TO EACH OF THE FIVE MAJOR SEWAGE DISPOSAL PLANTS.

	Disposal Plant	1925	1930	1935	1940	1945
Population, by Sanitary District	Des Plaines	50,000	60,000	75,000	90,000	105,000
	Calumet	190,000	225,000	255,000	290,000	320,000
	N. Side	690,000	800,000	915,000	1,015,000	1,125,000
	W. Side*	1,370,000	1,430,000	1,490,000	1,550,000	1,615,000
	S. W. Side	950,000	1,040,000	1,135,000	1,230,000	1,322,000
Total 5 Major Plants		3,250,000	3,555,000	3,870,000	4,175,000	4,487,000
Misc. Plants		105,000	155,000	200,000	250,000	298,000
Total Population of Dist.		3,355,000	3,710,000	4,070,000	4,425,000	4,785,000

*Excl. of 300,000 transient loop population.

The table showing the distribution of the total population of the district over the five plants leaves out of consideration the floating or transient population, largely centered over the area tributary to the West Side plant, which embraces the loop district. This floating population is estimated at 300,000 people, both for the present and for 1945, and in the quantities of sewage which are estimated as reaching the West side plant, the resident population has arbitrarily been increased 300,000 people to care for the transient population.

This figure of 300,000 is considered as representative of the purely transient population plus that part of the working or day population which is employed in Chicago, largely in the area to be served by the West side plant, and which lives outside of the area served by the Sanitary District. It necessarily is a more or less approximate figure, but is probably as accurate as can be reasonably determined. Some allowance obviously must be made in a city such as Chicago to care for this sewage load contributed to the total by those not enumerated in the Chicago census figures.

The quantity of sewage to be treated at each of the five major plants has been estimated from a study of the population tributary to each, and has been estimated upon two bases, viz. (a) under the present system of metering, and (b) universal metering of the water supply.

The greater part of the population residing within the Chicago Sanitary District receives its water supply from the City of Chicago. The total pumpage of the Chicago Water Works for the year 1923, averaged 807,000,000 gallons daily, which the Chicago Water Department estimates as having been supplied to 3,062,532 people, of which approximately 150,000 were outside of the city of Chicago but within the Chicago Sanitary District limits.

In addition to the pumpage by the Chicago Water Department, some water reaches the sewers from private water supplies developed by industries and from the supplies of suburban cities within the area of the Sanitary District of Chicago. There are a few industries developing considerable supplies, notably those in the Stockyards and Corn Products districts.

There is also a small population supplied from municipal supplies within the Sanitary District other than the City of Chicago, the largest of which is the Evanston supply. Others are those at LaGrange, River Forest, Forest Park, Summit, etc. While we have no data as to the total amount of water pumped by industries and municipalities other than Chicago, within the Chicago Sanitary District, it is believed that in total amount it does not exceed five percent of the water pumped by the City of Chicago. Most of the water pumped, in addition to that pumped by the City of Chicago, is furnished under metered conditions, with waste well restricted.

The total population of the cities and villages in the Sanitary District (excluding Chicago) has increased from 89,703 in 1900 to 276,930 in 1920. Based upon an average use of 100 gallons per day, the total water used by these villages would be about 30,000,000 gallons per day at the present time, or about four percent of the average daily pumpage of Chicago. The industries probably use enough well water to raise the total to approximately five percent of the Chicago pumpage. Table 5 shows the population of each of the cities and villages in the Sanitary District.

Infiltration of ground water into the sewers is quite indeterminate in amount. The Sanitary District of Chicago has substantially no figures which would furnish reliable information to be used as a basis for the amount of infiltration into the sewers of the various sections of the city under varying soil conditions. No measurements are recorded by the city. Such data as are available are fragmentary only.

The city of Chicago has designed its pumping stations on the basis of 100 gallons per acre per day infiltration in clay soils and 1000 gallons per acre per day in sandy soils. City sewer sizes are determined by flood flows. The greater part of the city of Chicago has a dense clay soil, through which infiltration into the sewers is low. A comparatively small area is sandy. The Sanitary District of Chicago has made its preliminary design of the West Side intercepters, using an infiltration allowance of approximately 2000 gallons per acre per day. The average flow, which is the governing consideration in sewage disposal plant design, is very much less than this amount. It is believed that, taken as an average over the entire Sanitary District area, the infiltration of ground water into the sewers is very small in amount. In the computations hereinafter made in Part IX, the infiltration has been based upon 750 G. P. D. per acre which results in the infiltration about one-sixth of the domestic flow or six percent of the total flow estimated for the West Side intercepter.

A part of the water supply never reaches the sewers. It is used for sprinkling and other uses which do not contribute to the sewage flow. The amount of water lost in this way is alos indeterminate.

Taken as a general average under the conditions prevailing here in Chicago, it is probable that if the infiltration of ground water into the sewers is considered equal to that part of the supply which does not reach the sewers, the result will be not far from correct. This has been the basis upon which the size of the sewage disposal plants outlined in this report has been predicted.

We have prepared a table based upon the estimated population and the water use under universally metered and unmetered conditions, showing the amount of sewage which it will be necessary to treat at each of the five major plants for each five year interval from the present to 1945.

The last line of this table shows the sewage flow per capita for the entire Sanitary District. It will be noted that, under metering, the total amount of sewage averages from 170 to 171 gallons per capita per day as compared to the water consumption previously estimated herein at 160 gallons per capita per day under completely metered conditions. The discrepancy is due to the fact that in estimating the quantity of sewage reaching the West Side plant, there has arbitrarily been added the flow originating from the 300,000 floating population in that area.

So far as the West Side plant alone is concerned, the basis is believed to be the correct procedure. It is also correct insofar as this floating population represents the population originating outside the boundaries of the Sanitary District of Chicago. Insofar as it includes the population originating within the Sanitary District of Chicago, and simply transferred during the working hours from the area tributary to one of the other major sewage disposal plants to the West Side plant area, it results in an over-estimate of the quantities taking the city as a whole.

TABLE 28.

QUANTITIES OF SEWAGE TO BE TREATED UNDER UNIVERSAL METERING AND PRESENT METERING OF WATER SUPPLY.

Plant	1925	1930		1935		1940		1945		
	Million Gallons Sewage Daily									
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	
Des Plaines ..	5	6	6	8	8	9	9	10	10	
Calumet	53	50	67	41	83	46	102	51	118	
North Side ...	193	176	240	145	297	163	354	180	416	
West Side	370	316	429	286	485	296	542	306	595	+ 114
S. W. Side....	256	229	312	182	370	197	430	222	490	
Totals	877	777	1054	662	1243	711	1437	769	1629	(1743)
Ave. G.P.D. per cap.	262	219	296	171	322	170	344	171	364	(390)

(a) Present system of metering.
(b) Universal metering.

This allowance is, however, in the nature of a factor of safety insofar as it is affected by the shifting of populations from one plant to the other. If half the loop is assumed as originating within the Sanitary District boundaries, this allowance for the West Side plant is equivalent to including an allowance of approximately 150 gallons per acre per day for infiltration.

Table 28 is a summarization of the quantities of sewage flow to be expected at each of the five major plants under universal metering and under present conditions of metering of the water supply from 1925 to 1945.

PART X.

FUTURE INTERCEPTING SEWER CONSTRUCTION.

At the present time there are approximately 150 sewer outlets emptying into the Chicago River and the Drainage Canal. The outlets on the North Branch as far south as Fullerton Avenue are all to be intercepted by the North side intercepting sewers for which contracts have already been let. These intercepters serve the North Side treatment works. The present outlets from Fullerton Ave. South and West along the river and main Drainage Canal as far as the village of Summit, are yet to be intercepted and the dry weather flow carried to the proposed West and Southwest Side disposal plants to be located in the vicinity of Summit.

All but about thirty-five miles of the total length of intercepters required have already been built. Of this thirty-five miles, twenty miles will be required to collect the sewage and carry it to the West Side plant and fifteen miles will be required for the Southwest Side plant.

Basis of Intercepter Design:

A glance at the map, Figure 3, shows the routes of the proposed West and Southwest Side intercepting sewers. In general they parallel the river and the Drainage Canal, extending along both sides of these channels from Fullerton Ave. on the North Side, southerly to the main channel where they are joined by intercepters laid from the lake westerly, thence through the highly congested central district and along the Drainage Canal to the vicinity of Summit.

In most of this length the congestion is such as to almost preclude open cut methods of construction. The Sanitary District has accordingly adopted tunnel methods of construction, for which the heavy clay soil of this district is admirably adapted. The tunnels are in general at shallow depths below the street surface.

Other cities such as Milwaukee, Detroit and Cleveland are using tunnel rather than open cut methods quite largely. On paved streets in Milwaukee it has been found economical to use tunnels in constructing pipe sewers as small as ten inches or twelve inches in diameter.

With the conditions prevailing in Chicago, the adoption of tunneling rather than open cut methods will probably be economical, and will greatly reduce inconvenience to the public.

The Chicago Sanitary District has tentative designs for the West and Southwest Side intercepting sewers, the results of which have been furnished to us for our study.

An analysis of the design of the West Side intercepters serving about 1,350,000 resident and 300,000 loop or transient population has been made. In general the analysis shows that approximately 143 gallons per capita per day has been allowed for domestic water supply (including the transient use as domestic) an average of approximately 2,050 gallons per acre per day (equivalent to 34 gallons per capita per day 1960 population) has been allowed for infiltration and an additional allowance for industrial water uses, amounting to approximately the equivalent of 120 gallons per capita per day. All of these units are based upon the sum of fixed and transient populations. The total water reaching the sewers under average conditions is, therefore, 300 gallons per capita per day under this design. This amount is increased by approximately fifty percent giving a peak rate flow of 450 gallons per capita per day, which is then further increased by one-third in order to provide for one-fourth of the sewer capacity always being available for ventilation. The sewers as tentatively designed by the Sanitary District are, therefore, laid out on a basis equivalent to 600 gallons per capita for the 1960 population.

It is believed that this total allowance, while it includes a larger allowance for ground water than we would consider necessary for Chicago conditions, is in the aggregate approximately correct as representative of the conditions of flow in the intercepting sewers if the Chicago water supply is to remain unmetered. It has previously been shown that if meters are not installed the per capita use in 1960 will approximate 440 gallons per capita per day. If this is increased by thirty-five percent to care for peak flows (i. e. 150 gallons per capita per day which is fifty percent of the 300 gallons per capita per day used by the District). The total of 600 G. P. D. per capita used by the Sanitary District would result. The Sanitary District design, therefore, would not allow any excess capacity for ventilation in 1960, if meters are not adopted.

It is, however, inconceivable that the Chicago water supply will remain unmetered another thirty-five years. It is not believed to be good economic engineering to design long lived structures, such as intercepters for populations expected thirty-five years in the future and under the worst possible conditions of water waste. The necessity for metering is so urgent and the benefits from it so great that it is in our opinion decidely unwarranted to base intercepting sewer designs upon a continuation of impossible water uses. Universal metering will effect a reduction in use per capita for the anticipated 1960 conditions of approximately 280 gallons per capita per day which amount in our opinion may be safely deducted in computing the required capacity of the intercepting sewer system. In other words, an intercepting sewer designed on the basis of 320 gallons per capita per day with universal metering will be fully as adequate as the sewers designed without metering on a basis of 600 gallons per capita per day, the figure used by the Chicago Sanitary District.

Basis of Design:

In Computing the capacity required for the West Side intercepters we have adopted the following bases:

(a) Population tributary 1,370,389 (furnished from Sanitary District figures), floating or transient population in loop 300,000 people.

(b) Domestic water use 75 gallons per capita per day of resident and floating population.

(c) Infiltration at the average rate of 750 gallons per acre per day.

(d) Industrial use, as estimated by the Chicago Sanitary District, with the exception of the loop population, the sewage of which we have considered as domestic.

The total average sewage flow from this district for 1960 is thus estimated as:

(a)	Domestic flow	125 MGD.	equivalent to	75 GPD. per capita
(b)	Infiltration	21 MGD.	equivalent to	12½ GPD. per capita
(c)	Industrial uses	204 MGD.	equivalent to	122 GPD. per capita
	Total	350 MGD.	equivalent to	209½ GPD. per capita

Adding to this average flow approximately forty-five percent (90 G.P.D. per cap) for the excess peak rate and allowing sewer capacity sufficient to provide one-third additional for ventilation, a total design capacity of 375 gallons per capita per day is secured.

With the above as a basis, the intercepting sewers for the West and Southwest treatment plants have been tentatively laid out.

The West Side intercepter includes approximately twenty-one miles of sewers, varying in size from seven feet to seventeen feet. The Southwest Side intercepter has a total length of approximately fifteen miles, varying in size from four feet to fourteen feet three inches in diameter.

The routes of the intercepters are as tentatively laid out by the Sanitary District and are substantially as shown on Figure 3. The invert elevations at the disposal plants will be approximately thirty feet below lake level.

Intercepting Sewer Costs:

In view of the large expenditures involved in the construction of intercepting sewers yet to be built we have thought it advisable to ascertain the facts relative to the costs of building intercepting sewers in other large cities of the country. We have accordingly made investigations of the cost of sewer construction in Milwaukee, Detroit, Philadelphi, Cleveland and St. Louis. All of these places have been visited and the facts relative to costs, labor conditions, difficulties encountered in construction and other facts having a bearing upon and being necessary to an adequate interpretation of costs were secured.

It was found that a large mileage of sewers up to fourteen feet in diameter have been constructed within recent years under contracts relative to which it was possible to secure complete information. An analysis of all of the recent contract lettings in all of these cities was made, and the data thus secured is shown in Figure 20.

Inasmuch as the construction of these sewers extended over the past period of approximately five years in most cases, during which time there have been rather violent fluctuations in labor and material costs, the costs in each particular instance have been reduced to present day equivalent costs in the cities in which these contracts were executed.

Further correction was then made in order to give adequate consideration to the relation of costs in these other cities to costs in Chicago. These adjustments were made on the basis of the labor scales prevailing in other cities and in Chicago, and upon the proportions of labor and materials entering into the several types of construction and sizes of sewers. These adjusted costs are shown in Figure 21.

Variation in Conditions:

The soil conditions in the various cities and under the large number of contracts analyzed varied quite materially. We endeavored to ascertain the facts in all cases in order that we might interpret the cost data secured.

Of the several sewer contracts executed on the Cleveland intercepting sewers, only three were constructed under conditions similar to those prevailing in Chicago through the district yet to be served with intercepters. Four of the sewers were constructed in whole or in part in quicksand or in wet soil conditions which made the use of air necessary. In our application to Chicago conditions these sewers were eliminated.

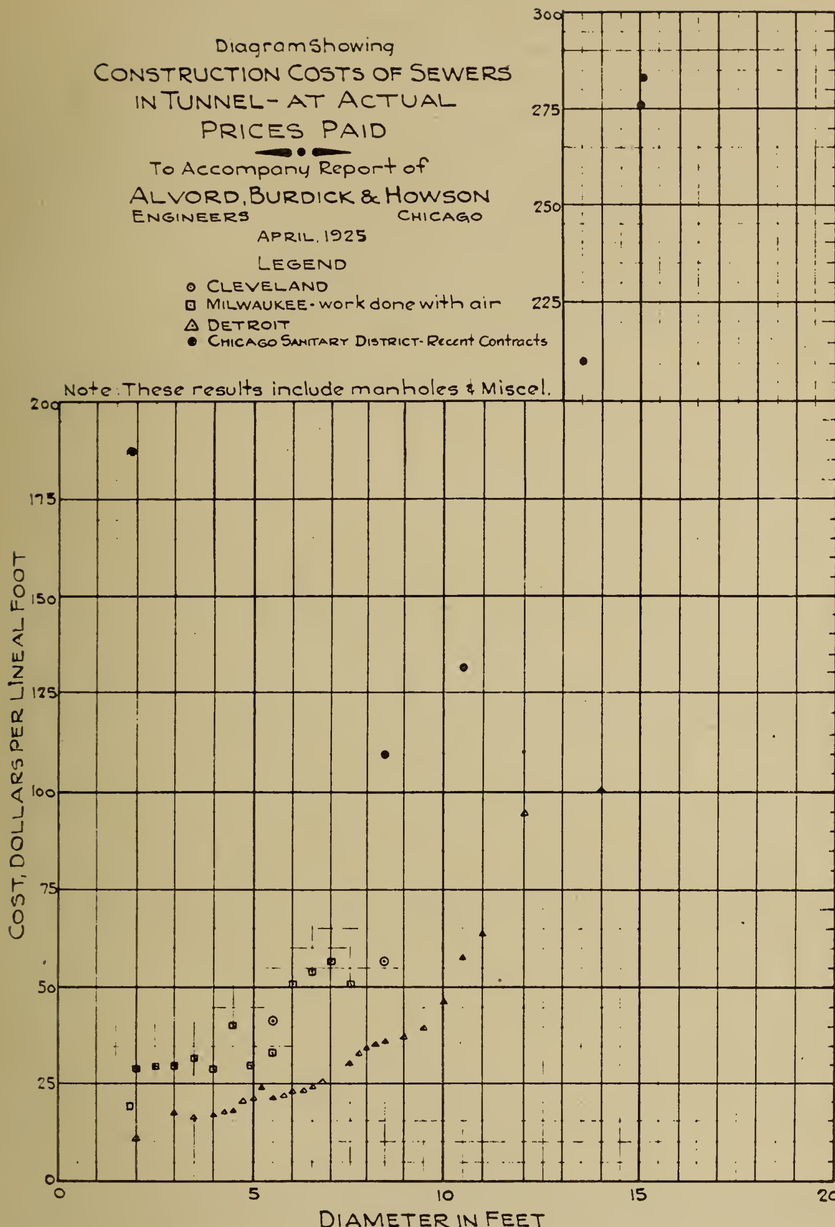


Figure 20.—Construction costs of sewers in tunnel, at actual prices paid.

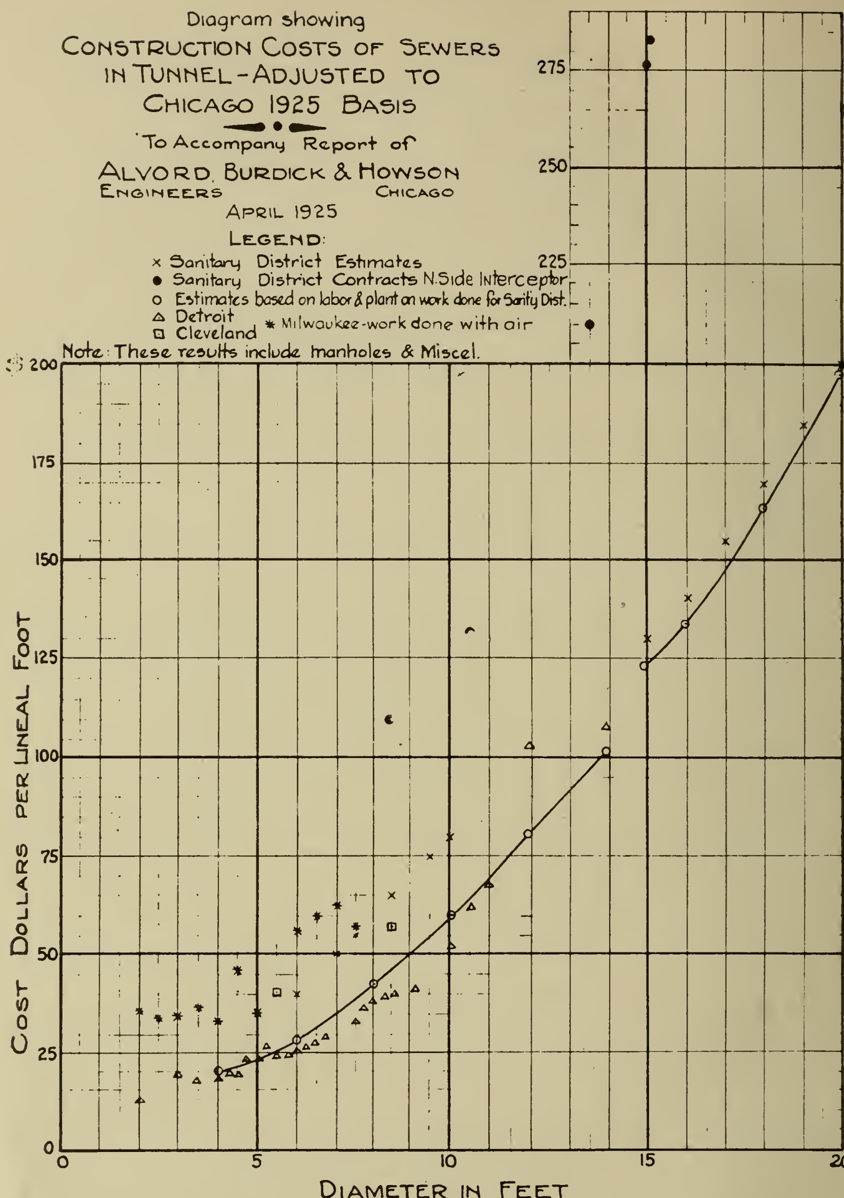


Figure 21.—Construction costs of sewers in tunnel, adjusted to Chicago 1925 basis.

At Detroit it was found that the conditions of excavation more closely resembled those in Chicago than in any of the other cities visited. The Detroit conditions are, therefore, peculiarly comparable, so far as costs are concerned. Detroit has also been very active in sewer construction work. Over fifty contracts covering sewers from twelve inches to fourteen feet in diameter have been executed in the past three years. Tunnel work has been done on sizes twenty-four inches and larger.

Analysis of Detroit's bids shows good competition to have been secured in which many of the best sewer contractors of the country participated. The range of prices bid indicates that the work is being done under conditions which secure good work at reasonable costs.

The Detroit contracts are platted on Figure 20 which indicates the uniformity of prices secured on the Detroit contracts.

At Milwaukee considerable intercepting construction has been executed in the past five or six years. Much of this work was in wet sand and much of it necessitated the use of compressed air with attendant higher costs.

The Milwaukee sewer bids analyzed covered sizes from twelve inches to nine feet. Good competition was secured on contracts and considering the difficult conditions of excavation found on most of the work the costs are reasonable and consistent.

In addition to making the comparative study of sewer costs in other cities, we personally investigated the conditions under which the North Side intercepters are now being built, and prepared independent estimates of the fair cost of doing work of that type. The estimates made in this way independently check very well with the actual cost in other cities adjusted for Chicago 1925 conditions. The results of the investigations in other cities and our estimates of the reasonable cost of intercepters are shown graphically on Figure 21. Upon this diagram we have also shown by solid dots the cost of five North Side intercepter contracts, let within the last year or two. It will be noted that these contract costs by the Sanitary District are more than double the prices at which other cities were able to let contracts with prices adjusted to Chicago conditions. The Chicago prices are in many instances practically three times the costs at which the work was let in such cities as Detroit and Milwaukee. Our estimates agree closely with the Sanitary District's estimates for future large sewers.

The excavation conditions in most sections of Chicago are at least as favorable as in any city studied. Our estimates assume conditions for the central district and the West Side, about the same as conditions encountered in the North Side intercepters now under construction.

Estimated Cost of West and Southwest Intercepting Sewers:

Using as a basis the full curved line, showing the cost of sewers of various sizes shown on Figure 21, the use of which assumes that it is possible to build intercepters in Chicago under conditions of efficiency and cost comparable to those obtained in other large American municipalities (adjusted for labor and material cost variations), we estimate the cost of the West side intercepting sewers, including ten percent for engineering and contingencies as $7,890,600.

Similarly we estimate the cost of the intercepting sewers for the Southwest plant at $4,495,700.

Based upon the Chicago Sanitary District engineer's design as to diameter, which is based upon continuation of the present metering policy, and upon the unit prices herein developed, the cost would be $10,996,100 for the West side sewers and $6,539,500 for the Southwest Side intercepter.

Had the estimates been computed using the contract costs on intercepting sewers recently let by the Sanitary District of Chicago, applied to the same sewer quantities as in the first and second paragraphs of this section, the totals would have been approximately $18,210,300 for the West Side and $10,895,500 for the Southwest Side plants respectively, both figures being more than double what are believed to be fair prices for this work.

Period Covered by Design:

The intercepting sewers as laid out herein contemplate 1960 conditions and as stated have a designed capacity equivalent to 375 gallons per capita as of that date, or from 450 to 500 gallons per capita as applied to present population.

The period for which intercepters should be designed is dependent upon a comparison of the costs and practicability of providing capacity at present for far distant needs and the same facts relative to providing the additional capacity at such time in the future as the necessity occurs. With sewers built in open cut the cost of duplication usually becomes excessive due to a more complete utilization of the streets by utilities and the increasing difficulties due to community growth and congestion. Such sewers are usually built for long periods in the future.

Where intercepters are built in tunnels, somewhat different conditions prevail. Additional sewers can be built in tunnel at a later date with little more difficulty and cost than experienced in the original construction. With sewers in tunnel the period covered by the design accordingly depends quite largely upon a financial comparison of building for ultimate needs or of building for a shorter period with additional capacity added later as needed.

We have made a financial comparison of the costs of intercepting sewers for the West and Southwest Side plants on two bases, both of which assume that by 1960 it will be necessary to double the capacity now to be provided. In one case we have assumed that the sewer now to be built will be constructed at its ultimate capacity, that is, twice what would be required up to 1960. In the second case we have assumed the sewer to be built now as required for 1960 conditions and that in 1960 a duplicate sewer will be built, the cost of which is reduced to present worth and added to the present cost for comparison with the first plan.

The cost comparison is as follows:

		W. Side	S. W. Side
(1)	Cost of sewer whose capacity is two times that reqd. for 1960 conditions	$14,469,400	$ 7,746,200
(2)	Cost of sewer for 1960 conditions	7,890,600	4,495,700
(3)	Excess cost of (1) over (2)	$ 6,578,800	$ 3,250,500
(4)	Present worth of cost of duplicating present sewer in 1960 @ 5%	1,430,000	815,000
(5)	Saving by postponing construction to 1960	$ 5,148,800	$ 2,435,500

The sewer designed for double the 1960 requirements would be of large diameter reaching twenty-four feet for the West Side plant. The costs used in these estimates are secured from Figure 21 for all sizes up to twenty feet. To secure a unit for sizes above twenty feet a curve of cost per foot of diameter was platted and the unit prices taken therefrom.

Obviously it will be better procedure to design conservatively both with respect to period of time and quantities. Thirty-five years is believed ample provision for time. Quantities should consider metering as being ultimately adopted.

We have given consideration to the general routing of sewers proposed by the Sanitary District and are of the opinion that approximately the routes selected will be desirably followed when the detailed surveys and plans are made.

We have investigated the practicability of joining the West and Southwest Side intercepters about two and one-half miles above the tentative location of the Southwest Side plant but find that the saving thus effected would probably be less than $100,000. Its practicability therefore is doubtful and can only be definitely ascertained by detailed investigation when the plans are drawn with full information available.

PART XI.

METHODS OF SEWAGE DISPOSAL AND PRACTICABLE EFFICIENCIES.

Why Sewage is Treated:

The water-borne wastes of a city are given the general designation of sewage; however, in recent years the tendency has been to restrict the meaning of the word sewage to those wastes produced by household activities and to designate other water-borne impurities as industrial wastes. In this discussion the word sewage will be used as inclusive of both domestic and industrial water-borne wastes.

Sewage is composed of more than ninety-nine percent of water and less than one percent of soluble, colloidal, and solid constituents. These latter constitutents, in turn, are partly inert or stable and partly organic or unstable. The unstable constituents of sewage are those which create sight and smell nuisances in overtaxed watercourses, and these unstable constituents may be rendered partially or wholly innocuous or inert by subjecting them to proper processes of treatment.

The destruction of the unstable constituents of sewage is a bacterial function which may be carried out in a watercourse or in treatment works in which satisfactory conditions are provided for bacterial activity. The processes by which unstable sewage constituents are destroyed in a stream are the same as those which result in their destruction in treatment works.

An important condition governing the bacterial destruction of sewage is that of oxygen supply, and in general, it may be said that in the presence of an ample supply of oxygen the process of destruction will proceed to completion in an inoffensive manner, and that in the absence of an ample supply of oxygen, the process of destruction will result in the production of offensive odors. In other words, aerobic conditions favor inoffensive destruction, whereas anaerobic conditions favor offensive destruction.

A somewhat analogous comparison is that of the operation of a steam boiler plant. When the furnace is properly operated, no smoke comes from the attack, but when the air supply is not properly adjusted, large volumes of smoke or unburned carbon come from the stack. A proper adjustment of the operation of the furnace eliminates the smoke nuisance, whereas an ample supply of oxygen will go far toward eliminating the smell nuisance in the bacterial destruction of sewage.

How Sewage is Treated:

The various agencies involved in the treatment of sewage may in a general way be classified as physical, chemical, bacteriological, and biological, none of which alone would suffice. The physical agencies are those of screening, sedimentation, aeration, diffusion, filtration, evaporation, etc. The chemical agencies are those involved in coagulation, sterilization, and in the mineralization of certain nitrified products. The bacteriological agencies are those in which the various species of bacteria are the active agents in putrefaction, fermentation, nitrification, and denitrification. The biological agencies are those in which low forms of animal and vegetable life destroy certain constituents of the sewage.

In the various methods of sewage treatment in use today practically all of the above agencies are involved to a greater or less degree. Sewage treatment methods in use today may be classified, in a general way, as follows: screening, sedimentation, sludge treatment, oxidation, filtration and sterilization.

Screening:

As practiced in the United States today, the screening of sewage may be classified on the basis of coarse and fine separation. Coarse screens (two to four inch clear opening) have a negligible value as a purifying process and serve simply to remove coarse solids which might obstruct passageways of pumps or be unsightly in treatment tanks or in a stream. Screens of this character usually remain in a stationary inclined position in the pathway of the incoming sewage and may be cleaned in position, or lifted for cleaning.

Fine screens ordinarily have a clear opening of one-eighth of an inch or less and usually rotate through the sewage stream. Most of them are power-driven and are provided with self-cleaning mechanism. The work accomplished by the fine screen is intermediate between that accomplished by coarse screening and very rapid sedimentation. The fine screen probably accomplishes less in proportion to its first cost and operating cost than do other methods of sewage treatment, except under certain conditions where fine screens are particularly adaptable.

Sedimentation:

The treatment of sewage by sedimentation has for its object the reduction of the strength of the sewage by the removal of the settleable solids. This is accomplished by passing the liquor through tanks at a very low velocity, which condition is conducive to a settling out of a portion of the solid constituents.

There are two general types of sedimentation tanks in use today; viz., those with one-story and those with two-stories. The one-story tanks are further divided into three classes, viz., those with large capacity for the sludge deposits which are removed at infrequent intervals, those with small capacity for the sludge deposits which are removed at frequent intervals, and those which are provided with a rotating and scraping mechanism for continuous sludge removal.

In the first type of one-story tank the incoming sewage is constantly in contact with actively decomposing sludge for considerable periods of time, and it becomes infected with the products resulting from the decomposition of the sludge. In this type of tank the sedimentation and sludge digestion functions are not separated.

In the second type of one-story tank, the injurious effect of the non-separation of the two functions is greatly reduced by frequent removal of the deposited sludge, while in the third type of one-story tank the separation of these functions is practically complete due to the continous removal of the deposited solids.

In the two-story type of tank the separation of the two functions is accomplished by having a lower story for sludge reception and digestion and an upper story for sedimentation. The upper and lower stories are so constructed that by an arrangement of sloping bottoms, communicating slots, baffles, and gas vents, the deposited solids enter the lower compartment automatically and the digestion process may proceed without interfering with the sedimentation process and without infecting the incoming sewage. The two processes thus proceed harmoniously, but sludge withdrawals must be made at proper intervals. In many of the installations of this type, more or less serious trouble from foaming at the gas vents has been experienced and corrective measures to date have only been partially successful.

Sludge Treatment:

Solids removed from sewage by the sedimentation process are usually designated as sludge, which, in composition, consists of from ninety to ninety-eight per cent water, and from two to ten percent of dry solids.

The treatment and final disposal of sludge is one of the most troublesome problems of sewage disposal. As sludge increases in moisture content, the volume produced per million gallons of sewage treated increases very rapidly. If the volume of sludge produced per million gallons of sewage be taken at 1.0 when the moisture content is eighty-five percent, the approximate volumes for higher moisture content would be as follows: For ninety percent sludge 1.5, for ninety-five percent sludge, 3.0, and for ninety-eight percent sludge 7.5; consequently those processes of sewage treatment which produce sludge of high moisture content, impose the burden of a treatment of large bulk per unit of dry solid content.

There are four general methods of sludge treatment in use today, viz., 1st, lagooning on land, 2nd, pumping into scows and disposing of it by discharging it into deep water at sea, 3rd, partially dewatering it on specially constructed sand filters, after which it may be used to fill waste places or spread on farm land and plowed in, 4th, partial or complete dewatering by pressing, centrifuging, or drying, after which it may be used as a fertilizer, or for filling in waste places.

The disposal of sludge at sea is obviously a method of limited availability. A high degree of dewatering of sewage sludge through the use of presses, centrifuges, and driers, with the intention of producing a marketable fertilizer, has as yet to be demonstrated as a feasible undertaking. The city of Milwaukee, after a thorough and painstaking study of sludge dewatering processes and the fertilizing value of sludge produced by the activated sludge method of sewage treatment, definitely committed itself to the production of fertilizer sludge and now has a very complete dewatering plant well under construction.

The treatment of sludge by methods Nos. 1 and 3 has been practised most extensively in the United States with varying degrees of success. The chief difficulty which has attended the use of these methods of sludge treatment has arisen by reason of the fact that inadequate disposal areas have been provided.

Oxidation:

There are four methods of sewage treatment which might be termed "finishing processes," and which result in varying degrees of stabilization of the soluble, colloidal and solid constituents of the sewage. In each of the four methods of treatment, the several constituents of the sewage are changed from an unstable to a stable condition largely by bacterial activities.

The four methods of securing a finishing treatment of sewage are the sand filter, the contact bed, the trickling filter, and activated sludge. These four methods of treatment vary widely in capacity per unit of area, and taking the capacity of the sand filter per acre of area as 1.0, the relative capacities of the other methods of treatment per acre of area are approximately as follows: Contact beds, 7.0, trickling filters 20.0, and activated sludge 150.0.

The sand filter when properly designed, constructed, and operated produces an effluent which is clear and sparkling, practically free of suspended matter, very low in bacterial content, highly nitrified, and with an oxygen demand which is so low as to obviate any dilution requirements in a stream. Treatment of the sewage of the Sanitary District of Chicago by sand filters preceded by clarification in settling tanks would require at the present time not less than 8,000 acres.

The contact bed is an oxidizing device and consists of a square or rectangular tank filled with coarse broken stone or other suitable material of varying depth and operated ordinarily on a fill-and-draw plan. The effluent from the contact bed is ordinarily not clear or well nitrified, has a comparatively high bacterial count, and an oxygen demand which requires some dilution for stability. Not less than 1,200 acres would be required to treat the sewage of the Sanitary District of Chicago for the year 1925, in addition to clarification in settling tanks.

The trickling filter is an oxidizing device similar to the contact bed in general construction but differing in the method of dosing. The trickling filter is dosed by a system of distribution pipes operated under a head and terminating with open spray nozzles properly located and spaced to give uniform distribution over the entire surface. The sewage is sprayed into the air and falls on the broken stone or other filtering medium through which it trickles to the underdrains which carry it away. The cycle of operation consists of a short dosing period, followed by a short resting period. Trickling filters which are properly designed, constructed and operated will produce effluents having a substantial total bacterial count, a varying suspended matter content, a marked reduction in oxygen demand, and often with a balanced oxygen relation if the applied sewage is not particularly strong. Not less than 400 acres of sprinkling filters would be required to treat the sewage of the Sanitary District of Chicago for the year 1925, in addition to a previous clarification in settling tanks.

The activated sludge process is a comparatively recent modification of older processes, and might be termed an accelerated bacterial treatment in water. The only sizable plants of this character in operation in the U. S. today are the two municipal plants at Houston, Texas. The literature describing the results of the experimental studies which have been made of this process is quite voluminous. Experimental plants of this character, which have been operated on both large and small scales, have given very promising results, and enough confidence in the process has arisen to justify its adoption for several very large installations.

The principal operations in this method of treatment are coarse screening, grit removal, fine screening, aeration in tanks, sedimentation, sludge reaeration, return of a portion of the activated sludge to the aeration tanks, and treatment and disposal of the excess sludge.

The final effluents from this method of treatment as produced experimentally and by a small number of municipally operated plants have resembled sand filter effluents with the exception that they have ordinarily not been so completely nitrified. The production of an effluent which will not need dilution falls within the scope of the possibilities of this method of treatment. The degree to which sewage may be rendered stable by this method of treatment is capable of some adjustment. This method of treatment is one in which careful and experienced supervision is especially desirable.

Sterilization:

It is possible to effect a removal of from ninety to ninety-five percent of the total number of bacteria in sewage by treatment with a sterilizing agent. The efficacy of sterilization will be governed by the size of dose, the comminution of the solids of the sewage, the distribution of the sterilizing agent, and the thoroughness and sufficiency of the contact of the sterilizing agent with the sewage.

Experience with the sterilization of sewage to date seems to indicate beyond doubt that it can be relied upon only to provide a lessening of the burden of water purification where a contact exists.

Sterilization destroys bacteria but effects no marked reduction in the organic load, consequently the sterilization of sewage has no marked effect on stream dilution requirements.

Practical Efficiencies:

Fine Screening—Table 29 is a partial list of fine screen installations in the U. S., and an inspection of this table will show that the

TABLE 29.

PARTIAL LIST OF FINE SCREENS.

	No.	Dia.	Sep. Ins.
New York City—Dyckman & 210th Sts.......	1	14′	3/64
	1	14′	4/64
Plainfield, N. J..............................	1	10′	4/64
Rochester, N. Y., Irondequoit Works..........	1	12′	24/64
	1	12′	8/64
	1	12′	4/64
Bridgeport, Conn.	1	22′	1/64
	1	22′	2/64
Long Beach, Cal..............................	1	14′	2/64
Daytona, Fla.	1	8′	5/64
Indianapolis, Ind.	12	6′ d. 8′ L.	30 meshes
Milwaukee, Wis.	8	8′ d. 8′ L.	6/64
Chicago, Des Plaines River Plant.............	1	14′	4/64

clear openings in the screens vary from three-eighths of an inch to one-sixty-fourth of an inch.

Table 30 shows the removal of total suspended solids by fine screens operating on municipal sewage and on industrial waste. An inspection of this table will show that from eight to thirty-six parts per million of suspended solids have been removed by fine screens from municipal sewage, and 103 parts per million from the strong packingtown waste of Chicago. The sewage which is screened at the New York city plant, located at Dyckman and 210th Streets, is a very fresh sewage (less than thirty minutes old) from a residential area.

The removal of suspended solids by fine screening will be governed by the width of the slots, the rate at which the sewage is passed through the screen, and the concentration and degree of comminution of the solids of the sewage.

The following results have been reported from the screen installation at the Irondequoit plant of the city of Rochester, New York:

Year 1918—6.31 cubic feet screenings per M. G.
Year 1919—6.58 cubic feet screenings per M. G.
Year 1920—4.58 cubic feet screenings per M. G.

Sedimentation:

The improvement in the quality of sewage resulting from sedimentation treatment will be governed by the concentration and comminu-

TABLE 30.

SHOWING REMOVAL OF TOTAL SUSPENDED SOLIDS BY FINE SCREENS.

	Source.	Width of slots in Inches	Suspended Solids Removed P.P.M	%
(A)	New York City—Dyckman & 210th Sts.	3/64	36	26.3
		4/64	20	16.6
(B)	Long Beach, California	2/64	28	....
(C)	Milwaukee, Wisconsin	8/64	18	....
	Milwaukee, Wisconsin	8/64	8	....
(D)	Milwaukee, Wisconsin	6/64	9	....
	Milwaukee, Wisconsin	40 meshes	20	....
(E)	Packinghouse Industrial Waste Tests,	30 meshes	103	18.8

(A) Eng. News-Record, Vol. 84 p. 171, 1920 by C. E. Gregory.
(B) Eng. News-Record, Vol. 82, p. 1012, 1919.
(C) 6th Report Milwaukee Sew. Com., p. 41.
(D) 8th Report Milwaukee Sew. Com., p. 72, 73.
(E) Report on Industrial wastes from the Stockyards and Packingtown in Chicago, Vol. 2, 1921, p. 182.

tion of the solids of the sewage treated, the detention period in the tanks, and the degree to which stored sludge interferes with the settling process.

Table 31 shows the improvement in sewage effected by preliminary sedimentation as determined by long and short time tests on fifteen of the largest sewage treatment works in the United States. The efficiency of these plants when based on the removal of total suspended solids varies from twenty-two percent to eighty-six percent, with a general average of fifty-five percent. The Proctor Creek plant at Atlanta, Ga., shows a removal of eigthy-six percent, but this result is not typical of plain sedimentation for such a large unit, and is accounted for by the fact that certain industrial wastes in the sewage react in such a way as to produce a chemical precipitation. The average result for sixteen years at Columbus, O., is fifty-five percent, and the average result at Baltimore, Md., for nine years is fifty-six percent. The average result for five years at Fitchburg, Mass., which is a smaller plant and which treats a fresher sewage, is seventy-three percent. It would therefore seem that a fifty-five percent removal of total suspended solids is a very reasonable expectancy, and that a better removal may be secured where conditions are more favorable.

A study of the settleable solids in daily composite samples of sewage collected during the past eight years at Columbus, Ohio, has shown that an average of fifty-one percent of the total suspended solids is settleable in a two-hour period in conical settling glasses. This result, however, only applies to the Columbus sewage.

Table 31 also shows the improvement in sewage effected by preliminary sedimentation on the basis of the oxygen demand. The determination of oxygen demand is not a routine test at any of the sewage plants listed in the table, consequently information of this character must be based on short time studies. Oxygen demand results on eleven separate plants show an average improvement of thirty-five percent, with extremes of three percent and sixty-three percent. The longest study along this line has been made at Columbus, Ohio, where oxygen demand tests have been a daily routine for sixteen years and the sixteen-year average improvement by sedimentation is twenty-nine percent. The Columbus sewage is stale and all of it is pumped, both of which conditions tend to reduce the efficiency of the sedimentation treatment.

It is considered that an improvement of thirty-five percent in oxygen demand is a reasonable expectancy where the factors affecting sedimentation are average.

TABLE 31.

SHOWING IMPROVEMENT IN SEWAGE EFFECTED BY PRELIMINARY SEDIMENTATION.

Location of Works	Year	Period Covered	Total Suspended Solids P. P. M.			Seattleable Solids Cu. Cm. Per Litre			Oxygen Consumed 30 Minute Boil			Biochemical Oxygen Demand Parts Per Million					Dissolved Oxygen Parts Per Million		Chlorine, P.P.M.	Ether Soluble Matter P. P. M.	Alkalinity P. P. M.	Population Contributing	Average Daily Sewage Flowing in M. G.
			Influent	Effluent	% Removed	Influent	Effluent	% Removed	Influent	Effluent	% Removed	Influent	Effluent	% Removed	Temp. Inc. Degrees C.	Days Incubated	Influent	Effluent					
Atlanta, Ga., Proctor	1913 1915	3 Years	323	55	85	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Lincoln, Neb.	1924	1 Year	299	159	47	3.3	0.8	75	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3.97
Canton, O.	1920	10 Days	261	93	64	5.3	0.3	94	61	38	38	213	129	39	20±	5	0.5	...	79	62	342	70,000	4.44
Columbus, O.	1920	11 Days	206	79	62	3.1	Tr.	100—	63	46	29	190	134	29	20±	5	1.7	...	113	100	211	225,000	21.2
Columbus, O.	1909 1924	16 Years	229	102	55	...	...	...	...	...	...	205	146	29	37	1	...	...	...	...	...	...	...
Fitchburg, Mass.	1920	11 Days	297	63	79	2.7	Tr.	100—	65	37	42	154	95	39	20±	5	0.3	...	70	63	97	38,000	3.35
Fitchburg, Mass.	1919 1923	5 Years	222	59	73	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Rochester, N. Y.	1920	15 Days	188	119	40	2.1	0.7	70	39	35	20	104	74	26	20±	5	0.9	...	82	34	175	240,000	33.0
Albany, N. Y.			...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Cleveland, O.	1924	2 Years	186	98	47	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Baltimore, Md.	1920	12 Days	159	107	35	2.9	0.6	79	43	36	16	120	125	Inc.	20±	5	0.2	...	86	40	136	520,000	55.0
Baltimore, Md.	1912 1920	9 Years	177	79	56	...	...	...	...	...	...	114	110	3	37	1	...	...	...	...	...	...	...
Lexington, Ky.	1920	9 Days	166	67	60	2.4	Tr.	100—	32	22	31	144	87	40	20±	5	0.1	...	92	58	196	28,000	2.5
Alliance, O.	1920	11 Days	152	69	55	2.0	Tr.	100—	38	26	32	92	68	26	20±	5	3.0	...	47	37	184	20,000	2.62
Atlanta, Ga., Intr.	1920	11 Days	106	67	37	2.4	0.6	75	35	21	40	62	23	63	20±	5	0.0	...	93	104	77	30,000	5.00
Atlanta, Ga., Intr.	1915	1 Year	140	44	68	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Schenectady, N. Y.	1923	1 Year	138	53	62	...	...	...	...	...	...	...	...	...	...	...	...	...	46	...	...	...	...
Atlanta, Ga., Peach	1920	11 Days	226	68	70	2.5	0.2	92	35	18	49	52	20	62	20±	5	0.0	...	86	83	68	* 75,000	*12.0
Atlanta, Ga., Peach	1913 1915	3 Years	125	57	54	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Calumet**	1923 1924	1 Year	74	34	54	...	...	...	...	...	...	64	35	46	20	5	4.15	2.33	...	...	...	...	...
Reading, Pa.	1920	10 Days	145	85	41	2.0	Tr.	100—	45	31	31	118	96	10	20±	5	...	...	120	25	164	* 60,000	*6.04
Reading, Pa.	1924	1 Year	115	89	22	...	...	...	49	39	20	...	...	...	...	...	...	...	...	...	...	...	...

*Rough Estimate.
**Sanitary District of Chicago.

Sedimentation and Sand Filtration:

The treatment of sewage by sedimentation and sand filtration in the United States today is, with one exception, limited to small municipalities and institutions. Numerous small plants of this character are in service today but definite information relative to rates of treatment and operating results is very scarce.

The largest sewage sand filter plant in the U. S. today is the municipal plant at Worcester, Mass., where, during the year 1923, 64.7 acres of sand filters were operated at an average daily yield of 55,000 gallons. A portion of the sewage of Worcester is treated by sand filtration by reason of the fact that natural sand areas are available.

The average results secured at Worcester, during 1923, by the sand filtration treatment were as follows:

Reduction in total albuminoid ammonia,	89%.
Reduction in total suspended solids,	100%.
Reduction in total oxygen consumed,	90%.

These average results represent a very high degree of treatment, with probably a negative dilution requirement.

Sedimentation and Sprinkling Filters:

The sprinkling filter, almost without exception, is dosed with clarified sewage and the effluent from the filter is often given a final clarification before being discharged into a watercourse. The improvement effected by tanks and sprinkling filters with and without final sedimentation is shown in Table 32.

An inspection of this table will show that of the total amount of suspended solids removed by tanks and sprinkling filters, eighty-five percent is removed by the tanks and fifteen percent by the filters. In the reduction of the oxygen demand by tanks and filters, the results in Table 32 show that of the total reduction, forty-five percent comes from the tank treatment and fifty-five percent from the sprinkling filter treatment. If the two Atlanta and the Baltimore results are eliminated, the ratio is for tanks forty percent and for sprinkling filters sixty percent.

A further inspection of this table will show that the reduction in oxygen demand in parts per million by tanks, with Baltimore results excluded, will vary, on the basis of average results, from thirty to sixty parts and that the reduction in oxygen demand by sprinkling filters, with the Atlanta results excluded, will vary, on the basis of average results, from seventy to ninety parts. The reduction by combined treatment in tanks, sprinkling filters, and final settling basins, with the Atlanta results excluded, will vary, on the basis of average results, from ninety to 135 parts. From a study of the best results obtainable, and as recorded in Table 32, a reasonable expectancy from tanks, sprinkling filters and final settling basins is as follows:

Removal of total suspended solids, 75% average result.
Reduction in oxygen demand, 85% average result.
Reduction in oxygen demand in p.p.m., 130 average result.

Data relative to the reduction in the number of bacteria by this method of treatment is limited to the total counts which have been made at the Baltimore sewage works for a number of years. Average values for a period of nine years from 1912 to 1920, inclusive, at the Baltimore sewage works are as follows:

Reduction in the total count on plain agar, 67%
Reduction in acid forming bacteria, 90%

TABLE 32.

SHOWING IMPROVEMENTS EFFECTED BY TANKS AND SPRINKLING FILTERS WITH AND WITHOUT FINAL SEDIMENTATION.

	Location	By Tanks	By Sprinklers	By Basins	By All
Total Suspended Solids Removal in % of Total	Atlanta ....(B)	37	23	..	60
	Atlanta ....(B)	70	13	..	83
	Columbus ....(B)	55	10	..	65
	Fitchburg ....(A)	79	4	3	86
	Lexington ....(A)	60	16	5	71
	Baltimore ....(A)	56	6	16	78
Oxygen Demand Reduction in % of Total	Atlanta ......(B)	63	31	..	94
	Atlanta ......(B)	62	31	..	93
	Columbus ....(B)	25	55	..	80
	Fitchburg ....(A)	38	49	..	87
	Lexington ....(A)	40	49		89
	Baltimore ....(A)	3	67	10	80
Reduction in Oxygen Demand in p. p. m.	Atlanta ......(B)	32	16	..	48
	Atlanta ......(B)	39	19	..	58
	Baltimore ....(A)	4	76	11	91
	Columbus ....(B)	39	87	..	126
	Lexington ....(A)	57	71		128
	Fitchburg ....(A)	59	75	inc.	133

(A) Tanks, sprinkling filters and final settling basins.
(B) Tanks, and sprinkling filters.

Sedimentation and Contact Beds:

Accurate operating results for tanks and contact beds are very limited; however, in Table 33 are shown the analytical data secured by the U. S. Public Health Service from a ten to twelve days' study of the Alliance, Ohio and Canton, Ohio, sewage works which employ this method of treatment. The average results from these two plants show that the improvement effected by this method of treatment was as follows:

Reduction in total suspended solids, 85%.
Reduction in oxygen consumed, 71%.
Reduction in oxygen demand, 80%.

The contact beds of these two plants treat between 600,000 and 700,000 gallons per acre per day, which is about one-third of the volume that can be treated satisfactorily by a sprinkling filter per acre per day.

Activated Sludge:

It is difficult to set a standard of practical efficiency for the activated sludge treatment of sewage without relying considerably on results secured by numerous experimental installations. Little doubt exists today as to the soundness of the principles involved, but some doubt does exist relative to the methods and appliances proposed for carrying out these principles. Machinery plays a greater part in this method of sewage treatment than in any other method in common use; also a very extensive air distribution system must be used, which comprises valves, pipes of many sizes, and in all cases final air outlets which are extremely small. The coefficient of dependability of some features of this process may be said to be somewhat uncertain; however, the several features of this process have been very carefully investigated by so many competent chemists and engineers and their conclusions have been so well founded that its adoption as a practical method of sewage treatment seems to be based on sound judgment.

In Table 33 will be found analytical data secured from a ten to twelve-day study of the north side and south side plants at Houston, Texas, analytical results secured from a two years' operation of the same plants, analytical results of a ten to eleven-day study of the plants at San Marcos, and Sherman, Texas; also results of twenty-three months of operation of the Des Plaines River plant of the Sanitary District of Chicago. The Des Plaines plant has been operated on a combined routine and experimental basis, consequently the results are probably not such as might be secured if it had been operated with a single purpose in view.

TABLE 33.

SHOWING IMPROVEMENT IN SEWAGE EFFECTED BY SEVERAL PROCESSES.

Method of Treatment	Location of Works	Year	Period Covered	Total Suspended Solids P. P. M.			Settleable Solids Cu. Cm. Per Litre			Oxygen Consumed 30 Minute Boil			Biochemical Oxygen Demand Parts Per Million				
				Influent	Effluent	% Removed	Influent	Effluent	% Removed	Influent	Effluent	% Removed	Influent	Effluent	% Removed	Temp. Inc. Degrees C.	Days Incubated
Activated Sludge	Houston, North Side	1922 1923	2 Years	316	32	90	......	......	......	......	.....	....	140	10	93	......	5
	South Side	1922 1923	2 Years	166	8	95	......	......	......	......	.....	....	....	......	......	......	5
	Houston, North Side	1920	12 Days	200	17	93	2.5	......	......	45	10	78	115	11	90	20±	5
	South Side	1920	10 Days	226	7	97	2.1	......	......	38	6	84	112	7	94	20±	5
	San Marcos, Texas .	1920	10 Days	110	3	97	2.2	......	......	29	85	71	67	16	76	20±	5
	Sherman, Texas	1920	11 Days	264	76	71	5.0	3.4	32	64	32	50	202	40	80	20±	5
	Des Plaines**	1922 1924	23 Mos.	160	38	77	......	......	......	......	.....	....	....	......	......	......	......
Tanks-Sprinkling Filters	Atlanta, Int. Cr.	1920	11 Days	106	42	60	2.4	Tr.	100—	35	10	71	62	4	93	20±	5
		1915	1 Year	140	44	68	......	......	......	......	.....	....	....	......	......	......	......
	Atlanta, Peach. Cr.	1920	11 Days	226	38	83	2.5	Tr.	100—	35	7	80	52	4	92	20±	5
		1913 1915	2¼ Years	125	58	54	......	......	......	......	.....	....	....	......	......	......	......
	Baltimore	1920	12 Days	159	41	74	2.9	Tr.	100—	43	12	72	120	8	93	20±	5
		1912 1920	9 Years	177	39	78	......	......	......	......	.....	....	114	23	80	37	1
	Columbus	1920	11 Days	206	81	55	3.1	1.0	67	63	28	56	190	49	74	20±	5
		1909 1924	16 Years	229	80	65	......	......	......	......	.....	....	205	37	82	37	1
	Fitchburg	1920	11 Days	297	42	86	2.7	Tr.	100—	65	16	75	154	21	85	20±	5
		1919 1923	5 Years	222	25	89	......	......	......	139	52	63	....	......	......	......	......
	Lexington	1920	9 Days	166	48	71	2.4	Tr.	100—	32	10	69	144	16	89	20±	5
	Lincoln	1924	1 Year	299	131	56	3.3	1.1	67	......	.....	....	....	......	......	......	......
	Reading	1920	10 Days	145	31	78	2.0	Tr.	100—	45	14	69	118	15	87	20±	5
Tanks Contact Beds	Alliance, O.	1920	12 Days	152	17	89	2.0	Tr.	100—	38	11	71	92	20	78	20±	5
	Canton, O.	1920	10 Days	261	41	81	5.3	Tr.	100—	61	8	71	213	37	82	20±	5

**Sanitary District of Chicago.

TABLE 33—Continued.

SHOWING IMPROVEMENT IN SEWAGE EFFECTED BY SEVERAL PROCESSES.

	Location of Works	Year	Period Covered	Organic Nitrogen Parts Per Million			Dissolved Oxygen Parts Per Million		Nitrogen As $NO_2 + NO_3$ P. P. M.		Chlorine, P. P. M.	Ether Soluble Matter P. P. M.	Alkalinity, P. P. M.	Contributing Population	Average Daily Vol. Treated in M. G.
				Influent	Effluent	% Removed	Influent	Effluent	Influent	Effluent					
Activated Sludge		1922													
	Houston, North Side	1923	2 Years	.....	....	....	0.0	4.1	0.0	3.5	......	......	....	....	5.16
		1922													
	South Side	1923	2 Years	.....	....	....	......	......	0.0	10.6	......	......	....	....	1.58
	Houston, North Side	1920	12 Days	.....	....	....	0.2	5.2	......	4.6	136	39	270	80,000	6.00±
	South Side	1920	10 Days	.....	....	....	0.8	7.4	......	6.0	101	36	304	20,000	1.50±
	San Marcos, Texas	1920	10 Days	.....	....	....	2.8	7.6	......	8.8	83	18	306	2,500	0.20±
	Sherman, Texas	1920	11 Days												
		1922		.....	....	....	2.5	6.2	......	1.2	129	69	415	....	0.33±
	Des Plaines**	1924	23 Mos.	8.05	2.22	72	......	......	......	8.5	......	......	....	....	....
Tanks-Sprinkling Filters	Atlanta, Int. Cr.	1920	11 Days	.....	....	....	0.0	5.4	......	3.1	93	104	77	....	....
		1915	1 Year	.....	3.6	....	......	......	......	5.6	......	......	....	50,000	....
	Atlanta, Peach. Cr.	1920	11	.....	....	....	0.0	5.7	......	2.1	86	83	68	....	....
		1913													
		1915	2¼ Years	.....	2.9	....	......	......	......	6.3	......	......	....	80,000	....
	Baltimore	1920	12 Days	.....	....	....	0.2	5.2	......	4.2	86	40	136	....	....
		1912													
		1920	9 Years	.....	....	....	......	......	......	6.8	......	......	....	....	....
	Columbus	1920	11 Days	.....	....	....	1.7	4.8	......	0.6	113	100	211	....	....
		1909													
		1924	16 Years	.....	....	....	......	......	......	4.0	......	......	....	....	....
	Fitchburg	1920	11 Days	.....	....	....	0.3	7.9	......	6.1	70	63	97	....	....
		1919													
		1923	5 Years	*4.75	1.49	69	......	......	0.9	8.5	61	......	....	....	....
	Lexington	1920	9 Days	.....	....	....	0.1	5.2	......	......	89	58	196	....	....
	Lincoln	1924	1 Year	.....	....	....	......	......	......	......	......	......	....	....	....
	Reading	1920	10 Days	.....	....	....	.....	3.7	......	5.1	105	25	164	....	....
Tanks Contact Beds	Alliance, O.	1920	12 Days	.....	....	....	3.0	5.7	......	2.8	47	37	184	....	....
	Canton, O.	1920	10 Days	.....	....	....	0.5	0.7	......	0.3	79	62	342	....	....

*Albuminoid Ammonia

**Sanitary District of Chicago.

Omitting from consideration the results from the Des Plaines and Sherman, Texas, plants, the results recorded in Table 33 indicate an improvement from this method of treatment as follows:

Removal of suspended solids, 94%.
Reduction in oxygen consumed, 81%.
Reduction in oxygen demand, 92%.

The north side and south side plants at Houston, Texas, treat approximately six million and one and one-half million gallons per day, respectively. The San Marcos, Texas, plant treats approximately 200,000 gallons of sewage per day.

The use of the activated sludge process for the treatment of packing and stockyards sewage has been tested experimentally by the Sanitary District of Chicago, and the improvement effected, as based on data recorded on pages 47 and 134 of the Report on Industrial Wastes from the Stockyards and Packingtown in Chicago, Vol. 2, 1921, San. Dist. of Chicago, is as follows:

Removal of total suspended solids, 91%.
Reduction of oxygen demand, 96%.
Reduction of organic nitrogen, 83%.

Warm Weather Efficiencies:

In view of the fact that during warm weather there is an acceleration of bacterial activities both in polluted streams and in bacterial processes of sewage treatment, it is evident that dilution requirements in a stream during warm weather are at the maximum, and, for the same reason, it would seem that the efficiency of sewage treatment would be higher wherever bacterial processes are involved.

A study of the average monthly efficiencies at the Baltimore works for a period of nine years, the sand filtration treatment at Worcester, Mass., for 1923, and the Columbus works for the year 1913, indicate that the average efficiency for June, July, August and September is above the average efficiency for the year in the following amounts:

Baltimore, four percent; Worcester, three percent; Columbus, three percent.

An average efficiency for the warm weather months of the year, of three percent above the average annual efficiency is a reasonable assumption for sand filter, contact bed, sprinkling filter and activated sludge treatment.

Conclusion on Efficiency:

In consideration of treatment works for the largest sewage disposal plant in the world, we believe we are warranted in expecting the best of operating results. We conclude that it will be practicable to secure the following net efficiencies in the proposed Sanitary District plants, in the warm or critical season of the year, expressed in percentage of the biochemical oxygen demand removed from the sewage compared to sewage as delivered before treatment.

Tankage,	35%.
Tanks and Sprinkling Filters,	88%.
Activated sludge on Domestic Sewage,	92%.
Activated sludge on Stock Yards waste,	95%.

Applicability of Other Means of Sewage Disposal:

The subject of sewage disposal for Chicago would not be complete without consideration of certain means for sewage disposal that have been extensively used abroad but which are not considered to be adapted to the local situation at Chicago, particularly when taking into consideration the expenditures that the Sanitary District has already made. We believe it will be useful, briefly to outline these methods of disposal and to show why it would not be practicable or economical to adopt them.

Broad Irrigation:

The oldest method of sewage purification is the disposal of the sewage upon farm or garden land, commonly called Broad Irrigation. The sewages of Berlin and Paris are thus treated, and the method has been extensively used in Germany, France and England.

Inapplicable to Chicago Conditions:

If Broad Irrigation should be adopted for Chicago, about 60,000 acres or ninety-three square miles, would be required under the average rate of application to land as practiced in England, where, in general, available land contains more or less clay.

If sandy lands could be found, similar to that available for sewage disposal at Berlin, about 25,000 acres or thirty-nine square miles, would be required. It is believed that no such large areas are available, without carrying the sewage a long distance from Chicago.

No surface soils of a sandy nature are available nearer to Chicago than the east line of Gary, which is approximately forty miles distant from the Chicago loop district. A sufficient area could probably be found east of Gary, but the land is very rough and large expenditures in grading, or in pumping, would be required to make it useful.

A sewer about twenty-five feet in diameter would be required to accommodate the present total sewage of the Sanitary District. This sewer would cost about $1,500,000 per mile. Approximate estimates indicate that the initial investment in an outlet sewer and pumping works alone would exceed the cost of the intercepting sewers and the more modern methods of sewage disposal, for which we have previously estimated the costs. In addition it would be necessary to purchase the lands and put them into condition to receive sewage.

Site Below Joliet:

Before the drainage canal was built the suggestion was made to carry the Chicago sewage through a tunnel and dispose of it by gravity upon lands adjacent to the Des Plaines River below Joliet. This might have been possible with the quantities of sewage produced by Chicago thirty or forty years ago. At the present time it would not be possible to find an acreage sufficiently large to treat the sewage by Broad Irrigation, delivering the sewage by gravity flow. Lands might be found to which the sewage could be pumped.

The land at this location is of a sandy and gravelly nature. It would probably be well adapted to sewage farming. Rough estimates indicate that the cost of development, including tunnel and pumping, would not be less than the figures previously given covering sewage farming on the lands east of Gary. Therefore the costs would materially exceed the costs of works, herein elsewhere estimated.

Broad Irrigation Not Practicable:

There are other and more important reasons why broad irrigation would not be applicable.

(a) Sewage farming is viewed with disfavor by American health authorities, as dangerous to public health.

(b) Climatic conditions are much less favorable in this region than in Western Europe by reason of the severe winters.

(c) The American public is less tolerant of local nuisances than the European public, and is less inclined to properly maintain its sewage works. A sewage farm would be an intolerable nuisance unless well operated.

Other Disposal Methods:

We have herein elsewhere mentioned contact beds and sand filters as means for secondary purification, which have been more or less extensively usd by small cities and large public institutions. Either of these methods, by reason of the large areas required, would necessitate large expenditures for intercepting sewers to carry the sewage to more or less distant and remote locations. We believe that the relative areas required, as stated elsewhere in this report, are sufficient to indicate their higher cost as compared to the methods of sewage purification upon which we have prepared detailed estimates.

PART XII.

SEWAGE DISPOSAL COSTS IN OTHER CITIES.

Chicago, through the Sanitary District, is undertaking a great sewage disposal program. To date, although the second largest city in the United States, it has not constructed and operated disposal works of magnitude commensurate with its wastes.

Certain other cities have had considerable experience in the construction of sewage disposal works of the types generally considered as applicable to Chicago conditions. The costs of these works are capable of analysis considered as units, so that knowing the number of units of each plant item required, costs of similar plants in individual cities may be compared. If in this comparison the varying costs of labor and materials are brought to a common basis, the results are quite reliable as an indication of fair costs under the conditions pertaining to that basis.

In order that we might have first hand information as to the costs of construction and operation of the larger sewage disposal plants of the country, and have sufficient familiarity with the plants and their operations to interpret the cost of construction and operations and translate them to Chicago conditions, we visited the more important plants, including Baltimore, Cleveland, Philadelphia, Albany, Indianapolis and Milwaukee. At all of these plants we were courteously extended all of the available information relative to cost of construction and operation. This information has been supplemented by other cost data in our possession.

We gave particular attention to the costs of construction and cost of operating:

(a) Tankage plants.
(b) Tankage and trickling filters.
(c) Activated sludge plants.
(d) Pumping Stations.

which types of construction must necessarily be included in any comprehensive study of the Chicago situation. We also investigated sewer construction and costs in a great many cities.

Adjustment of Costs to Chicago 1925 Basis:

In each of the several cities visited to secure costs of sewer and sewage disposal plant construction the costs of labor were found to vary.

It was also found that the construction studied in the several cities had been executed at different time periods and accordingly under varying price level conditions.

In adapting these data for use in studying reasonable Chicago construction costs, it was accordingly necessary to make two adjustments, viz:

(a) For location.

(b) For time.

The first adjustment was made by studying the labor costs for the various types of labor involved in each construction project and ascertaining the weighted average relation of those costs in the city being studied to those prevailing in Chicago. This resulted in securing a factor which applied to the costs in the city studied, would reasonably indicate the costs in Chicago as of the same period. In cities for which there were no printed data available as to labor costs inquiry was either made by letter or the costs prevailing in the nearest city for which the data available were used. Table 34 shows the rates for skilled construction, skilled operating and common labor in a number of cities expressed in percentage of Chicago rates for the same classes of labor. The comparison is as of 1925.

The adjustment for time was made by using the United States Department of Labor data relative to fluctuations in prices for building materials, and the prices paid by the City of Chicago for skilled construction labor, common labor, skilled operating labor and engineering or supervisory services.

Figure 22 shows diagrammatically the cost index of building materials from 1913 to 1925, based on United States Department of Labor data.

Figure 23 shows the variations in the rates paid by the City of Chicago for various classes of labor entering into the construction and operation of sewers and sewage disposal works.

In the application of these data to the various types of construction it was necessary to estimate approximately the percentages of materials and labor and the relative proportions of each class of labor required.

All time corrections were computed as of the date of letting contracts. In some cases where several contracts were involved the resulting time factor was a weighted composite of the individual contracts. In case of defaulting of the original contractor and the reletting of the work the latter date and contract cost were used for the date and payments under the original contract.

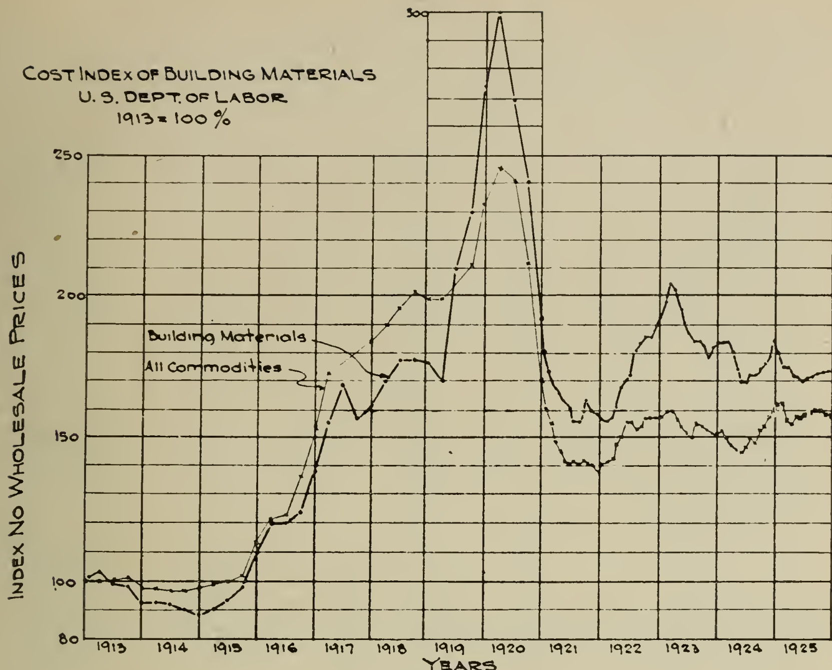


Figure 22.—Cost index of building materials.

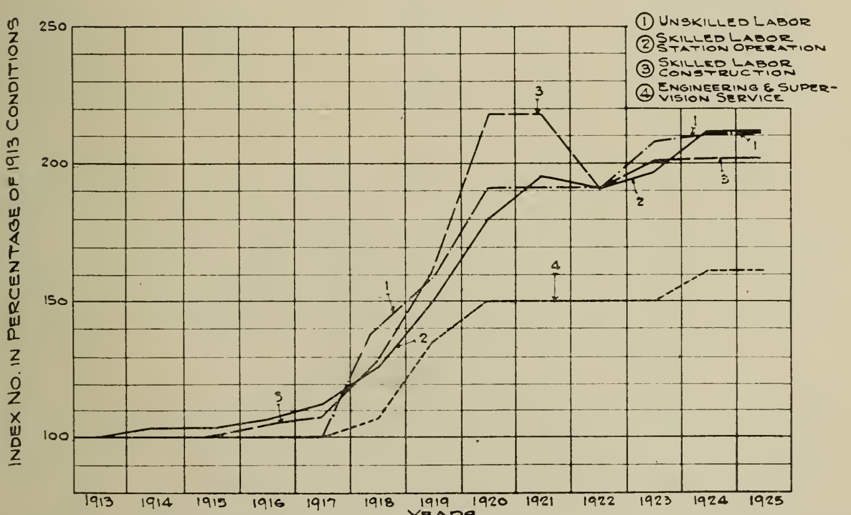


Figure 23.—Variations in skilled and unskilled labor rates in Chicago, based on City of Chicago records, 1913 being 100%.

TABLE 34.

TABLE SHOWING % RATIO OF SALARIES PAID TO SKILLED AND UNSKILLED LABOR IN VARIOUS CITIES, BASED ON CHICAGO PRICES IN 1925 BEING 100%.

City	Common Labor	Skilled Labor Construction	Skilled Labor Operation
Albany, N. Y.	85.0	92.5	87.0
Atlanta, Ga.	36.4	78.8	61.8
Baltimore, Md.	48.5	96.0	68.0
Boston, Mass.	78.8	84.5	85.1
Chicago, Ill.	100.0	100.0	100.0
Cleveland, Ohio	106.0	99.5	103.8
Columbus, Ohio	48.5	88.4	83.3
Fitchburg, Mass.	60.6	84.1	81.6
Houston, Texas	48.5	96.6	81.0
Indianapolis, Ind.	54.5	95.9	95.5
Lincoln, Neb.	48.5	84.6	73.5
Milwaukee, Wis.	72.6	81.9	79.5
Marion, Ohio	54.5	78.6	
New Orleans, La.	60.6	81.1	82.0
Philadelphia, Pa.	60.6	92.5	88.0
Reading, Pa.	60.6	86.4	75.7
Rochester, N. Y.	84.9	91.5	86.9
Syracuse, N. Y.	84.9	84.7	80.5
Urbana, Ill.	66.6	92.1	84.0
Lexington, Ky.	48.5	73.8	73.8
Canton, Ohio	66.6	87.8	70.0
Alliance, Ohio	66.6	87.8	70.0
Detroit, Mich.	72.8	93.5	95.0
St. Louis, Mo.	106.0	116.0	102.7
Madison, Wis.	64.6	87.0	76.8

Tankage Plants:

The largest tankage plants of the country, which at the present time are operating without secondary treatment, are those of Cleveland (Westerly Plant), Rochester, (Irondequoit Plant), Philadelphia and Albany. In each of these plants we ascertained the facts relative to first costs, date of construction, and the costs of operation.

The data relative to construction costs are shown on Table 35. Inasmuch as these costs were incurred during a period of rapid and great fluctuations in prices, all of these costs have been reduced to the basis of 1925 conditions, and then further adjusted for the difference in conditions prevailing in each of these towns as compared to Chicago.

The costs reduced to the 1925 Chicago basis average $5.00 per capita and $30,750 per million gallons daily capacity.

At the bottom of this table are shown similar figures for the Calumet plant of the Sanitary District of Chicago. The per capita cost of the Calumet plant is $26.40 and the cost per M.G.D. capacity is $86,000. The tabulation of bids on the Calumet plant shows that the concrete for the tanks, 28,000 cubic yards, was let at a price of $64.00 per cubic yard exclusive of reinforcing steel. The steel, 3,000,000 pounds, was let at a unit price of twenty-three cents per pound. The concrete complete, therefore, was let at a unit price exceeding $85.00 per cubic yard. The work included thirty tanks permitting multiple use of forms and plant.

In making the comparison of construction costs for utilization in preparing estimates for Chicago plants yet to be built, all figures were reduced insofar as possible to a unit volume or capacity basis. On tankage plants for example the comparison is based upon the displacement

TABLE 35.

CONSTRUCTION COSTS OF TANKAGE PLANTS (2 Story Type) INCLUDING SCREENING, GRIT CHAMBERS AND SLUDGE DISPOSAL.

	Population designed for	Year Built	Quantity designed for MGD	Actual Construction Cost Total	Conversion Factor	Construction Costs Based on Chicago Prices of Material and Labor, 1925. Total	Per Capita	Per M.G.D.
**Cleveland (Westerly)	288,000	1916-23	36	$ 944,130	1.06	$1,000,000	$3.47	$27,800
Rochester, N. Y. (Irondequoit)	200,000	1916	34	500,250	1.87	935,000	4.67	27,500
(a) Philadelphia	300,000	1917-23	60	1,698,770	1.23	2,085,000	6.95	34,800
Albany	156,000	1915	30	443,080	2.03	901,000	5.77	30,000
Average							5.22	30,025
Weighted average							5.00	30,750
Chicago, Calumet Plant	179,000	1920-23	55.0	*$5,207,569	.91	*$4,747,000	$26.40	$86,000

*Corrected for 1 M. G. D. activated sludge and 4.44 acre ft. of filters and for land.
**No sludge drying beds—Cost adjusted on basis of 1919.
(a One-third built under original contract—two thirds under new contract let in July, 1920.
No Intercepters or Pumping Stations included.

volume of both the flow and digestion chambers in order to eliminate the variations in detention periods, sludge storage per capita, strength and amount of sewage and the momentary under or overbuilt condition of the plant. The average and weighted average of the costs for each part of the plants, such as screens, grit chambers, tanks, sludge beds, etc., were secured for use in estimating reasonable construction costs for Chicago conditions. The detailed data are shown in Table 38.

Weighted averages were computed in order that the relative effect of size of units upon cost might be taken into consideration.

Table 36 shows the operating costs of these Imhoff tank plants. It shows also the cost of operating the separate digestion tanks at Baltimore in which the operating costs are excellently sub-divided so that the tank and sludge operations are available. We have also shown the facts relative to the Calumet plant of the Chicago Sanitary District on this table.

TABLE 36.

OPERATING COSTS OF TANKAGE PLANTS.

City	Year Considered	Contributing Population	M.G. Treated	Annual Operating Costs Total	Conversion Factor	Operating Costs reduced to Chicago 1925 asis—Labor Only Changed Total*	per Capita	per M.G.
*Cleveland	1924	87,000	4,800	$ 33,847	0.975	$ 32,929	$ .378	$6.85
Rochester	1919	240,000	12,050	30,809	1.48	45,625	.190	3.78
**Philadelphia ..	1924	117,000	8,100	28,420	1.31	37,280	.319	4.61
Albany	1920	104,358	5,220	21,127	1.29	27,202	.261	5.21
Baltimore	1923	690,000	20,100	75,842	1.07	81,352	.135	4.04
Average							.256	4.90
Weighted Ave..							.192	4.47
Calumet, Chicago Sanitary Dist.	1924	90,000	10,600†	$199,567†		$199,567†	$2.22	$18.82

*No sludge drying beds—sludge pumped to Lake Erie.
**No sludge drawn to beds in 1924.
†Deducted 1180 M. G. estimated sludge operation @ $21.95 = $25,800.

At the Westerly Cleveland plant the sludge instead of being dried on beds is discharged into the outlet sewer. The total operating expenses of this plant were credited with the cost of chlorination which is practiced during the summer season.

At Philadelphia the plant is provided with sand sludge drying beds but no sludge was removed during 1924.

Baltimore, a separate sludge digestion type of plant, has the lowest per capita expenditure for tank and sludge bed treatment of any of the large plants studied.

It will be noticed that the weighted average cost of operating Imhoff tank plants adjusted to Chicago 1925 conditions was 19.2 cents per capita and $4.47 per million gallons treated. The Calumet plant in Chicago, built in 1920, with costs adjusted for a small experimental plant and reduced to 1925 conditions on the same basis as the other plants was $2.22 per capita and $18.82 per million gallons. The per capita cost was ten times the average of the other plants, and the cost per M. G., due to the higher per capita use, was still over four times the average and nearly three times the highest of the other plants.

Comparative cost of construction of these plants is shown diagrammatically on Figure 24.

The operating costs of Tankage plants in cities other than Chicago vary from 13.5 cents to nearly 38 cents per capita, adjusted to the

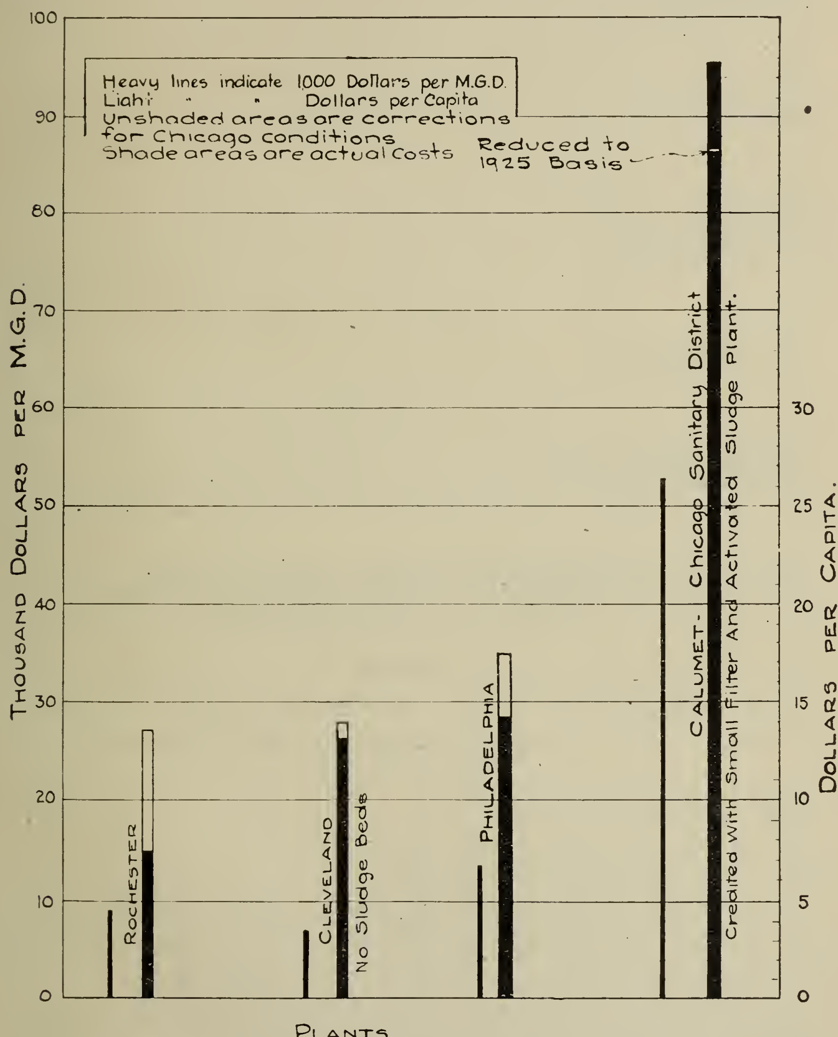


Figure 24.—Cost of constructing Imhoff tank disposal plants, based on 1925 Chicago conditions.

Chicago 1925 basis and from \$3.78 to \$6.85 per million gallons treated referred to the Chicago 1925 price basis. These facts relative to operating costs, together with the operating cost of the Calumet plant of the Chicago Sanitary District are shown diagrammatically on Figure 25.

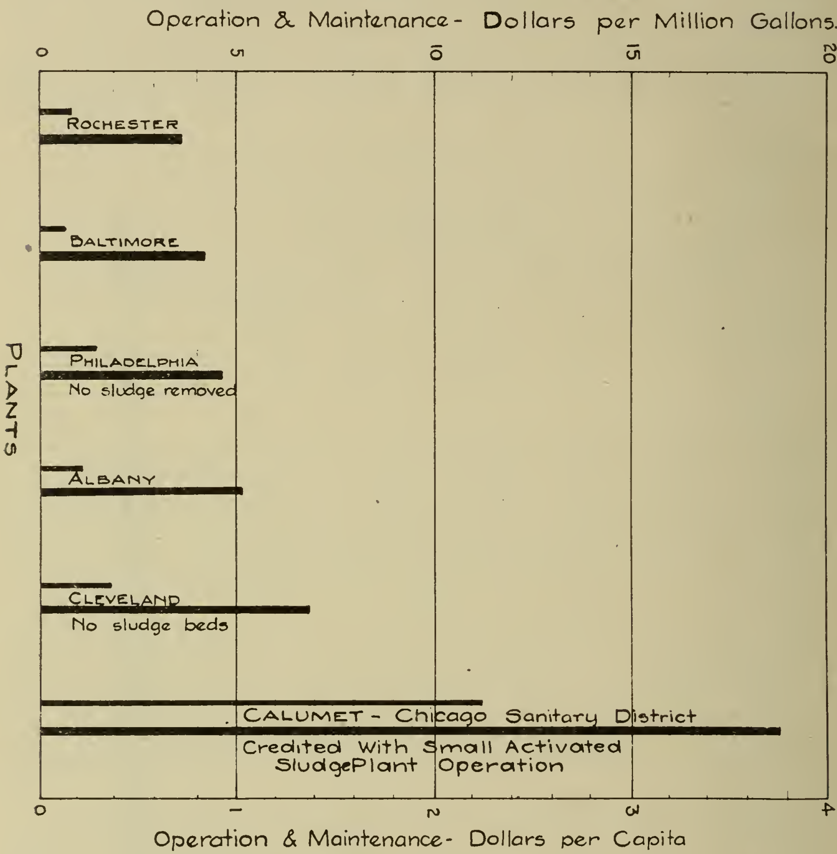


Figure 25.—Cost of operating tank disposal plants, based on 1925 Chicago conditions.

Heavy lines indicate \$ per million gallons.
Light lines indicate \$ per capita.

Imhoff Tank, Sprinkling Filter Plants:

In a manner similar to that just outlined we investigated the costs of construction and operation of eight (8) Imhoff tank sprinkling filter plants, all cost being reduced to the 1925 Chicago basis.

Insofar as possible the costs of construction of these plants were likewise subdivided into the various units of the plants, such as screens, grit chambers, settling tanks, digestion tanks or digestion compartments sprinkling filters, secondary tanks, sludge beds, etc. These costs were further reduced to the cost per unit of capacity, either per capita, per million gallons or unit of organic load, so that insofar as possible the unit prices thus secured might be available for use in estimates for Chicago costs.

The comparison of the unit construction costs of these plants is shown on Table 35 hereinbefore referred to under Imhoff Tanks.

On Table 37 we have shown the summarized costs of the sprinkling filter plants taken as a whole, without respect to the variations in design periods, rates, etc. These costs while more general than those secured from the analysis of the several parts of each plant nevertheless are of interest in showing the average costs of complete plants under widely varying designs. An estimate for any particular set of design conditions can be prepared by applying the unit costs set forth in Table 38 to the corresponding units determined upon.

A study of the operating costs of the tank-sprinkling filter plants was also made, the results of which are shown on Table 39. This table shows contributing population, million gallons treated during the year, the actual operating costs furnished us, these costs reduced to Chicago 1925 conditions and expressed in total, per capita, and per million gallons.

All of these plants are complete and the costs of operation include all such items as labor on coarse screens and grit chambers, labor and power on fine screens at Baltimore (the only plant in this number having fine screens) sludge handling, sludge drying, cleaning of sprinkler nozzles, operation of laboratory, superintendence, maintenance and repairs.

The detailed costs under each of these subheads are not available for the several plants in comparable form and are accordingly omitted herein.

It will be noted that the weighted average cost of operating tank sprinkling filter plants was 26.1c per capita or $8.82 per million gallons treated, based on Chicago 1925 conditions.

Activated Sludge Plants:

Three large activated sludge plants are now in construction, namely Milwaukee, Indianapolis and the North Side plant in Chicago. The Milwaukee plant is practically completed, and it is expected will go into operation this year. All construction has either been completed or is under contract so that the entire cost of the work is now ascertained within reasonable limits.

Mr. T. Chalkeley Hatton, Chief Engineer of the Milwaukee Sewerage Commission, has very kindly furnished us with a most excellent de-

TABLE 37.

CONSTRUCTION COST OF TANKS AND SPRINKLING FILTER PLANTS.

City	Population designed for	Year built	Quantity designed for M.G.D.	Construction Cost	Construction Cost based on Chicago prices of material & labor 1925		
				Total	Total	Per Capita	Per M.G.D.
Atlanta, Ga.	105,000	1913-14	15	$ 445,924	$ 1,397,570	$ 13.30	$ 93,000
Baltimore, Md.	620,000	1911-24	55	3,265,102	6,627,800	10.69	120,500
Columbus, O.	261,000	1908-17	20	740,250	1,396,800	5.35	69,840
Fitchburg, Mass.	55,000	1913	5.5	325,820**	758,810**	13.80**	138,000**
Lexington, Ky.	50,000	1918	5	216,662	395,500	7.99	79,900
Lincoln, Neb.	80,000	1922-23	6.5	358,138**	445,230**	5.57**	68,500
Urbana, Ill.	50,000	1924	4	437,979**	501,900**	10.03**	125,500**
*Marion, Ohio	40,000	1923	4	522,800**	666,040**	16.65**	166,500**
Average						10.48	107,720
Weighted Average						9.60	105,000

*Glass covered sludge beds.
**Includes pumping stations.

TABLE 38.

COMPARISON OF UNIT CONSTRUCTION COSTS OF TANK—SPRINKLING FILTER PLANTS—BASED ON CHICAGO CONSTRUCTION COSTS OF 1925.

City	Population designed for	M.G.D. designed for	Buildings & improvements per M.G.D.	Screens per M.G.D.	Settling tanks per 1000 gal. vol.	Sludge beds per sq. ft.	Filters per acre ft.	Secondary tanks per 1000 gal. vol.	Mscl. per MGD	Eng. Admin. per MGD
Baltimore	620,000	55	$10,000	$ 604	$ 50.40	$ .36	$ 12,450	$ 8.95	$ 5,580	$ 8,890
Cleveland	288,000	36	3,810	1550	135.00	.....	.....	.....	4,260	4,220
Columbus	261,000	20	3,810	.....	72.00	.51	9,250	19.25	1,050	6,750
Atlanta	105,000	15	418	7,260	113.00	1.36	21,750	.....	16,400	13,470
Fitchburg	55,000	5.5	9,390	4,510	94.40	.74	25,850	54.60	22,600	14,810
(a) Marion	40,000	4.0	28,300	1,785	78.70	3.53	19,060	146.30	12,780	10,450
Urbana	50,000	4.0	10,280	.....	111.00	.92	15,250	.....	4,570	11,400
Lincoln	80,000	6.5	5,620	.....	54.20	.45	17,900	.....	4,900	4,230
Rochester	240,000	34	6.770	.....	78.50	1.31	.....	.....	3,220	.....
Average			8,954*	3,142*	87.47	1.15	17,359	.....	8,373	9,278
Weighted Average			6,960*	1,990*	69.70	.59	13,600	.....	5,900	8,040
Weighted Average—Imhoff Tanks Only................					102.30					

*Excl. of Rochester.
(a) Glass covered sludge beds.

TABLE 39.

OPERATING COSTS OF TANKS AND SPRINKLING FILTER PLANTS.

City	Year Considered	Contributing Population	M.G. treated	Annual Operating Costs	Operating Costs Reduced to Chicago 1925 Basis		
				Total	Total	Per Capita	Per M.G.
*Baltimore	1923	620,000	2,100	$103,983	$179,488	$ .2991	$ 8.93
Columbus	1923	261,000	5,109	17,386	27,804	.1066	5.44
Fitchburg	1919	38,300	1,223	11,596	20,846	.5440	17.04
Lexington	1920	28,000	913	6,600	10,120	.3615	11.09
*Lincoln	1924	49,600	1,450	9,750	14,550	.2935	10.03
Urbana	1925	31,500	913	8,040	11,500	.3650	12.60
*Madison	1924	51,500	2,185	12,777	17,212	.3340	7.87
Average						.328	10.43
Weighted Ave.						.261	8.82

*Separate Sludge Digestion tank plants.

TABLE 40.

CONSTRUCTION COST OF MILWAUKEE ACTIVATED SLUDGE PLANT.

Data of Milwaukee Plant Furnished by Mr. T. Chalkley Hatton, Chief Engineer.

Item	M.G.D. Designed for	Population Designed for	* Cost of Milwaukee Plant Total	Cost on Chicago 1925 Basis		
				Total	Per M.G.	Per Capita
Grit Chamber and Flume	317	862,000	$ 147,015	$ 169,000	$ 533	$ .196
Filter and Dryer House	85	589,000	1,817,100	2,088,000	24,580	3.540
Cage Screen House	317	862,000	213,449	245,500	974	.285
Sludge Storage Bldg.	85	589,000	307,210	353,000	4,160	.599
Fine Screen and Admin. House	317	862,000	447,641	515,000	1,625	.598
Aeration and Sed. Tanks	85	589,000	1,971,085	2,265,000	26,650	3.850
**Power and Boiler House	85	589,000	1,473,678	1,696,000	19,950	2.880
Miscellaneous	85	589,000	682,963	785,000	9,240	1,333
Totals			$7,060,141*	$8,116,500*	$87,712	$13.281

*Exclusive of pile foundations and breakwaters special to Milwaukee.
**Excludes low level pump pits and equipment.

tailed analysis of the costs of this plant, which is reproduced in summarized form on Table 40. In this table we have adjusted the Milwaukee costs for Chicago conditions and expressed the results in cost per million gallons and per capita for each of the several parts of the plant.

Mr. Hatton has also made a detailed study of the estimated costs of operating this plant based upon observations and data collected during the extended experimental work at Milwaukee. These estimates of operating cost are contained in the Eighth Annual Report of the Sewage Commission of the City of Milwaukee. We are advised by Mr. Hatton that although these estimates were made about three years ago, they are believed to represent conditions at the present time except for fixed charges.

We have also been furnished through the courtesy of Mr. Charles H. Hurd, Consulting Engineer of the Indianapolis Commission, an analysis of the construction cost of that plant, which is reproduced in abstracted form on Table 41.

In addition to these two large activated sludge plants, both of which are substantially ready to start operation, there have been two activated sludge plants in Houston, Texas, which have been in operation for over five years. These plants have capacities of ten and five million gallons per day respectively. Neither of the Houston plants provide for dewatering of the sludge although considerable experimental work on sludge dewatering has been carried on from time to time.

The two Houston plants are the only activated sludge plants in this country except the Des Plaines plant of the Chicago Sanitary District, which have had real operating experience, although the Milwaukee experiments were conducted on a sufficiently large scale to make them quite indicative of operating difficulties and costs.

The data relative to the cost of construction of the Milwaukee, Indianapolis and two Houston plants and of the Des Plaines River plant of the Sanitary District of Chicago, which is substantially the same size as the small Houston plant built in 1920, is shown in Table 42.

It will be noticed that the weighted average cost of construction of the Milwaukee and Indianapolis plants under 1925 Chicago conditions is $10.45 per capita or $74,300 per million gallons daily capacity. The Des Plaines plant has a per capita cost of $30.65 and a cost per million gallons per day of $306,500.

These facts relative to construction costs of all plants are shown diagrammatically on Figure 26.

The cost of operating the Houston plants and the estimated cost of operating the Milwaukee plant, as worked out in detail by Mr. Hatton, and the actual cost of operating the Des Plaines plant of the Chicago

TABLE 41.

CONSTRUCTION COST OF INDIANAPOLIS ACTIVATED SLUDGE PLANT

Indianapolis Data Furnished by Mr. Chas. H. Hurd, Consulting Engineer

Item	M.G.D. Designed for	Population Designed for	Construction Cost Total	Cost on Chicago 1925 Basis Total	Per M.G.D.	Per Capita
Grit Chambers	72	400,000	$ 50,590	$ 61,500	$ 857	$ .155
Pump Station and Thickener Tanks	72	400,000	402,137	490,000	6,810	1.226
Admin. and Lab. Bldg.	72	400,000	114,270	139,200	1,940	.349
Act. Sludge Plant	50	278,000	1,190,786	1,452,000	29,000	5.225
Dehydration Plant	50	278,000	222,060	271,000	5,410	.975
Totals					$ 44,017	$ 7.930

TABLE 42.

CONSTRUCTION COSTS OF ACTIVATED SLUDGE PLANTS.

City	Population designed for	Year built	Quantity designed for M.G.D.	Construction Costs Total	Construction Costs based on Chgo. prices of material and labor, 1925		
					Total	Per Capita	Per M.G.D.
*Milwaukee	589,000	1920-24	85**	$7,060,141	$8,116,500	$13.78	$ 95,500
Houston (North)	133,400	1916-17	10	257,371	568,500	4.27	56,850
Houston (South)	66,600	1916-17	5	115,313	255,000	3.83	51,000
Indianapolis	278,000	1920-24	50	1,805,000	2,200,000	7.93	44,017
Average						7.45	61,842
Weighted Ave. complete plants						10.45	74,305
Des Plaines	50,000	1919-24	5	$1,441,835	$1,532,315	$30.65	$ 306,500

*Includes sludge dewatering plant.
Excludes pile foundations and breakwaters special to Milwaukee; also low lift pump pitsand equipment.
**Part of structures designed for 317 M. G. D.

Sanitary District for the year 1924, are shown in tabular form on Table 43 and diagrammatically on Figure 27.

The Des Plaines plant of the Sanitary District of Chicago has an operating cost approximately eight times the estimated cost of operating the Milwaukee plant expressed on the per capita basis, and ten times these figures when expressed in terms of million gallons treated.

The Des Plaines operating costs include some items properly chargeable to experimental work.

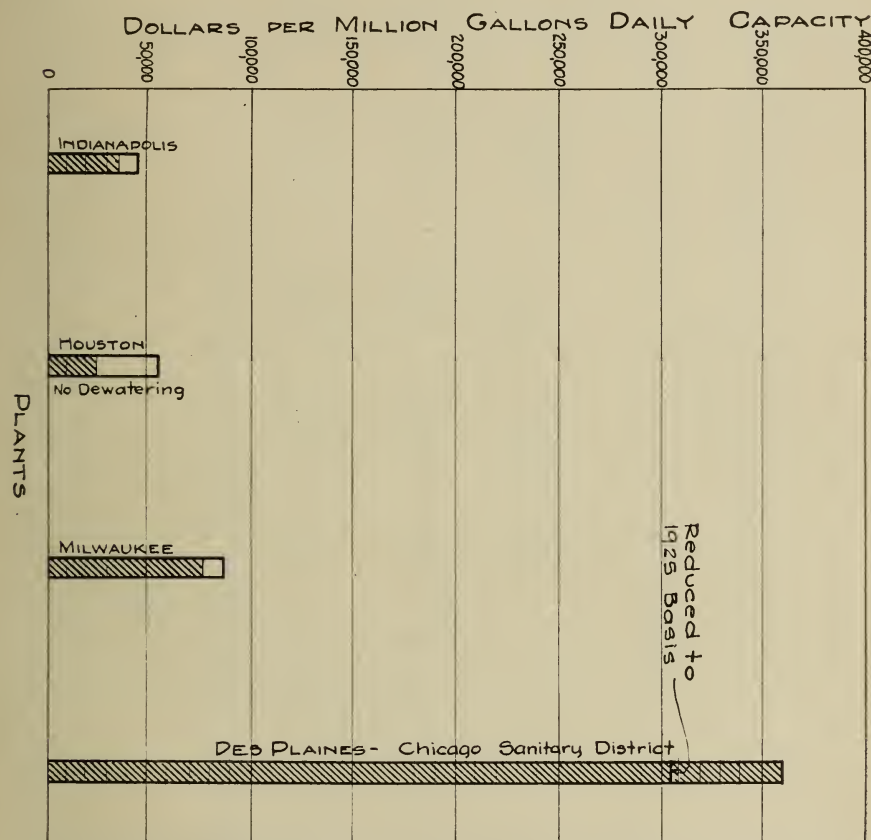


Figure 26.—Cost of construction of activated sludge plants, based on 1925 Chicago conditions.

Shaded areas are actual costs.
Unshaded areas are corrections for Chicago conditions.

TABLE 43.

OPERATING COSTS OF ACTIVATED SLUDGE PLANTS.

City	Year Consid-ered	Contribut-ing Popu-lation	M.G. Treated	Annual Operating Costs Total	Operating Costs reduced to Chicago 1925 Basis—Labor only changed		
					Total	Per Capita	Per M.G.
Houston	1923	100,000	2,550	$ 41,000	$ 55,538	$ .555	$ 21.77
Milwaukee without sludge disposal.....	1922	589,000	31,000	280,636*	325,200	.552	10.48
Average						.553	16.12
Weighted Ave.						.553	11.35
Milwaukee with sludge disposal........		589,000	31,000	600,074**	680,674	1.16	21.95
Des Plaines-Chicago Sanitary District...	1924	40,000	1,560	342,406	342,406	8.56	220.00

*Operating cost excludes cost of low lift pumping = $12871. and includes $9000. extra for labor of "half" men which was charged to sludge disposal in Milwaukee estimates of Sept. 9, 1921.

**Exclusive of cost of low lift pumping = $12871. in Milwaukee estimate.

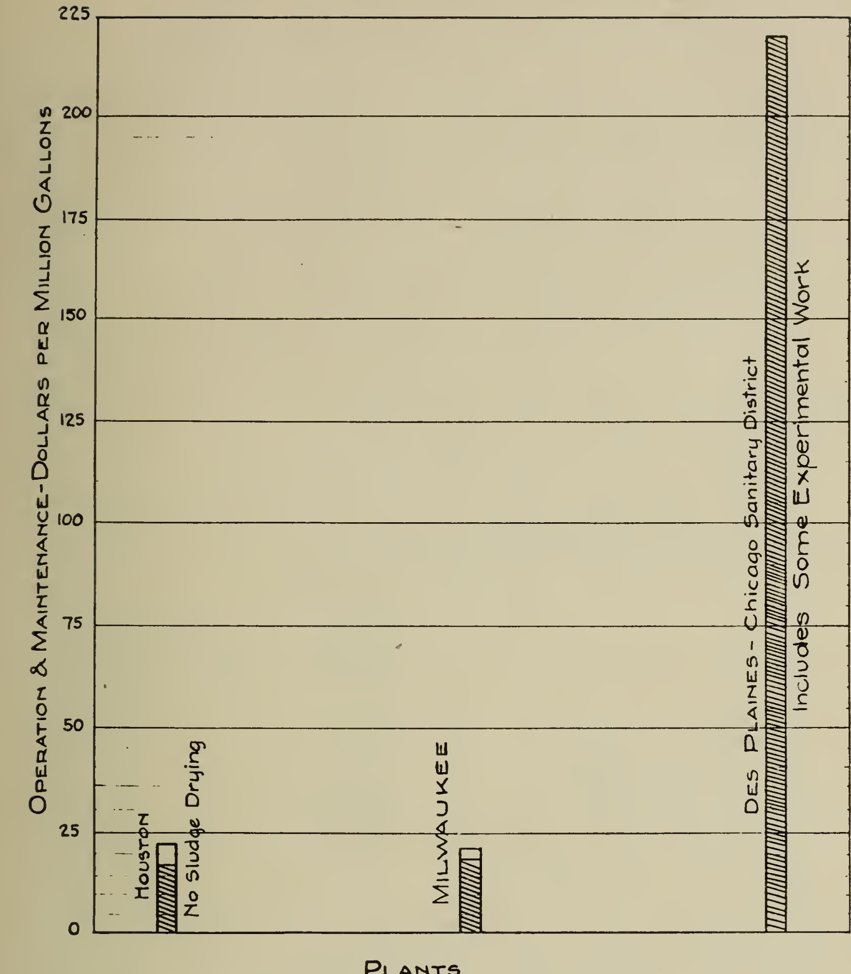


Figure 27.—Cost of operating activated sludge plants, based on Chicago conditions.

Shaded areas are actual costs.
Unshaded areas are corrections for Chicago conditions.

Pumping Station Costs:

As due to the level character of the topography in the Chicago district, practically all of the sewage in Chicago requires pumping before treatment, the costs involved in the construction and operation of sewage pumping stations becomes a large item.

In addition to ascertaining the facts relative to costs of pumping stations and pumping station operations at Chicago we collected data relative to cost of construction and operation of sewage pumping stations in other cities. There are many such stations scattered throughout the country, but unfortunately for our purposes most of these stations are smaller in size than those required in Chicago, and most of the larger ones were built so long ago as to make the costs of construction subject to less accurate adjustment to the 1925 Chicago basis than would be the case if they had been built more recently.

We were, however, able to secure sufficient operating data relative to large sewage pumping stations in four cities to furnish a very good idea as to the fair and reasonable cost of operating them. On Table 44 we show the cost of operating a large number of sewage pumping stations including the stations at Baltimore, New Orleans, four stations in Boston and the Albany sewage pumping station, together with several stations operated by the City of Chicago and the Chicago Sanitary District.

Abstracting from the larger tabulation only those stations which have an annual output of about 200,000 million foot gallons per year above which there is little reduction in the unit cost of pumping station operation, we have the following data:

City	Million Foot Gallons Output	Annual Cost per Million Foot Gallons—Chicago 1925 Basis
Baltimore	591,000	19.5¢
New Orleans (8 Stations)	485,000	14.1
Boston (4 Stations)	1,297,000	18.0
Albany	198,500	17.4
Columbus	160,800	20.0
Milwaukee (Kinnickinnick)	183,000	19.6
Average		18.1¢
Chicago—Sanitary District.		
39th St. (1920)	432,900	59.5¢
Lawrence Ave. (1919)	131,800	65.3
Calumet (1924)	274,000	49.1
Average		58.0¢

The Chicago Sanitary District pumping station operating costs, excluding power charge, average approximately three times those of similar stations elsewhere including the cost of power.

The operating costs are compared on a basis of costs per million foot gallons as actually reported and as adjusted for the 1925 Chicago conditions.

TABLE 44.

OPERATING COSTS OF SEWAGE PUMPING STATIONS.

City	Year Consid-ered	M.G. Pumped	Ave. Head	M.G. Feet	Annual Cost Total	Annual Cost Per M.G. Ft.	Annual Cost Reduced to Chgo. 1925 Basis Total	Annual Cost Reduced to Chgo. 1925 Basis Per M.G. Ft.
Misc. Plants—								
Baltimore	1923	8,150	72.5	591,000	$83,013	14.0¢	$115,339	19.5¢
Columbus—Main Sta.	1923	5,376	29.9	160,800	27,231	16.9	32,168	20.0
Columbus—E. Side Sta.	1923	756	62.2	47,000	12,007	25.5	14,845	31.5
Houston—Willow St.	1923	2,370	20.0	47,400	11,101	23.4	14,980	31.6
Houston—Scott Sta.	1923	770	23.0	17,700	8,582	48.5	11,870	67.1
New Orleans (Sew. & drainage) 8 stations	1922	24,250	20.0	485,000	62,083	12.8	68,681	14.1
Boston (4 stations)	1923	36,244	35.8	1,297,000	201,923	15.5	233,933	18.0
Milwaukee:								
Kinnickinnick	1924	76,201	2.4	183,000	29,529	16.1	35,819	19.6
Milwaukee River	1924	19,901	3.2	63,700	6,880	10.8	7,988	12.6
Philadelphia:								
Mungo Creek	1924	4,146	12.0	49,700	19,525	39.3	21,015	42.3
Pennypack Creek	1924	592	50.0	29,600	11,225	37.9	12,753	43.1
Oak Lane	1924	81.4	50.0	4,070	3,510	86.2	3,824	94.0
Albany	1920	5,220	38.0	198,500	32,442	16.4	34,598	17.4
Operated by City of Chicago—								
Stony Island Sta.	1918	9,318	6.8	63,400	27,306	43.1	38,044	60.0
Stony Island Sta.	1919	11,702	6.5	76,000	34,610	45.5	42,955	56.5
Stony Island Sta.	1920	10,158	6.4	65,000	41,749	64.2	41,749	64.2
Stony Island Sta.	1923	12,027	6.6	79,300	44,924	56.6	44,924	56.6
Kensington Sta.	1918	1,381	13.4	18,510	17,325	93.6	22,918	123.9
Kensington Sta.	1919	1,393	13.5	18,800	18,916	100.4	23,264	123.5
Kensington Sta.	1920	1,395	13.6	19,000	24,141	127.0	24,141	127.0
95th St. Sta.	1918	9,915	11.7	116,000	27,574	23.8	37,947	32.7
95th St. Sta.	1919	10,903	11.2	122,000	31,667	26.0	39,999	32.8
95th St. Sta.	1920	11,600	10.8	125,000	37,749	30.1	37,749	30.1

TABLE 44—Continued.

OPERATING COSTS OF SEWAGE PUMPING STATIONS.

City	Year Consid-ered	M.G. Pumped	Ave. Head	M.G. Feet	Annual Cost Total	Annual Cost Per M.G. Ft.	Annual Cost Reduced to Chgo. 1925 Basis Total	Annual Cost Reduced to Chgo. 1925 Basis M.G. Ft. Per
Sanitary District:								
39th St. Sta.	1918	38,300	12.5	496,800	$177,609	35.8¢	$227,121	45.8¢
39th St. Sta.		6,100	3.0					
39th St. Sta.	1919	35,600	12.5	481,600	147,225	30.6	173,893	36.2
39th St. Sta.		12,200	3.0					
*39th St. Sta.	1920	35,400	12.0	432,900	257,880	59.5	257,880	59.5
		400	2.2					
Lawrence Ave. Sta.	1918	21,200	5.8	135,800	69,823	51.4	90,971	67.0
		4,740	2.7					
Lawrence Ave. Sta.	1919	16,900	5.8	131,800	71,389	54.1	86,094	65.3
		12,500	2.7					
Lawrence Ave. Sta.	1920	11,850	5.8	69,700	101,663	145.8	101,663	145.8
		306	2.7					
Lawrence Ave. Sta.	1924	6,060	2.4	88,200	241,426	274.0	241,426	274.0
		12,900	5.7					
Calumet Sta.	1924	10,700	25.6	274,000	133,400	49.1	133,400	49.1

* This item has been credited with 18000 K. W. H. per day @ 1.00¢ per K. W. H.

The figures on this table are shown in diagrammatic form on Figure 28 and 29.

Basis of Cost Estimates in this Report:

The foregoing studies and cost analyses were used as a basis for estimating the reasonable costs of sewers and sewage disposal works required for each of the several flows considered as possibly available for the sewage plant effluents of the Chicago Sanitary District.

This adjusted comparative method of ascertaining fair costs of construction and operation of public works is believed to furnish an excellent criterion as to the costs which should practicably be secured. Its advantages include the following:

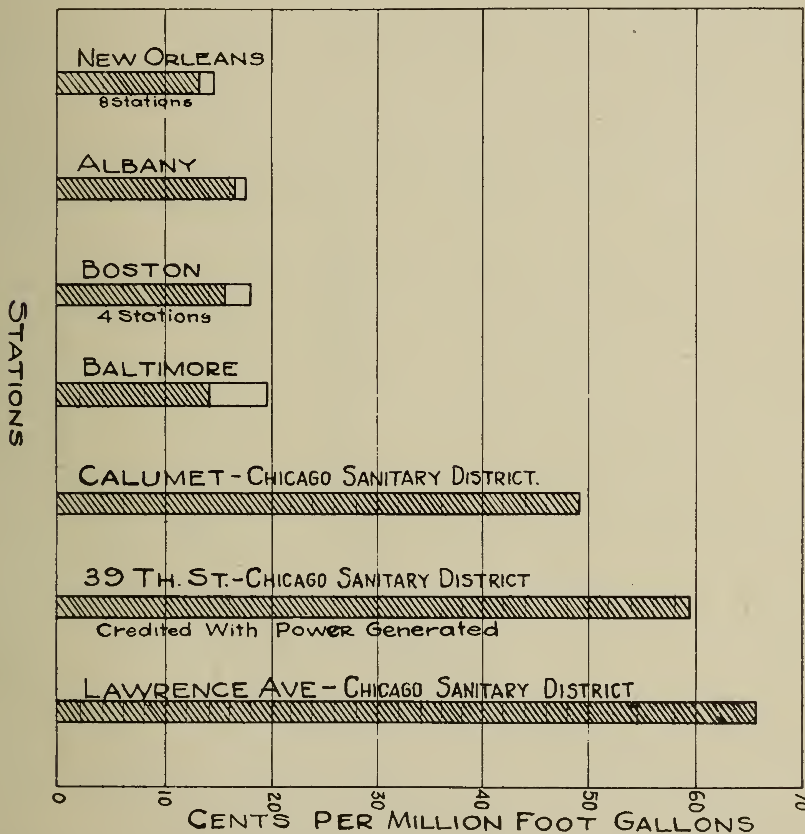


Figure 28.—Operating costs of large sewage pumping stations (over 200,000 million foot galons per year).

Shaded areas are actual costs.
Unshaded areas are corrections for Chicago conditions.

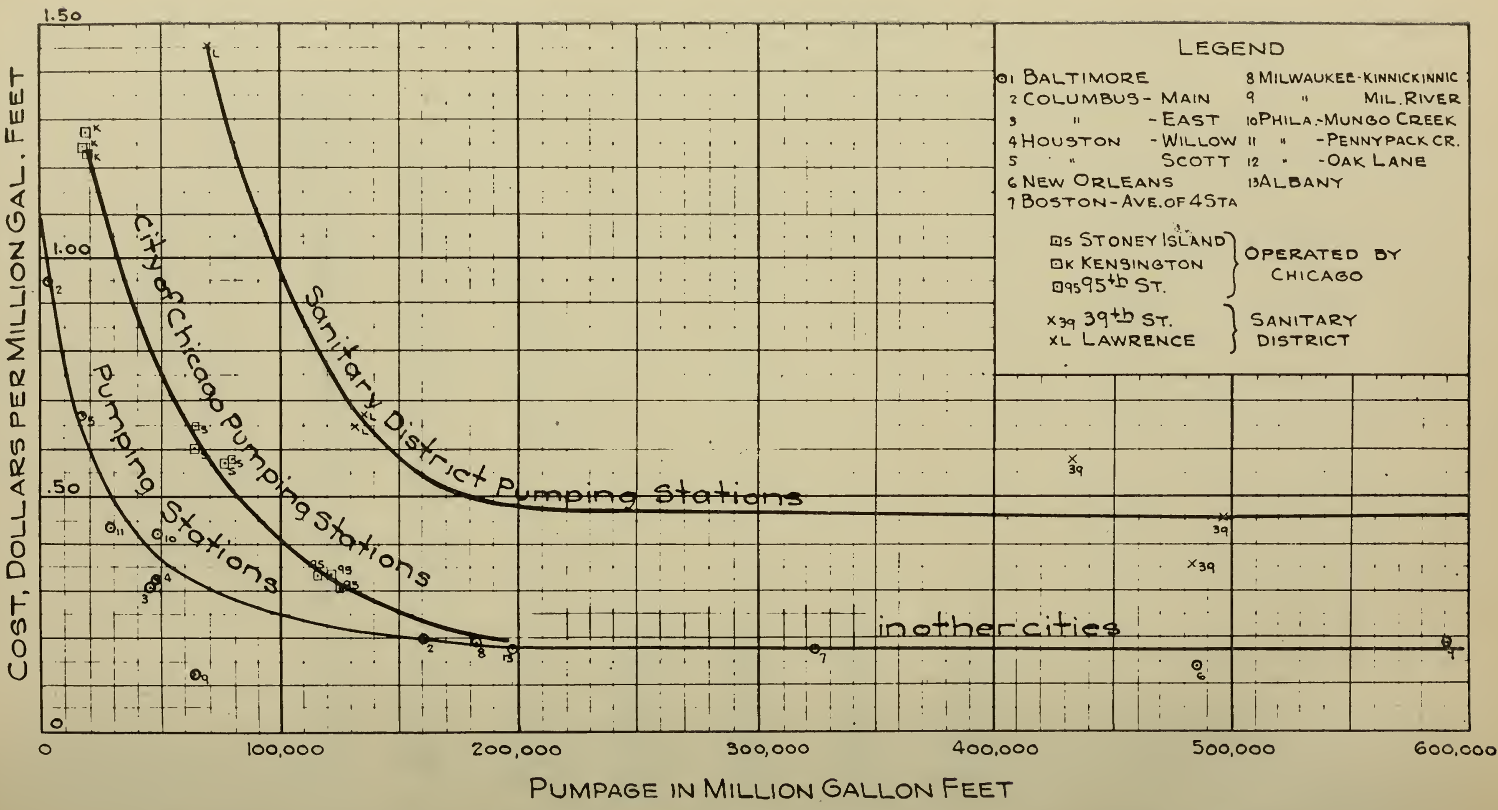


Figure 29.—Unit cost of operation of sewage pumping stations, based on 1925 Chicago conditions.

(a) Being based upon analyses of costs of like work in other municipalities, it automatically allows for the *average* percentage of inefficiency found in public enterprises.

(b) The study embracing a large number of cities, in this case including a study of costs at Baltimore, Albany, Rochester, Philadelphia, Cleveland, Milwaukee, Indianapolis, Houston and many other important cities, gives a representative average basis of municipal costs.

(c) The application of these unit costs in this study presupposes that the Sanitary District of Chicago will execute its construction program and its operations with efficiency and freedom from political interference equal to (neither better nor worse) than those found practicable in other public bodies executing similar work.

(d) This method is particularly applicable to large operating units in which the several operations are of sufficient magnitude to establish complete organizations such as is the case at all Chicago plants.

This method and the data contained in Chapter X relative to sewer costs and in this Chapter XII relative to sewage disposal plant costs have been used as the basis of estimates of costs of plants and operation for several flows studied, all as outlined in Chapters XIII, XIV, and XV.

PART XIII.

REQUIRED WORKS FOR 10,000 CUBIC FEET PER SECOND FLOW.

Basis of Cost Estimates For All Projects:

With a total flow in the drainage channel at Lockport of 10,000 cubic feet per second, there will be available during the warm months of July and August approximately 365,000 pounds of oxygen per day in 1935 and 354,000 pounds per day in 1945. (See Table 17.) Of this total amount a relatively small part will be required to provide for the effluents from the sewage disposal plants which are now under construction or which are included in the tentative plans of the District to be constructed in the very near future, all of which it is assumed will soon provide complete secondary treatment.

The oxygen requirements for the effluents of these plants are estimated as shown in Table 45.

The amount of oxygen left for disposing of the effluents from the West and Southwest plants will be approximately 330,585 pounds in 1935 and approximately 314,210 pounds in 1945. We have endeavored to ascertain the extent of treatment for the West and Southwest Side sewage, which will utilize this available oxygen to the fullest extent and with the most efficiency.

If deposits are to be prevented in the Illinois River at least tankage must be installed at both the West and Southwest plants. The installation of tanks alone will reduce the B. O. D. of the sewage reaching the two plants from 532,500 pounds to 346,000 pounds per day. As this amount exceeds the 330,585 pounds available in the total flow in the channel of 10,000 C. F. S. some secondary treatment will be required even in 1935.

The addition of sprinkling filters to the Southwest plant will reduce the B. O. D. of the two plant effluents to 242,800 pounds per day for 1935 and 254,900 pounds per day for 1945 conditions. This treatment will so reduce the B. O. D. that the total flow in the channel of 10,000 C. F. S. would supply an adequate amount of oxygen up to as late as about 1960.

Briefly summarized a total flow of 10,000 C. F. S. will provide adequately for the dilution of treated sewage from the Sanitary District to 1960 providing:

TABLE 45.

OXYGEN REQUIREMENTS OF CHICAGO SEWAGE (BASED ON 5 DAY B.O.D.) AT CERTAIN PURIFICATION PLANTS—BEFORE AND AFTER PURIFICATION.

Plant	Pounds Oxygen Required 1935				1945		
	Raw Sewage	Plant Efficiency	Effluent	Type Plant	Raw Sewage	Effluent	Type Plant
Des Plaines	13,650#	.92	1,095#	(a)	19,100#	1,530#	(a)
Calumet	46,400	.88	5,680	(s)	58,200	7,000	(s)
N. Side	166,500	.92	13,300	(a)	204,500	16,400	(a)
W. Side	326,000		X		349,000	X	
S. W. Side...........	206,500		X		241,000	X	
Corn Products	63,750	.95	3,190	(s)	71,250	3,560	(s)
Stock Yards	203,000	.95	10.150	(a)	226,000	11,300	(a)
Totals	1,025,800		33,415		1,169,050	39,790	

(a) = Activated Sludge.
(s) = Sprinkling filters and tankage.
(X) = To be determined according to available water for dilution.

(a) Activated sludge plants are in operation for the North Side, Des Plaines and Stockyards.

(b) Tanks and Sprinkling filters are in operation for the Argo, Calumet and Southwest Side.

(c) Tanks are in operation at the West Side.

Estimated Cost of Works Required for 10,000 Cubic Feet Per Second Flow:

We have estimated the cost of the works required to handle the sewage of the Sanitary District of Chicago, based upon a total flow of 10,000 cubic feet per second in the Drainage Canal. This estimate is as follows:

	Construction Costs	
	1935 Conditions	1945 Conditions
Des Plaines Activated Sludge	$ 264,700	$ 439,300
Calumet—Sprinkling Filters	1,564,420	2,021,700
North Side—Activated Sludge	5,600,800	5,947,300
Argo—Sprinkling Filters	2,544,200	2,808,800
Stockyards—Activated Sludge	7,804,800	8,601,600
West Side—Intercepters	7,890,600	7,890,600
West Side—Tanks	10,120,440	10,699,700
S. W.—Intercepters	4,495,700	4,405,700
S. W. Side—Sprinkling Filters	13,793,500	16,362,000
Miscellaneous Plants	3,336,000	5,336,000
Total Estimated Costs	$57,415,240	$64,692,700

It will be noted that an expenditure of approximately $57,000,000 is required for the 1935 sewage load even with 10,000 C. F. S. flow. If the industries were to pay one-half the cost of the Corn Products and Stockyards plants this total would be credited with approximately $5,000,000.

An additional expenditure of approximately $7,000,000 will be required to provide the additional capacity for 1945 conditions. Even a 10,000 cubic feet per second flow requires, as promptly as possible, complete treatment; that is, either tanks and sprinkling filters or activated sludge for all of the sewage of the Sanitary District of Chicago, with the exception of that of the West Side district which may have tankage only for the present.

Operating Expenses:

The cost of operating the pumping and treatment plants outlined under the 10,000 c. f. s. project is estimated as follows:

	Operating Expenses 1935	Operating Expenses 1945
Des Plaines—Activated Sludge	$ 78,500	$ 102,240
North Side—Activated Sludge	882,500	1,042,500
(a) Stock Yards—Activated Sludge	552,600	611,800
Calumet—Sprinkling Filters	197,800	244,900
(a) Corn Products—Sprinkling Filters	77,200	86,160
South West Side—Sprinkling Filters	1,043,300	1,273,200
West Side Tanks	1,182,500	1,264,000
Miscellaneous Plants	350,000	380,000
Total Treatment Oper. Costs	$ 4,364,400	$ 5,004,800
(b) General Office Expense	360,000	440,000
(b) Bridge and Channel Expense	253,000	264,000
Total Cost of Operating Sanitary District (Exc'l fixed charges)	$ 4,977,400	$ 5,708,800

*Credited with sale of sludge @ $10./ton.
(a) No credit given for possibility of industries assuming part of this cost.
(b) Estimated from past study of records of Sanitary District.

We have made no detailed analysis of the necessity for the amounts shown as "General Office Expense" and "Bridge and Channel Expense". The amounts included in the estimated operating expenses of the Sanitary District for each project are the same in each case and are based wholly upon a study of expenditures actually charged to these items in the past by the District.

PART XIV.

REQUIRED WORKS WITH 4167 CUBIC FEET PER SECOND FLOW.

With 4167 cubic feet per second total flow in the Drainage Canal there would be available during the summer months of July and August approximately 113,200 pounds per day of oxygen in 1935 and 103,000 pounds per day in 1945. Of this total it has been shown in Part XIII that approximately 33,415 pounds in 1935 and 39,790 pounds in 1945 would be required to care for the effluent of the Des Plaines, Calumet, North Side, Argo and Stockyards plants. There would therefore be available from the flow of 4167 c. f. s. approximately 79,785 pounds of oxygen per day in 1935 and 63,210 pounds in 1945 to care for the effluents from the West and Southwest Side treatment plants.

The total oxygen requirement of the sewage reaching these plants in 1935 and 1945 is estimated as follows:

	1935	1945
West Side Plant....................	326,000#	349,000#
Southwest Side Plant..............	206,500	241,000
Totals	532,500	590,000

These totals are seven to nine times the oxygen available from the 4167 c. f. s. flow after the other plant effluent requirements have been satisfied.

The type of treatment adopted therefore must be such that it will reduce the bio-chemical oxygen demand in 1935 by approximately eighty-five percent and in 1945 by approximately eighty-nine and one-half percent. Th two most practicable methods of accomplishing this reduction are by tank-sprinkling filter plants and by activated sludge treatment.

We have made a comparison of the costs of construction and the costs of operation of these two methods of sewage disposal as applied to the West Side and Southwest Side conditions for 1935 and 1945 respectively. We have also estimated the annual costs, which are made up of interest which we have taken at four percent, depreciation which we have taken at two percent on sprinkling filter plants and four percent on activated sludge, and operating costs. The higher depreciation allowance for activated sludge plants is adopted because of the process requiring more mechanical equipment of relatively short life and which due to the present experimental nature of the process suffers higher obsolescence than sprinkling filters which have been in use a generation or more.

In both the cost of construction and the cost of operating activated sludge plants we have based our estimates upon two sets of conditions:

First. Complete plants, including equipment for sludge pressing, drying and storage and including in the operating expenses a credit for the sale of sludge and

Second. Based upon no drying or storage of sludge but instead upon pumping the sludge to abandoned quarries and vacant land along the drainage canal.

Table 46 shows the comparative first and annual costs of construction under each of these three alternatives. It will be noticed that so far as first cost is concerned approximately $10,000,000 is saved in investment in the construction of an activated sludge plant with no sludge pressing or drying equipment as compared to either of the other plants. The annual cost of operation of a disposal plant of this type, however, is approximately $300,000 greater than that of the tanks and sprinkling filters in 1935 and approximately $500,000 per year greater in 1945.

The cost of activated sludge treatment, including complete sludge drying, and crediting the operating cost with a revenue from sludge sales equivalent to $10.00 per ton of sludge, is about fifteen percent to twenty percent higher than that of either the sprinkling filter or the activated sludge plan with lagooning of sludge.

The sludge produced by the activated sludge method is about ninety-eight to ninety-nine percent moisture as compared to eighty-five to ninety percent moisture for Imhoff tank sludge. In volume, therefore, it is from seven to ten times as great as tank sludge from sewage of the same solid content. The sludge disposal problem with the activated sludge process is a difficult one. Sludge drying is possible but the practicability of drying it at a cost less than the amount which can be realized from its sale as fertilizer has not as yet been fully demonstrated. It is possible to lagoon this sludge and for this purpose the Sanitary District of Chicago has available a large amount of land and abandoned quarry capacity.

In order to secure some idea as to the practicability of lagooning or disposing of large quantities of wet sludge in the abandoned quarries, we have given this phase of the matter some little attention. We have been furnished by the Sanitary District with a study which has been made by the district of the abandoned quarries along the main drainage channel. Ten abandoned quarries with a total storage capacity of nearly

TABLE 46.

COMPARATIVE COSTS, TANKS AND SPRINKLING FILTERS vs. ACTIVATED SLUDGE
for
WEST AND SOUTH-WEST SIDE PLANTS.

	A Tanks and Sprinkling Filters		B Activated Sludge Including Sludge Disposal		C Activated Sludge No Sludge Drying. Lagoon sludge in quarries and along canal.	
Construction Costs—	1935	1945	1935	1945	1935	1945
Cost of W. Side Pl't	$21,431,700	$22,837,100	$21,287,900	$22,544,600	$15,694,900	$16,675,600
Cost of S. W. Side Pl't	13,793,500	16,362,000	14,424,400	16,496,700	10,919,400	12,427,700
Total Cost	$35,225,200	$39,199,100	$35,712,300	$39,041,300	$26,614,300	$29,103,300
Annual Costs—						
Fixed Charges:						
Interest @ 4%	$ 1,419,008	$ 1,567,964	$ 1,428,492	$ 1,561,652	$ 1,064,572	$ 1,164,132
Depr'n @ 2% and 4%	704,504	783,982	1,428,492	1,561,652	1,064,572	1,164,132
Operation:						
W. Side	$ 1,637,500	$ 1,749,200	$ 1,776,000*	$ 1,941,000*	$ 1,861,300	$ 2,033,000
S. W. Side	1,043,300	1,273,200	1,248,000*	1,409,000*	1,205,700	1,480,000
Total Annual Costs	$ 4,804,312	$ 5,374,346	$ 5,880,984	$ 6,473,304	$ 5,196,144	$ 5,841,254

*Credited with the sale of sludge at $10.00 per ton.

5,000,000 cubic yards were located between Summit and Lockport. Nearly half of the total capacity is located immediately adjacent to Summit.

It is the Sanitary District's plan to utilize these quarries for disposal of the sludge from the North side activated sludge plant, which is now under construction, and from which the sludge will be conducted to the quarries through a cast iron force main.

The sludge as pumped will contain approximately two percent of sludge materials and ninety-eight percent of moisture. It will amount to approximately 1,100,000 gallons per day at the present time, increasing to approximately 1,790,000 gallons per day by 1945. After this extremely wet sludge is pumped into the quarries which have depths as great as approximately 100 feet, and as the quarries fill, the sludge will be to a certain extent dewatered due to the hydraulic pressure exerted.

If there was no dewatering effect the total capacity of all the quarries would be sufficient for the sludge from the North Side plant alone for only about two years and four months. If the sludge dewaters itself to ninety percent moisture as an average, these quarries would be sufficient for the North Side sludge for a period of twelve years. If the sludge should be dewatered due to its depth and pressure to eighty percent moisture these quarries would be sufficient for the North Side plant sludge for about twenty-four years.

In addition to the abandoned quarries, the Sanitary District owns a strip of land in many places nearly a mile in width and extending over most of the reach from Summit to Lockport, a distance of some fifteen miles. The total area between summit and Lockport is approximately 3,200 acres. Most of this land is of little value from the agricultural standpoint and is lying idle at the present time.

If the West and Southwest plants were also to be provided with activated sludge type treatment, and the sludge lagooned in the quarries and on this vacant ground, the amount of sludge to be handled would be greatly increased and its disposal would become a much more difficult problem. The quantity of wet sludge to be taken care of from the North Side, the West and Southwest Side plants combined would be over four times that to be handled from the North Side alone. All the quarries covered by the Sanitary District survey would be filled in less than seven months by the sludge pumped from these three plants if it is assumed that there would be no reduction in the moisture content below the ninety-eight percent at which it reached the quarries.

If the moisture content were reduced to ninety percent all of the quarries would last for only two years and ten months, and if the sludge moisture were reduced to eighty percent all of these quarries would last only five years and seven months.

The question of disposing of this vast amount of wet sludge is therefore a real problem. It is so great in quantity that an area of approximately nine square miles, that is one mile in width and nine miles in length extending along the drainage canal, would be covered with wet sludge to a depth of one foot each year. The land owned by the Sanitary District would have to take a dosage of nearly twenty inches per year. There would of course be some very material shrinkage in the drying out of this sludge. However, there is no data available from which it is possible to determine with any degree of certainty what the conditions of sludge drying under these conditions of lagooning would be.

It might be found that by skillful utilization of the land and quarries for lagooning, the sludge from all three plants could be disposed of without the installation of sludge pressing and drying equipment for a considerable period. The uncertainties are, however, very great.

In view of the fact that the activated sludge treatment will reduce the oxygen demand of the effluent below that of sprinkling filter plants (ninety-two percent compared to eighty-eight percent B. O. D. reduction) and thus extend the period for which expenditures now to be made at the West and Southwest plants will be adequate and in view of the further fact that the costs of constructing the two types of plants are substantially the same including complete sludge handling equipmnt in the activated sludge treatment, it is believed that the procedure for handling the sewage of the West and Southwest Side districts with a total flow restricted to 4167 C. F. S. is through activated sludge which will adequately treat the sewage with a flow in the channel of 4167 C. F. S. as late as 1952.

While it might be practicable to lagoon the sludge at least for a time it is believed that complete sludge handling equipment should be provided for in this project and this has accordingly been done.

We have estimated the cost of the disposal works required for a 4167 cubic feet per second flow as follows:

Estimated Cost of Works Required for 4167 C.F.S. Diversion.

	1935	1045
Des Plaines Activated Sludge Plant.............$	264,700	439,300
Calumet—Sprinkling Filters	1,564,420	2,021,700
North Side—Activated Sludge Plant............	5,600,800	5,947,300
*Corn Products—Sprinkling Filters.............	2,544,200	2,808,800
*Stockyards—Activated Sludge Plant............	7,804,800	8,601,600
(a) West Side—Activated Sludge..................	21,287,900	22,544,600
West Side—Intercepters	7,890,600	7,890,600
(a) S. W. Side—Activated Sludge..................	14,424,400	16,496,700

S. W. Side—Intercepters	4,495,700	4,495,700
Miscellaneous Plants	3,336,000	5,336,000
Total Estimated Costs	$69,213,520	$76,583,300

* San. Dist. has started suit to require industries to bear part of this cost.
(a) Sludge drying included.

It will be noted that a total expenditure of over $69,000,000 will be required by 1935 for intercepting sewers and sewage disposal for the complete treatment of the sewage of the West and Southwest side plants to the degree which will enable the effluent from these plants together with the effluent of the other plants within the Sanitary District of Chicago to be adequately provided with the necessary oxygen by a flow of 4167 cubic feet per second in the Drainage Canal. By 1945 an additional $7,000,000 of investment will be required to take care of the increased demand due to population and industrial growth. By 1952 with a flow of 4,167 C. F. S. additional refinement to still further reduce the B. O. D. will probably become necessary.

Both of the above figures include the entire cost of disposal works for the stockyards and Corn Products wastes. If half of the cost of these works is properly chargeable to the industries creating these wastes, approximately $5,000,000 should be deducted from the figures for both the 1935 and 1945 debts.

The cost of operating the pumping and treatment plants outlined under the 4,167 C. F. S. project is estimated as follows:

	1935	1945
Des Plaines Activated Sludge	$ 78,500	$ 102,240
Calumet—Sprinkling Filters	197,800	244,900
North Side—Activated Sludge	882,500	1,042,500
(a) Corn Products—Sprinkling Filters	77,200	86,160
(a) Stockyards—Activated Sludge	552,600	611,800
*West Side Activated Sludge	1,776,500	1,941,000
*S. W. Side Activated Sludge	1,248,000	1,409,000
Miscellaneous Plants	350,000	380,000
Totals	$ 5,163,100	$ 5,817,600
General Office Expense	360,000	440,000
Bridge and Channel Expenses	253,000	264,000
Total Fair Cost of Operating District	5,776,100	6,521,600

*Credited with the sale of sludge @ $10/ton.
(a) No credit given for industries possibly assuming part of this cost.

PART XV.

REQUIRED WORKS WITH MISCELLANEOUS FLOWS.

In addition to the channel flows of 10,000 c. f. s. and 4,167 c. f. s. discussed in detail in Parts XIII and XIV, respectively, we have made studies of the requirements and the costs of sewage disposal with flows of 2,000, 6,000, 7,500, and 8,500 c. f. s.

Required Works with 2,000 C. F. S. Flow:

With 2,000 c. f. s. flow there would be available during the months of July and August approximately 20,200 pounds of oxygen per day in 1935, and 10,000 pounds per day in 1945. As hereinbefore shown, the oxygen requirements for the effluent of the Des Plaines, Calumet, North Side, Corn Products and Stockyards plants are 33,415 pounds of oxygen in 1935 and 39,790 in 1945.

Inasmuch as the effluents from the above plants require more oxygent even at the present time than is available in the 2,000 c. f. s. total flow in the channel, it is obvious that there is no practicable means of meeting the requirements of the pollution standard hereinbefore outlined with so small a flow in the channel.

Many cities are so located that standards less adequate are necessarily adopted; however, a pollution standard which provides for a thriving fish life in Illinois River cannot practicably be complied with when the total flow in the Drainage Canal is as low as 2,000 c. f. s.

Required Works with 6,000 C. F. S. Flow:

With a total flow of 6,000 c. f. s. in the Drainage Canal, the available oxygen during July and August would be approximately 192,000 pounds per day in 1935 and 182,000 pounds in 1945. Of this amount 33,415 pounds in 1935 and 39,790 pounds in 1945 will be required for the effluents of the Des Plaines, Calumet, North Side, Corn Products and Stockyards plants, leaving 158,585 pounds in 1935 and 142,210 pounds in 1945 for the West and Southwest plant effluents. The following table shows the requirements of these two plant sewages with varying types of treatment:

Type of Treatment		B.O.D. of Effluents from Both Plants	
West Side	Southwest Side	1935	1945
Raw Sewage	Raw Sewage	532,500 lbs.	589,000 lbs.
Tanks	Tanks	346,000 lbs.	383,000 lbs.
Tanks	Sprinkling Filters	236,800 lbs.	254,900 lbs.
Sprinkling Filters	Sprinkling Filters	63,900 lbs.	70,600 lbs.
Sprinkling Filters	Tanks	173,100 lbs.	198,700 lbs.
Activated Sludge	Activated Sludge	42,600 lbs.	47,100 lbs.
Sand Filters	Sand Filters	0 lbs.	0 lbs.

From the above table it is apparent that nothing less than sprinkling filters for both plants will accomplish the results. The flow of 6,000 c. f. s. accordingly requires the construction of tanks and sprinkling filters at both the West and Southwest plants.

We have estimated the cost of the disposal works required for a 6,000 cubic feet per second flow as follows:

Estimated Cost of Works Required for 6,000 C.F.S. Flow.

	1935	1945
Des Plaines Activated Sludge Plant	$ 264,700	$ 439,300
Calumet—Sprinkling Filters	1,564,420	2,021,700
North Side—Activated Sludge Plant	5,600,800	5,947,300
*Corn Products—Sprinkling Filters	2,544,200	2,808,800
*Stockyards—Activated Sludge Plant	7,804,800	8,601,600
West Side—Sprinkling Filters	21,431,700	22,837,100
West Side—Intercepters	7,890,600	7,890,600
S. W. Side—Sprinkling Filters	13,793,500	16,362,000
S. W. Side—Intercepters	4,495,700	4,495,700
Miscellaneous Plants	3,338,000	5,336,000
Total Estimated Costs	$ 68,726,620	$ 76,740,100

*San. Dist. has started suit to require industries to bear part of this cost.

Both of the above figures include the entire cost of disposal works for the stockyards and Corn Products wastes. If half of the cost of these works is properly chargeable to the industries creating these wastes, approximately $5,000,000 should be deducted from the figures for both 1935 and 1945.

The cost of operating the pumping and treatment plants outlined under the 6,000 c. f. s. project is estimated as follows:

Plant	1935	1945
Des Plaines—Activated Sludge	$ 78,500	$ 102,240
Calumet—Sprinkling Filters	197,800	244,900
North Side—Activated Sludge	882,500	1,042,500
(a) Corn Products—Sprinkling Filters	77,200	86,160
*(a) Stockyards—Activated Sludge	552,600	611,800

West Side—Sprinkling Filters	1,637,500	1,749,200
S. W. Side—Sprinkling Filters	1,043,300	1,273,200
Miscellaneous Plants	350,000	380,000
Totals	$ 4,819,400	$ 5,490,000
General Office Expense	$ 360,000	$ 440,000
Bridge and Channel Expense	253,000	264,000
Total Fair Cost of Operating District	$ 5,432,400	$ 6,194,000

*Credited with the sale of sludge @ $10/ton.
(a) No credit given for industries possibly assuming part of this cost.

Required Works With 7,500 Cubic Feet Per Second:

With a flow in the channel of 7,500 c. f. s. there will be available 257,000 pounds of oxygen per day during the months of July and August in 1935 and 246,000 pounds in 1945. It would be possible to keep the total oxygen demand of the sewage and industrial wastes of the entire district below this amount of available oxygen by having constructed activated sludge plants at Des Plaines, the North Side and Stockyards, and sprinkling filter plants at Calumet, the Corn Products Plant and at the West Side Plant, with tanks at the Southwest Side Plant. Soon after 1945 a part of the sprinkling filters for the Southwest plant would have to be constructed, as by that time the oxygen demand of the effluents would exceed the available oxygen.

It has, therefore, been assumed that for 7,500 c. f. s. flow the West plant would be a complete sprinkling filter plant constructed at once, and that the Southwest plant would have tanks only. Under this program the oxygen provided by the 7,500 c. f. s. flow would be sufficient to care for the effluent from all plants as late as 1947.

The estimated cost of construction under this program is as follows:

	1935	1945
Des Plaines Activated Sludge	$ 264,700	$ 439,300
Calumet Sprinkling Filters	1,564,420	2,021,700
North Side Activated Sludge	5,600,800	5,947,300
Corn Products Sprinkling Filters	2,544,200	2,808,800
Stockyards Activated Sludge	7,804,800	8,601,600
West Side Sprinkling Filters	21,431,700	22,837,100
West Side Intercepter	7,890,600	7,890,600
Southwest Side Settling Tanks only	6,545,000	7,548,000
Southwest Side Intercepters	4,495,700	4,495,700
Micellaneous Plants	3,336,000	5,336,000
Total	$61,477,920	$67,926,100

The cost of operating the pumping and treatment plants outlined under the 7,500 c. f. s. project is estimated as follows:

	1935	1945
Des Plaines Activated Sludge	$ 78,500	$ 102,240
Calumet Sprinkling Filters	197,800	244,000
North Side Activated Sludge	882,500	1,042,500
(a) Corn Products Sprinkling Filters	77,200	86,160
*(a) Stockyards Activated Sludge	552,600	611,800
West Side Sprinkling Filters	1,637,500	1,749,200
Southwest Side Settling Tanks only	754,300	920,200
Miscellaneous	350,000	380,000
Total	$ 4,530,400	$ 5,137,000
General Office Expenses	360,000	440,000
Bridge and Channel Expenses	253,000	264,000
Total Fair Cost of Operating Sanitary District	$ 5,143,400	$ 5,841,000

*Credited with the sale of sludge @ $10.00 per ton.
(a) No credit given for industries assuming part of this cost.

Required Works with 8,500 Cubic Feet Per Second Flow:

With 8,500 cubic feet per second flow, the oxygen available would amount to approximately 300,000 pounds per day in 1935, and 289,000 pounds in 1945. A study of the utilization of this amount of oxygen shows that it would require no more construction up to as late as 1945, than would be required for 10,000 cubic feet per second, or, in other words, that the difference in the oxygen supply between 8,500 and 10,000 second feet flow is insufficient to permit of the adoption of a less efficient type of treatment at any one of the plants yet to be constructed.

The dilution afforded by 8,500 c. f. s. is obviously less than that afforded by 10,000 c. f. s. but the difference is not sufficient to permit the adoption of a less degree of purification at either the West or Southwest plant considered as a whole. The providing of secondary treatment for a part only of either plant is considered an unwarranted refinement in this comparison, it being considered preferable to express the advantage of 10,000 c. f. s. over 8,500 by stating that the expenditures with 10,000 c. f. s. will be adequate until 1960 while further expenditures will be required by 1945 if the flow is 8,500 c. f. s.

The works required, therefore, for 8,500 cubic feet per second diversion are considered the same as those required for the 10,000 cubic feet per second diversion, which was outlined quite fully in Part XIII. The construction costs and the annual cost of operation are the same as therein set forth.

An expenditure of $57,415,240 would be required for construction up to 1935. The annual cost of operating the District in 1935 (exclusive of fixed charges) is estimated as $4,977,400.

By 1945 the total construction expenditure will have reached $64,692,700 and the cost of operating the District increased to $5,708,800 (exclusive of fixed charges).

PART XVI.

REVIEW OF EXPENDITURES UNDER VARIOUS FLOWS

In Parts XIII, XIV and XV the utilization of the oxygen provided by flows of 2,000, 4,167, 6,000, 7,500, 8,500, and 10,000 cubic feet per second has been discussed and estimates of the cost of constructing and operating the various disposal works best adapted to the utilization of this oxygen has been outlined. The figures of construction and annual cost of operation for 1935 and 1945 which cover conditions for each of these flows, have been summarized as shown in Table 1.

A study of this table shows that so far as 1935 is concerned an expenditure of $57,415,240 will be required, even with 10,000 cubic feet per second, and that this expenditure would only be increased $11,000,000 or approximately twenty percent in order to meet the more exacting requirements of a flow as low as 4,167 cubic feet per second.

The cost of operation in 1935 (exclusive of fixed charges) of the works required with 10,000 cubic feet per second flow would be $4,364,000 per year, and $5,163,100 or about eighteen percent higher, with the flow of but 4,167 cubic feet per second.

In other words, the difference between the completeness of the treatment processes required under the 10,000 and 4,167 cubic feet per second projects under the 1935 conditions represents a difference in expenditures for plant construction of approximately $11,000,000 (20%) and a difference in operating costs of approximately $800,000 (18%) per year.

As applied to the 1945 conditions, the 10,000 cubic feet per second project will require a total expenditure of approximately $64,692,700 as compared to approximately $76,583,300 if the flow were but 4,167 cubic feet per second, the latter construction cost being nineteen percent higher than the former. The cost of operation for 1945 conditions will be approximately $5,004,800 with 10,000 cubic feet per second and approximately $5,817,600 with 4,167 cubic feet per second flow, the latter being sixteen percent higher than the former.

The construction outlined under the 10,000 cubic feet per second flow will, however, be adequate to meet the conditions to approximately 1960, while the construction outlined under the 4,167 cubic feet per second diversion will become inadequate about 1950. Additional expenditures will be required at an earlier date under the 4,167 cubic feet per second plan than under the one outlined for 10,000 c. f. s.

We have prepared a diagram showing the adequacy of the various flows with varying degrees of sewage treatment. This diagram shows the length of time for which various projects will be adequate and when additional treatment or greater quantities of dilution water are necessary.

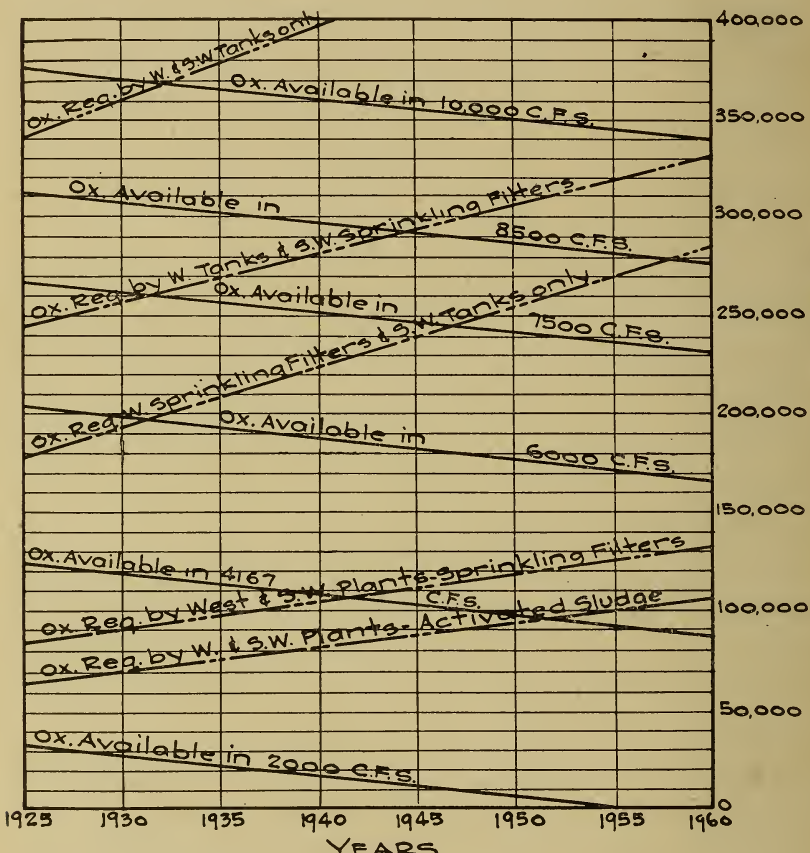


Figure 30.—Adequacy of various dilutions with various degrees of sewage disposal, based on (1) activiated sludge at Northside & Stock Yards, and (2) tanks and filters at Argo and Calumet.

		Reduction in B. O. D.
Basis:	Imhoff tanks	35%
	Imhoff tanks and sprinkling filters	88%
	Activated sludge, domestic sewage	92%
	Stock yards and corn products	95%

All of these costs include the full cost of the Stockyards and Argo plants, for the collection of a part of which the Sanitary District of

Chicago has instituted suits against the Packers and the Corn Products Company, respectively.

These estimated costs are also based upon the construction of a separate plant to handle the Stockyards wastes. It would seem that there might be very substantial savings effected by the combining of this waste with the domestic sewage of the West and Southwest Side plants. which would result in diluting this strong waste approximately fifteen parts of domestic sewage to each part of Stockyards waste, and enable it to be readily handled by the secondary treatment to be added at the South and Southwest Side sites. This possibility is so important and involves such large expenditures that we have given it somewhat detailed consideration.

Separate Activated Sludge Plant for Treatment of Stockyards Wastes vs. Sprinkling Filter Treatment of Combination of Stockyards with West and Southwest Plant Sewages:

The possibility of combining the industrial waste from the stockyards with the immense amount of sewage to be treated at the West and Southwest Side plants, which will be so located as to be substantially one plant, is suggested by the fact that the Southwest Side intercepting sewer runs practically by the site of the proposed Stockyards disposal plant. The combining of all of these sewages and thus obviating the costly construction and operation of an activated sludge plant is further suggested by the necessity of building either the West or Southwest Side plant complete at an early date, under any flows in the channel herein considered; and both plants for any flow under 7,500 c. f. s. whereas it has apparently been the thought of the Sanitary District that the construction of these plants to give any greater degree of purification than tankage was a matter of the far distant future.

The Stockyards wastes, while very strong and having a high oxygen demand, are small in volume, amounting at the present time to only 32,000,000 gallons per day, increasing to 40,000,000 gallons per day average in 1940. The necessary sewer capacity to transport this small additional flow from the Stockyards to the West and Southwest Side plants is not a material item.

We have estimated the effect of adding this amount of flow to the Southwest Side intercepter, and find that it will increase the cost of this sewer only $472,000.

Effect of Stockyards Wastes upon Sewage at West and Southwest Side Plants:

The total quantity of sewage to be handled by the West and Southwest Side plants under complete metering amounts to 468,000,000

TABLE 47.

QUANTITIES AND CHARACTER OF WEST, SOUTHWEST AND STOCKYARDS SEWAGES.

	West Side Plant			Southwest Side Plant			Stockyards Plant	5 Day B.O.D. Values	
Year	Population	Sewage Flow MGD	Gals. per cap per day.	Population	Sewage Flow MGD	Gals. per cap. per da.	Sewage Flow MGD	West and Southwest Plant Sewage	Combined West side, Southwest side, and Stockyards Sewages
1930	1,730,000	316	182	1,040,000	229	220	35.0	120	144
1935	1,790,000	286	160	1,135,000	182	160	36.5	136	174
1940	1,850,000	296	160	1,230,000	197	160	38.2	136	174
1945	1,915,000	306	160	1,322,000	222	160	40.0	136	170

Note—5 day B. O. D.
Human population, 0.18 pounds oxygen per capita per day.
Stock Yard sewage, 5650 lbs. oxygen per million gallons.

gallons per day in 1935 and 528,000,000 gallons per day in 1945, as compared to the volume of the Stockyards wastes of 32,000,000 and 40,000,000 gallons per day respectively, at these two periods. The Stockyards waste, however, has a very high oxygen demand, and we have made some study of the practicability of handling the combined domestic sewage and stockyards wastes of these amounts with sprinkling filter treatment.

Table 47 shows the facts relative to the sewage flow and the strength of the sewage to be handled by the West and Southwest Side plants with and without the addition of the Stockyards wastes. It will be noted that even with the Stockyards waste added to the domestic sewages of the West and Southwest Side district, the combined oxygen demand in 1946 will be but 170, as compared to an average for Columbus of 190 parts per million.

We have further made investigations as to the relative amount of packinghouse wastes in Chicago, as compared to other cities, the results of which are summarized in Table 48.

It will be noticed that the total pounds of live stock slaughtered in Chicago per person tributary to the West and Southwest Side plants is somewhat less than that in Indianapolis, and only slightly above that at

TABLE 48.

IMPORTANCE OF PACKING HOUSE WASTES IN VARIOUS CITIES.

City.	Year.	Total Pounds of Animals Slaughtered	Pounds Slaughtered Per Capita.
(a) Chicago	1922	3,896,017,318	1442 d
	1923	4,326,242,144	1601 d
	1924	4,186,373,884	1549 d
(b) Milwaukee	1922	440,000,000*	963
	1923	497,000,000*	1069
	1924	461,200,000	1008
(c) Baltimore	1922	353,000,000	482
	1923	395,000,000	538
	1924	397,000,000	542
(c) Madison, Wis.	1924	71,000,000	1385
(c) Indianapolis	1922	517,000,000	1645
	1923	555,000,000	1768
	1924	526,000,000	1673
(c) Peoria	1922	38,000,000	493
	1923	38,800,000	510
	1924	43,100,000	566

(a) Head and weights of each class available.
(b) Head and part of weights available.
(c) Head available, weights estimated from data available for all markets or adjacent markets.
(d) Based on population tributary to West and S. W. side plants, including 300,000 transient population.
*Estimated on basis of 1924.

Madison, Wis. At the latter place it is being handled mixed with domestic sewage at a plant which has a loading of 3,400 people per acre foot of stone beds and the stone beds are being dosed at a rate of approximately two and one-half million gallons per acre per day, and producing an excellent effluent.

At Indianapolis where the pounds kill per capita is greater than at Chicago, the packing wastes are to be mixed with the domestic sewage and the mixture treated at the sewage disposal plant by the activated sludge method and the use of but one cubic foot of air per gallon of sewage.

At Milwaukee a packing house waste two-thirds as great proportionately as that at Chicago is to be treated with other trade wastes mixed with the domestic sewage, all at one disposal plant.

The Baltimore sprinkling filter plant handling a concentrated domestic sewage with a packing house waste one-third as great proportionately as that at Chicago has been operating satisfactorily for years at a dosage rate of 3,500 people per acre.

It is believed that it should be possible to dose the filters of the South and Southwest Side plants with domestic sewage computed at a rate of 160 gallons per capita per day to which has been added about eight percent by volume of packing house wastes, and maintain a rate

TABLE 49.

SAVINGS EFFECTED BY COMBINING STOCKYARDS WITH WEST AND SOUTHWEST PLANTS (1935 CONDITIONS).

	Stockyards Alone Activated Sludge	Additional Cost at West & S. W. Plants due to Stockyards Tanks & Filters
First Cost:		
(1) Intercepters		$ 472,000
(2) Disposal Plant	$ 7,804,000	4,028,000
Total	$ 7,804,000	$ 5,500,000
Annual Cost:		
Interest @ 4%	$ 312,192	$ 220,000
Depreciation	@ 4% 312,192	@ 2% 110,000
Operation	552,600*	206,000
Total Annual Costs	$ 1,176,984	$ 436,000
Savings:		
(1) In first cost		$ 2,304,000
(3) In Annual Cost		740,984
(3) In Operation		346,600
(4) In operation capitalized @ 4% plus saving in First Cost		10,969,800

*Includes credit for sale of 36,000 tons of sludge at $10.00 per ton.

of 3,000,000 gallons per acre per day by increasing the depth of the stone filters to eight feet.

With this as a basis we have made a study of the savings which might be effected by combining the Stockyards wastes with the West and Southwest Side plants, the results of which are shown in Table 49.

It will be noted that the saving in first cost is $2,304,000, based on 1935 conditions. It will somewhat exceed this amount based upon 1945 conditions. This is also based upon the use of eight foot instead of six and one-half foot stone beds. If it were found practicable to use the six and one-half foot depth, as is quite possible, the saving would be further increased by $1,200,000.

Due to the elimination of the costly operation of the activated sludge plant at the Stockyards (which is estimated to be $91,600 per year in 1935, exclusive of the credit from the sale of sludge) and the substitution therefore of the less costly treatment by stone filters, there will be a saving in operating cost of $346,600 per year. This saving, capitalized at four percent and added to the saving in first cost, shows a total saving of $10,969,800 with eight foot filters and $12,169,800 with six and one-half foot filters, which might be effected by combining the Stockyards sewage with that of the West and Southwest plants, and treating it by tanks followed by sprinkling filters rather than by the activated sludge method.

It must be pointed out that if this procedure were to be adopted all of the grease and coarse solids possible should be recovered before turning the wastes into the intercepting sewer. It might be accomplished by screening or short tankage with Dorr Clarifiers which for this investigation it has been assumed would be built and operated by the industries.

This procedure offers possibility of savings which are so large and so important to the Sanitary District, as well as to the Stockyards interests, that they are certainly worthy of more investigation than we have been able to give to the subject.

Even if the Stockyards were to pay half the cost of the treatment plant, their share of that cost being understood to be approximately $4,000,000, that contribution would little more than offset the saving in construction cost that could be effected, if the procedure outlined herein is practicable. In addition, the saving in operating expense would be $346,600 per year which is four percent interest on over $8,500,000 so that considered broadly, and on the investment basis, the Sanitary District would be giving up $11,000,000 to $12,000,000 as compared to receiving fifty percent share of a separate plant built to handle the packinghouse wastes.

This procedure is suggestive of the possibility of important savings, and by a method which, in our opinion, offers considerable assurance of being practicable, particularly as this investigation shows the necessity for building the West and Southwest side plants at an early date.

Period Required for Construction:

Our instructions include the determination of the time that reasonably would be required to build the necessary works and place them in operation. We are instructed to disregard the ability to raise funds, namely, to assume that funds would be available as needed. We interpret this instruction to require the development of a program which shall be as rapid as possible and yet not so rapid as to be wasteful. The effect of varying the amount of diluting water upon the magnitude of the construction undertaking is not sufficient in amount to have any material effect upon the length of the construction period required. We have therefore limited this consideration of time required for construction to one flow, viz. 6,000 c. f. s.

The following is a summarization of the expenditures required for the 6,000 cubic feet per second flow.

Construction Item.	Estimated Cost to 1935.
Des Plaines Plant	$ 264,700
Calumet Plant	1,564,420
North Side Plant	5,600,800
Argo Plant	2,544,200
Stockyards Plant	7,804,800
West Side Plant	21,431,700
Southwest Side Plant	13,793,500
Miscellaneous Plant	3,338,620
West Side Intercepter	7,890,600
Southwest Side Intercepter	4,495,700
	$68,729,040

The total expenditure of nearly $69,000,000 required for 1935 is, as above shown, to be divided $12,386,300 for intercepting sewers and $56,342,740 for seven major and several smaller disposal plants.

The intercepting sewers cover a length of approximately thirty-five miles. In constructing the North Side intercepting sewers the Nash contract covering four miles, and an aggregate expenditure of $1,998,000 was executed in one year. Five contracts aggregating ten miles and an expenditure of $5,488,000 were completed in two years.

We have assembled the data relative to construction progress on Sanitary District contracts and also on other public or semi-public construction of large magnitude, as shown in summarized form on Table 50.

It will be noticed from this table that construction progress of a type comparable to sewage disposal plants has been rapid in many cases. The construction of the Chicago Produce Market at a cost of $17-000,000 in approximately six months' time, is a most striking illustration of what can be accomplished in the way of rapid construction of a type consisting largely of duplicate units, such as is also the case with sewage disposal plants.

Based upon the progress on prior Sanitary District contracts and elsewhere there should be no difficulty in building the twenty miles of West Side intercepters and the fifteen miles of Southwest Side intercepters so as to be finished by the end of 1930. This would require less than double the progress secured on the North Side intercepters.

The expenditures for the Des Plaines, Calumet and North side plant enlargements can all be finished in the next two or three years. So far as disposal plants are concerned, the real question as to time therefore hinges upon the Argo, Stockyards, West and Southwest side plants.

The Sanitary District in arranging its program of design and construction has estimated that the West side plant, including tanks and sludge handling facilities, can be completed by December, 1929. We see no reason why, if plants are started promptly, the construction of the stone sprinkling filters for the secondary treatment cannot be completed within a year thereafter, viz. December, 1930, and possibly simultaneously with the tanks.

The Southwest side involves construction similar to that at the West side, but only approximately two-thirds as great in amount. It should, therefore, be practicable to design and build the southwest side plant so that it will be finished without difficulty by the end of 1930.

The Argo and Corn Products plants are comparatively small, although they involve a more thorough study of experimental work and a more complicated design than is required for the West and Southwest side plants. It is believed, however, that they can be designed and built so as to be ready for operation by 1930.

Summarization of the Construction Period Reasonably Required:

It would be our opinion that five years' time, under average construction conditions, would be a reasonable minimum estimate of the time required to design and build the intercepters and sewage treatment plants at the costs herein outlined. Even with the most unfavorable

TABLE 50.

CONSTRUCTION PROGRAM ON LARGE PUBLIC WORKS.

Description	Approximate Cost	Start of Work or Date of Contract	Date of Completion	Period or Construction	Approximate Length	Ave. Exp. per Year in Period
Sanitary District Work:						
Main channel*	$29,700,000	1892	1900	7 yrs.		4,200,000
Calumet-Sag Channel	14,000,000	1911	1922	11 yrs.		1,300,000
North Shore Channel	4,100,000	1907	1910	3 yrs.		1,400,000
Calumet Treatment Works	6,125,000	1902	1922	2 yrs.		3,000,000
North Side Treatment Works	5,900,000	1923	1926**	3½ yrs.		1,700,000
Calumet Pumping Station	1,500,000	1918	1921	3 yrs.		500,000
Calumet Power Plant	1,165,000	1919	1922	3 yrs.		600,000
Evanston Pumping Station	512,000	1918	1921	3 yrs.		170,000
North Shore Sewer (1)	690,000	1913	1916	3 yrs.	7 mi.	230,000
Evanston Sewer	1,252,000	1916	1919	3 yrs.		400,000
North Side Intercepting Sewers						
Section 1	1,998,000	1921	1922	1 yr.	4 mi.	1,998,000
Section 3	2,625,000	1924	1926**	2 yrs.	1.8 mi.	1,300,000
Section 4	2,111,000	1924	1926**	2 yrs.	1.6 mi.	1,000,000
Section 5	1,498,000	1924	1926**	2 yrs.	1.5 mi.	750,000
Section 6	874,000	1924	1926**	2 yrs.	1.1 mi.	440,000
Chicago Produce Market	17,000,000	1925	1925	6 mo.		34,000,000
Union Station (Chicago) (2)	60,000,000	1916	1925	9 yrs.		6,660,000
Greater N. Y. Water Supply	176,000,000	1907	1917	10 yrs.		17,600,000
Milwaukee Sewage Disposal Plant	8,167,000	1918	1925	7 yrs.		1,160,000
Milwaukee Intercepting Sewer	5,622,000	1915	1923	8 yrs.	33 mi.	700,000
Tulsa Water Supply	6,800,000	1922	1924	2 yrs.		3,400,000
Detroit Filtration Plant (3)	5,480,000	1920	1923	3 yrs.		1,800,000

*Includes cost of Main Channel and Des Plaines River Improvement but not main channel extension.

**Date of completion in contract

(1) Sewers Built in Tunnel.

(2) Cost of Station cnly. Does not include cost of terminal arrangements Total $95,000,000.

(3) Does not include cost of Pump Stations.

construction conditions, the contingency of labor troubles, and similar delays, we can see no reason why the period should exceed eight to ten years.

All of the above is predicated upon the ability of the Sanitary District to finance the program within the construction period.

Acknowledgment:

In the preparation of this report the Sanitary District of Chicago has furnished to us numerous data and studies bearing upon the problems here considered. There has also been placed at our disposal the valuable studies of the U. S. Public Health Service relating to the Des Plaines and Illinois Rivers, which we have freely used. The Illinois State Water Survey has furnished many valuable data relating to the past conditions in the downstream rivers, and we are particularly indebted to the Illinois State Natural History Survey for information on the same streams, particularly relating to the welfare of fish life.

In connection with our work we have been assisted by Mr. Clarence B. Hoover, Superintendent, Division of Water and Sewage Disposal, Columbus, Ohio, a practical sewage plant operator for the past sixteen years. We have also been assisted by Mr. T. McLean Jasper, Research Laboratory, University of Illinois.

Respectfully submitted,

ALVORD, BURDICK & HOWSON,

(Signed) CHAS. B. BURDICK,
(Signed) L. R. HOWSON,

Chicago, Illinois,
April 16, 1925.

PUBLICATIONS OF THE STATE WATER SURVEY.

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