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CONTENTS AND INDEX

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THE ST. LOUIS WATER WORKS.

I. Historical.

BY M. L. HOLMAN, MEMBER OF THE ENGINEERS' CLUB OF ST. LOUIS.

[Read March 7, 1894.*]

IN opening the series of addresses on the St. Louis Water Works, I will give, as my contribution, what history I have been able to collect from public documents and other sources.

In the year 1829 the city of St. Louis contracted with Messrs. John C. Wilson and Abraham Fox for the building and operating of a water works to supply "clarified" water for a term of twenty-five years; the works to belong to the city at the expiration of the contract.

This contract gave the contractors the exclusive right to supply water for public and private purposes, the charges being limited to $20 per year for families and $100 per year for hotels and manufactories. The city further conceded a bonus of $3,000 cash on the completion of the works; a lot of ground 40 feet by 125 feet on the river bank and a half acre of ground for a reservoir site.

In 1830 the city purchased of William H. Ashley a lot of ground 170 feet by 160 feet on the "little mound" located at the corner of Ashley and Collins Streets for a reservoir site, and a lot 250 feet by 250 feet from the U. S. Government for a pumping site.

* Manuscript for this series of papers received from November 24, 1894, to January 19, 1895.—*Secretary Assn. Eng. Socs.*

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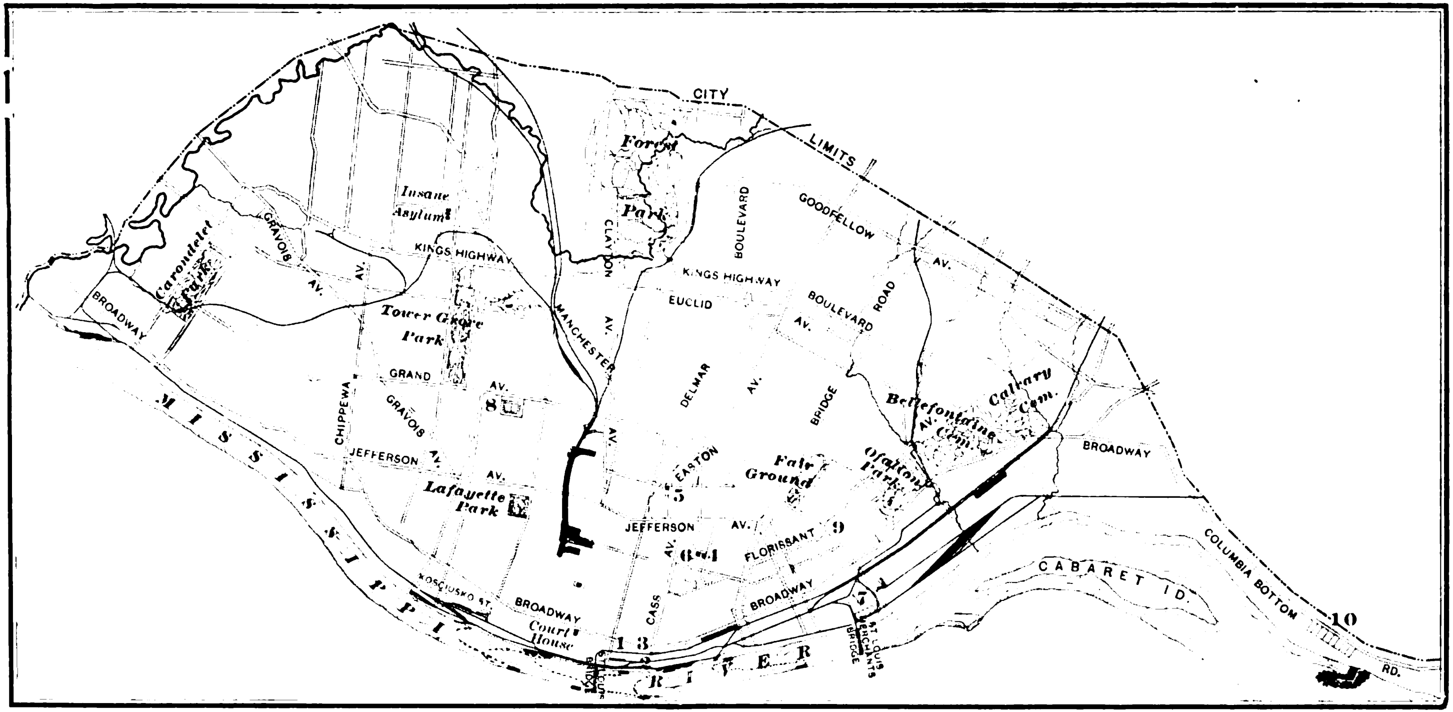

CITY OF ST. LOUIS.—SKELETON MAP.

1. Little Mound, Ashley and Collins Sts.
2. Site for Pumping Station, foot of Smith St.
3. Reservoir, Bates and Collins Sts.
4. Benton St. Reservoir.
5. Park.—Former site of Temporary Reservoir, Gamble St. near Garrison St.
6. Reservoir built 1854–5.
7. Bissell's Point Works.
8. Compton Hill Reservoir.
9. Standpipe of Bissell's Point System.
10. New Water Works at Chain of Rocks.

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The contractors were to supply, free of charge, water to twelve fire hydrants, the hospital of the Sisters of Charity and a fountain on the grounds of William Ashley. The water was to be distributed through cast-iron pipes laid not less than 3½ feet under ground. Water was to be delivered to the reservoir in one year and to the hydrants in eighteen months.

But little progress was made under this contract, notwithstanding the fact that the then mayor, Daniel D. Page, gave his private note to secure payment for water pipe ordered of Vanleer & Company. The contractors were forced by want of capital to suspend work, and the city was forced into a new contract, dated April 2, 1831, with Mr. Fox, in which he was released from all the conditions of the first contract except the fountain for Mr. Ashley; this fountain being a part of the consideration in the purchase of the reservoir site. In this contract the city agreed to assume three-fourths of all expenses and take charge of and complete the works.

The city borrowed $25,000 in 1831 in order to proceed with the works. The supply of water was in all probability begun in the fall of 1831. Old reports refer to this date, but positive statements of water supply do not appear until the summer of 1832.

The early management was under the care of a committee of the City Council, and it appears that the work was carefully conducted. Until 1847 the plumbing and all work connected with the supply of private houses was conducted solely by the city, which manufactured for that purpose its own lead pipe and fixtures.

In July, 1835, the city purchased the interest of Mr. Fox in the works, paying $18,000 therefor.

The total cost of the works to this time was about $54,000, not including interest-bearing notes given in pay for pipe. The city then became sole owner of its water works.

The first pumping engine was built for the works by Francis Pratt, of Pittsburg. The steam cylinder was 10 inches diameter by 4 feet stroke. The pump was double-acting, and the piston was 6 inches in diameter and of 4 feet stroke. This engine proved to be a failure and was replaced by two rotary pumps which the city had purchased for fire engines. These rotaries were set up in a small building at the foot of Smith Street. The water was delivered into a reservoir at the corner of Bates and Collins Streets. This was the first reservoir used by this city. The reservoir was 62 feet by 55 feet, with a depth of 15 feet. The flow line was 90 feet above the city directrix. The walls were of masonry, lined with brick, and the bottom was paved with brick on a tight plank floor.

These facilities supplied sufficient water for ordinary uses, but failed

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to give an adequate fire supply on account of the smallness of the distribution pipes. Although a settling basin was constructed near the engine house it does not appear to have been used, all evidence going to show that water was pumped direct to the city reservoir without settling.

In 1836 a new pump main 10 inches in diameter was laid, and in 1839 a new engine was started. It was direct-acting. The steam cylinder was 13 inches and the water cylinder 13 inches in diameter, and both were of 6 feet stroke.

In 1838 a new pump main 12 inches in diameter was laid and a new reservoir was decided upon, but the project was abandoned.

In 1845 a new reservoir was erected on the site of the old one. It was a wooden tank 100 feet square by 12 feet deep. The walls of the old reservoir were used as a support for the middle part of the bottom, and a dry stone wall was laid up to carry the edges of the tank. The tank rested on these walls and on intermediate posts. It was built of oak, framed and spiked, and the seams were caulked with oakum.

The use of both reservoirs continued, the upper one being used for supplying the higher districts. It seems that the city was at that time divided into two districts.

After a few years' use of the double system, the old, or lower level, reservoir was abandoned and the distribution was thrown onto the upper reservoir. By the year 1849 frequent repairs to the wooden tank became necessary, and in 1852 it was abandoned.

In 1846 the superintendent of the works first suggested that the supply of water for the city be drawn from the Meramec River. The discussion on this question continued until 1854, when the then superintendent reported against the scheme.

In 1846 the third pumping engine was erected. The machine was of the crank and fly-wheel type. The steam cylinder was 20 inches diameter by 7½ feet stroke. The pump was double-acting, 15 inches diameter and of the same stroke as the steam engine. The engine gave trouble on account of bad foundations, and in 1847 it "laid down" and was rebuilt. In 1852 the fourth engine, costing $25,000, was erected; steam cylinder, 26 inches diameter by 10 feet stroke; pump, double-acting, piston, 22 inches diameter by 10 feet stroke. It was originally started as a condensing engine, but the condenser was abandoned in 1852.

In 1847 the third reservoir was begun. This was the old Benton Street Reservoir. It was 250 feet square, with a working depth of 15 feet. Elevation of flow line, 115½ feet above datum, cost $74,000 (approximate). The pump main to this reservoir was a 20-inch cast-iron pipe and was laid up Mullanphy Street. The reservoir was finished in 1849. It was provided with a sloping bottom and a system of flushing

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sewers for the purpose of removing sediment, but the scheme was a failure.

In 1854 the fourth reservoir was begun, the claim being that the flow through a large reservoir would be at a low velocity, and that the sedimentation would be correspondingly good. This reservoir had a bottom laid out in the shape of a nest of very flat inverted pyramids, the bottoms being provided with valves, and a system of flushing sewers. The reservoir was 527 feet by 237 feet, with a depth of 47½ feet. The cost was about $200,000 and water was first pumped into it in 1855. This reservoir gave the city a great deal of trouble; the cleaning scheme proved a failure, and the walls required constant repair and careful watching. The water line was carried 138 feet above datum. This reservoir, after many vicissitudes, was finally abandoned and removed, and the site divided up, part being retained for public purposes and the remainder sold.

During the building of the new works, or from 1867 to 1872, a temporary reservoir on Gamble Street near Garrison Avenue was built and was used in conjunction with the old reservoir. In 1867 the sediment in the old reservoir was twenty feet deep.

The fifth pumping engine, with steam cylinder 30 inches diameter, stroke 10 feet, pump double-acting, piston 22 inches diameter, stroke 10 feet, was put in to keep up with the demand for water. In 1858 a new pump main 30 inches diameter was laid up Cass Avenue, and the 20 inch main was turned in on the distribution system. The old pumping engines, Nos. 2 and 3, were sold for scrap in 1857, and the Benton Street reservoir was abandoned in 1855.

At the old pumping station an engine with steam cylinder 34½ inches diameter by 10 feet stroke, and double-acting pump 28½ inches by 10 feet stroke, was put in to keep up the supply during the building of the new works (1865–72). This old station, with its pumps and piping, was operated until 1871, at which time the Bissell's Point Works started. A breakdown at this High Service Station necessitated starting the Bates Street engines again, but on June 19, 1871, they were shut down for the last time.

This station was wrecked and the machinery sold at auction, and after its removal the location was used for a pipe yard. The property was subsequently turned over to the Harbor Department for wharf purposes.

This is briefly the history of the St. Louis water works from the time of their inception up to 1867, for the old works; and up to 1871 for such temporary work in connection with the old works as was necessary during the building of the new works.

The new water works date from 1863, when the General Assembly

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of this State passed an act entitled "An Act to enable the City of St. Louis to extend the Water Works thereof and for other purposes." This act authorized the city to construct works to take water from any point on the Mississippi River and conduct it to the city. It also created a board of four commissioners, to be elected by the Common Council of the city, to carry out the provisions of the act. It further provided for an issue of bonds for the purpose of constructing the new works, limiting the amount to $3,000,000.

The City Council, at its May session, 1864, passed Ordinance No. 5339, establishing and regulating the Board of Water Commissioners, in conformity with the general act of 1863. But, owing to general dissatisfaction, no action was taken under this ordinance, and, in January 1865, the General Assembly amended the Act of 1863, placing the appointment of the commissioners with the Governor of the State, who appointed Messrs. Dwight Durkee, Dr. Philip Weigel, N. C. Chapman and Stephen D. Barlow.

This board organized on March 18, 1865, and, on the 27th, submitted to the City Council the appointment of Jas. P. Kirkwood as Chief Engineer, which was approved.

On May 11, 1865, the Board directed the Chief Engineer to proceed with the surveys and plans for a system of water works. The plans and estimates were submitted on August 29, 1865, adopted by the Board October 6th and forwarded to the City Council for its action on October 12, 1865.

This scheme contemplated the location of the Low-Service works at the Chain of Rocks; the work to consist of a pumping station, settling basins and filter beds; the filtered water to be conducted by gravity flow in a conduit to Baden, and there pumped by the High-Service Plant to a reservoir to be built at Rinkels with a high water line 204 feet above datum; an auxiliary reservoir to be built on Compton Hill to furnish full supply for the southern part of the city. The works were designed for an ultimate capacity of 40,000,000 U. S. gallons per day. This scheme was rejected by the City Council in March, 1866. The Council recommended, after report by sub-committee, that the filter beds be abandoned and the works located at Bissell's Point.

During the consideration of this report by the Council, Mr. Kirkwood was sent to Europe to examine and report upon methods there in use for filtering water.

In April, 1866, the first Board of Commissioners resigned, and a second board was appointed. This board organized in August, 1866, with Geo. K. Budd as president and C. S. Solomon as secretary. In November of the same year it submitted to the Council plans for extending the old works, prepared by Freeman J. Homer, City Engineer.

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In December, 1866, another plan was submitted, prepared by Mr. Kirkwood in accordance with the following:

Resolved.—That the Engineer be directed to prepare a general plan of works, founded on the following basis, to wit:

That the water be taken from the Mississippi River, in the neighborhood of Bissell's Point.

That settling basins be established there without the accompaniment of filtering works.

That a small storage reservoir be constructed on the City Commons.

And that the whole be arranged, so far as practicable, so as to admit hereafter of the convenient addition of whatever further works may then become expedient or necessary, and that the engineer be instructed to report the estimated cost of the works in question.

The plan reported by Mr. Kirkwood, in answer to the above resolution, is substantially the one upon which the new works were constructed.

In February, 1867, an ordinance looking to the enlargement of the old works and authorizing the issue of $275,000 in bonds, was passed. In March, 1867, the Board of Water Commissioners made a demand on the Comptroller for the bonds, appointed Mr. Homer superintendent, and instructed him to proceed to carry out the plan proposed by him in November, 1866. This scheme fell through and no work was done. The report and plans were printed in the second report of the Board of Water Commissioners.

On March 13, 1867, the General Assembly passed an Act authorizing the issue of bonds to the amount of $3,000,000 and appointing a new commission.

This commission, after it got into working shape, consisted of Geo. K. Budd, Alexander Crozier and Henry Flad, and under this board the works were built.

The Commission organized March 22, 1867, and on the 23d the former board turned over to them the old records belonging to the department.

On the 26th Mr. Kirkwood was requested to resume the duties of Chief Engineer from which he had been relieved by the former board on March 18th.

Mr. Kirkwood declined further service as Chief Engineer, and recommended Mr. Thos. J. Whitman for that position. Mr. Whitman reported for duty May 7, 1867.

Mr. Whitman was in favor of the Chain of Rocks location for the low-service works, adding his opinion to that of Mr. Kirkwood and all other engineers who had examined the situation carefully. He found, however, that the exigencies of the supply and the limitations of the law left but one thing to do, viz., to go ahead with the

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work on the Bissell's Point plans. The works thus built, with which most of you are familiar, consist of an inlet tower, or intake, on the river bank at Bissell's Point; a low-service pumping plant; settling basins; a high-service plant; a stand pipe; large extensions to the old pipe system; and a storage reservoir on Compton Hill. These works, extended up to 1872 by the addition of two pumping engines, had a working capacity of about 32,000,000 U. S. gallons per twenty-four hours.

It must be borne in mind that all water furnished to the city is pumped twice; first, from the river into settling basins by the low-service plant; and second, from the basins into the distribution system and reservoir by the high-service plant.

In 1876, the city of St. Louis adopted a charter and changed its system of local government; the water works, with the exception of the collection of the revenue, being placed in the hands of a Water Commissioner, who acts as Chief Engineer and executive head of the department.

Additions to the high-service pumping plant were begun in 1881, and continued up to 1894. A new pumping station, complete, with pump mains and stand pipe being completed, making the total high-service capacity from 60–65,000,000 U. S. gallons per day (twenty-four hours).

To keep up the supply of water to the high-service plant, a temporary low-service plant was put in, having a capacity of 30,000,000 gallons per day. This plant, built on an inclined way, moves on wheels up and down the incline according to the stage of water in the river. The general scheme of this plant has been followed by the city of Cincinnati to afford temporary pumping facilities.

After several ineffectual attempts to secure the necessary legislation authorizing the extension of the low-service works, the City Council passed Ordinance No. 14212, approved September 7, 1887, establishing a low-service station at the Chain of Rocks. This station consists of an intake tower, an intake tunnel, a pumping plant and a system of settling basins.

The works are designed for a capacity of 100,000,000 U. S. gallons of settled water per day. Work on this plant is now nearing completion.

On December 26, 1893, Ordinance No. 17339 was approved, authorizing the further extension of the high-service plant.

The work on this plant has been started, but little, beyond the sub-foundation work, has been done. This plant is designed to furnish water to the districts of the city and county that lie at an elevation beyond the reach of the Bissell's Point works.

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In closing, I will remark that it now seems that the city has got fairly to work along lines which, if followed, will insure to it an adequate supply of water, fulfilling all modern requirements.

II. Points of Interest in the Design and Construction.

By S. Bent Russell, Member of the Engineers' Club of St. Louis.

[Read March 21, 1894.]

In this paper I shall merely outline a few of the problems that were met in the engineering work, with the hope that they may prove of interest in connection with the other papers on the new water works.

Our first work was done on

THE NEW CONDUIT.

The two ends of our line were fixed at the old and new intakes. See Fig. 1.

Between these two points it was necessary to follow around a concave bend in the river so that the shorter line would, of course, be the closer to the bank. To secure the work in high water it was necessary to run the line along the edge of a terrace or berm known as the second bottom. As this conduit draws its water from the bottom of the new settling basins at the Chain of Rocks, and delivers it into the top of the old settling basins at Bissell's Point, there was not much choice in the matter of slope and elevation of the conduit.

The maximum flow line of the conduit is about four feet above the highest flood of the last twenty years and has a slope of 1 in 10,000, or about one-half foot per mile, which is somewhere near the slope of the Mississippi.

Near the old pumping works the line crosses low ground for nearly a mile, the masonry resting on a fill about five feet deep. There was some talk of using iron pipes over this stretch, but this idea was abandoned. A primary bank, raised to the elevation of the spring line of the conduit arch, was built and allowed to settle many months before placing the masonry and cover bank.

This primary bank rests on bottom land which is underlaid by quicksand some ten feet thick on top of the country rock. As soon as the cover bank was built its weight seemed to carry down the primary bank and masonry together. This settlement of the masonry amounted to from one to six inches, and was, I think, due to the displacement of the underlying quicksand; but that is a matter for discussion.

As the line crosses three important creeks, bridges were needed.

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These were carried down to a rock foundation so that the conduit at these points is not allowed to settle.

THE CROSS-SECTION

of the conduit masonry is perhaps of special interest. In order that an empty tunnel in soft earth may have the greatest strength against distortion, its cross-section should be an ellipse with the major axis vertical. There are several practical objections, however, to making the height so great. We therefore cut the ellipse through the minor axis, remove the lower half and substitute an *inverted beam*. This bears the stresses in the arch the same as if the ellipse were complete. See Figs. 2 and 3.

If instead of the beam we had substituted a flat inverted arch resting on soft earth, the section would probably be somewhat distorted before the thrust of the inverted arch was balanced by the *passive* pressure of the earth behind the side walls.

As shown in Fig. 3, the section is only an approximation to a semi-ellipse, being made with vertical side walls and a full center arch. The bottom is designed to act as a beam, but is hollowed out in segmental form, as this gives an increased water way at slight expense. The outside of the side wall was carried up vertically so that the concrete might rest against the undisturbed earth in the walls of the trench.

About seven-eighths of the line was in cut. The conduit was everywhere covered with three feet of earth. All railroad crossings are bridged over so as not to rest on the masonry or cover bank.

Overflow weirs are provided at distances of about two miles. Manholes are about one-fourth of a mile apart. Large chambers are arranged at each end and at each change of water section, so that cleaning machines can be put in, floated down and removed without difficulty. To permit this, there are, of course, no obstructions allowed in the waterway, which remains of the same form from end to end of the 11-foot conduit, and from end to end of the 9-foot conduit.

Before proceeding further with the plant itself, let us take up the subject of

ORGANIZATION

and methods of the engineer corps. The civil engineering force included four divisions: the conduit division, the river-work division, the basin division and the drafting division. Excepting the last-named, each division was composed of a division engineer, a field party and inspectors of contract work. There were three offices—one at Bissell's Point, one at the Chain of Rocks, and one, half way between these, at Baden. Each party was provided with teams for transportation.

To prepare for construction, preliminary surveys were made for

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each piece of work. Frequent soundings and borings were made, to determine the elevation of the rock. Our experience taught that the evidence obtained from borings must be used with discretion. What is reported to be bed-rock often proves at a later date to be but a lonesome boulder. In important cases, therefore, trial shafts were sunk before the contracts were let.

To comply with the law, all important construction was done by contract let to the

LOWEST BIDDER.

Hence to obtain good work it was necessary to have the plans and specifications very full and complete. Our contracts might be divided into two general classes—*A*, where a lump bid is made for the whole work; *B*, where a bidder names a price per unit of measurement for each class of work and the value of the bid is determined by the engineer's estimate of quantities. Form *A* was generally used for machinery, buildings, etc., and Form *B* for earth and rock work, masonry, pipe lines, railroad tracks, etc.

When form *A* was used the greatest care was necessary in the preparation of plans and details, as alterations of plans generally caused extra expense to the city. Any losses caused by errors in these plans were borne by the city.

SPECIFICATIONS

were first drafted by the engineer of the division, checked over in the drafting department and revised by the principal assistant engineer. They were then submitted to the Water Commissioner, and by him laid before the Board of Public Improvements.

PLANS

were made by the draftsmen, checked over by the first draftsman and then by the engineer of the division including the work. They had then to be approved in order by the principal Assistant Engineer, the Water Commissioner and the Board.

All drawings are numbered and indexed in a card catalogue of the kind used for libraries. We have, I think, about 1,400 drawings catalogued. Field notes too are numbered and indexed in the same catalogue with the drawings.

In preparing our contracts, we endeavored to divide between the two parties to the contract the risks of unforeseen difficulties. We thus on the one hand avoided excessive prices due to contractor's risk, and on the other hand made it the contractor's interest to keep down the cost of the work.

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After the contract was let, the only

SECURITY

the city had, was in the bond of the contractor. By retaining a percentage on monthly payments the security was gradually increased until the work was completed.

Under the law, the Board of Public Improvements can take no account of an individual contractor's actions in the past, and this condition has added considerably to the difficulty of obtaining good work. In the

EXECUTION OF CONTRACTS

rigid inspection was the rule. Inspectors were frequently located at shops, mills, quarries, etc. In the field, wherever a foreman was needed, there would be an inspector. All water-tight work and underground work was given special attention. From our system of letting contracts there was necessarily no consideration shown a contractor on account of low prices.

Effort was made to keep accurate accounts of all force and material used by the contractor.

Materials were tested when practicable. As the item of cost of cement was in the hundred thousands, especial attention was given to the tests of this material.

When a piece of work was completed

FINAL DRAWINGS

were made, showing it as actually built in detail, while records are kept showing all tests of material used, etc.

We will now return to the plant itself, taking up the

INTAKE AND PUMPING STATION.

The first work done was in making soundings of the river and borings in the shore, preliminary to designing the plant. Submarine borings in the rock were desirable, but were omitted as being too expensive. Before finally deciding on a tunnel, a prospect shaft, 90 feet deep, was sunk on the proposed line. This was accomplished with considerable difficulty, owing to the water encountered.

The problem of designing the intake was an interesting one. The low water channel was found about 1,500 feet from the shore. Between it and the river bank is bare rock bottom, showing projecting reefs at low water. The difficulties in the way of laying a pipe out to the channel were great. It was thought wiser to tunnel under the river.

The intake tower offered some interesting problems. Such a tower, with its gates, screens, etc., is by no means as easy to build in twenty

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feet of water as a bridge pier would be. A masonry tower was decided on, and a suitable site on the rough rock bottom was selected by careful soundings. The tunnel was kept as near to the bottom of the river as was thought safe, so that in case of necessity compressed air could be used to check the inflow of water.

The question of lining the tunnel was discussed. While it was driven through solid rock and would not need any support, the large amount of sediment in the water to be taken, made a uniform and high velocity of flow quite necessary to prevent an excessive formation of sand bars. The section adopted is a circle 7 feet diameter inside of the lining. This will give 100 millions of gallons in twenty-four hours, with a velocity of about 4 feet per second. In case the tunnel becomes obstructed, it can be drained and cleaned. Both the river and the shore ends of the tunnel drain to a sump in a shaft on the river bank, and a short branch tunnel, controlled by a gate, taps this sump and drains to a large shaft in which pumps may be set.

There was some discussion as to the best location for screens to intercept the fibre in the water. Coarse gratings were put over the tower gates to stop large drift, but the fine screens were put in a chamber at the outflow end of the tunnel near the engine house, where they can be watched and frequently cleaned.

We started the tunnel under the river from the shore shaft on a rising grade of 1 in 200. For the first 600 feet our grade followed very closely the stratification of the limestone. Then the roof rock began to dip rapidly the other way. To keep to our plans we would have had to cut through this stratum. There were, however, indications of a wet seam above this layer of rock, and it was thought prudent to follow the trend of the rock. We did this, driving a 7 x 10 foot heading until we had nearly reached the end, when the rock dipped so rapidly that we were forced to cut through the roof layer. It was not until our heading was driven the entire length that we laid out the final grade for the brick lining. It was then decided to lower the axis of the lining so as to avoid cutting into the roof rock except at the channel end of the tunnel. This change of grade was quite expensive, but to have avoided it might have proved much more costly.

Although we stopped off large quantities of water in our working shaft, we still had a steady downpour of 50 or 60 gallons per minute in the shaft while we were driving the tunnel. About 1000 feet from the shore we crossed a fissure that poured about the same amount of water into the tunnel. There was a little seepage all along the line. The water gave us considerable trouble in lining the tunnel. At the fissure above mentioned, where there was a sheet of water pouring through the roof right across the tunnel, we prepared for the brick lining by putting in a

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wrought iron shield curved to 54-inch radius, and provided with gutters and spouts to lead off the water. This shield was hoisted into position under the cataract and the brick arch carried through underneath it, leaving the shield concealed in the brick work.

In lining the tunnel we worked down the grade. Short pipes were laid through the wall where needed to relieve springs of water. When we had a long stretch of tunnel lined, and the water running along the invert had become troublesome, we built across the tunnel a brick dam provided at the base with a 6-inch outlet pipe and valve. Before starting a length of invert the valve was closed and the seepage allowed to accumulate above the dam. When the stretch of invert was ready, and the upper end of the tunnel was full of water to the top of the dam, the valve was opened and our reservoir emptied out. Two of these dams were built, and they proved very useful in storing the seepage water until it could be released without inconvenience.

IN DESIGNING THE INLET TOWER

at the channel end of the tunnel, account was taken of the enormous strains which might result from ice gorges resting on and wedging against the structure.

As a small base was desirable on account of the expense and difficulty of placing a large coffer-dam, the superstructure was given additional height and weight to increase the stability.

To increase the resistance against shearing, large anchor bolts were set, passing through the lower five courses of masonry, and reaching several feet into the rock ledge. As shown in Fig. 6, the up-stream end of the tower is formed into an ice-breaker. On account of the wide range in the stages of the river, gates were provided at different levels. At high water the lower gates will remain closed, and those which are more accessible will be used. The gates in the north chamber will generally be used, as, in case of their failure to shut, the gate in the party wall can be used to keep the water out of the tunnel.

The shore end of the tunnel empties through the screen chamber into the

WET WELL

from which the pumping engines draw.

In locating this part of the work, after sinking many bore holes and prospect shafts, it was found best to build at a point about 700 feet inshore, where the excavation would be in more stable material. In the design of this plant the flood height of the river was again a factor. The engine pits, etc., must be proof against high water, and on the other hand the pumps must be little, if any, above the low water level. Hori-

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zontal pumps would not seem appropriate under these conditions, and hence deep pits and vertical pumping engines had to be adopted.

The conditions of the pumping problem were these. The water must be delivered at a fixed elevation, to supply the settling basins. It must be drawn from an elevation depending upon the stage of the river.

There is some controversy as to the best arrangement for such a case, some contending that the water should be held back by means of gates, so that the pump will work under a constant suction lift, while others would allow the pressure in the suction to vary with the stage of the river so as to reduce the average lift. At the Chain of Rocks the pits and gates have been so arranged as to permit the use of either method. A wet well or fore bay is provided, in which the water may be allowed to stand at the level of the water in the channel of the river, or may be kept at the constant level of low water. Before the cheapest and best form of wet well could be agreed upon, it was necessary to consider whether the well should be built as part of the same structure as the engine pits, with only a masonry dam between them, or whether it was better to use a separate structure, as was finally adopted; whether the well should be rectangular or circular; whether there should be one or several, and whether it or they should be large or small.

In getting out the details, the design of

THE RETAINING WALLS

formed an interesting study. Allowance was made for the support given by cross-walls. Part of the overturning moment is balanced by the transverse strength of the masonry. In preparing the plan of the engine house we were limited by the great depth of the substructure. A rectangular building was inevitable, if we would have a solid foundation.

It was thought safer also to have the boiler-house independent on its own foundations, so that it might settle without distortion.

The delivery well, into which the engines pump, was located on rising ground in front of the pumping station where there was a good clay foundation for the masonry. Each engine is provided with an independent delivery pipe which spills into this basin. A free spill was given so that there can be no return flow when a pump is stopped.

THE BOILER HOUSE

was planned for a single row of boilers, as this arrangement is best for ventilation and light. The chimney, 6 x 150 feet in interior dimensions, is of brick. It stands on a separate foundation extending to ledge rock. Flues and steam mains are overhead. Considerable effort was made to

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find an economical way of getting the coal from the railroad train into the furnace. What might be called the reservoir system was finally adopted, on the ground that it would be the most uniform in operation. By this plan all coal must be handled three times.

From the gondola car it is unloaded into the coal house. It is then shoveled, as needed, into iron charging cars, and from these into the furnace. The coal-house forms a reservoir so that the contractor can unload his cars as they come in, while on the other hand the coal passer has always about the same distance to go for his coal. This method gives a much more sightly stoking-room than is had where the coal is delivered directly in front of the boilers.

BUILDINGS

were made rectangular in plan, with tin roofs. The engine and boiler-houses were built with riveted steel roof trusses.

TRACKS

for coal-car handling were laid out with some care. There is a siding for loaded trains and one for empties. Another siding runs through a long coal shed for reserve coal, to be used only in case of strikes or other emergencies. A siding runs into the machine shop, and another runs into the engine house, so that machinery can readily be moved from one building to the other. Two forty-foot track scales are provided for weighing cars.

THE SETTLING BASINS

offered many interesting problems, and it will be hard to give a readable list of them in the short space which I have allowed myself. The first and most important question that came up was whether the basins should be designed for a uniform continuous flow of water or whether the water should be allowed to come to rest and be given a period of undisturbed settlement before it is drawn off into the conduit leading to the high-service pumps. By which plan should we get the best results with a given expenditure?

The difficulties in the way of arriving at the truth in this question were considerable. There was no way of comparing the two methods, on a large scale under similar conditions of sediment, etc.

A basin designed for the plan of quiet settlement or of *filling and drawing*, could not easily be altered so as to use the continuous flow system to the best advantage.

Each scheme has its advantages and its drawbacks, so that it is not merely a question of volume or area or amount of masonry. Inlets and outlets must be considered. Constant flow basins usually receive and

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deliver their waters over long shallow weirs. They may be built with paved sloping banks. Basins which are drawn off at short intervals must have vertical walls, as the mud would settle on the slopes and in the drawing would be exposed or would slide down. In the matter of banks, therefore, the constant flow basin would be cheaper. The best form for a continuous flow basin is hard to determine. Some think that the water should flow over many weirs; but others dispute this. The filling and drawing plan offers the greater elasticity in operation, as the basins may be gradually drawn down in case of need without seriously interfering with their operation. We thus take advantage of their storage capacity, to prevent a shortage of water in case of accident to our pumping machinery.

The old basins at Bissell's Point were designed for filling and drawing and have given good results. As the water in the river, however, is never twice alike, it would be hard to get scientific expressions of the clearing obtained.

After thoroughly sifting the testimony, the evidence seemed to be stronger on the side of the quiet settlement plan. The following are some of the arguments which would seem in

THEORY

to support this conclusion.

It is very difficult to add water to a vessel containing still water without disturbing the latter.

Any one can learn this by trial. Take a glass of still water containing light sediment at the bottom, and try to add water to the glass without disturbing the sediment at the bottom. On the other hand it is easy to draw water out of a vessel without disturbance. One can readily decant or siphon water out of a glass and yet leave the sediment at the bottom. Now the kinetic energy introduced in filling a basin must be absorbed in friction, and the internal friction of liquids decreases with the velocities of the currents, so that it takes a long time to use up *all* of the energy in this way.

In flowing water the particles never move in parallel straight lines. In the case of water flowing through a cylindrical pipe it is probable that each particle of water is always moving in a curved path, that is, each group of particles always has some angular velocity. The paths of the particles may be likened to the fibres in a rope which have something of the form of a compound helix. Each fibre is twisted around the other fibres of the strand while the strand is twisted around the other strands. It is only by some such system of compound curves that the observed phenomena of flowing water can be explained. Water flowing into or through a reservoir must break up into currents or masses, each mass having both linear and angular velocity.

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It is by means of these angular velocities that flowing streams are enabled to sustain solid matter. The swifter the stream, the greater the angular velocities in a vertical plane, and hence the greater is the carrying power.

Let us imagine a cylinder with horizontal axis filled with jelly or similar material. In the jelly is a leaden weight. While the cylinder is at rest the weight sinks with a uniform velocity *m*. Now revolve the cylinder with a uniform angular velocity *a*. The weight will tend to describe a circle not concentric with the cylinder. If we eliminate the effect of inertia, the body will move in a closed path and will never sink below a certain level as long as the angular velocity remains unchanged. Hence, with a given depth of water and a given angular velocity, sedimentary particles of a certain limiting size will subside, while those a degree finer will be held in suspension.*

Applying these theories to the clearing of water, we see that the aim must be to reduce to a minimum the angular velocities in the water. If we could suddenly bring a body of muddy water to a state of absolute rest the water would become clear in a remarkably short space of time.

In a constant flow basin the slower the movement of the water the faster it will clear. With a given volume of basin the best result should be obtained by stopping all flow for a time, as is done in the system of filling and drawing. As soon as the inflow of water ceases the internal velocities begin to decrease, rapidly at first but at a diminishing rate. The finer and lighter the sediment, the longer it will take to reduce the velocity of internal currents to the clearing point. A slight decrease in the size of the grain makes a great increase in the time required for settlement.

After having decided on using the fill-and-draw system we took up the question of

THE NUMBER AND SIZE OF THE BASINS.

Taking twenty-four hours as the time of settlement, we used the following expression to denote the working capacity of a set of n basins holding q gallons each:

$$(n - 1\tfrac{1}{2})\, q.$$

That is, we consider that while a basin is being filled, no settling will take place, and that the settling during drawing is equivalent to one-half that of a full basin for the same period. Observations made in our old basins show that the water continued to improve as the basin is being drawn off.

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* For discussion of this principle see paper by J. A. Seddon, in JOURNAL OF ASSOCIATION OF ENGINEERING SOCIETIES, Vol. VIII, 1889.

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In the new plant, just completed, Fig. 4, we have six basins of 22,000,000 drawing capacity each. By the formula, this gives, for the system, a working capacity of 99,000,000 gallons every twenty-four hours, with twenty-four hours' settlement.

Six to eight basins would seem to be the economical number for our conditions.

It is believed that with a given *volume*, the depth of the basin does not affect the time of clearing.

The economical depth would be that which, with a given expenditure, would hold the greatest volume. It was feared, however, that water less than twelve feet deep might spoil in hot weather, and hence the actual depth was made greater than the computed economical depth.

While not so direct in plan, it was thought wiser to bring the water to the basins on the west side, which is away from the river, as this location puts the *filling conduit* on higher ground, so that it can be built of masonry. The water is drawn from the basins at the side towards the river, as the basins are some six feet deeper at this side. The drawing gates are placed at the very deepest part of the basin, just over the mud-gate which opens into the sewer.

It was thought unnecessary to provide drawing-gates at different levels, as was done in the old Bissell's Point plant; for the water has been shown to be of practically equal clearness at all depths after a few hours' settling.

Connections between the basins and the drawing and filling conduits were made with 60-inch cast iron-pipe, laid in five-foot lengths, with lead socket joints. Allowance was thus made for unequal settlement in the basin walls and conduits, as the lead joints will allow some movement without leakage.

The six basins are as nearly identical in form as they could be built. Each basin has independent connecting pipes and gates, and each basin has an independent flushing sewer to the river.

FOR FURTHER INFORMATION

regarding the general features and details of the plant in question, the reader is referred to the illustrated and descriptive articles in the following journals. In these he will find much that must be understood in the discussion of the points I have outlined, but which, in order to save space, I have omitted to repeat:

The *Engineering Record* for 1892 containst he following series of articles on the St. Louis Water Works Extension:

I. General description of conditions, maps, general elevations and details of inlet tower and gate house, and description of coffer-dam. April 9, 1892.

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II. Hydraulic cylinders in gate-house, details of gates, frames and racks. April 16, 1892.

III. Inlet tunnel and shafts. May 7, 1892.

IV. Wet well, screen chamber, engine-house foundation and delivery well. May 21, 1892.

V. Settling basins, and filling and drawing chambers for same. August 6, 1892.

VI. Sections of 11-foot and 9-foot conduits. August 13, 1892.

VII. Maline Creek Aqueduct Bridge. September 3, 1892.

VIII. Culverts under conduit. September 17, 1892.

IX. Terminal chamber of conduit and connections. October 22, 1892.

X. Construction of masonry conduit. November 12, 1892.

The *Engineering News* has published the following articles:

Settling basins and details. April 18, 1891.

Inlet tower and tunnel. July 4, 1891.

Brick chimney. July 26, 1894.

III. New Machinery.

BY JOHN A. LAIRD, MEMBER OF ENGINEERS' CLUB OF ST. LOUIS.

[Read April 4, 1894.]

IN this paper on the New Machinery for the St Louis Water Works, the writer will give a short description of the different engines under contract, with some details of specifications, lettings, prices, steam connections and proposed system of operating and maintaining. He also hopes to be able at some future time to give the Club some information respecting the duty trials of the different types of engines.

The Water Department has now under contract seven pumping engines of four different types. Their aggregate cost with the boilers will be in the neighborhood of $800,000. High-service engine No. 6 is a single cylinder, low pressure condensing beam engine of about 16 million gallons daily capacity. It is being built by the Southwark Foundry and Machine Co., of Philadelphia, at a cost of $110,500.

The first pair of engines for the Chain of Rocks low-service station are compound condensing duplex of 20 million capacity each. They are being built by H. R. Worthington, and will cost, in round numbers, $300,000.

The second pair of engines for Chain of Rocks are compound condensing engines of 30 million capacity each. They are being built by the Edw. P. Allis Company, at a cost of $156,000. Finally, the two

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Baden high-service engines are three cylinder, triple expansion condensing engines of 10 million gallons daily capacity each. They are also being built by the Allis Company. They will cost $132,000, and undoubtedly will represent the very latest and best steam practice.

The contracts were all let to the lowest bidders, according to the usual method of letting city work.

High-service engine No. 6 is of the old beam and fly-wheel type which has served the department so well for the past twenty-four years. There were three bidders at the letting:

Fulton Iron Works	$128,000
Holly Manufacturing Co.	119,000
and Southwark F. & M. Co.	110,500

The contract was awarded to the Southwark Company, and the machine is now being erected in place at Bissell's Point. The indications are that she will be ready for steam about the middle of June. There is very little of special interest in this engine. The main shaft is of nickel-steel, and is the first piece of that remarkable alloy, of any size, which has come to St. Louis. It was made by the Bethlehem Iron Company, and was forged entirely by hydraulic pressure, with a 7-inch hole through the center, and tempered in oil. Test specimens cut out of each end of the finished forging showed a tensile strength of 92,000 pounds, and an elongation 22 per cent. in 4 diameters.

The first bids for engines to be placed at the Chain of Rocks were opened in July, 1890. The specifications did not call for two engines of 20 million gallons daily capacity, but for two engines capable of delivering 600 million gallons in 720 consecutive hours. It is quite unnecessary to say anything on the relative merits of the designs proposed at the letting, as the subject was very well aired at the time. There were three bids presented, as follows:

Builders' Iron Foundry.	$342,000
Holly Manufacturing Co.	314,000
Henry R. Worthington	299,500

The contract was awarded to the Worthington Company, and the engines are now erected in place at the Chain of Rocks. They are compound duplex condensing engines, with the Worthington high-duty attachment. Each engine has two high pressure and two low pressure steam cylinders, which are respectively 21 and 42 inches in diameter, and four single acting plungers 36 inches in diameter, and under each steam cylinder, all of 80 inches stroke. The engines are balanced by means of walking beams, at the ends of which are placed the oscillating cylinders of the high-duty attachment. The beams are built up of

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two diamond-shaped steel plates 1 inch thick, separated 14 inches by cast-iron distance pieces. This, although very weak laterally, is strong and light as a beam. As all of the work is done while the plungers are going down, the beam will always be transmitting the work being done in one cylinder, and this effort will be a pull, tending to raise the beam in the bearings. These machines are 70 feet high, and they stand in the middle pit, which is 50 feet square. There is no masonry foundation, the bed plates resting on the pit bottom, and no connection to the walls except by gangways. The pit is not floored over, and all galleries, stairways and landings are of open work as on marine engines. This allows light to penetrate to the bottom of the pit, and the engineer, standing on the upper gallery, can see clear to the bottom. There is no need of artificial light in the daytime anywhere about the pumps, except inside of them. The joint between bedplates and pit bottom is from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch thick. It was made by grouting with Portland cement. The foundation bolts were also grouted in, and, after the cement was set, we were not able to produce any perceptible movement by hauling down hard on the sixteen $2\frac{1}{2}$-inch foundation bolts.

There is a surface condenser in the delivery pipe, and an independent jet condenser for emergency. The other parts of the engine do not differ materially from those of the well-known Worthington type. In building the Chain of Rocks engine-house the Water Commissioner departed from the time-honored custom of allowing the contractor to use any means which might be at his disposal for erecting the engines, and installed a 15-ton electric traveling crane, capable of sweeping the entire engine-house and having a vertical hoist of 80 feet on the blocks. This crane would also furnish material for a paper, and I will say that it is almost a thing of beauty, and that it has been a joy up to date. It is the first complete power crane which has been placed in a pumping station, and I know of only one crane which has a greater hoist of block. On the day upon which it was turned over to the Worthington Company, they lowered 150,000 pounds of bed-plate 60 feet into position in the pit. Almost any one can design a crane that will *hoist* a given load, but it takes extraordinary capacity to design one which will *lower* the load with perfect satisfaction. This crane has not caused a moment's delay since it was turned over to the contractor, although it has been looked after and operated by an ordinary helper, who had to be taught how to run it.

In the old stations all of the boilers deliver their steam into one great main, to which all of the engines are connected. At the Chain of Rocks there will be three batteries of boilers and three pairs of engines, with a separate steam main connecting each battery of boilers to a pair of engines. In addition to the main connection we have by-

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passes by means of which steam can be taken from any boiler for any engine in case of emergency.

The C. W. Hunt system of tracks, charging cars and ash cars, which is in use at Bissell's Point, will be used at Chain of Rocks. Track scales are provided for weighing coal and ashes, and all of the feed water will be metered. This gives an opportunity to compare the duties of different types of engines running in the same house and on the same work; in fact, to make the running of the engines and boilers a perpetual duty trial. The duty required by the specifications is 85,000,000 foot-pounds of work per 1,000 pounds of commercially dry steam, correction being made for entrainment above 3 per cent. Both capacity and duty trials are for 720 consecutive hours.

The two engines under contract by the Allis Company, for the North Pit at Chain of Rocks, are each to pump 900 million gallons in 720 consecutive hours, and are the largest in the department. The letting took place in November last, and there were five bidders, as follows:

Holly Manufacturing Co.	$287,000
H. R. Worthington	220,000
Southwark F. & M. Co.	203,000
Rankin & Fritsch	193,000
Edw. P. Allis Co.	156,000

The contract was awarded to the Allis Company, and work has been begun on them in their shops. The machines are vertical cross compound, with surface condensers and fly-wheels. The steam cylinders are 28 and 54 inches in diameter. Each engine has two single acting plungers 48 inches in diameter; all 108 inches stroke. If the well-known Reynold's triple expansion pumping engines were to be relieved of one cylinder, one fly-wheel and one pump, the result would be the Chain of Rocks type. These machines, like the Worthington's, will rest on the bottom of the pit and will have no masonry foundations. The duty required is 100 million on a thirty days' test.

The bonus, amounting to about $375 per million, offered by the city in the specifications for the first pair of engines, as a reward for superior efficiency, cut no figure whatever in the bidding. In writing the specifications for the first pair of Baden engines it was proposed to improve upon this. The duty required was 125 foot-pounds per 1,000 pounds of dry steam on a twenty-four hour test. The bonus offered was in the ratio of $1,000 for each million foot-pounds of above 125. Almost any builder of modern pumping machinery will claim a duty of at least 140 millions upon his particular type of machine, and the idea was to give these men a chance to put up their hard-earned dollars for the purpose of corroborating their oft-repeated statements. The result of the letting

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was a surprise to every one connected with it. There were six bidders for the two engines, as follows:

Groschon High Duty Pumping Engine Co.	$223,000
Southwark Foundry and Machine Co.	220,300
Holly Manufacturing Co.	198,000
Rankin & Fritsch	173,000
H. R. Worthington	155,000
The Edw. P. Allis Co.	132,000

As a matter of course, the contract was awarded to the Allis Company, and they have begun work on the machines in their shops.

The specifications called for two triple expansion pumping engines of 10 million gallons daily capacity each, to pump against a pressure of 125 pounds, with 125 pounds steam pressure. They will be located in the high-service station No. 3 at Baden. They are of the well-known Reynold's type of vertical triple expansion engines. The steam cylinders 31, 56 and 80 inches diameter respectively, the plungers are single acting, 25½ inches diameter and all are of 64 inches stroke. Each engine has two reheaters, and all the cylinders are jacketed; the high-pressure cylinders with live steam, and the intermediate and low-pressure cylinders with steam at reduced pressure. They are provided with surface condensers, and the air and boiler feed pumps are connected to the low-pressure plunger head. All of the plungers are so loaded that the steam will have to do the same work in lifting the plungers and its connections on the up stroke as in going down and forcing the water. The Reynold's Corliss valve motion is used and Corliss valves are set in the cylinder heads. This brings the clearance spaces down to a minimum. On the high-pressure and intermediate cylinders the percentage of clearance is less than 1½, and on the low pressure less than half of 1 per cent. This is as low as it would seem possible to make it and helps to account for the splendid duty shown by this type of engine. The one feature which distinguishes these machines from all other pumping engines of this size, is the pressure relief valves, which are designed so that a gate in the discharge pipe can suddenly be closed while an engine is running at full speed, in which event all of the water would be by-passed back into the suction pipe. As these pumps will deliver into what is practically a closed system, some such device would seem to be necessary. In starting up, the load may be taken off the relief valves and the engine started slowly, churning the water through the by-pass. Gradually increasing the load on the relief valves, the long column of water may be started very slowly. When the load is increased to the point when no water comes through the by-pass, the pump will have its full load, and any sudden increase in pressure will only cause the relief valves to open proportionately.

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On the other hand, the engines are provided with regulators to prevent racing, and if a break in the main should take off all the load, the regulator would stop the engine. If these appliances satisfactorily fill the requirements of the specifications, the machine will be admirably adapted to the very hard service for which they are designed. The plant will be arranged substantially as the one at the Chain, and it is proposed to use a 20-ton electric traveling crane.

It would be very interesting to analyze the various designs which have been submitted at the different lettings and come to some definite conclusion as to the real reason for the great difference in the prices asked by responsible builders on the same specifications. Taking even the three lettings, the machines are nearly all the same weight, and it is difficult to see why the prices vary from $342,000 to $132,000; and, in one letting, from $287,000 to $156,000. It was evident on the face of the bids at the Baden letting, that the Allis Company was the only one that had sufficient confidence in its machine to pay any attention to the bonus clause. So far as the other builders were concerned, that clause might have been struck out. Worthington's design was the lightest and the cheapest, and, but for the bonus, would have taken the contract. But 125 millions is a high duty for that type of engine, and the bidders could not feel safe in cutting their price when there was a possibility of paying a forfeit at the rate of $2,500 per million, that the duty fell below 125.

Rankin & Fritsch made a good, fair bid upon a design by Mr. F. W. Dean, of Boston, figured very carefully down to the lowest living price. The design did not differ materially from the Allis engine, and the engine would have been of nearly the same weight. But these bidders were handicapped in two ways. The design would have cost them at least $10,000, and never having built an engine of this class, they would not have been justified in making a guarantee of more than the 125 million duty required. Taking $10,000 from the bid for the design, leaves $163,000 for two machines, or $81,500 each. There were several reasons for the high bid of the Southwark Foundry and Machine Company. In the first place they spared no pains in getting up the design, but made it the very best they knew how. Their machine was also much heavier than any of the others. Its total weight was about 2,300,000 pounds, while the Allis, and Rankin & Fritsch engines weighed only about 2,000,000 pounds each. Southwark's price per pound was 9.5 cents, and Allis' 6.6 cents, but, adding the $30,000 which they expect from the bonus, we get 8.1 cents; while the $50,000 bonus which they may succeed in getting, makes their bid 9.1 cents, which is not so far from Southwark's price. The Allis Company figured on doing 140 million duty, and cut their bid accordingly. This duty

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would bring them $30,000 on both machines, and this, added to their bid, brings it to $162,000, or $81,000 for each engine, which is remarkably close to what Ranken & Fritsch figured for building the Dean machine. These figures look very low in comparison with the price paid for the Worthington engines. They weigh 1,675,000 pounds, and the contract price is $299.500, making the price per pound 18¾ cents. Of course these are only very rough comparisons, but they show plainly that the city paid an enormons price for the first two machines. Part of the difference between this and the cost of the later engines is due to reduction in the cost of material. It almost seems that in the short time intervening between the first and the last letting, pumping machinery of this class has passed from a stage when it is built to that of being manufactured.

It is very interesting to note the change which has taken place in pumping engine design in a little over three years. At the letting in 1890 all designs were for beam engines. In 1893 Worthington was the only pumping engine builder in the country who cared to bid on a beam engine. As imitation is counted the sincerest flattery, Edwin Reynolds must feel very highly complimented, for all but one of the great pump builders in this country are paying tribute to the genius of the man who designed and built the first triple expansion pumping engine in America, by substantially copying his design of marine engine applied to pumping engine practice.

The North Point engine at Milwaukee designed under the general supervision of Mr. Reynolds, with a duty of 154 million foot-pounds per 1000 pounds of dry steam, and an indicated horse-power per hour on 11.6 pounds of dry steam, holds the world record for economy in steam using.

When the Chain of Rocks and Baden stations are completed, the works will be able to furnish 100 million gallons daily with only about two-thirds of each plant in operation. Then it is proposed to put the machines on regular watches like the men, only the engines will work two-thirds of the time, and the men one-third; while the engines are resting they will be given a thorough overhauling, as marine engines are given while they are in port. This will add to their life, and it is hoped that it will show an increase in the economy of the machines. When an engine has stood a run of say two weeks, she will be shut down, and one of the crews which has been running, will open up the pump, take off the cylinder-heads, examine all packing, bearings and valves, make all adjustments, and in short give the machine an overhauling similar to what the builders give just before running a duty trial. While this is going on in the engine room, another crew will open up the boilers, give them a thorough cleaning, renew grates and other parts requiring renewal,

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examine all valves, fittings and distribution pipe, and put the boilers in exactly the condition which the boilermaker would put them in when preparing for a duty test. By this means the entire plant will be kept constantly tuned up to concert pitch. Whenever an engine is started up after being overhauled, steam cards will be taken from all of the cylinders to see that everything about the valve motion is in adjustment.

By means of a complete set of log books, the duty performed by every engine or battery of boilers on any watch may be laid before the chief engineer. This gives a check, not only on the duty that the engines are doing, but on the work of the men, and the fireman who does his work conscientiously and gets a high rate of evaporation, will be paid more than the one who just manages to make steam enough to keep the engines going. It will also be known, by the duty the machines give, how well the crew does its work in overhauling and tuning them up. With a system something like this it will be possible to elevate the grade of work in all departments, and to educate the firemen to be something more than mere coal-heavers. Why should the city spend one and a quarter million dollars for new machinery of the latest high-duty type and not have the very highest grade of work procurable in the fire-room as well as in the engine-room? The maximum efficiency will not be reached in a month, or perhaps in a year, but by giving the men substantial proof that they are paid to use their heads as well as their hands, we shall, in a comparatively short time, have in charge of of the new machinery a corps of men as much more efficient than the old crews as the new engines are better than the old ones.

This leads naturally to the question as to how much saving can reasonably be expected from the use of the high-duty engines; as to the duty obtained from the old engines, no careful duty trial has been made, so far as I know. Reducing to duty the quantity of coal burned, the high service engines give a little over 30,000,000 foot-pounds per 100 pounds of coal. Assuming five pounds evaporation, which is a little low, we get 65,000,000 on a 10-pound basis. Or, reduced to steam per horse-power per hour, we get something near thirty pounds.

As to what may be expected of the new engines, I will consider only the high service, as the ratio of duties between the new and the old low service engines will be as high as corresponding ratios on the high service.

It would not be safe to take results of twenty-four-hour duty trials as a basis of computation, and the only figures I have at hand for comparison, which are worth considering, were given me by Mr. Benzenberg, City Engineer of Milwaukee. He says that the North Point engine, which is very similar to our Baden machine, designed by the

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same man and built by the same company, gives a monthly duty of 120,000,000 foot-pounds per 100 pounds of coal, without any deductions. The coal used is anthracite, and gives about 8¾ pounds evaporation. This brings the monthly duty up to 136,000,000 on a 10-pound basis. Can we reasonably expect as high results on the Baden engines? It would seem so. The water pressure is higher, the steam pressure a little higher, and the clearance spaces on all the cylinders a little less. Surely it would not be out of the way to expect 130,000,000 on a 10-pound basis. Granting this, the coal bill will be reduced one-half, as also the cost of coal-passing and firing, and one engineer will run two engines. But the item of wages will cut very little figure, for a certain number of men must be employed in connection with a plant of this size. Let us suppose we do the same work and save half of the coal. One of the old 15,000,000 engines takes fifteen tons of coal to a watch of eight hours. They will run two-thirds of the time, or two watches a day, through the year.

Then, on a 15,000,000 gallon engine, we would save fifteen tons per day, or 5,475 tons per year. At the present contract price for coal, this amounts to $7,150—quite a respectable sum—which, capitalized at 5 per cent., gives $143,000, which would more than build a high-duty engine of equal capacity.

I have gone very hastily over the subject of the new machinery for the water-works. As most of the work remains to be done and none of the engines have been started, I have only been able to tell what we proposed to do and give the results we hoped to obtain. There will be material for several papers of very high scientific as well as practical value on the duty trials of the several machines. The water commissioner intends having all tests conducted by experts of acknowledged ability and experience in this class of work. Mr. C. C. Worthington, in speaking to the writer about the proposed tests, said that he would consider the reports of the same, if made under the general supervision of Mr. Holman, a most valuable addition to pumping-engine literature.

IV. Quality of the Supply.

By Robert E. McMath, Member of the Engineers' Club of St. Louis.

[Read April 18, 1894.]

A few years since, a question as to the quality of Mississippi, and especially Missouri, river water would have been treated with derision, but now even the old time St. Louisian must admit that the foundation of his faith is badly shaken. A vast area is tributary to the Mississippi at the point where our supply is to be taken, and each small district

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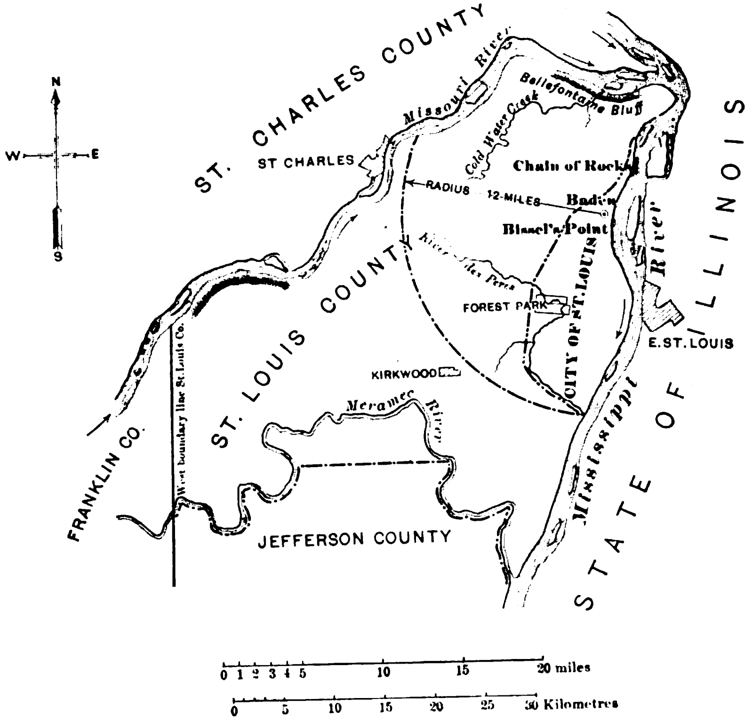
pays that tribute in a manner characteristic of itself. The result is a composite of waters from many sources. Mingled with the water is the debris of mountain and plain, as matter in suspension or in solution. Of the matters in suspension, whether of vegetable, animal or mineral origin, none adds any desirable quality or character to the water. By common consent it is desirable to be rid of them all. Of matters in solution, some may be neutral, beneficial or harmful for one or more of the uses to which water is put in a great city. A water pure according to scientific standards would suit no one. If chemists, individually connected with the varied interests of water users, were called upon for formulas of the ideal



SKELETON MAP OF ST. LOUIS COUNTY, MO. SCALE, 1 INCH = 12 MILES.

water, a strange diversity would be developed. Nature's mixture, as we have it, probably comes as near the mean of such ideals as is possible, for it contains a little of everything from everywhere. Recently some of our people have awakened to the probability that our water has an undue contribution of something from Chicago, and hence in large part the query which furnishes occasion for this paper.

As to the source of our supply I remark, first, that this must of necessity be the river. Second, that the location at the Chain of Rocks

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is plainly designated by nature, for that is the only possible point of supply on the Mississippi, and it is also on the only practicable line by which a supply can be brought from the Missouri.

The first of these propositions needs no argument, except to put aside the occasionally suggested scheme of using Meramec water, by reminding you that the Meramec drains a mineral region and is liable at low stages to be mineralized to an extent unfitting it for use as drinking water. Concerning the scheme to bring in the water of St. James Spring, I will say no more than to suggest that water which has probably traversed a series of bat guano caves is not necessarily pure, even though it be clear.

To establish the second proposition, I call attention to the fact that the Bellefontaine Bluff on the Missouri is the only place, until we approach the limits of St. Louis County, where the river runs along a permanent bank. That bluff can be reached from the Chain of Rocks by a tunnel four and a half miles in length that will deliver Missouri water into the wet well at the Low Service Station.

Since the river has disposed of a site above St. Charles, once considered possible, by leaving that site more than a mile inland, there are but two places where a permanent intake could be maintained, that at Bellefontaine and one near or beyond the west line of St. Louis County, distant by an air line twenty-one miles from the nearest point in the west boundary of the city, at Shrewsbury Park. The same point being, by air line sixteen miles from Bellefontaine Bluff. The conclusion is that the location at the Chain not only serves the wants of the city of to-day, but absolutely commands the water supply of that greater St. Louis which some people can see with the mind's eye.

Much criticism has been expended on those who overruled for a time the recommendations of Mr. Kirkwood that the Chain of Rocks be the location of the Low Service and Baden that of the High Service stations, and who established both at Bissell's Point; but the fact that we find among those whose counsels prevailed, such men as Gerard B. Allen and James B. Eads warns us against too hasty judgment. A glance at the city map will suffice to prove that Bissell's Point is well located as a point of distribution. It is not now a proper location for an intake, and, as a result, the city has on its hands a low-service house and three well-worn engines, and a boiler-house with a battery of antiquated boilers for which it will shortly have no further use; but the settling basins, as filter beds or as a storage reserve, retain their full value, as do also the high-service houses and engines, less wear and tear. The Kirkwood plan was good, as is evidenced by the fact that we are now carrying it out, so far as location is concerned; but it outran the resources and actual needs of the day when it was proposed. The map

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shows us the Cold Water or St. Ferdinand Creek emptying into the Missouri near the upper end of Bellefontaine Bluff. This creek drains an area which, even now, is being invaded by the suburban site speculator, and which at no remote date will receive the sewage of a large population. But if we indulge the visions of our prophetic eyes, we are liable to fall into the error of the housewife who, by preparing for an extra good dinner, left breakfast uncooked. We therefore adopt the Chain of Rocks for the location of pumping and settling works, and point to the Bellefontaine Bluff as a possible future intake point.

What shall we say as to the location of the high-service stations?

Let it be understood that we are dealing with the question of a water supply for St. Louis from 1894 to 1920 at farthest.

If arcs of different radii be struck from the Baden location as a center, it will appear that a greater area can be supplied from that point than from any other which can be reached by gravity flow from the settling basins. The location is on a direct line from the settling basins to the northwest corner of Forest Park. Hence it is an eligible location for the supply of the western part of the city and of the adjoining suburban territory.

The highest ground in the city limits north of the Pacific Railroad is almost centrally divided by the line mentioned. The line to the high elevations south of the Pacific Railroad is also direct and as short as any. The highest elevation within the city limits north of the railroad is about 180, above directrix, at the southwest corner of Forest Park; the highest south of the railroad is 205, at the Female Hospital. The highest graded point in the old city limits (prior to 1876) north of the railroad is 140; south of the railroad, 159.

Taking 30 pounds pressure at street grade as standard, a reasonably satisfactory supply from the present works north of the railroad is limited by the grade contour of 130, while south of the railroad the limit is that of 125 to 120. These facts suggest that the Baden Station should be designed to supply the high levels, and that the Bissell's Point Station be maintained to supply the lower levels.

Should it be deemed necessary to filter the water for domestic use, a third standard of pressure may well be considered. For very many manufacturing establishments filtered water will be no better than settled water. Most of these establishments are now, and for transportation reasons they always will be, located on ground below the grade contour of 75. If, therefore, a plant be operated to deliver settled, but unfiltered, water in this low district, manufacturing interests will be promoted by a less water rate than would be possible if filtered water alone were supplied, and the further problem of finding employment for ground now depreciating in value will be solved. Still farther, if users of large

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quantities of water locate on the low lands north of Bissell's Point, it will be entirely practicable to supply them at a still lower rate with settled water direct from the conduit.

To carry out this idea, one of the high-service houses at Bissell's Point would handle water, filtered probably in the present settling basins, and pump 30 million gallons per day against a head of about 220 feet; the other pumping daily 30 million gallons of unfiltered water against a head of about 130 feet. The Baden Station might be divided into two services, the one part pumping against 220 feet head, the other against about 315 feet. Of course, economy demands that, so far as possible, territory which requires the high head should be served separately.

Consideration has been given to the suggestion of a supplementary detached station for the highest service; but the weight of argument seems to be in favor of concentrating all pumping machinery at the main stations.

From this outline of a possible development of the water works, a matter having a close relation to the consideration of quality, I pass to the still more closely related question of purity; meaning, by purity, freedom of the water from any mixture or contamination which would render it dangerous to human health.

From what I have already said you will have gathered that, as we are at present situated, the water supply must be taken from the Mississippi River at the Chain of Rocks, or, as an alternative, from the Missouri River at the Bellefontaine Bluff.

When the Chain of Rocks was adopted as the location whence the supply for the immediate future should be taken, it was virtually assumed that water there taken would be wholly from the Missouri. The well-known phenomenon that an apparent line of demarkation between the waters of the two rivers is noticeable at the city front was triumphantly quoted as demonstration that none but Missouri water could reach the proposed intake. Hence it was urged that to go to the Missouri itself was an unnecessary expense. While coming down the river in October, 1887, I saw what led me to the conclusion that at that time, and probably at all low stages, a mixture of the waters of the two rivers took place immediately at their junction.

What I saw was the water of the Missouri dropping into that of the Mississippi over a fan-shaped reef extending across the mouth of the Missouri; the muddy water of the Missouri, plunging under the clearer water of the Mississippi, came to the surface in irregular boils and patches, some rising near the Illinois shore. Later, I noticed that although the water appeared densely muddy when looked at vertically from the steamer's deck, yet the bow-wave, when first started from the

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stem and broken, showed comparatively clear. I was thus compelled to recognize the fact that Mississippi water tended to overlie that of the Missouri, and hence that it might, and probably did, extend well over to the Missouri shore, and that consequently some proportion of Mississippi water would be taken into a supply drawn at the Chain of Rocks.

Reporting what I had seen to Mayor Francis and my associates on the Board of Public Improvements, and thus raising a question as to the sufficiency of the traditional belief, I also suggested the advisability of making an investigation, chemical and biological, of the water of the Illinois River, in order to determine, if possible, whether any risk to the health of St. Louis would be incurred by taking our water supply at a point where it is well nigh certain that water which has passed through the sewage pumps at Bridgeport will in some proportion enter that supply.

Being at the time a believer in the doctrine that dilution and opportunity for oxidation would certainly render sewage harmless, my expectation was that such an examination would bring out strong evidence that the supply might be taken there without risk of harm. Later evidence has shaken my faith in the doctrine, but has not proven the contrary.

As a consequence of my report, the Water Commissioner, taking due precautions to guard against misleading results, obtained samples of water from the Mississippi above the influence of the Missouri, from a corresponding point in the Missouri, and at the Chain of Rocks, and obtained a chemical analysis of them by Prof. W. B. Potter, Manager of the St. Louis Sampling and Testing Works. The details are fully set forth in the report of the Water Commissioner for the fiscal year ending April, 1888, pages 71, 72 of the Report of the Board of Public Improvements.

These results confirm the observations I have described, and prove that, although the characteristics of Missouri water greatly predominate at the Chain of Rocks, the influence of the Mississippi water is clearly manifest. The increase of the mixture of the waters with the distance traversed is shown by the results at Bissell's Point. It must therefore be taken as an established fact that at low stages, or during the fall and winter months, the water which has been furnished our city from Bissell's Point has contained a considerable proportion of Mississippi River water, and probably some of it from the Illinois and the Bridgeport pumps; also that the supply taken at the Chain of Rocks will contain a diminished proportion of water from the same sources

Since the foregoing evidence was obtained, the city of St. Louis has been visited by a serious outbreak of typhoid fever, lasting through the fall and winter months of 1892 and into 1893. Our Board of Health,

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by its official action, laid the outbreak to the charge of a contaminated water supply, and so gave publicity and official sanction to a report injurious to our city.

The progress of this outbreak, as per official report, was:

	Deaths.	Cases.
January, 1892	13	22
February, "	8	22
March, "	7	18
April, "	9	14
May, "	8	13
June, "	6	32
July, "	15	35
August, "	8	70
September, "	23	142
October, "	45	261
November, "	111	1923
December, "	189	945
January, 1893	36	114
February, "	17	35
March, "	8	40
April, "	8	
May, "	3	
June, "	2	
July, "	11	
August, "	42	
September, "	32	
October, "	20	
November, "	25	
December, "	11	
January, 1894	2	
February, "	7	
March, "	8	

The summer of 1892 was a flood season in the Mississippi, and the bottom lands north of Grand Avenue were submerged for many days. The sewer outlets along the entire city front were blocked by backwater for months. Yet it is reported that the 1st, 2d, 3d, 4th, 5th, 6th, 8th, and 13th wards, where these influences were most potent, furnished comparatively few cases. The disease was chiefly prevalent between Twelfth Street and Vandeventer Avenue, Victor Street on the south and Herbert Street on the north; or, by house numbers, between 1200 and 3900 east and west, 2500 south and 3500 north.

It is not apparent why a charge was brought against the water supply, which had certainly the same character throughout the city when some of the most densely populated wards were nearly exempt. It will also be observed that the disease was present to a sufficient extent to have put the health authorities on their mettle during the early

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months. The decided spread began in June, reached its maximum in cases in November, and quickly fell. The cause can hardly be found in the water supplied, for the increase began when the river was approaching a flood stage, when certainly the probability of contamination by sewage from other cities must have been infinitesimal. As the river approached a low stage, and the probabilities of sewage contamination increased, the disease abated; and when the rigors of a severe winter covered the streams with ice, and so brought the sewage of Chicago and other up-river cities to our doors under conditions as unfavorable to self-purification as can well be imagined, the disease fell to its normal I think that the water supply is entitled to a verdict of acquittal, having shown an alibi. A further cry was made, and the city was nigh being dragooned into a large expenditure to hasten the transfer of the intake to the Chain—by temporary expedients that would have seri ously interfered with the permanent works. But that the flow from Harlem and other suburban creeks had nothing to do with the typhoid scare is well evidenced by the fact that very few cases of the fever occurred within their drainage areas.

I conclude that as yet no evidence has appeared to justify an unfavorable opinion as to the quality of our water supply. Further, the analyses of 1887, already referred to, indicate that, contrary to traditional ideas, the Mississippi water is not only clearer than that of the Missouri, but has materially less sulphuric acid, lime, magnesia, chlorine, iron and alumina, and is lower in hardness. Therefore, so far as chemistry is concerned, it is the preferable water.

The quality of our water, so far as appearance and usefulness are concerned, is open to improvement. The mud, and sometimes the coloring matter, are unbearable. In days not very remote, the St. Louisian who did not argue that the mud was a positive advantage, was the exceptional character. The one who does so argue is now the exception. Still, I think that all of us, when in other cities, particularly in those which take their supplies from the great lakes, find something lacking, and we long for a satisfying draught of Mississippi water. I am not disposed to attempt telling you affirmatively what the lack is; but negatively I will say it is not the absence of mud. Experience and experiment has taught our water-works men that settlement for twenty-four hours in a reasonably quiet basin will clear the water of nearly all of its sediment. A cloudiness will remain after a long period of rest. Apparently, the interest of purity rather favors the adoption of a twenty-four-hour period for settlement. It is also to be noted that at the breaking up of winter there is usually a time when a persistent dark color, a disagreeable black deposit and an unpleasant flavor prevail; and these are not removed by settlement. In summer flood time the mud is at its maximum; but the

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water, when settled, is free from unpleasant flavor, although it retains a stain.

What may we expect when the new works are in operation? So far as freedom from mud is concerned, I know of no reason to look for better results than were realized when the Bissell Point works were first completed, results which continued until the capacity of the settling basins became overtaxed.

Our spring and summer supply never gave us clear water, and probably never will. I anticipate that the advancing tastes and habits of our people will demand something better than can be attained by settling alone. Whether that something will require filtration, or may be practically attained by some process of clarification, is an unsolved question of great importance. The success of many filters depends largely upon the use of some coagulant, of which alum may be named as a representative, because most frequently used. If just the right proportion of alum is used, no trace of it can be found in the effluent, and, of course, no harm can follow. If a coagulant is to be used to assist filtering, is it not better to use it at the low-service works, and for all the water pumped, than at filter stations near the high-service pumps, further inland, for perhaps a part?

That a substantial gain, as to quality, would follow a more complete clarification, is indicated by the average results of a series of analyses of samples taken from mid-channel, from the distributing well and from the clear well.

The average results from 16 groups taken at stages of water ranging from 67.6 to 100.2 (directrix = 100), and in season from mid-winter to mid-summer, show:

	Parts in 1,000,000.		
	Channel.	Dist. Well.	Clear Well.
Alb. Ammonia	1.046	1.033	0.411
Free Ammonia	0.038	0.046	0.019
Nitrites	0.0002	0.0003	0.00018
Nitrates	0.383	0.381	0.442
Oxygen consumed	31.60	33.00	15.90

Or, assembling series of similar dates, in order to show the gain by sedimentation:

Date of Collecting.	Gauge of River.	Temp. of Water.	Oxygen Consumed. Parts per 1,000,000 by Weight.		
			Channel.	Dist. Well.	Clear Well.
June 27, 1893	89.9	27° C.	41.40	47.80	17.80
July 8, 1893	89.5	27° C.	46.80	44.60	15.40
July 12, 1893	85.0	27° C.	45.80	48.60	20.80
July 19, 1893	84.0	28° C.	43.40	44.00	18.20
July 26, 1893	79.6	28° C.	38.40	38.40	15.20
August 31, 1893	72.0	22° C.	21.40	25.80	17.10
November 5, 1893	70.4	10° C.	7.80	5.80	5.20
December 6, 1893	67.6	1° C.	7.00	7.00	5.60

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If the sedimentation, occurring during the passage of the waters through our present settling basins, reduced the carbonaceous matter by an average of 60 per cent. when the river was 20 feet or more above low water, then, with the better settling facilities, afforded by the new works, we may confidently expect a much higher percentage of purification.

A comparison of determinations of albuminoid ammonia would sustain this conclusion, but purification in this respect will not necessarily be accompanied by a corresponding improvement in appearance.

If to natural settling we add the clarification due to use of a coagulant, we may well expect a water as free from objectionable matter, organic and inorganic, as is practicable; still, not a water to satisfy the fastidious, for at times it will have a dark shade, and at all others more or less of a whitish cloudiness.

To meet the last requirement, filtering must be resorted to. But, it may be asked, should the city be compelled to filter the entire supply in order to meet a demand arising from only a part of its people? Probably less than half the water supplied would be improved for the use to which it is put by this last and costly process. Considering the fact that filtered water rapidly deteriorates, would it not be better to leave the filtering to those who want it?

These are questions any one may ask, but who has the answer ready?

As yet, I have not touched upon the question that perhaps, in your minds, is most vital to the quality of our water, viz.: How will it be affected by the completion of the Chicago drainage scheme?

Let us assume the worst conceivable condition: the Missouri and Mississippi dead low; their joint volume about 45,000 cubic feet per second, and the Illinois frozen from its mouth up, so that whatever may under present conditions enter the Chicago canal, will be delivered at the mouth of the Illinois as if it had come through a closed pipe. Then, as was the case in 1892–3, nearly 2 per cent. of the water passing St. Louis will have passed through the Bridgeport pumps. When the drainage canal is in operation, with a flow of 10,000 cubic feet per second, the proportion of water that has been subject to Chicago influence will be 18 per cent., a prospect which, of itself, is not reassuring. Let us look closer.

Estimating the sewage proper as equal to the water supply, we may roughly estimate that of the delivery of the Bridgeport pumps 20 per cent. is sewage and that the remaining 80 per cent., while originally lake water, has been in very bad company during its leisurely trip through the Chicago River. Under the proposed condition of 10,000 cubic feet flow per second, the sewage proportion will fall to about 4 per cent., and the 96 per cent. will have passed through Chicago without stopping.

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Using these proportions, it seems that $\frac{3}{10}$ of one per cent. of the present low stage Mississippi flow has been in the condition of sewage, and that this proportion will rise to $\frac{7}{10}$ of one per cent, when the $2\frac{1}{2}$ million mark of Chicago population within the sanitary district shall have been reached. Hence, unless we are helped by mere dilution from the beginning, the quality of Mississippi water will, as a whole, have suffered from the Chicago scheme.

But these and similar arguments prove nothing in reality, although the figures represent facts.

The underlying question is: Does water, which washes nearly everything else, wash itself? In other words, does it, by any process, rid itself of filth after contamination? We know that it does: by sedimentation and by chemical change, in which lower forms of organic life may have an important part.

But how are we to know, when the chemist assures us that all the ammonia that left Chicago has passed into harmless nitrates before reaching St. Louis, that some colony of pathogenic bacilli has not made the voyage with unimpaired vitality? I have no answer to this question. When we think of all the risks and dangers we are said to incur with every breath we inhale, every morsel we eat and every draught we drink, we may well wonder that our harp of a thousand strings keeps in tune so long. While ignorant of these risks, the race lived and it probably will continue to live in spite of what biologists tell us.

Scientists are to be commended for their patient and painstaking researches, for seeking to penetrate the mysteries which surround us; and if, under strong temptation, they sometimes tell us things before they know them themselves, as possibly some have done in the matter of St. Louis water, we engineers need not throw stones at them, for we have glass sections in our own house.

Much has been said locally about the scheme by which Chicago aims to cast her filth before us. It may be wrong for her to do so, but St. Louis cannot of herself collect the proof; partly because she cannot find the men and the means for the demonstration, and partly because any action in this direction will be attributed to jealousy, and any proof furnished will be much discredited on account of traditional rivalry.

The questions involved are of the utmost importance, not only to the cities immediately interested, but to all the cities and states on the earth. It is, therefore, proper that the United States Government be asked to make a full investigation of the facts presented by the Illinois River, and of the effect of Chicago sewage on it, especially when the river is frozen.

A disinterested examination would lead to wise legislation, regulating, controlling or prohibiting the discharge of sewage into streams and

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rivers, small and great, by Minneapolis, St. Paul, Omaha, Kansas City, St. Louis and smaller cities.

As the population of this country becomes more dense, the question of the quality of water supply will become more important, and our efforts may of necessity turn from the prevention to the cure of pollution.

To completely guard the purity of our streams is not possible, and hence the purification of water will probably become a necessity; but that probability should not lead to indifference as to the pollution of the streams.

Returning for a final glance at the Chicago plans, I will say that already a very large part of Chicago's territorial area, and a considerable part of her present population, are outside of the sanitary district to be served by the canal. Moreover, the canal is only an outlet for Chicago drainage, and it must be remembered that drainage is a matter entirely distinct from the disposal or treatment of sewage. Chicago's sewer system will have to be radically remodeled to complement the drainage plans. Perforce she will have to separate sewage from storm water, and will have to pump a large part of the sewage. Under this necessity, imposed by natural conditions, it will be comparatively easy for the State of Illinois, or, in default of her action, for the general government to impose a further condition that the sewage be purified before delivery into the waters of a navigable stream.

When I promised the Secretary of the Club to undertake one of a series of papers on the new water works, I did not appreciate the poverty of the information available to me concerning quality of supply. Certainly, there is much that might, and should, be known concerning Mississippi or Missouri water, the variations of quality with season and stage, and other matters of inquiry.

No systematic study of our water had been made prior to 1893, and then only by chemical analysis. In preparing this paper, I have had in my hands the report of Chemist John T. Wixford to Water Commissioner M. L. Holman, with liberty to use it; but, with the exception of a few figures showing grouped results and a general statement of conclusions, I have made no use of the information it contains, chiefly because I am persuaded of the truth of the statement somewhat fully presented in the report by Mr. Wixford, that the usual lines of inquiry in examinations of water supply are of little or no value when applied to Mississippi water. Such studies usually take note of color, odor, taste, turbidity, solids in suspension (and their composition). They involve the determination of dissolved gases, and special determination of chlorine, organic carbon and nitrogen, ammonia salts, nitrites and nitrates, and also take account of hardness.

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The color of unfiltered Mississippi water varies from muddy-brown to whitish, according to the character of the suspended matter. Filtered, the color is a faint yellowish-green. The odor is inappreciable, and the taste is agreeable, except for a short period at the breaking up of winter, at which time the color is dark and persistent. The origin of this color and taste is not known; but it is not probable that a remedy or preventive lies within human power. The turbidity is always considerably greater at high stages than at low, and when the river is rising than when it is falling. The causes are uncontrollable. The solids in suspension are, both in quantity and in variation, far beyond the possibility of discovering the influence of sewage contamination, and their determination would have no value.

The dissolved gases are constituents of the atmosphere, and are harmless. They thus indicate no recent sewage contamination. It is needful, first, to know the normal quantities, as it is only the excess that is to be taken into account. This, for varying conditions and temperatures, is not practicable.

The chlorine test is valueless, because we do not, and cannot, know the normal scale. The Massachusetts State Board of Health has published a map showing the iso-chlors for that State, which vary from 0.65 part of chlorine per 100,000 near the coast to less than 0.10 part in the western part of the State. If an iso-chloric map of the Mississippi and Missouri basins were made, the maximum would probably surround the Kansas salt fields; but as we never could tell what proportion of the flow at any time came from a particular part of the drainage area, we could make no use of the map.

Organic matter, animal or vegetable, is mainly composed of carbon, hydrogen, nitrogen and oxygen in varying proportions. Animal matter decomposes more rapidly than vegetable matter, and contains more nitrogen. By decomposition, these elements are converted into carbonic acid, water and nitrates. The changes are the result of the activity of micro-organisms, and do not take place in their absence.

Albuminoid ammonia represents the nitrogen in organic matter which has not begun to decompose. In itself, it does not indicate whether it comes from animal or vegetable matter. By one determination, July 12, 1893, there was present 1.799 part in 1,000,000.

Analyses by the Massachusetts Board of Health give 5.302 parts in 1,000,000 as the average yield of Lawrence sewage. Hence, Mississippi water at mid-summer stage may have one-third as much albuminoid ammonia as average sewage. It is not necessary to follow out Mr. Wixford's computation to show that it would take the sewage of 454 cities like St. Louis to account for this proportion of albuminoid ammonia.

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Hence, to look for trace or proof of sewage contamination by analysis, is as hopeless as the search for a needle in a haystack.

Not to follow the technical report further, it is suggested that a study of our water supply involves the development of a broader field of investigation than has yet been traversed, and one which can scarcely be covered by the limited resources of our water department.

V. The Filtration of City Water Supplies in the Light of Recent Researches.

By Robert Moore, Member of the Engineers' Club of St. Louis.

[Read May 2, 1894.]

One of the most important and difficult problems with which the modern city is confronted is how to obtain an adequate supply of wholesome drinking water.

The first solution in point of time is,in the great majority of cases, found in surface wells, one of which is sunk for the supply of each house or small group of houses. For a time this source of supply is satisfactory both as to quantity and quality, and it may be that for many years no water works beyond the town pump are demanded by any public or private need. With the lapse of time and the growth of population, however, the water obtained from surface wells is found to deteriorate in quality. The cesspools after a time pollute the wells and under favoring conditions convert them into breeders of disease. The favorite home of typhoid fever, the world over, is the country village. But as a rule other considerations of less intrinsic importance have a greater influence in producing a desire for something better. The private citizen wants to have water brought into his dwelling, and an ample supply of water under pressure becomes necessary as a protection against fire.

The next step, therefore, is to bring the water of the nearest lake or river into the town, and the private well is supplanted by the public water pipe. This step is attended not only with an enormous gain in security from fire and in comfort of living, but also, in nearly all cases, with a marked improvement in the public health. Statistics compiled by the Massachusetts State Board of Health * show that in the twenty years from 1865 to 1885, during which all the larger towns had introduced public water supplies, the deaths from typhoid fever had fallen from a rate of 13.04 to 3.09 per 10,000, a decrease of 70 per cent.

This reduction of the death-rate, however, is not universal, and

* Twenty-second Annual Report, p. XXII.

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even in the same city is not always constant. In a few cities having a public water supply we find the typhoid death-rate to be increasing rather than decreasing. Three well-marked instances of this kind are cited by the Massachusetts State Board of Health,* to wit: Holyoke, Lowell and Lawrence; and a notable instance of the same kind is found in our neighboring city, Chicago. In each of these cities careful investigation has shown the water supply to be unmistakably polluted by causes which can be positively identified. In the case of Chicago the rise in the typhoid fever rate has been shown by Dr. F. W. Reilly, Secretary of the Illinois State Board of Health, to follow the freshets whereby the waters of the open sewer known as the Chicago River have been carried into the lake and thence into the city water pipes; whilst periods of long-continued dry weather, during which the Bridgeport pumps are able to reverse the natural flow of the river, are followed by corresponding depressions in the fever curve.

These cases, however, are only illustrations of what is likely to happen hereafter to many other cities. The increasing density of population in the territory draining into our lakes and rivers is certain to cause pollution, and in the cities dependent upon them as sources of water supply, the public water pipes are sure in time to become carriers of disease. How to ward off this new danger is a problem which has for a long time troubled many cities in the old world and which is beginning now to trouble not a few cities in the new world.

The first and most natural suggestion by way of remedy is to change the source of supply, substituting a new one that shall be free from danger. This was done by Glasgow, which, prior to 1859, took its water from the Clyde, but which since then has taken it from Loch Katrine, thirty-four miles distant in the Highlands. As a result, the city has shown itself, in every epidemic of cholera since then, to be cholera proof, although it had always before been one of the most vulnerable. This is also being now done by the city of Manchester, which is building works to take its water from Thirlmere, more than eighty miles distant in the Lake District.

Such a change of sources evidently affords a complete solution of the problem, and not a few have maintained that it is the only solution. For example, Mr. Chas. Watson Folkard, Associate of the Royal School of Mines of England, in a paper read January, 1882, before the Institution of Civil Engineers, after a discussion of the various methods of water analysis, uses this language: †

"The conclusion that once-contaminated water never purifies itself sufficiently for dietetic purposes becomes inevitable; and, as chemical

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* Twenty-second Annual Report, for 1890, p. 525 and following.

† Proceedings, Institution of Civil Engineers, Vol. 68, p. 66.

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analysis fails to give reliable evidence as to its fitness or the reverse, the author believes that the only safe test of the wholesomeness of a given water is by tracing it to its source and ascertaining that no objectionable impurities gain access to it. This will at once condemn all rivers flowing through a populous country; and, if it be considered that a river is the natural drain of a district into which everything soluble or suspensible finds its way, it will not be a matter of wonder that this should be the case. No Conservancy Board can keep pollution out of a river; it must receive all the rain falling within its watershed (excepting, of course, that which is evaporated) together with the overflowings of cesspools and the sewage of towns within the same area. It is part of the great circulatory system of the earth, which it is vain for man to attempt to control. This being so, it is evident that rivers, except near their source, can only afford polluted water, and a problem utterly insoluble by man is presented, viz., the purification of foul water on a large scale."

In the discussion which followed, in which a number of very able men, including Prof. John Tyndall, took part, the preponderance of opinion was in full agreement with the author. That drinking water for individuals and for communities should be taken only from sources that were not "contaminated nor contaminable" was the judgment of nearly all.

But, unfortunately, for the great majority of towns such sources as these are inaccessible. For most of them there is practically no choice. St. Louis, for example, unless she would do worse, must draw her water-supply from the Mississippi or the Missouri; Louisville and Cincinnati, from the Ohio; and Chicago, from Lake Michigan. Each must take what there is at hand and make the best of it. The real problem, then, for many cities now, and for nearly all cities at sometime hereafter, is how to render wholesome a water supply that has been contaminated.

The earliest device for obtaining a pure supply from a river whose water is for any reason objectionable, is to take the water, not from the river directly, but from wells sunk in the sand near by. By this method, which is sometimes called "natural filtration," a water free from sediment or visible impurity, is obtained, and if the quantity required be not large the result may be entirely satisfactory. In the greater number of cases, however, this method is not attended with success. Most often there is a deficiency in quantity, and not infrequently the quality also is at fault. As is well known, the water obtained from wells alongside the Mississippi River near St. Louis is much harder than the river water, and is usually unfit for use in steam boilers. At the water works near Lake Tegel, one of the works for the supply of Berlin, the water was at first taken from wells alongside the lake. But experience showed it to be so rich in iron and so favorable to the development of objectionable vegetable growths

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that the water was rendered useless. The wells were therefore abandoned and the water is now taken directly from the lake.

The next device in the order of time was the artificial sand filter, first constructed by Mr. Jas. Simpson, Engineer, for the Chelsea water works of London in 1839. This consists essentially of a shallow reservoir with a collecting drain through the center and with lateral drains of porous tiles or bricks, without mortar, leading into the central drain. On top of this system of drains are laid from three to four feet of gravel and sand increasing in fineness to the top. Through this sand bed the water is allowed to percolate slowly into the collecting drains, whence it is led off to the pumps for distribution.

This simple device was from the first so effective in removing sediment and improving the appearance of the water that in 1852 its use was by law made obligatory upon all the London water companies except for water from deep or artesian wells, and it has ever since been in continuous and successful operation. The example of London was soon followed by other cities, both in England and on the Continent, so that when Mr. Kirkwood visited Europe in 1866 on behalf of the Board of Water Commissioners of the City of St. Louis, he found filtration plants in operation in Berlin, Altona, Nantes, and Marseilles, as well as in Leicester, York, Liverpool, Edinburgh and Dublin.

So long as the pollution of water was regarded as due solely to particles of dead organic or inorganic matter in suspension, this method of purification left nothing to be desired. By its use, turbid waters were rendered clear and, so far as the eye could judge, pure. But when, in the progress of scientific investigation, it became evident that the harm of polluted water lay, not in dead matter at all, but in living organisms invisible to the naked eye, and that the clearest and most sparkling water was sometimes the most deadly, a strong revulsion of opinion took place, and the benefits of filtration came to be generally regarded as delusive. This sentiment is well voiced in the paper of Mr. Folkard and the discussion thereon, already referred to.

"Filtration," says he, "is another remedy put forward as infallible by those who have not grasped the subject. How can filtration affect substances dissolved in water? And, as far as the minute organisms found in putrescent bodies are concerned, they could pass a hundred or a thousand abreast through the interstitial spaces of ordinary sand as used for this purpose." *

And Mr. Homersham declares that in some respects and at some seasons filtration really injures the water by the collection of a layer of

* Proceedings, Institution of Civil Engineers, Vol. 68, p. 68.

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organic matter on top of the sand which furnishes "pabulum for the insects" as he terms them.*

This, added to the difficulty of finding and recognizing the morbific germs—a difficulty so great that, as Dr. Tidy expressed it, "one could no more analyze a water for a germ of typhoid than one could analyze a brain for an idea"—left the matter in a quite hopeless condition which seemed to justify the opinion of Mr. Folkard already quoted, that the purification of foul water on a large scale was "a problem utterly insoluble by man" and that there was no defense against impure water except boiling or distillation. This, however, is a defense which is almost impossible of application on a large scale and, as those who have tried it in their own households know, very difficult of application even on a small scale.

Now, as it happened, in the very year in which this paper was read, 1882, Dr. Robert Koch of Berlin gave to the public† his then newly discovered gelatine-plate process, which made it possible to fix, cultivate and even count the micro-organisms in any sample of water. This at once put the biological analysis of water, which Dr. Tidy had just declared to be an impossibility, upon the footing of an exact science, and students were not wanting to apply the new method to the investigation of the phenomena of the filtration of water through sand.

Among the earliest in this new field of inquiry was Percy Faraday Frankland, Professor of Chemistry in University College, Dundee, and son of Dr. Edward Frankland, official water analyst for the Registrar General and for the Local Government Board of England. Prof. Frankland began at once to study, by the aid of the gelatine-plate process, the various methods of water purification, and in particular to ascertain, by a series of observations running through several years, the results actually attained by the filters of the London water companies. The facts thus found are set forth in a paper read by him before the Institution of Civil Engineers in April, 1886, and in two papers submitted to the Royal Commission on Metropolitan Water Supply and published with other documents accompanying their report of September 8, 1893. In brief, his findings are these:

(1) That the chemical changes effected in the water by the filters of the London companies, summarized in the following table, are so small as to be quite insignificant.

* Proceedings, Institution of Civil Engineers, Vol. 68, p. 70.

† Mittheilungen, Kaiserliches Gesundheitsamt, 1882.

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TABLE SHOWING THE CHEMICAL RESULTS OF THE FILTRATION OF THAMES WATER BY THE LONDON WATER COMPANIES, EXPRESSED IN PARTS PER 100,000.

		Before Filtration.	After Filtration.
Total solid matter		28.40	26.20
Organic carbon		.123	.119
Organic nitrogen		.025	.022
Ammonia		0	0
Nitrogen as nitrates and nitrites		.077	.089
Total combined nitrogen		.102	.111
Chlorine		1.6	1.6
Hardness	Temporary	11.5	10.9
	Permanent	7.1	7.1
	Total	18.6	18.0

(2) That the filters have a most remarkable efficiency in removing micro-organisms from the water. The record of three years' working of the filters is given in the following table, which shows that on an average, out of every 100 micro-organisms in the untreated river water, the numbers stated in the table were removed by the water companies before distribution.

Water from the	1886	1887	1888
	Organisms.	Organisms.	Organisms.
Thames	97.6	96.7	98.4
Lea—East London Co.	96.5	95.3	95.3

From a later series of observations made in 1892, Prof. Frankland finds the average number of bacteria per cubic centimeter in the filtered waters to be only 29, or a trifle more than ⅛ of one per cent. of the average number in the Thames water—20,000. And, as the numbers in the filtered water seem to bear no relation to those in the unfiltered water from day to day, he considers it certain that of those found in the filtered water nearly all are attributable to post-filtration sources. In other words, the efficiency of the filters in the removal of bacteria is practically 100 per cent.

(3) That this extraordinary biological efficiency of the filters depends upon the formation of a superficial gelatinous deposit or membrane upon the top of the sand, which membrane acts as an almost impervious obstacle to the passage of micro-organisms, and that it is of the greatest importance that this membranous film should not be ruptured by the application of excessive or irregular pressures in the filtration.

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It thus appears that Mr. Folkard's army of microbes marching "a hundred or a thousand abreast through the interstitial spaces" has somehow been put to rout, and that the cause of their discomfiture is found in the superficial layer of organic matter which, according to Mr. Homersham, should furnish them with pabulum—all of which illustrates anew the extreme danger of *a priori* reasoning in matters of physical science.

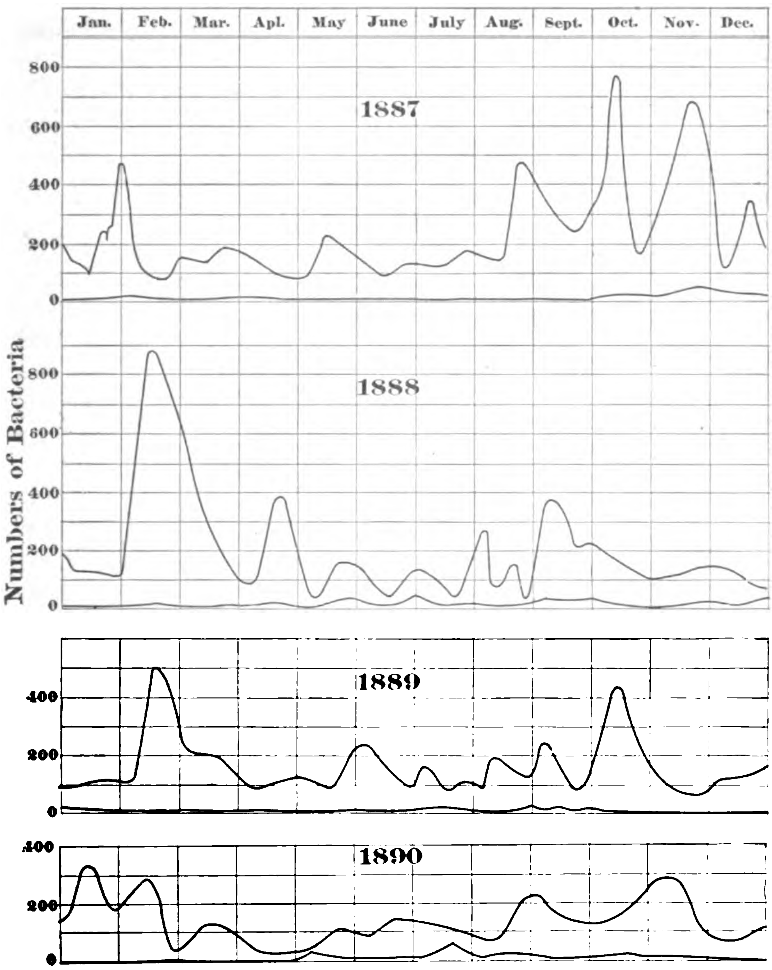

FIG. 1. NUMBERS OF BACTERIA IN FILTERED AND IN UNFILTERED WATER AT ZURICH, SWITZERLAND, 1887—1890.

In each of the four diagrams the upper and lower curves show respectively the conditions obtaining before and after filtration.

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Other observations of the same character, running in each case through a series of years and all pointing to precisely the same conclusions, have been made by the Massachusetts State Board of Health at Lawrence upon a number of experimental filters, and by the authorities of Berlin and Zurich upon the filters used for the city water supply.

The Lawrence experiments show that when filtering at a rate of from two to three million gallons per acre per day, which gives a velocity of 6 to 9 feet in twenty-four hours, 99½ per cent. of the bacteria in the applied water can be removed by filtration. At slower rates practically all can be removed. At Zurich, where the ordinary velocity of filtration is 25 feet in twenty-four hours, or more than double the London rate, the average number of bacteria per cubic centimeter in the water after filtration is 20. As, however, the number in the water before filtration is unusually low—about 200—the percentage of removal is only 90, or much less than in either of the other cases.

Fig. 1, showing the results of the working of these filters during four years from 1887 to 1890 inclusive, is interesting as showing the tendency of the number of micro-organisms in the filtered water to remain constant without regard to the fluctuations in the number in the water before filtration, a fact already noted in the London and in the Lawrence experiments, and strongly suggestive of the conclusion that the bacteria in the effluent are due to the drains of the filter itself and not to the applied water.

But the benefits of filtration are seen more clearly in the mortuary records than in the records of the laboratory. At Zurich, for example, the typhoid mortality in 1880, before the construction of the present filters, was 4 per 1,000 of the population. Since then it has dropped to 0.4 per 1,000, a decrease of 90 per cent. The effects of filtration in London are shown in Fig. 2, taken from a paper read before the American Statistical Association in January, 1892, by Prof. Sedgwick and Mr. Allen Hazen, which shows the typhoid mortality in London since 1870 as compared with that of several American cities. It is reproduced here with the addition of the typhoid curve for St. Louis since 1867. From this it will be seen that notwithstanding the fact that London draws its water supply from two small rivers draining a territory densely populated, it has had for more than twenty years a typhoid rate continuously lower than that of any large American city.

Even more significant is the report of Dr. William Farr, Registrar General, upon the experience of London with cholera in 1866*, in which he points out that the field of greatest fatality was almost coincident in its boundaries with a section of East

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* See Report of Registrar General, July 25, 1868, pp. xv and following.

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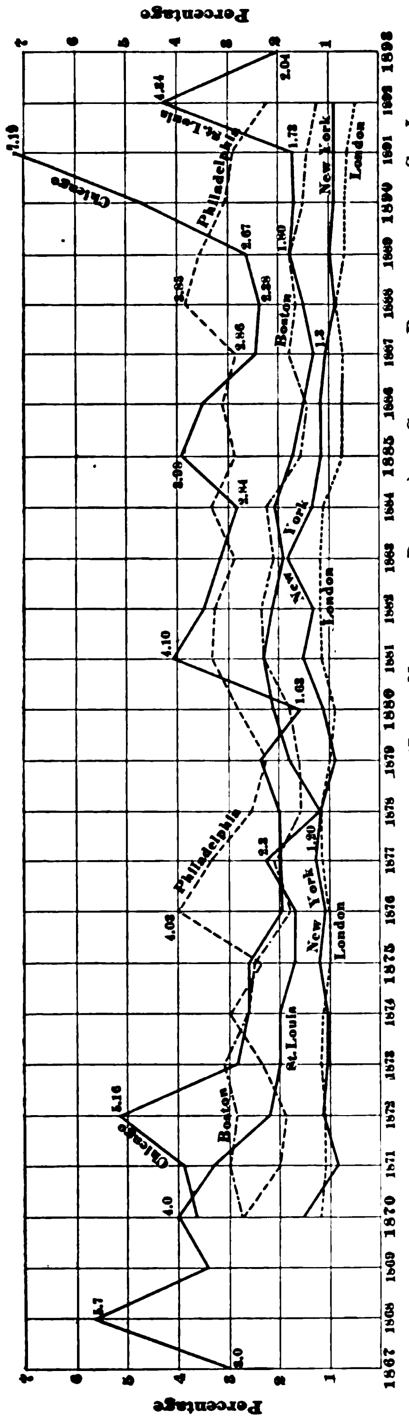

FIG. 2. EFFECTS OF TYPHOID FEVER (IN PERCENTAGE OF TOTAL NUMBER OF DEATHS) IN CHICAGO, PHILADELPHIA, ST. LOUIS, BOSTON, NEW YORK AND LONDON, FROM 1867 to 1893.

London, which, for a time just then, was supplied with unfiltered water—a fact to which he attributes the deaths of nearly 4,000 persons. Of like purport is the now familiar story of Hamburg,* which upon the advent of cholera in 1892, and in spite of the warning given a few years before, by an epidemic of typhoid, was found still drinking the unfiltered water of the Elbe. As a result, nearly 8,000 persons lost their lives from cholera in eight weeks, whereas the adjoining city of Altona, which drank from the same stream after it had received the sewage of Hamburg, but not until the water had been filtered, was, except for certain imported cases, almost wholly exempt from it.

Indeed, no fact in sanitary science is now more firmly established than that properly conducted sand filtration is an almost perfect defense against the dangers of polluted water.

Of the immense and ever growing importance of this fact to all cities dependent upon rivers for their water supply, not a word need be said. But certainly the name of James Simpson, the Engineer who, building "better than he knew," constructed, more than fifty years ago, the first filtration plant, and whose

* Proceedings, Institution of Civil Engineers, Vol. 88, p. 507 and Vol. 114, p. 425.

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work has already saved so many thousands of lives, should be held in grateful remembrance as that of one of the benefactors of mankind.

The bearing of all this upon our own city is self-evident; but a few words, by way of reminder of some of the special features of our own case, will perhaps be pardoned. As is well known, in the plans for new water works for St. Louis, made in 1865 by Mr. James P. Kirkwood, was included a recommendation of filtration. In 1866 Mr. Kirkwood went to Europe on behalf of the Board of Water Commissioners, to make a detailed study of the subject; and, in his report, a copy of which is in the library of the Club, is found a plan for filtration works at St. Louis. Almost the sole object in view at that time was the clarification of the water by the removal of the sediment which was then, as it is now, a cause of reproach to us by the outside world and a source of serious offense even to the citizens native born. With the lapse of time, during

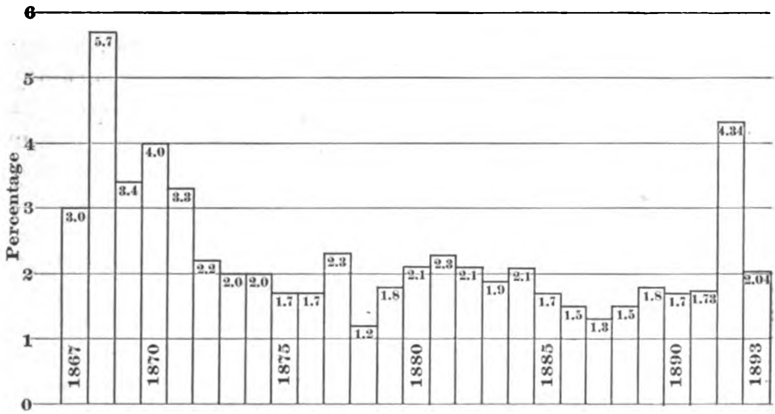

FIG. 3. EFFECT OF TYPHOID FEVER (IN PERCENTAGE OF TOTAL NUMBER OF DEATHS) IN ST. LOUIS, FROM 1867 to 1893.

which we have made so much progress in other directions, this reason for filtration has certainly not lost anything of its force.

But a more cogent reason is found in the diagram of relative mortality given in Fig. 2, on which the typhoid rate for St. Louis from 1870 to 1892 inclusive (2 ½ per cent. of the total mortality) is seen to be more than double that of London ($\frac{9}{10}$ of one per cent.) for the same period. To make more evident the special characteristics of the St. Louis curve it is shown separately in Fig. 3. On this you will note especially the very high rate from 1867 to 1871, the drop in 1872 and the continuously lower rate from that year on until 1891, the sharp rise in 1892 to 4 $\frac{34}{100}$ per cent., and the equally marked decline to 2 per cent. in 1893. Worthy of consideration also are the coincident facts that 1872 was the first year

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after the removal of the water works intake from the foot of Bates Street, where the water was mingled with the sewage of Rocky Branch and Gingrass Creek, to Bissell's Point, where the water was then comparatively pure, and that in 1893 the pumps, whereby the sewage of Harlem Creek is now discharged into the river below the water works, were first put into operation—facts which in both cases suggest a possible, not to say probable, relation of cause and effect.

But be this as it may, it is certain that our water supply is at times subject to serious infection, which, as time passes, is sure to be largely increased, and equally certain that by means of proper filtration works, coupled with the closing of all wells, our typhoid rate can be reduced to or below that of London. With our present population this means the saving of 1,300 cases and 160 lives each year. And all this can be brought about at a first cost not exceeding two millions of dollars and an annual cost, including interest, of not more than one hundred and fifty thousand dollars—sums which are trifling when compared with the benefits which their expenditure will insure.

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