CHAPTER VI

Slow Sand Filtration in the United States and Canada

Filtration in the United States made a bold and early but unsuccessful start in 1832 with an upward-flow backwash filter at Richmond, Va. This was only five years after Thom's filter of much the same type was put in use at Greenock, Scotland, and three years after the completion of Simpson's downward-flow, manually cleaned filter at London. Not until 1855 was there another municipal filtration venture in the United States and that was a small charcoal, sand and gravel filter or strainer at Elizabeth, N.J.

In Canada, a lake-intake filter crib was built in 1849 at Kingston, Ont., and in 1859 an infiltration basin was built on the lake shore at Hamilton, Ont. Neither of these, however, would qualify as successful filters.

Up to the end of 1860 there had been constructed only 136 water works in the United States and ten in Canada. A large percentage of these supplied water from springs or other sources free from turbidity and at least relatively free from pollution. Although slow sand filtration was thoroughly established in England and Scotland, and to a lesser extent in Continental Europe, before the American Civil War, no such plants were in operation on this side of the Atlantic. The Civil War put a damper on water works construction in both the United States and Canada.

After the Civil War, water works construction in America was resumed at a rapid rate but for many years nearly all attempts at filtration were utterly inadequate.

America made three most notable contributions to filtration: (1) The rapid filter was introduced by inventors and promoters in the 1880's and early 1890's and put on a sound engineering basis by working-size scientific experiments divorced from proprietary interests, then further advanced by various elements of mechanical equipment and by filter operators. (2) Improvements were made in slow sand filters, beginning with the studies at the Lawrence Experiment Station of the Massachusetts State Board of Health and carried for-

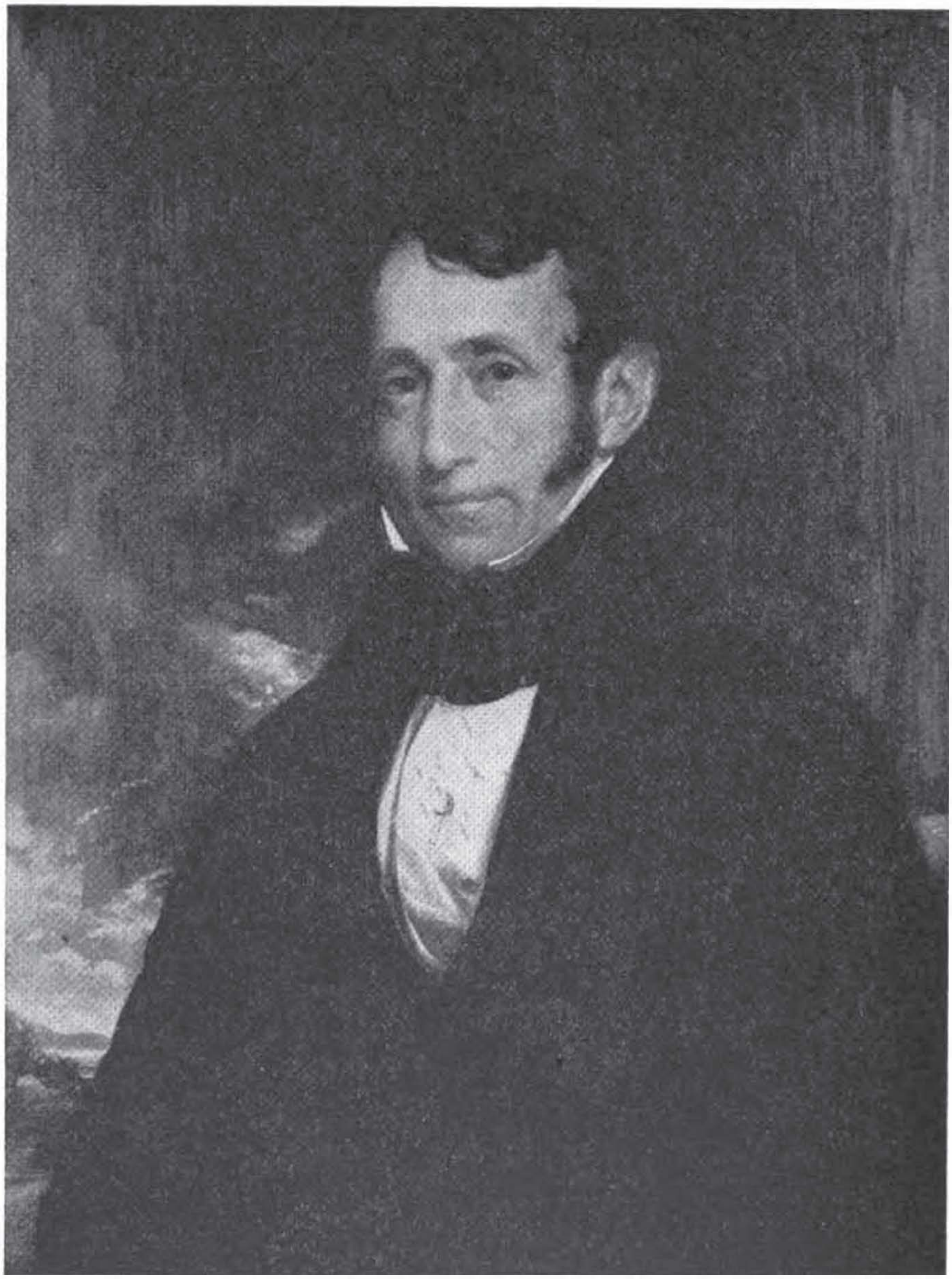

FIG. 30. ALBERT STEIN (1785–1874)
Engineer who designed first municipal filter in America for Richmond, Va., 1832, applying principles of upward flow with reverse-flow cleaning
(From painting by John Neagle, Philadelphia, 1837, in possession of Thomas Stein, Toulmanville, Ala.)

ward at other testing stations and at working installations, the latter contributing notable improvements in methods of operation. (3) Chlorination was initiated, early in the twentieth century, first as a bactericidal adjunct to rapid filtration, and then in conjunction with sand filtration.

The First Filters in America

The first American city to attempt water filtration was Richmond, Va. Early in 1832, a water works which included a small upward-flow filter of gravel and sand was completed. When this proved a failure, a filter operated by downward flow was soon constructed and it too failed. In both cases the filters were of small area and unable to cope with the highly turbid water of the James River. The city then waited a century before it obtained a complete purification plant. Much of this period, however, involved a wait for full development of the means to purify very turbid water, in this case contaminated with troublesome industrial wastes.

Richmond's first water works was designed by Albert Stein, a German-American engineer, who arrived in Richmond in the spring of 1830. At that time the city depended on wells and springs for its water, pipes having been laid in a few streets. Stein aroused interest in water works and was engaged to make preliminary plans and estimates, which were approved at a freeholders' meeting and later at a special election. The council then appointed a "Watering Committee" which engaged Stein as designing and constructing engineer at a fee of $6,500, to be paid on completion and acceptance of the works.

At sunrise, July 24, 1830, the Watering Committee met on the "Canal Bank near the little Arch," approved the sites of the dam and reservoir selected by Stein, and instructed Stein to begin construction of the pump house. For a time after construction began, the committee continued meeting at sunrise every Friday, to inspect the work.

On January 7, 1832, Stein reported to the committee that the works were completed. The total cost to that date, including material on hand, was $76,861, against the original estimate of $92,600. Neither figure included Stein's fee of $6,500, not yet paid. On February 17, the Watering Committee reported to the Council that it had "inspected the works in all their parts" and had made "full experiments with all the machinery, at the pump house as well as at the reservoir, and on and along the whole line of pipes, and that it had that day come to Resolutions:

> That Mr. Stein, our Engineer, has faithfully and to our entire satisfaction performed the duties required of him, by the contract in the premises.—That the works ought to be received of him in discharge of his contract and that the same be and they are received by your Committee, *as competent to furnish an abundant supply of sweet and pure water for the use of our city* [Author's italics] (1).

Tap No. 1, for the first house supplied with water, was made March 5, 1832. On May 1, 1833, there were 295 water subscribers.

Stein described the new works in a report submitted to the committee on January 7, 1832 (2). Water was lifted to a reservoir by a 0.4-mgd. pump, driven by a water wheel. The reservoir was 194 ft. long, 104 ft. wide, 10 ft. 8 in. deep and held nearly 1 mil.gal. It was divided into four "apartments, of which two were for filtering. All the apartments were connected at the bottom by 10-in. cast-iron pipes, with gates attached." Each filter was 22½ ft. long and 16 ft. wide. This would give an area of only $\frac{1}{60}$ acre for both filters against a pump capacity of 0.4 mgd.

The filter is rather vaguely described as "a body of gravel and sand through which the water percolates upwards," the gravel being at the bottom and the material becoming "finer and finer toward the top." When the "quantity of pure water falls short by lodgment of sediment among the gravel and sand, the water is made to enter at the top, and in passing downward with considerable force carries along with it the sediment into the reservoir [below the filter] from which it is carried off through the ascending main by means of a branch pipe with a stopcock attached to it."

Evidently the filter rested on a "floor," or false bottom [not described], 3 ft. above the bottom of the filter basin, thus affording "sufficient space to remove the sediment, which may remain at the bottom after the body of gravel and sand has been cleaned." From this it may be inferred that the filter was cleaned by reverse-flow wash.

In a semicentennial paper on the Richmond works, James L. Davis, Water Superintendent, stated that the filters were 5 ft. deep (3).

Stein expressed doubt that the filter was large enough "to produce the required amount of pure water." If an increased demand should make a second filter necessary, he said, it would be advisable to place it near the second reservoir—apparently then projected below the first reservoir and filters.

Stein declared that the Richmond filter was the first one he had "formed upon a large scale and I believe it is the only one formed in the United States for the purpose of producing pure water for a town."

So far as can be learned, the description thus condensed from Stein's report is the first and only locally recorded contemporary mention of Stein's filter. Loammi Baldwin's report on a new supply for Boston, dated October 1, 1834, cites a letter from the city clerk of Richmond, saying that a reservoir equal in size to the first, with a filter between the two, was being constructed "with a view of clearing the water, which at times has been too muddy for use. The first filter does not seem to have had much effect in purifying the water. The second differs from it, in filtering water downwards instead of ascending, and it is expected to render the water fit for use at all times, with the aid of settlement in the New Reservoir" (4).

Charles E. Bolling, a later superintendent, stated in 1889 that the filter was pronounced a failure and its use abandoned in 1835. Presumably he meant the second unit (5).

In view of the immediate failure of Stein's filter to provide "an abundant supply of good and pure water," and since he questioned the capacity of the filter immediately after its completion, why did he not put in a larger filter? It is possible that he did design and build the second filter to meet his obligation.

Stein was right in believing that the United States afforded no precedent for a municipal filter. But few were in use anywhere in the world. His contemporary, Baldwin of Boston, said of the Richmond filters: "This reversing the course of water through the filter appears to be like the plan adopted by Mr. Thom at Greenock" (4). The Greenock filter was put into use in 1827, some years after Stein came to America. It was described by Thom in a pamphlet published in Scotland in 1829 (see Chap. V). It is conceivable, but unlikely, that Stein saw a copy of this pamphlet before he designed the Richmond filters. Or he may have known of Peacock's British patent of 1791 and pamphlet of 1793 on an upward-flow filter, washed by reverse flow. Whether or not Stein knew of the Peacock and Thom filters, the one he built for Richmond was absurdly small, particularly so for a water much more turbid than that in any city supply previously subjected to filtration.

It was a bold venture for Richmond to adopt Stein's plans for water works, including a pumping plant and filters, for at the close of 1830 only 44 cities in the United States had public water supplies, mostly small gravity works, none of which included filters.

What was the background of this engineer—leader of this bold adventure? Albert Stein was born in Düsseldorf, Prussia, December 9, 1785 (6). After being educated as a civil engineer, he began work on a topographical survey of the Rhenish Provinces. In 1807, he was appointed hydraulic engineer by Murat, then Grand Duke of Berg by the favor of Napoleon I, whose cavalry had been led by Murat. After the fall of Napoleon and the cession of the duchy to Prussia, Stein resigned his position and came to America. He reached Philadelphia in 1816, where he seems to have had some relation with Frederic Graff, Chief Engineer of the Philadelphia Water Works. In 1817, Stein submitted plans for water works at Cincinnati. About that time, also, he made surveys for a canal from Cincinnati to Dayton. For a few years beginning in 1824 he was engineer for deepening the tidal section of the Appomattox River at and below Petersburg, Va. He was engineer for water works at Lynchburg, Va., in 1828–30. While building the Richmond works, Stein designed for Nashville, Tenn., water works which were completed in 1832. In the period 1834–40, Stein was at New Orleans, building a reservoir for the water works there, a canal from the city to Lake Pontchartrain, and making a survey and plan for the improvement of the Southwest Pass of the Mississippi. In 1840 he leased a small, privately owned water works system at Mobile, Ala., which he improved and operated. He died July 26, 1874, on his estate at Spring Hill near Mobile.

Although Richmond did nothing effective to improve its water supply until well into the twentieth century, settling basins were proposed from time to time. In 1860, the city council asked the superintendent, Davis, and its city engineer, W. Gill, to make plans for a new reservoir "with a proper filter." They proposed filters cleaned by reverse flow (1). A new reservoir was put in use January 1, 1876. Later, under Superintendent Charles E. Bolling, and the health officer, Dr. E. C. Levy, two narrow settling basins, about a mile long, with provision for drawing off the sediment alternately, were provided. On December 22, 1909, large coagulation basins were added. Chlorination with hypochlorite was begun June 26, 1913, on Levy's recommendation, following a few cases of typhoid fever in Richmond. In 1914, apparatus for applying liquid chlorine was installed. But not until August 29, 1924, was a complete purification plant available, with coagulation basins, mechanical filters, aerators and a clear-water basin, the whole of 30-mgd. capacity (1).

There remained a trouble that had been increasing for a quarter century. Dr. Levy had reported the discharge into the river of deleterious matter from sulfite pulp mills at Covington. These wastes seriously interfered with water purification. Although the owners spent large sums in alleviating pollution, other mills appeared on the river banks and nullified the benefits. "For the last few years," wrote Whitfield in 1930, "this condition has become serious" (1).

Carrying on the story, Marsden C. Smith, Engineer of Water Works, stated in 1934 that not only had the pollution been reduced but improved methods of preparing water for filtration had increased the effective capacity of the plant 50 per cent and in addition had produced a vastly better effluent at reduced cost (7). Among other improvements were continuous instead of seasonal treatment for algae control in the raw water settling basin; pH control of the raw water by the addition of lime or acid just before applying the coagulant; mechanical mixers or flocculators to improve coagulation; taste and odor control by activated carbon "fed in batch at the beginning of a filter run directly onto the filters"; ammonia and chlorine combined in place of chlorine alone to disinfect the filtered water; and, to reduce corrosion, "the final pH is now being corrected by a combination of aeration and chemical treatment" (7).

What wonder, in view of all these agencies used in 1934, that Stein's small settling reservoir and small upward-flow filters of 1832 proved utterly inadequate! Or that, having put in a second unsuccessful filter, Richmond went on with muddy water for 75 years and rounded out a full century before it had an adequate purification plant!

Nineteenth Century American Literature on Filtration

Before detailing American progress in water filtration, it will be illuminating to see what native guides to the art of filtration were available to the American engineer during the nineteenth century. These were few and inadequate until about 1870.

Loammi Baldwin II, called the Father of American Engineering, in his report of 1834 on a new water supply for Boston, embodied excerpts from foreign descriptions of the Greenock upward-flow, backwash filters of Robert Thom and the somewhat similar filters of Albert Stein at Richmond.* He barely mentioned the Quai des Celestins filters opened in 1806 at Paris and the filters and filter galleries at Glasgow, dating from 1808–10. Baldwin visited European engineering works in 1807 and again in 1823–24 and was the first American engineer on record to make such a tour. So far as appears in the Boston report, he saw no filters while abroad. The foreign data in the Boston report dealt chiefly with the flow of water in conduits, as was natural, since the report recommended a gravity supply for Boston, with no proposal for filtration (4).

Charles S. Storrow read diligently in the extensive civil engineering library of Loammi Baldwin at the time of his graduation from Harvard in 1829. In December of that year he went to Paris where he attended the Ecole des Ponts et Chaussées and lectures at the Ecole Polytechnique. In 1835 he published the first American treatise on water works (8), but the book was written in 1832 while he was in Paris. It was chiefly concerned with hydraulics but included a few lines advising combined settling and storage reservoirs, plus filters, and six paragraphs on Thom's and Simpson's filters (see Chap. V). Apparently Storrow did not see the Quai des Celestins filters while in Paris.

Dr. Robley Dunglinson, in his American book, *Human Health,* also published in 1835 (9), treated briefly filtration, boiling, softening, distillation and aeration—the last to restore deficiency of air caused by distillation. He gave a concise summary of Lowitz's studies on the use of charcoal in water treatment, announced in 1790. His most significant statements, in view of the date, pertained to chlorination, which will be discussed later (see Chap. XIV). He mentioned no specific water purification plant, not even the filter put in use at Richmond in 1832, near the University of Virginia, where he was professor of chemistry.

* The first Loammi Baldwin—cabinet maker, surveyor, soldier of the Revolution, canal builder, "man of learning" and originator of the Baldwin apple—was made an Honorary Graduate of Harvard in 1785. His civil engineering library and those of his sons, Loammi and George, were presented to the town of Woburn, Mass., home of at least three generations of Baldwins [*Dictionary of American Biography,* which cites "Sketch of the Life and Works of Loammi Baldwin, C.E.," by Prof. George L. Vose (1885)]. William D. Goddard, Librarian, Woburn Public Library, states that the Baldwin Library of 2,110 volumes was given by a Baldwin descendant to the Woburn Library in 1899 and transferred to the Massachusetts Institute of Technology in 1914.

The Journal of the Franklin Institute, founded in 1826, made available in 1838 a translation of Arago's report on the Fonvielle pressure filter, which worked at a high rate and was cleaned by backwashing (10) (see Chap. IV). It is not likely that many American engineers read Arago's report or even saw Dr. Dunglinson's book. For many years there were no American additions to literature on water treatment.

Kirkwood on Filtration in Europe.—When the American Civil War was over, James P. Kirkwood, an eminent water works engineer of Brooklyn, N. Y., was engaged by the city of St. Louis, Mo., to recommend improvements to its water supply. He advised filtration and was sent abroad to gather information on filtration in Great Britain and on the Continent. While he was abroad, the city decided not to build filters. On his return he submitted a report which was finally published in 1869 (11).

Kirkwood's St. Louis Report described and illustrated the filters and filter galleries of nineteen European cities. Until the report of 1895 by Allen Hazen, another American engineer who went to Europe, Kirkwood's was the only book in any language devoted to the filtration of municipal water supplies. He described the filters of Leicester, Liverpool, seven of the eight London metropolitan water companies, Wakefield and York, England; Edinburgh, Scotland; Dublin, Ireland; Marseilles and Nantes, France; Altona and Berlin, Germany; and Leghorn, Italy. Filter galleries described were those at Perth, Scotland; Angers, Lyons and Toulouse, France; and Genoa, Italy.

The object of filtration through sand underlaid by coarse material, says Kirkwood in his general summary, is to remove suspended matter, including not only earthy materials but also "fine vegetable fibers and the minute organisms, vegetable or animal, which in all river waters prevail more or less during certain of the summer months."

Not for a long time, says Kirkwood, would our rivers carry as much organic matter in suspension as did European streams. He therefore turns his attention to the "clayey discoloration" of American rivers. According to him, this renders their water very objectionable to sight and for industrial uses and is no contribution to health and cleanliness. Custom, as on western rivers, might reconcile persons to the use of muddy water, especially where clearness is associated with the hard and unpalatable waters of limestone springs. Such of the sediment of muddy waters as will fall by its own weight in 24 hours could

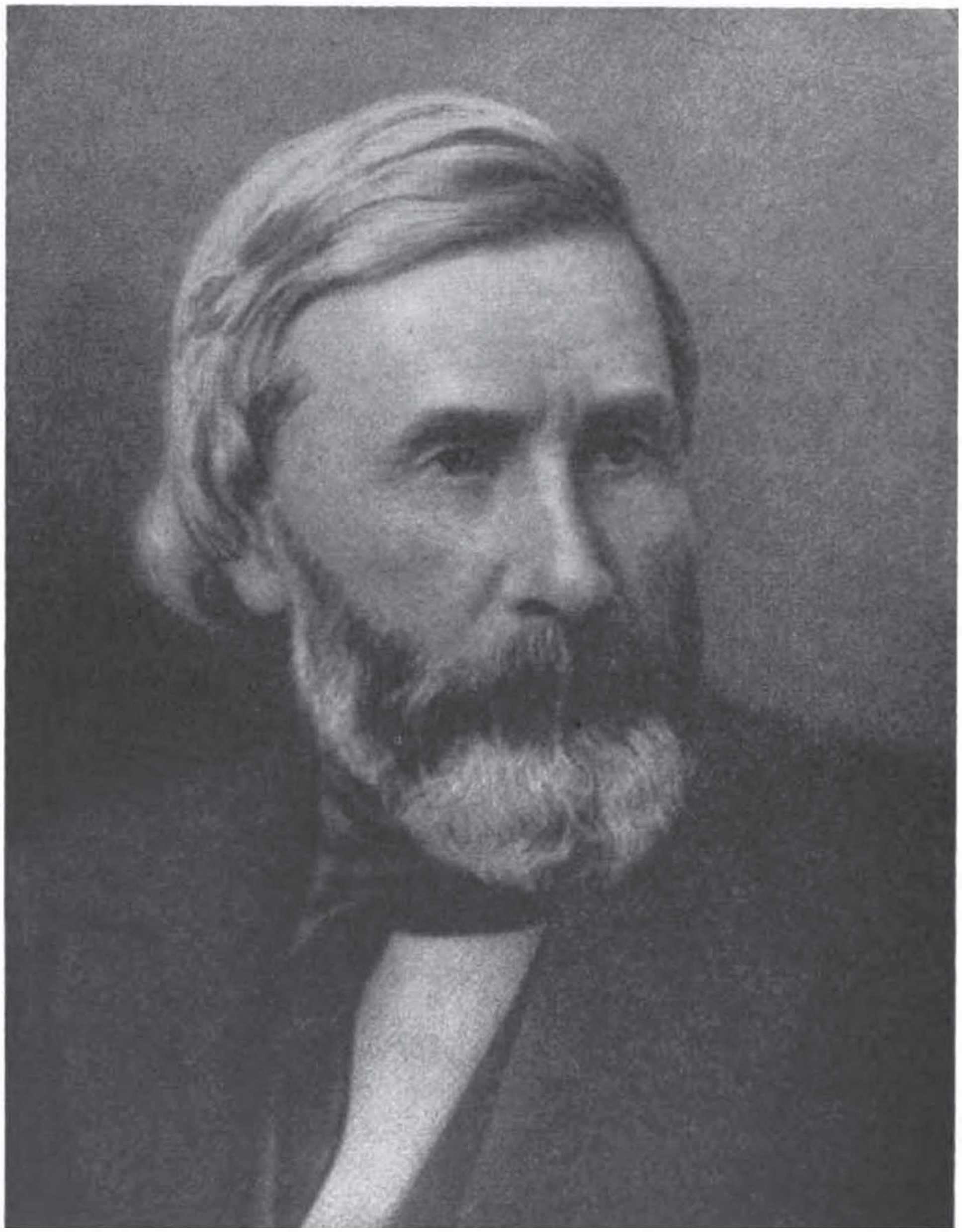

FIG. 31. JAMES P. KIRKWOOD (1807–1877)
Engineer who designed first successful slow sand filters in America for Poughkeepsie, N.Y., 1872; author of early treatise on European filtration practice; second president of American Society of Civil Engineers
(From "Early Presidents of the Society," *Civil Engineering*, 6:338 (1936))

be more economically removed by sedimentation than by filtration. In fact, successful filtration presupposes sedimentation.

Abroad, wherever sole reliance had been placed on filtration it had failed, as in France, or had but partly succeeded, as at one of the London works. Settling reservoirs, writes Kirkwood, were being used more and more as a relief to filters at London, although recognition of their economy had come slowly. Besides reducing the load on filters they had become valuable expedients for water storage, especially on the Lea, or New River works of London. At Liverpool, Leicester, Edinburgh and Dublin the large valley reservoirs required to store compensation water for mill owners served also for presedimentation.

Of the five "natural filters" or filter galleries seen by Kirkwood, three were in France. To him these seemed to be as satisfactory as the filter plants of that country were unsatisfactory. Any deficiencies in the galleries were in quantity rather than quality of product.

Kirkwood virtually sums up the best practical points of the filter plants he had visited by presenting in a short text and two plates a design for filters at St. Louis. He assumed, on the basis of experiments, that 24 hours' detention in settling basins were enough and that four basins should be provided: one for filling; one for settling; one for decanting; and one being cleaned. He assumed a rate of filtration of nearly 3.4 mgd. per acre, allowing for the area out of service for cleaning. Having remarked previously "that the English filters are all deficient as regards any arrangement for measuring the precise flow from each filter or the precise head on each filter while it is in action," he provided in his St. Louis design a small well at the end of the main drain of each filter, a sluice gate working downward, with the top of the sluice acting as a weir, thus indicating the head on the filter and its yield.

On the quality of water in relation to health, Kirkwood says little. He presents the prevalent theory that, by filtration, water cannot be "dispossessed" of any "noxious gases which may have . . . [been] absorbed" from sewage pollution, "nor of some of the very minute organisms due" to pollution. Besides the inadequate knowledge on these subjects at that time, it should be remembered that Kirkwood's instructions in December 1865 were "to proceed at once to Europe and inform himself in regard to the best process in use for clarifying river waters used for the supply of cities, whether by deposition alone, or by deposition and filtration combined." His commission was well executed, but St. Louis, as has been pointed out, had rejected filtration before Kirkwood's return.

Poughkeepsie and Hudson, N. Y., employed Kirkwood as filtration engineer in the early seventies and he was consulting engineer for the water works at Lowell and Lawrence, Mass., both of which included filter galleries, but with these contacts his filtration work ended.

An American Pioneer on Quality of Water.—Professor William Ripley Nichols of the Massachusetts Institute of Technology was for some years the leading American authority on the quality of water supplies. In 1878 he contributed a long review of filtration to the annual report of the Massachusetts State Board of Health (12). In it he set forth clearly and simply the theory and practice of "natural" and "artificial" filtration (infiltration galleries and slow sand filtration) at home and abroad. It contains a notable section on algae in reservoirs and the resultant tastes and odors. His conclusions were:

Sand is the only practical medium for large-scale filtration.

There is as yet no evidence that sand filtration will efficiently purify polluted water, although, properly carried out, it will "lessen the liability of ill effects."

All visible suspended and an appreciable part of dissolved organic matter may be removed by sand filtration.

For the present, artificial filtration should be regarded as a means of removing suspended matters only, "although under the management of a person of intelligence, education and experience, the simple sand filter is capable" of reducing the organic matter. Such management cannot be expected in ordinary practice. Removal of color and taste, in the light of experience, should be regarded as incidental, varying much with the condition of the filter.

It would not be worth while for a town to build sand filters, he continues, unless it were willing to spend enough money in construction and operation to make the scheme efficient. Requisites for efficiency include ample settling basins; at least duplicate filters, which should be covered; frequent cleaning and renewal of filtering material; and covered clear-water reservoirs, which should be emptied and cleaned if required. Finally, says Nichols, no town should undertake artificial filtration unless it is willing to face the possibility of spending $2.50 per mil.gal. for operation alone (12).

Much of the information and opinion in Nichols' essay of 1878 is repeated in his book of 1883 (13). This is the first American book devoted entirely to the sanitary aspects and the chemistry of water supply.

In 1884, Nichols was even more skeptical than in 1878 regarding the advisability of filtration for American cities. But he was chiefly concerned with the reduction of color, tastes and odors. His extensive experience as consultant had been chiefly confined to such waters as were found in Massachusetts and adjacent cities in New York. In the United States, he said, large-scale filtration was almost unknown, while in Europe filtration of surface supplies was general. The reason for this difference was usually attributed to the cost of filtration and the difficulties due to hot summers, and in Northern states, cold winters. When consulted, he had been deterred from advising filtration neither by cost nor climate, but by the fact that experiments, by himself and others, and experience at existing works had convinced him that sand filtration would not remove the color generally affecting American surface supplies nor the disagreeable tastes and odors to which they are liable. Although carefully conducted sand filtration can improve such supplies, Nichols doubted whether it was worth the cost, especially if it were unsatisfactory at the season when most necessary (14).

Fanning's "Water Supply Engineering."—Colonel John T. Fanning, who in the last third of the nineteenth century was dean of American hydraulic engineers, completed a large treatise on water works in 1876 and published it in 1877 (15). It was the first American treatise on water works to appear since Storrow's little book of 1835. Fanning reviewed the quality of water and noted that it was a vehicle for the spread of diarrhea, dysentery and typhoid. He summarized the chief means of water purification devised abroad, including plain sedimentation, coagulation by iron salts, the use of charcoal in filters, filters and infiltration galleries. He mentioned recent filter basins and galleries in America, and cited the filters recently completed at Poughkeepsie as the first of the kind in America. He emphasized the need of roofing filters against the effects of both low and high temperatures.

Croes on Filtration in America.—The possibilities and limitations of filtration as seen in 1883 by an engineer of large experience and wide observation were briefly stated in the introduction to a paper by J. J. R. Croes (16). The object of filtration then was to remove visible impurities. With clarification there was a limited reduction of chemical impurity. Processes of filtration applicable on a large scale, it was generally believed, "do not make a polluted water fit for use."

Fig. 32. Allen Hazen (1869–1930)
Author of first treatise on art and science of water filtration; Chief Chemist of Lawrence Experiment Station of Massachusetts State Board of Health during filtration experiments
(From photograph made during Hazen's period at the Lawrence Experiment Station (probably 1892); made available for use here by his son Richard Hazen)

The principle of filtration, Croes says, is that, by the slow passage of water through very small orifices, matters in suspension are deposited on the orifices. If the water is passed through rapidly or under great pressure, the sides of the orifices are washed clean. These words were written on the eve of rapid mechanical filtration. The paper is highly valuable for its brief descriptions of filters built in the United States and Canada up to its date. The descriptions were drawn from the author's *History and Statistics of American Water Works,* a series of articles that had been run in *Engineering News* from early 1881 until 1886 (17).

Lawrence Experiment Station.—Charged with the duty of giving advice on water supply and sewerage, the reorganized State Board of Health of Massachusetts established, late in 1887, the Lawrence Experiment Station. Its function was to study water and sewage treatment. This it is still doing in the 1940's. In 1890, the board published a special report (18). One volume dealt with the *Examination of Water Supplies;* the other, *Purification of Sewage and Water,* reviewed the experimental work at Lawrence. The experiments on water treatment centered largely on nitrification of organic matter by intermittent sand filtration, but much attention was also given to the reduction of bacteria. The early chemical results, including reduction of matter in solution, were better than the bacterial. At the outset of the experiments, the filtration rates were so low that they were worthless, but soon the rates were increased to a practical point and the bacterial results were considered satisfactory. On the basis of the results, a water filtration plant for the city of Lawrence was designed and built under the direction of Hiram F. Mills, engineer-member of the State Board of Health. The filter was put into use in September 1893. Here, as well as in the preceding experiments, nitrification of organic matter, particularly to reduce available food for bacteria, was considered of great importance, so intermittent filtration was used.

Time, it may be interjected, soon showed that, for water, intermittent filtration was a fallacious practice taken over from sewage treatment where oxidation of the large amount of organic matter to prevent a putrefaction nuisance was often demanded. True, the Merrimac River supply at Lawrence was heavily polluted. How this pollution compared with that of the Thames at London, Mills and his colleagues do not appear to have considered. At London, a high bacterial removal by continuous slow sand filtration had been demonstrated by Percy Frankland, shortly before the Lawrence experiments were begun (see Chap. V) but Mills did not know this or else disregarded it.

The opening of the Lawrence filter plant was followed by a marked reduction of typhoid in that city. This, and the prestige of the Massachusetts State Board of Health, established American confidence in filtration at a time when water-borne typhoid, endemic and epidemic, was taking a heavy toll; at a time, also, when American cities and water companies were at last willing to pay the cost of efficient purification.

Epochal confidence in water filtration was created in America by the Lawrence experiments and the city filter, and by the studies by Allen Hazen, Chief Chemist at Lawrence, of effective size and uniformity coefficients of sand grains and of frictional resistance to the passage of water through sand and gravel (19).

Hazen's Pioneer Treatise on Filtration.—Hazen's work at the Lawrence Experiment Station was soon followed by a trip to Europe where he studied the workings of many slow sand filters, including some of those visited by James Kirkwood 30 years earlier. Hazen's observations were embodied in his book of 1895. Kirkwood had gone abroad with little knowledge of the art of filtration at a time when the relation between water and public health was not understood. Hazen had the advantage of the greatly improved knowledge of his day. Kirkwood made a valuable report on his foreign observations but Hazen wrote the first treatise on the art and science of water filtration (20). The scanty treatment of rapid or mechanical filtration in Hazen's book is understandable in view of his previous connection with the ultra-conservative Massachusetts State Board of Health and the newness of mechanical filtration in 1895. This deficiency was partly remedied in the edition of 1900.

Reports and Journals.—In the last decade of the century came: the report of Edmund B. Weston, Assistant Engineer at the Water Department, on experiments with rapid and modified slow sand filters at Providence, R.I., but centering on one make of rapid filter (21); the classic report by George W. Fuller, Chief Chemist and Bacteriologist, on tests of rapid filters at Louisville, Ky. (22); Hazen's report on tests of slow and rapid filters at Pittsburgh (23); and a second report by Fuller, this one describing tests at Cincinnati of modified English slow sand filters and of American or rapid filters (24). These were forerunners of many later reports on municipal filtration experiments conducted by skilled engineers, chemists and bacteriologists, unrivaled in scope and importance elsewhere in the world.

New means for disseminating information on water purification among water works engineers and superintendents were provided in the seventies and eighties by the organization of the American Water Works Association (1881) and the New England Water Works Association (1882), each with its published proceedings, and by the establishment of engineering journals which devoted much of their space to water works problems and progress. These, with the proceedings of national engineering, chemical and bacteriological societies, made available the latest ideas and accomplishments in the art and science of water purification, in striking contrast to the paucity of information in the first half of the nineteenth century.

Early Makeshifts and Failures

Makeshift Filters or Granular Strainers.—After the failure of the upward-flow filter at Richmond in 1832, no further attempt at large-scale filtration was made until about 1870. In fact, diligent search disclosed no filter installation of any kind or size until 1849. Then came various devices that at best were only rapid, granular strainers. Structurally, these were cribs, boxes, chambers, trenches and banks. Media employed, singly or in combination, were sand, gravel, charcoal and sponge. More pretentious and more efficacious were the filter galleries and some of the later upward-flow filters.

Altogether 51 filters of various types were built in the United States and Canada in the period 1849–93. Roughly these were divided as follows (16, 17, 25, 26):

Filter Cribs: Eleven, built from 1849 to 1882, beginning at Kingston, Ont.

Charcoal, Sand and Gravel Filters: Sixteen, built between 1855 and 1893, the first at Elizabeth, N.J., and followed at Elmira, N.Y., in 1857, and at Stockbridge, Mass., in or about 1862. The different media at Stockbridge were separated by perforated tile. (Not counted here are some of the upward-flow filters.)

Sponge, Charcoal and Sand Filters: Eight, in the period 1875–82, the first at South Norwalk, Conn. All but one of these were designed by William B. Rider of that town. Raw water passed laterally through the sponge and charcoal into a small chamber. The eighth filter in this class was built at Hannibal, Mo., in 1882. Water passed through

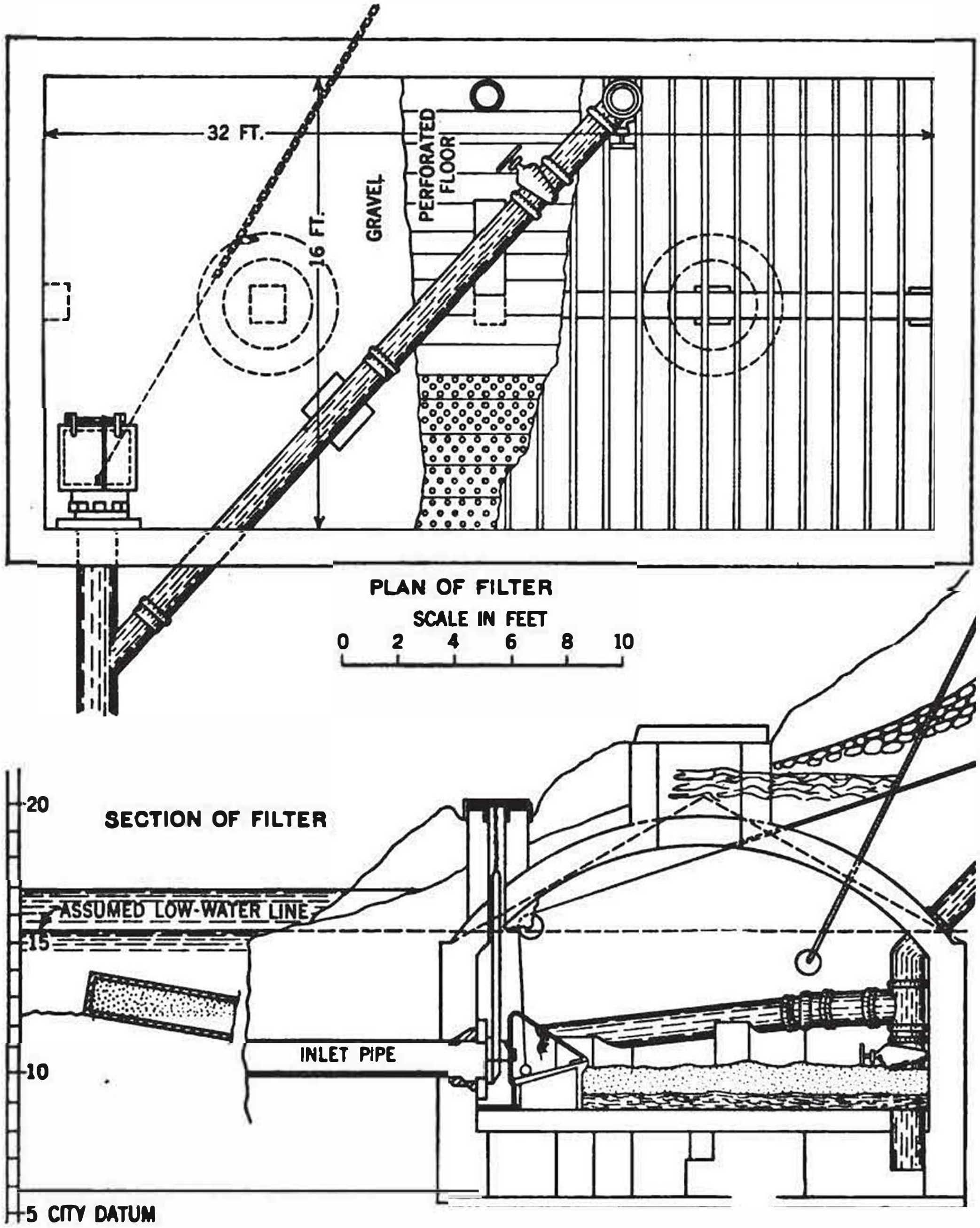

FIG. 33. MINIATURE SLOW SAND FILTER AT MARSHALLTOWN, IOWA, 1876
One of the earliest filters west of the Atlantic seaboard states; designed by T. N. Boutelle, engineer
(From original drawing supplied by H. V. Pedersen, General Manager, Marshalltown Water Works)

3 ft. of sponge and 2 ft. of sand and gravel before reaching the pump well.

Filter of Sponge Only: One, at Alton, Ill., in 1882.

Sand or Sand and Gravel Filters: Fifteen, built between 1866 and 1883. The first of these was built at Annapolis, Md. Water was passed through 3 ft. of sand and gravel into a "brick trough" located 3 ft. beneath the bottom of the reservoir. The trough was covered by wooden slats ½ in. apart. At Carthage, Mo., in 1882, a relatively large filter was provided. It was 25 x 50 ft. and 12 ft. deep. At Clinton, Iowa, in 1874, sand and gravel were placed in boxes which could be raised for cleaning. At Marshalltown, Iowa, in 1876, a miniature slow sand filter was built. It was 16 x 32 ft. in plan, roofed by a masonry arch. Its engineer was Thomas N. Boutelle, who two years later designed a covered upward-flow filter for Burlington, Iowa.

Abortive Attempts at Filtration.—Nearly all the filters of charcoal, sponge and sand just reviewed were small. However useful or useless they may have been, they served for a time and doubtless were pointed to with pride. In striking contrast were a half dozen large-scale abortive filter projects dating from 1871 to 1893.

The first of these, completed late in 1871 at Providence, R.I., was a large infiltration basin (see below). Also in 1871, Columbus, Ohio, completed a filter. It had an area of 8,742 sq.ft. and consisted of 7 in. of sand on 47 in. of broken stone. In 1873, at Springfield, Mass., an elaborate set of lateral-flow excelsior filters, placed in tiers of crates which could be lifted for renewal, came to grief as soon as put into use (see below). At Toledo, Ohio, in 1875, a single filter, instead of the three (with presettling reservoirs) planned by the engineer to treat water of the turbid Scioto River, soon clogged up. In 1880, at Brockton, Mass., 55,000 sq.ft. of the bottom of a reservoir on Salisbury Brook were prepared to act as a filter by laying 4-in. drain tiles 8 ft. apart, 30 in. below its bottom. The yield was so impregnated with iron that it was never utilized. In 1887, at Easton, Mass., a similar reservoir was completed but never used. In 1893, the water company at Wilkes-Barre, Pa., built a filter in a recently constructed impounding reservoir to alleviate complaints of taste and odor. The unit had an area of 12,000 sq.ft. It was supported on planks 2 ft. above the bottom of the reservoir. On the planks was a 10-in. layer of 2-in. broken stone, covered with 6 in. of river gravel and topped by only 4 in. of Long Island sand. From this, the water passed to and through a chamber 6 x 6 ft. in plan, containing two trays of animal charcoal 1.5 ft. deep above 3 ft. of coke. In 1895 the company installed a 10-mgd. rapid filtration plant (27).

Filter Projects Never Executed

Eleven cities in the United States and one in Canada considered filtration between 1836 and 1876 without a single adoption. In some cases the process was only mentioned as an undesirable possibility.

Boston, June 16, 1836.—Robert H. Eddy, a civil engineer, in a report on possible sources of water supply (28), advised going far enough afield to get water that would not need filtration—a doctrine followed by Boston from that day to this.

Pittsburgh, Pa., October 1847.—A communication from J. H. Laning, of Cincinnati, "on the subject of a smoke consumer and water filterer" was laid before the common council. The portion on the smoke consumer was referred to the special committee on that subject and the balance to the water committee. The select committee concurred. That seems to have ended the matter.

Albany, N.Y., 1849 and Later.—George W. Carpenter, a civil engineer, reported on May 14, 1839 (29), on a possible supply from the Hudson River and assumed that it would be passed "through a coarse filtering bed to free it from such materials as might injure the pumps." W. J. McAlpine, a civil engineer, in a report August 3, 1850, advising a supply from Patroon Creek, answered objections to its hardness and frequent turbidity by saying that there was no remedy for hardness, but that turbidity "can be easily corrected either by filtering the water or by extending the pipes to the upper pond," enlarging it and building a division wall to form a settling basin (30).

Philadelphia, 1853–54.—On October 27, 1853, the city council directed its watering committee "to inquire into the practicability of erecting at Fairmount a filter of sufficient capacity to filter all the water (from the Schuylkill River) before it enters the distributing system." This action resulted in a notable engineering report by Frederic Graff, superintendent of water works, supplemented by a report by two chemists (31). The studies resulted in the conclusion by all hands, including the watering committee, that filtration was unnecessary. After mentioning some of the London filters and their chemical results and comparing analyses of the water being supplied to Philadelphia with that of a number of other American cities, Graff declared: "I am fully convinced that no adequate result can be obtained by the enormous expense which it would be necessary to incur in building and keeping in order such large filter beds [717,392 sq.ft.] as we should require, and probably the certainty of constant supply and efficiency of the works might be impaired by such troublesome and expensive and, I think, needless apparatus." The Watering Committee reported to the city council on May 3, 1854, that, in the light of the analyses presented, it was "perfectly satisfied with the extraordinary quality of the Schuylkill water" and that there was "no necessity whatever for its filtration."

Trenton, N.J., About 1856.—The Tenth Census of the United States, in data gathered about 1881 regarding the water works of Trenton, listed a filter "50 x 60 ft. in area; tile at bottom, 4 layers of gravel" (25). A report made on May 3, 1856, to the directors of the water works stated that construction of a filter, apparently in a reservoir then nearly completed, was proposed. No record of such a filter has been located in city offices and libraries in Trenton.

Chicago, 1860–63.—On March 7, 1860, the water commissioners passed a resolution requesting E. S. Chesbrough, Chief Engineer of the Sewerage Board, "to submit a project and estimate for extending the inlet pipe so far out into the lake that the water obtained shall be free from the wash of the lake shore and the flow of the [Chicago] River." On February 25, 1861, Chesbrough reported: "In order to obtain pure and clear water at all times it is proposed to construct a filter bed at the east end of the lot on which the present pumping works stand." He proposed to inclose his filter by a cofferdam 1,400 ft. in circumference. He envisaged winter difficulties in cleaning the filter. As an alternative that would serve for a time he considered a 40-mil.gal. settling reservoir, inclosed by cribwork. In conclusion, he advised postponement of construction until after further studies with the aid of chemical analyses (32).

In 1862 or 1863, consideration was given to building a "filter trench" or gallery 3,000 ft. long, carried 10 ft. below lake level. Skepticism as to its success prevailed. Decision to build a new lake-intake tunnel was made (33). Subsequently longer and larger lake tunnels were built; a huge pumping station was erected to divert a part of the sewage-laden Chicago River into the Illinois & Michigan Canal; the

Chicago Drainage District was created and the Chicago Drainage Canal was built for more extensive diversion and dilution of the sewage; then several immense sewage treatment works were constructed to lighten the burden of disposal by dilution. At long last a program of water purification was adopted (34). A 320-mgd. unit was under construction in 1942, but when the entire one-billion-gallon filtration program was finished nearly a century had elapsed since water filtration was proposed but rejected.

Cincinnati, Ohio, July 3, 1865.—Filtration was proposed by James P. Kirkwood in 1865 but apparently his advice was not given serious consideration (35). Rapid filters were completed in 1907.

St. Louis, Mo., 1865–66.—James P. Kirkwood's relations with the St. Louis water commissioners and their rejection of filtration has been described above. Subsequent events are reviewed below.

Oswego, N.Y., September 1866.—Filtration was considered but dismissed on the ground that sedimentation would suffice, in a report by William J. McAlpine (36). Water from the Oswego River, he said, was sometimes too turbid for domestic use but, as the quantity required for drinking, cooking and washing would not be 10 per cent of the water pumped, it would be cheaper to have a filter in each house. Or, if desired, water after standing a few days in the storage reservoirs "might be run through a large filter for a few specified hours each day," after which each family could draw off and store enough water for a day. Such a filter would not cost much but was not included in his estimate. Filters of gravel and sand, with a capacity of 1 mgd., were "in constant use at Kingsford's Starch Factory," * wrote McAlpine, yielding "beautifully clear" water (37).

Schenectady, N.Y., February 1, 1868.—In a report advising a supply from Sand Creek, William J. McAlpine says that the Bonnie Kill plan would require "filter beds; and even then the works will not [give] water as pure as in the accepted plan" (38). A supply from a filter gallery was introduced in 1871 (see below).

Manchester, N.H., November 23, 1869.—"A set of expensive filtering apparatus" comprising three units of ¼-acre each would be required

* The Kingsford Starch Works were established in 1848 by Thomas Kingsford, who came from England shortly before then. Filters were in use in 1850, and probably in 1848. Thomas Kingsford III stated in 1940 that he could find no data on the filters except that they used a large quantity of charcoal and sand (37).

for a supply from the Merrimac River, reported J. B. Sawyer, a civil engineer, to the City Aqueduct Co. He advised Lake Massabesic instead (39). Later, the city built works drawing on that source.

Lowell, Mass., Summer of 1869.—After reviewing the various possible sources of supply, including the Merrimac River, either settled or filtered, J. Herbert Shedd, a civil engineer from Boston, recommended Beaver Brook, without treatment (40). Experiments with settling and with filtering Merrimac River water led to the conclusion that if that source were adopted filtration would be preferable to sedimentation because of the necessity for large and costly settling reservoirs. The authorities proposed to build a settling basin and filters, then a settling basin only, but soon built a filter gallery, instead. In 1876, a filter, feeding into the gallery, was built beside the river (25). Mechanical filters were considered at length by the water board in 1888–90 but were not adopted (41). A decarbonation, iron-and-manganese removal plant, including rapid filters, to treat water from driven wells was completed in 1915.

Detroit, August 15, 1874.—George S. Greene of New York City and G. Weitzel of Detroit recommended the construction of two filters, at an estimated cost of $370,000, with others added for each 100,000 increase in population. The size and character of the filters was not stated. Instead, a settling basin was built. In 1923 rapid filters were completed.

Montreal, March 23, 1876.—At the suggestion of some of the members of the water committee, Louis Lesage, Superintendent of Water Works, "was directed to study the question of filtering basins and to prepare plans, with an estimate of cost." This he did but he concluded that it would be sufficient to provide a settling reservoir with a capacity for a few days' detention to clarify the water of the St. Lawrence when turbid in the spring (42).

Laggard Growth of Slow Sand Filtration

No successful slow sand filters for city supply were built on this side of the Atlantic until 1872, 40 years after the earliest ones had been constructed in England and fifteen years after they had been put into use in Germany. At the close of 1900 there were approximately twenty slow sand filters in the United States and five in Canada. Even then they were far outnumbered by rapid filters. In 1940 there were about

100 slow sand filtration plants in the United States as compared to about 2,275 rapid filters. All in each class had hygienic purification as their primary objective. In addition there were a few slow sand filters, many rapid filters and still others variously classified or unidentified in purpose (43).

Canada, in 1940, had about twelve slow sand and 120 rapid filters.

Poughkeepsie, N.Y.—Poughkeepsie, a city then having a population of 20,000, built the first slow sand filter in America. The filters were part of the first complete water works system of Poughkeepsie, put into use late in 1872. Creditable as the plant was for the time and place, it was but a simple beginning. Most notable of the changes which have taken place since are the adoption of coagulation, chlorination and prefiltration.

Poughkeepsie's filter plant is the more notable because through all these years it has treated one of the most polluted and potentially dangerous water supplies in the world; and because the Hudson River was adopted as a source of supply by the water commissioners of the day against the advice of their engineers, chief of whom was James P. Kirkwood, the father of slow sand filtration in America.

In 1855 a report on four possible sources of supply was submitted to a special water committee by William McCannon (44). He recommended near-by Morgan Pond. Its only rival, in his opinion, was the Hudson River, but it was objectionable because of turbidity during spring freshets and "brackishness during a long-continued south wind," especially at low stages of the river. Turbidity could be overcome by a settling reservoir but there was no cure for brackishness. No positive action was taken until 1869, when under legislative authority "an overwhelming" popular vote was cast in favor of building works and of a water commission created for the purpose (45).

In its first report (February 7, 1870), the commission said that before appointing a construction engineer they had engaged James P. Kirkwood as consulting engineer and W. Davis as resident engineer (46). In company with these engineers, the commissioners had visited the available sources of supply. The waters of the Hudson River, Fallkill, Crum Elbow and Wappinger's Creek had been chemically analyzed.

Strangely, although reports by both Kirkwood and Davis had been received and the latter was printed at length, the commission passed over Kirkwood's report with the statement:

Mr. Kirkwood says in his report now on file: "My opinion at present is in favor of the Fallkill as on the whole the best. . . . The water appears excellent. The larger part of the water, and probably all of it, could be delivered by gravity" (46).

Not a word on what their consulting engineer said about the Hudson! Thomas Lawlor, Director of Public Works, wrote in 1935 that the Kirkwood report has never been found although a very diligent search was made over a period of years (47).

Davis's report of January 31, 1870, was chiefly a categorical account of his surveys of the sources of supply considered but it contains this significant remark on the Hudson: "The water, if taken from this source, to free it from mechanical impurities will have to be passed through filters." Nothing is said about pollution (46).

In marked contrast with this weak remark by Davis, was the strong condemnation of the Hudson in the first report made by the chief engineer, J. B. G. Rand, on April 12, 1870 (48), two months after the report of the commission. Rand submitted cost estimates for a water supply from the Fallkill, the Hudson River and Wappinger's Creek. The purest water of the three was the Fallkill. Wappinger's Creek was hard and polluted by chemical refuse. As to the Hudson River, Rand declared that:

———regard for the recent taste of the people would prevent us from taking water from any source which has received sewage, and might therefore contain the living germs of cholera, typhoid fever, dysentery, tape worms, etc., without using every reasonable means to guard against them—the question is not so much—is the water wholesome now, as what will be its condition in the future. . . . I know no means of getting rid of this noxious matter on a large scale. By careful filtration large quantities may be greatly improved, but not entirely freed from the poison (48).

Settling basins, but not filters, were included in Rand's estimates for a supply from the Hudson River. His intake location (subsequently adopted) was presumably chosen to avoid direct pollution by the sewage of the city, but was subject to tidal influence and to the discharge from a projected State Hospital outlet sewer.

A stand against taking a supply from the Hudson was made by the Poughkeepsie *Daily Eagle* in the summer of 1870, as extracts from editorials of the period indicate:

July 30, 1870: The Water We Are Expected to Drink.—The opinions of all the engineers who had examined the subject—Mr. Kirkwood, Mr. Davis and Mr. Rand—gave decided preference to the Fallkill.

August 27, 1870: THEY HAVE DECIDED. . . . Previous to their decision, the matter had been discussed pro and con in the newspapers but we had no official word from the commissioners or their agents, except the reports of the engineers, Messrs. Davis and Rand. Both these showed plainly that the Fallkill was in their opinion the best source of supply. . . . Mr. Rand [held that the river was] almost out of the question. Mr. Kirkwood, the best authority in this country on hydraulics, agreed with Mr. Rand on all points and was in fact the advising and consulting engineer in the whole investigation. . . .

At a subsequent meeting of the Board a member moved that Mr. Kirkwood be requested to give his opinion in writing as to the sources of supply, but the majority promptly voted down the motion, thus in effect declaring that they were determined on river water or nothing, right or wrong, no matter who or how many advised another source. . . .

There must have been some reason why the opinions of all the engineers and chemists should have been disregarded and a conclusion in direct opposition to their advice should have been adopted (49).

Despite the black picture of the Hudson, Kirkwood's recommendation of the Fallkill, and the opposition of the *Daily Eagle,* the water commission reported on February 1, 1871, that "after mature deliberation" it had chosen the Hudson as the source of supply (46). It was maintained that, with filters, the cost would be considerably less than with a supply from any other possible source. Moreover, "analyses and practical tests prove the Hudson to be of superior quality."

Kirkwood resigned as consulting engineer December 31, 1872. How much of a part he took in designing the works and how much of it was done by Rand as chief engineer the reports of the water commission do not disclose. Fowler, who wrote in 1888, after having been in charge of the works for seventeen years, gave full credit to Kirkwood.

The treatment plant, as described in the water commissioner's report for 1872, consisted of a small inlet basin intended for the deposit of "heavier particles of mud"; two filters, having an area of ⅓ acre each; and two small clear-water basins, operated in series. The depth of the filters was 72 in., with 24 in. of sand; 18 in. of gravel graded ¼ to 1 in. in size; 6 in. of 2-in. broken stone; and 24 in. of 4- to 8-in. stone "fragments." The cost of the treatment works, including land, was $76,915. The works were put into use about December 1, 1872.

The filters were used intermittently for several years, according to the condition of the river water. In 1875, they were used a total of about six months, except when being cleaned; in 1876, almost constantly. In the next two years the entire supply was filtered, except when stopped by ice or algae. The report of the commission for 1878 states: "The consumers, accustomed to drink filtered water, will accept nothing else; nor will they accept any . . . complication of circumstances" for the non-use of the filters (46).

Tastes and odors due to organic growths seem to have given trouble from the start. To obviate these, Davis, in the summer of 1875, began the practice of bypassing the filters when the temperature of the river water rose to 70°F. and tastes and odors could be detected in the water in the distribution system.

Davis, who was resident engineer in constructing the works and became superintendent in 1871, was succeeded in 1881 by Charles E. Fowler, who continued in office until his death January 4, 1908.

When Fowler took office in January 1881, he found the filters not in use because a heavy coating of ice made cleaning difficult. The ice was removed and the units restored to service, after which all the water supplied to the city was filtered up to April 1892 (50). Three times in the early winter of 1895, 500 tons of ice were removed from the filters. On the third occasion, the sand froze and the cleaning took 24 men two days (51). In 1903, an elevator was installed in the new filters to help remove ice.

In several of his annual reports (46), Fowler noted trouble from algae growths on the filters. From August to September 1889, these required constant attention and the labor of two men. From July to October 1891, algae growths stopped filtration within ten or twelve days after they appeared and in another period within seven days. In 1891, the two clear-water basins were covered with wooden roofs to exclude sunlight and dirt.

On December 17, 1896, after the filters had served 24 years, a large unit in two equal compartments was added, bringing the area up to 1⅓ acre. The top layer of the new filter was 31 in. of Long Island sand. This rested on gravel, below which was broken stone. At the bottom, 6-in. tile underdrains were laid. Until June 1, 1897, both old and new filters were used, but the new one did nearly all the work. The old ones had become so compacted that they passed but little more water after than before cleaning. The 15 in. of sand had become clogged throughout. Sand had been carried down to the bottom of the 4 ft. of gravel and stone. The sand was removed down to the gravel and 30 in. of the new sand put in. Although Fowler had advised roofing the filters years before, construction was not authorized until 1904. The new units were covered and in use in November of that year and the old ones in August 1906. Groined concrete arches were used to cover the filters and to replace the wooden roof of the clear-water basins.

In a paper read in 1898, Fowler said (51) that when he took charge of the filters in 1881, the dirty sand was cleaned by passing it through two 12-ft. troughs containing running water. In 1886, a trough 200 ft. long was substituted, reducing cost of washing from $2.50 to $0.61 per cu.yd. In 1892 he installed a "hollow tank," with motor-driven perforated revolving arms, whereupon cost was $0.64 per cu.yd. In 1895–96 cost was reduced to $0.54 by introducing a jet washer. In March 1897, use of a double jet reduced cost to $0.24 per cu.yd. In 1914, the primitive method of loading sand into barrels and wheeling it out gave way to removal by ejectors. The following year an ejector system of washing the sand thus removed was adopted (52).

The first chemical analyses of raw and filtered water at Poughkeepsie were made in November 1887 by Professor William Ripley Nichols. Similar analyses were made by Professor Thomas M. Drown in 1889 and 1891. These analyses, said Fowler (51), showed reductions in albuminoid and free ammonia and thus a "material increase" in filter efficiency between 1887 and 1891. Two bacterial counts reported by Professor Drown in 1891 showed a reduction from 1,160 in the raw to 62 in the filtered water in one case and from 1,576 to 34 in the other, or 95 and 98 per cent. But in January 1892, a reduction of only 82 per cent was noted. Four sets of bacterial counts made by D. B. Ward, M.D., before the filters were enlarged, were given in the annual report for 1896 (46) thus:

	Raw-Water Inlet Basin	Clear-Water Basin	Percentage Removed
February 14	1,064	736	31
February 26	80	50	37
May 22	102	32	68.6
June 5	4,016	85	97.8

In 1898, after two filters had been added, Dr. Ward made twelve bacterial counts. The range shown was: inlet basin, 27,000 to 4,200 per ml. on November 10; percentage removal by old filter, 99.7 on January 6 and 73.33 on November 12; new filter, 99.36 on February 4 and 88.76 on December 12, the respective counts before and after filtration being 13,950 reduced to 88 and 2,240 reduced to 272.

A coagulating and settling basin, with in-and-out baffles, was put into use December 27, 1907, a few days before Fowler died. A coagulant was used intermittently until 1929; since then continuously. Another important event of 1907 was cutting out the connection through which the filters had sometimes been bypassed.

A rapid or mechanical filter of the high-pressure type was given a trial at some date before Fowler wrote his paper of 1892 (50). The result during a period of turbidity, using alum as a coagulant, "was clear, bright water, but the quantity of alum required was not only very great but an appreciable amount was left in the effluent." (This may have been because of low alkalinity of the water.)

In the same article Fowler noted that the "Anderson process" would be given a trial in connection with the filters in the hopes that it would produce a colorless water and remove the clay turbidity that sometimes clogged the beds. Annual reports of the water commission for 1892–94 (46) show that mechanical difficulties and illness of the engineer in charge of the "revolving purifier" (to produce comminuted metallic iron coagulant) prevented a test of the process.

A drought beginning in the summer of 1908 reduced flow in the Hudson to such an extent that the salt water line had reached upstream to Poughkeepsie by early fall, resulting in a perceptible salty taste in the drinking water. When winter cured that ill, it brought another, for the river froze over and began to yield a raw water "concentrated with sewage, but with no turbidity," rendering both sedimentation and coagulation processes ineffective. And when the filters also failed to respond to any treatment, significant bacterial counts were soon encountered in the filter effluent.

To meet this situation, George C. Whipple, as consultant, recommended the application of chloride of lime in place of alum. Thus, on February 1, 1909, by means of the coagulant apparatus, chloride of lime was introduced into the low-lift pump suction line. By February 12, a temporary dosing appliance, consisting of two barrels and a "regulating box," permitted transfer of the application point to the inlet of the sedimentation basin. And on March 17, 1909, in view of the notable success of the process, regular chlorination was begun with a permanent apparatus (53).

Abandonment of the Hudson River for an upland gravity source of supply was considered by Allen Hazen in a report made in 1913. He thought the works capable of treating 5 mgd. for several years.

He outlined a plan for extensions during the next ten years, including additional coagulation basins and filters. Advisory control of the filters by Hazen's firm was begun in 1913 and continued until his death in 1934. Chester M. Everett and then Malcolm Pirnie succeeded Hazen.

Prefilters designed by Hazen, Whipple & Fuller were put into use early in 1920. They were of the rapid or mechanical type, in four units having a total area of 1,645 sq.ft., and a combined rated capacity of 4 mgd. The prefilters were duplicated early in 1928.

A simple aerator was installed in 1920 and a more elaborate one in 1926. The first aerator consisted of 1,000 ¼-in. holes drilled in the top of a pipe which discharged settled water into a basin before it passed to the slow sand filters. The second aerator, as described in the 1926 report of the chief engineer, Walter E. Walker, included 94 conically arranged nozzles throwing a fine, widely distributed spray. It received water from the prefilters under a low head before it went to the final filters. It was designed by Hazen & Whipple (46). Pirnie, then with that firm, described aerators of this type at Poughkeepsie, Providence and elsewhere (54). Removal of 40 to 70 per cent of carbonic acid gas (CO_2) was effected by the spray nozzles in 1931. A single spray nozzle, designed by Chester M. Everett, was used in the winter of 1932–33. It eliminated frazil ice but was only about 75 per cent as effective as the regular nozzles, wrote Cole, in the annual report of the water works for 1932–33 (46).

Later changes at Poughkeepsie included pre-ammoniation, tried experimentally in 1931 to keep down chlorine taste and odor in winter and algae in summer and soon adopted for regular use; use of lime to prevent the red-water plague in hot-water systems, begun in 1933; and black alum, tried in 1933 and put into use on a large scale November 30, 1934.

Raw sewage from the State Hospital was discharged into the Hudson River 2,000 ft. above the water intake for 60 years, but the state began to treat the sewage August 12, 1933. Although the year was half gone the count of bacteria in the river water for 1933 was the lowest in years, averaging 2,742 per ml., but ranging from 25,000 to 300. The range for coagulated and settled water in 1933 was 170 to 0, with an average of 3.4; prefiltered, 150 to 0, with an average of 3.8; laboratory tap, 4 to 0, with an 0.2 per ml. average. All *Esch. coli* samples from the laboratory tap were negative in 10-ml. and 1-ml.

samples (46). Turbidity and color reductions by means of coagulation, sedimentation and double filtration were notable. In July 1942, all 1-10-ml. raw-water samples were positive; settled-water samples ranged from negative for 1-ml. to 50 per cent positive for 100-ml. samples; double-filtered water showed less than 0.02 per cent positive in 100-ml. samples (52).

Typhoid deaths from 1881 to 1890 and cases and deaths from 1891 to 1935 have been compiled from various sources with the aid of Dr. W. H. Conger, Health Officer at Poughkeepsie (55), and Mr. Cole (52). The data are too voluminous for presentation here. Broadly, they show a heavy but erratic typhoid toll up to 1910 and a rapid decline to zero for the half-decade 1931–35. Improvement in the character of the water supply contributed largely to the reduction but data are not available for evaluating the factors. Without question, the rate would still be high if the water were not adequately treated.

This is the history of the first municipal slow sand filtration plant in America. Water treatment at Poughkeepsie has been from the start a struggle against heavy odds in which the engineer, the chemist and the bacteriologist have cooperated and triumphed.

Hudson, N.Y.—Two years after Poughkeepsie completed the first slow sand filter in America a second one was put in use by its up-river neighbor, Hudson, N.Y. That was late in 1874. Like Poughkeepsie, Hudson disregarded the advice of its engineers and pumped water from the Hudson River instead of taking an upland gravity supply.

In 1876 a joint stock association began delivering spring water to houses and to sidewalk cisterns equipped with pumps (56). After operating for 30 years as "proprietors of the aqueduct," the owners, under the name "Hudson Aqueduct Co.," by which they were commonly known, were granted a charter by the legislature. The company continued to supply spring water until 1908, when it was dissolved.

Water commissioners, appointed by the city council in 1872, engaged William J. McAlpine as engineer. In a report dated September 19 (57), McAlpine favored a gravity supply from Lake Charlotte rather than pumped and filtered water from the Hudson, which had been proposed by the city council. The lake, he believed, would give purer water than the river, with less likelihood of interruptions to service, but the capital and operating costs would be larger.

Contamination and defilement of the Hudson from the upriver towns and Erie Canal water were mentioned by McAlpine but he refrained from "any stronger expression of opinion" on the "river water, in deference to its practical use by your shipping for so many years without apparent injury."

In the event that a supply were to be taken from the river, McAlpine advocated a filter in the distributing reservoir, consisting of a "pyramidal mound" of stone covered with sand and gravel. A longitudinal passage at the bottom of the mound would contain supply, distribution and waste pipes and also a pipe for collecting the filtrate. Gates in a chamber outside the reservoir would control the pipe connections.

The water commission transmitted McAlpine's report to the city council in September 1872, with an endorsement of his plan for a gravity supply from Lake Charlotte. A referendum vote on May 7, 1873, on sources of supply stood: Hudson River, 184; Hudson Aqueduct sources (springs), 108; Lake Charlotte, only 67; aqueduct and river, 1; total, 361 (58).

On September 1, 1873, J. B. G. Rand was appointed engineer for the proposed works. He had been chief engineer of the new water works and filters at Poughkeepsie, completed late in 1872, and afterwards had visited filters in England and on the Continent. Water was admitted to the distribution system on November 1, 1874.

Water drawn from the Hudson River at a depth of about 8½ ft., at a point where the river was 35 ft. deep, was forced up the hill to a filter with an area of a little over 0.2 acre, then passed into an adjoining clear-water reservoir with a capacity of 3.2 mil.gal. The filter was 72 in. deep, as at Poughkeepsie, with practically the same depths and character of the various layers of media. In his report for 1874–75, Rand said that he had made plans for covering both basins, to prevent trouble and expense due to ice in winter and "aquatic plants" in summer (59). These were not adopted.

At the close of his report for 1874–75 Rand stated that a 10-in. gravity supply main from Lake Charlotte would cost less than $70,000, or $12,000 less than the capitalized cost of coal alone for pumping from the Hudson. The pumping plant at the river could be held in reserve for emergencies.

A second filter, with an area of 0.53 acre, was designed by Professor John Emigh, of the Rensselaer Polytechnic Institute, Troy, N.Y., and put into use in September 1888. Although provided with only central underdrains on each axis, Emigh proposed to clean the filter by reverse-flow wash from a central inlet, supplemented occasionally with surface scraping (59; report for 1887–88). The method proved unsuccessful.

H. K. Bishop, who became superintendent of public works in 1899, immediately pointed out the need for renovating the filters of 1874 from top to bottom, supplementing the central underdrains by laterals, and the need for more boilers and pumps as well. But why, he asked, should money be spent for improving, extending and operating the works at the river to force to an elevation of 310 ft. water polluted with the sewage of the city and of the towns and cities on the Hudson and Mohawk rivers when plenty of pure wholesome water could be found which would run downhill to the reservoirs? All things considered, a gravity supply of pure water would cost less per year than a pumped and filtered supply from the polluted Hudson (59).

A typhoid epidemic in 1899–1900 emphasized the need for safer water. In his report for 1901, Bishop, in urging action for a new supply, wrote: "The season is now approaching when we may expect to have the dreadful typhoid with us again."

But until 1905, Hudson continued to pay heavily in sickness and deaths for choosing and continuing the river as a source of water supply against the advice of successive engineers. For years the filters were not under technical control and no attempt was made by either the water or the health department to correlate the water supply with the abnormally high typhoid cases and deaths. Not until 1900 was such a study made, and then not by a city official. A young physician, who had graduated from a civil engineering course at Cornell, delved into the vital statistics of the city and presented before the local University Club a remarkable study, including figures for 1885–1900, of water supply and typhoid at Hudson (60). This was Clark G. Rossman, M.D., who became Commissioner of Public Works of Hudson in 1935 and still filled the position in 1941.

The primary reason for the heavy typhoid toll in Hudson, Dr. Rossman showed convincingly, was the pollution of the Hudson River by the sewage of up-river cities and towns, strongly reinforced by the sewage of the city itself. The filters were unable to cope with this pollution. Typhoid was higher in winter than in summer and autumn, contrary to general experience. The curve was highest when the winters were coldest and the river covered with ice the longest. The punishment was all the more severe because the filters were not covered and heavy ice prevented cleaning through the long winters. Thus the sewage-polluted water was least exposed to air and light when the weather was coldest. This coincidence Dr. Rossman established by records showing periods during which the river was closed to navigation.

His paper and the reports of Superintendent Bishop that followed, coupled with a steep rise in the typhoid curve, led to the introduction, in 1905, of a new water supply. C. C. Vermeule was the consulting engineer and Bishop was the chief engineer of construction. The Hudson River pumping station was shut down late in the year. The new supply was delivered into one or both of the existing filters. Eventually the old one was converted into a reservoir.

Late in 1941, J. McClure Wardle, Superintendent of Public Works (61), wrote that since 1934 the water had been pretreated at the storage reservoir with chlorine and ammonia to extend the filter runs from six weeks to six months, thus permitting filtration throughout the winter. Postchlorination and postammoniation gave what for a time were considered good results, but, when it was found that during the summer months bacterial counts were sometimes high and gas formers were present, free residual chlorination was adopted. That has practically eliminated gas formers and brought the total bacterial count down to reasonable proportions.

The typhoid rate reached its worst in 1904 with 152 cases, 17 fatalities and a death rate of 167.1 per 100,000. After the abandonment of the Hudson, the rate dropped rapidly. Doubtless other causes than the quality of the water were responsible for much of the typhoid before and after the date of Rossman's paper, but what the typhoid rate would have been if the river water had been used unfiltered is appalling to contemplate.

St. Johnsbury, Vt.—The third slow sand filter in America was completed late in 1882 by the St. Johnsbury, Vt., Aqueduct Co. After functioning more than a dozen years it was replaced in the nineties by the earliest of the picturesque group of circular filters with steeply pitched roofs which catch the eye of tourists passing from St. Johnsbury to Littleton in the White Mountains of New Hampshire. All these filters treated water from Stiles Pond, introduced in 1827 to supplement a still earlier supply from springs. At the start, the pond water had been passed through a "filter" in a bulkhead. A filter of coarse sand only 400 sq.ft. in area and 15 in. deep was provided. In 1882 a much larger unit was built alongside the small one and the latter was reconstructed. The two units had an area of 2,101 sq.ft., and a depth of 30 in.; 18 in. "finest sand" on top, then 6 in. of fine and 6 in. of coarse gravel (62).

In 1895 the company built a slow sand filter 50 ft. in diameter. To this there were added two of the same size in 1897 and a fourth in 1912 (63). These were built after plans by E. H. Gowing of Boston

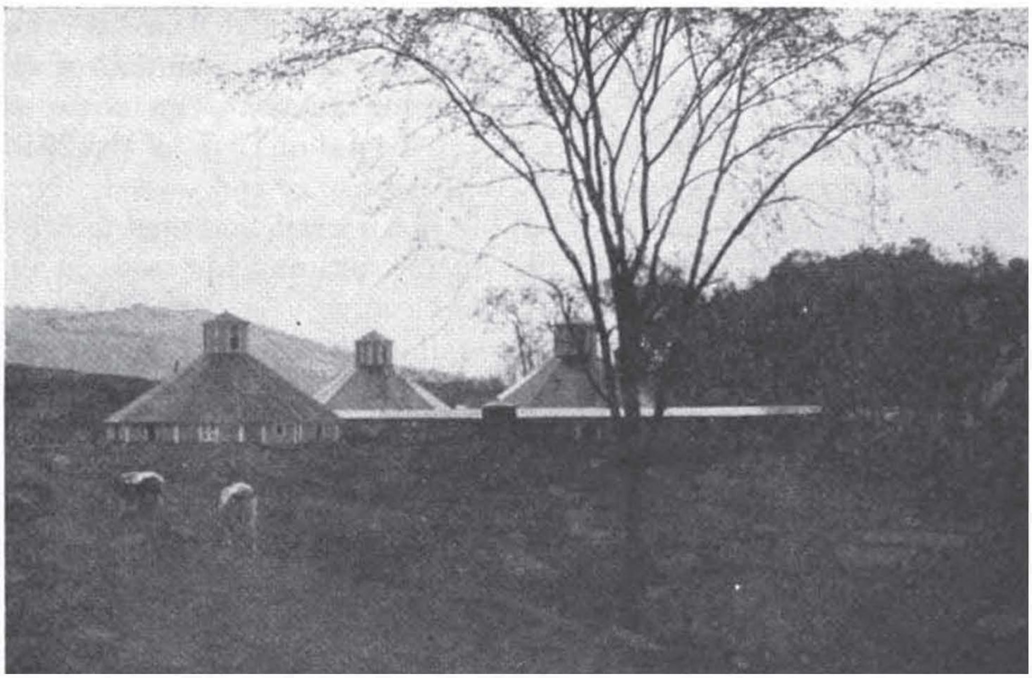

FIG. 34. COVERED SLOW SAND FILTERS AT ST. JOHNSBURY, VT.
Three of four filters built by the village in 1895–1912 to supersede private company filters of 1882
(From photograph supplied by R. C. Wheeler, Barker & Wheeler, Engineers)

(64). Their combined area was 7,850 sq.ft., or nearly 0.18 acre. These filters were still being used in 1942. The filters of 1882 were abandoned about the time the first circular filter was completed.

The round filters were inclosed in a twelve-sided building having a pyramidal roof (65). The inside of each building—sides, roof down to the ceiling, and ceiling—was sheathed with 1-in. unmatched boards. Doors and windows were double. In 1934 during excavations for a new pipeline, a 13-in. brick wall was found. This probably inclosed the filter of 1882 (66), which was rectangular and was also inclosed in a wooden building (65).

The need for inclosing filters at St. Johnsbury will be apparent to those familiar with winter temperatures in the Passumpsic River Valley. United States Weather Bureau records show average monthly temperatures at St. Johnsbury for the 27 years 1894–1930 for the four winter months as: December, 20.7°F.; January, 15.7°; February, 16.8°; March, 22.8°. By single days the lowest temperatures were: November, —13°; December, —43°; January and February, each —38°; March, —22°; and, for good measure, May, —1°.

C. H. Bowman, resident attendant at the filters, stated in 1935 that "a film of ice" sometimes formed on the water above the filter but did not "bother much" when the filter was being cleaned. One or two of the four filters were cleaned each week. A total of 12 in. of the 20-in. layer of sand was taken out on an overhead trolley and wasted. New sand was taken from a pit, screened but not washed, and used to bring the layer back to its 20-in. depth. In the autumn, lily seeds in the pond water necessitated more frequent cleaning. In 1935, a Venturi recording meter was installed on the main outlet from the filters.

The drainage area of Stiles Pond is sparsely populated. A sample of pond water taken in May 1932, and examined by James M. Caird of Troy, N.Y., had a color of 20, a slight turbidity and "a number of organisms, including *Dinobryon* and *Asterionella*."

What person was responsible for the slow sand filters of 1882 and why they were built at that early date is now only a matter for conjecture. A descendant of one of the Fairbanks brothers, chief owners of the Aqueduct Co., states that members of the family had traveled abroad, read widely, were interested in improvements, and "probably the idea was theirs" (67).

Competing water works were built by the village of St. Johnsbury in 1876. Water was pumped from the Passumpsic River, within the village. As the river was subject to some local pollution and to turbidity, sawdust and shavings when the stream was in flood, the works included a small upward-flow filter, which appears to have been a failure. Late in 1892, a Jewell rapid filter was built. It was operated without a coagulant and was abandoned in 1894 (68).

In 1905, a project for filtering the Passumpsic supply was rejected by popular vote. In 1906, the State Board of Health condemned the village supply, leaving the Aqueduct Co. without competition. In

1924, the village bought out the company. Rapid filtration was recommended by Barker & Wheeler in 1932, but not adopted (66). In 1942, the consumption of water from the slow sand filters was about 1.5 mgd. (65).

Examination by the State Board of Health of numerous samples of filtered water from Stiles Pond for the period 1925–41 showed a few coliform organisms in only six instances (69).

These annals of the quest for pure water in a small New England village * supplement the meager and scattered data that have previously been published regarding the third American slow sand filter plant. They also bring into the St. Johnsbury picture the village-owned upward-flow filter antedating the first filter of the company, followed by a hitherto almost unknown rapid filter installation.

A Few Subsequent Slow Sand Filters.—Ilion, N.Y., put the fourth slow sand filter in operation September 20, 1892. It was still being used 50 years later (70). Nantucket, Mass., built a filter and aerator for removing tastes and odors in 1892 but since algae gave no trouble that year it was not used until 1893 (71). It was not a success (see Chap. XVI).

The intermittent filter at Lawrence, Mass., which began service in the latter part of 1893, stands sixth chronologically among American slow sand filters but for a time it was ranked first in importance. Its design was based on the treatment of both sewage and water at the Lawrence Experiment Station of the Massachusetts State Board of Health. It was the first practical demonstration in America of the bacterial efficiency of filtration (72). Intermittent filters were built at Mt. Vernon, N.Y. (73), and at Grand Forks, N.D. (74), in 1894, but never again for municipal supplies in America except for use at Springfield, Mass., in 1906, to cope with algae growths in the notorious Ludlow Reservoir pending introduction of a new supply (Chap. XVII).

Albany, N.Y.—Filters at Albany, N.Y., were completed in 1899 to treat the polluted water of the Hudson. In their design Allen Hazen profited by his experience at the Lawrence Experiment Station and the observations abroad and at home embodied in his book on filtration (20). He employed pre-aeration and presedimentation but not intermittent filtration.

* The population of St. Johnsbury village was 3,360 in 1880; 5,660 in 1900; and 7,437 in 1940.

Albany began pumping water from the Hudson in 1875 to supplement near-by gravity sources of supply, some of which had been introduced at the beginning of the century. Strong opposition to utilizing the river developed and was continual despite filtration and the subsequent elaboration of the plant to include coagulation, chlorination and prefiltration. In 1932 the river was abandoned for a distant gravity supply, treated by rapid filtration and various accessories.

The quest for pure water at Albany began in the seventeenth century. Some of the events at that time and up to the Hudson River Tragedy, as the adoption of that source became, will be noted briefly.

On April 30, 1680, Dankers and Sluyter, in a journal of their American tour, stated that the inhabitants of Albany, a town of 80 or 90 good houses, "have brought down a spring of water, under the fort, and underground into the town, where they have in several places always fountains of clear, cool water" (75). These houses were located between the old Dutch stockade of Fort Orange and the new English fort. An entry of August 1686 in Reynolds' *Albany Chronicles* (77), says that water was then furnished from a pond or "Fountain" created by a dam at the head of Yonkers (State) St., from which it was delivered through 2-in. bored logs to "a city well in each of the three wards." It may be inferred that this supply was introduced some years before 1680, for on Sept. 14, 1686, the city council ordered the pipes repaired because in some places they were decayed or at least had become "so leaky that the wells are quite useless" (77).

Pehr Kalm, an eminent naturalist from "Swedish Finland," noted on June 20, 1749 (79), that the "water of the several wells" in Albany was very cool but had an "acid taste, which was not very agreeable." He found "little insects in it, which were probably monoculi." They were pale in color, very narrow, and ranged in length from one-half to four "geometrical lines." Their heads were about the size of a pin. Their tails were in two branches, each ending in a black globule. They swam "in crooked or undulated lines almost like tadpoles." Water containing monoculi, Kalm said, did not seem to harm the inhabitants of Albany but he thought it not wholesome to those unaccustomed to it. He had been obliged to drink water containing monoculi several times, after which his throat felt as though there were a pea or a swelling in it.

In the first edition (1789) of his *American Geography*, Jedediah Morse (80) said the well water of Albany was "extremely bad, scarcely drinkable by those who are not accustomed to it. Indeed all the water for cooking is brought from the river and many families use it to drink." In a revised edition of his book (1793) Morse said that the inhabitants were about to construct works to bring in good water.

Minutes of the Albany Water Works Co., from March 1800 to 1851, when the property of the company was acquired by the city, show that in 1800 the company was then supplying or ready to supply water (81). Theodore Horton states (82) that the earliest works included dams and reservoirs on two small streams north of the city from which "bored logs with circular wrought-iron straps" led to "masonry cisterns located at various points in the lower part of the city." The cisterns, he adds, "were first used for fire purposes and to pump from but later the pipes were extended into residences." The wooden pipe was soon replaced by cast-iron mains, costing $150 a ton.

Cholera, which caused hundreds of deaths in the summer of 1830, was attributed by some "to the impurity or peculiarity of the water in city wells." The health board had the waters of fourteen wells examined by Drs. Romeyn Beck and Philip Ten Eyck, who pronounced them "free from any impurities which could be injurious to health."

In the years 1841–49, six engineers reported on pumped supplies from the Hudson and Mohawk, and gravity supplies from Patroon's Creek and Norman and Hunger Kills (83, 84, 85, 86). By far the most noted of these engineers was Major David Bates Douglass, who had planned the first Croton Aqueduct. In 1846 he recommended Patroon's Creek as "decidedly the softest and purest of all" sources considered, the others being the Hudson and the Mohawk. A committee endorsed his recommendation and transmitted the report to the city council, which took no action (84). George W. Carpenter proposed a supply from the Hudson River, passed through "a coarse filtering bed to free it from such materials as might injure the pumps," but again no action was taken (87). The great fire of August 17, 1848, started by "a washerwoman's bonnet" in the Albin Hotel, spurred the city authorities to action. Although it was not so disastrous as the Chicago fire of 1871, attributed to Widow O'Leary's cow and an overturned lantern, the Albany conflagration swept over 37 acres and destroyed 600 buildings. On November 7, 1848, a popular vote of

4,405 to 6 was cast in favor of city-owned works (76). On April 9, 1850, the legislature created a special commission with authority to build works to supply the city with "a sufficient quantity of pure and wholesome water." The act required the city to buy the works of the Albany Water Works Co. and to employ a civil engineer as superintendent of water works (87).

William J. McAlpine was appointed chief engineer of the projected works on May 1, 1850. After considering the reports of the last decade, he recommended Patroon's Creek. Its frequent turbidity, he said, could be easily corrected either by filtration or by constructing a division wall in the pond and allowing the incoming water to settle in one basin before it passed to the other, but a filter, he thought, would save the cost of a division wall (88). The water commissioners adopted McAlpine's plan, which called for a gravity supply from an impounding reservoir on Patroon's Creek. Until the new works should be completed "the waters of Maezlandt Kill, the old fountain head," would be continued in use. On May 1, 1851, the city began operating the works bought from the old company. On November 4, water was let into the new aqueduct from Rensselaer Lake (87). George W. Carpenter became superintendent on April 7, 1853 (87), and served for 39 years. During that period he made some of the earliest and most noteworthy reports on tastes and odors due to organic growths in the reservoirs.

Need for more water led the commissioners to engage James P. Kirkwood early in 1872 to submit a plan and estimate for pumping water from the Hudson to the existing Bleecker Street Reservoir. Apparently his opinion on the quality of the water was not requested (89). That subject was left to Professor Charles F. Chandler of Columbia University (90). His report of May 15, 1872, introduces one of the most tragic chapters in the history of American water works. He approved the quality of a source of supply already dangerously polluted and bound to become more so as the cities above Albany on the Hudson and Mohawk rivers increased in population and industry —a supply destined to cause thousands of cases and hundreds of deaths from typhoid. Based on only one sample, collected and sent to New York by Carpenter on March 14, Chandler pronounced the Hudson water safe. His method of analysis is interesting if not amusing. "The suspended impurities which rendered the water turbid being temporary in character, were allowed to subside." The clear water was examined for various salts, organic and volatile matter and hardness.

"The organic matter in water," he wrote, "really demands the closest scrutiny." That derived "from sewage, though highly dangerous in certain stages of decomposition, [is] speedily changed by the oxygen held in solution in running water, to forms which are innocuous." The Hudson water, Chandler said, was satisfactory in organic content.

Natural aeration was given much weight by Chandler. Glens Falls, the Falls of the Mohawk and the State Dam at Troy, he said, "are the most effective means contrived by nature and art for preparing the water for the use of your citizens." Except at Troy, no sewage of consequence, Chandler wrote, is discharged into the river. Its volume "is so small in comparison with that of the river" that "the most careful examination of the water has failed to reveal anything to sight, taste, smell or analysis, which can be considered as throwing the slightest suspicion upon the purity of the Hudson, or its fitness for supplying a perfectly wholesome beverage for the city of Albany."

In transmitting, with approval, the Kirkwood and Chandler reports of 1872 to the council the water commissioners said that, while some of the citizens favored the Hudson, "a large number have so strong prejudice against its use that, no matter how clearly its purity may be demonstrated, they are unwilling to have it selected. . . . It is extremely difficult to educate the public mind up to the belief that the impurities flowing into a stream, no matter what its volume, its velocity, or its length, do not retain their deleterious and objectionable forms" (89). The commissioners adopted the Hudson, thinking to educate opponents by forcing the water down their throats. But apparently they had misgivings for they said in their report that although Kirkwood's estimates included nothing for filters they believed their cost could be met with the means available. The special committee of the city council to which the commissioners' report was referred, endorsed "the plan recommended by the Water Commissioners . . . including the necessary filteration [*sic*] . . . or a subsiding reservoir." The resolution to adopt the plan was rejected by the council, 11 to 4, then reconsidered and laid on the table. There it lay for a year. On June 9, 1873, it was taken up and adopted, 12 to 4. Filtration did not come until 1899.

Opposition to the Hudson had been voiced by the Albany Institute directly after the date of Chandler's report. It declared that within eight miles of Albany a tremendous load of sewage and industrial wastes was being poured into the river by upstream cities and towns, and pointed out that if the people of Albany supinely submitted to the pending water supply plan, the results would be disastrous to the health of the city. The committee advocated complete utilization of Patroon's Creek, as originally intended, and reforestation of its drainage area. The report was adopted by the Institute on June 12, 1872 (91). The Institute, at a meeting attended by three civil engineers and five physicians, again condemned the Hudson (92). The Albany Homeopathic Medical Society, whose opinion had been requested by the city council, disapproved the river in a report submitted on June 9, 1873. "Irrefragable evidence," it said, "holds that the organic material most active in the production of disease is of an animal nature," not removable by "any known means of filtration." Notwithstanding condemnation by engineers, physicians and others, the council approved the Hudson River project on the very day the adverse report of the Homeopathic Society was received. I. C. Chesborough took engineering charge of the project in August 1873. Water was first pumped to the Bleecker Reservoir on September 14, 1875, and repumped to the Prospect Hill Reservoir on February 3, 1878. Thus ended the first chapter in the Hudson River Tragedy.

The filters, assumed by the water commission in 1872 to be necessary, and, with a settling reservoir as an alternative, approved by the city council, had not been built. Advocacy of a gravity supply not needing filtration continued. For some years the commission and council were at odds, the latter opposing the Hudson River supply. The council refused funds for another pump to lift water from the river; asserted that the commission, to bolster up its pet Hudson River supply, had let the upland storage reservoirs fill with debris and sediment. The council opposed a bill before the legislature to grant power to the commission to go over the council's head and borrow money, and nearly voted to ask the legislature to oust the commissioners and substitute men of its choosing. But the legislature sided with the water commissioners and, on May 12, 1884, granted them full power to extend and improve the existing works and made it mandatory for the council to issue $400,000 of bonds for improvements.

Grover Cleveland, then governor of the state of New York, was petitioned by river-pier owners and boating clubs to direct the State Board of Health to investigate the pollution of the Albany Basin. The petitions were referred to the board and an investigation was made by its committee on sewerage, assisted by Horace Andrews, a civil engineer. In a report of November 22, 1884, Andrews said that the lower end of Patroon's Creek, carrying considerable sewage, emptied into the Hudson about 3,000 ft. above the water works intake. All the sewage of Albany discharged either into or below the basin. Float experiments showed that at flood tide the entire volume of water flowed upstream, sometimes 3,400 ft. or more. "Manifestly," he said, "it is most improper" to pump water to the reservoirs for the last three and one-half hours of each flood tide and the first one and one-half hours of each ebb tide. The committee of the state board recommended that the governor declare the basin "a nuisance dangerous to health" and prohibit the discharge of sewage into it. It also advised an investigation of possible new sources of water supply for Albany (93).

The city council adopted a resolution December 15, 1884, requesting the water commission to desist from letting a contract for a new pumping engine "until the people may be heard from" on a question affecting "the health and lives of a hundred thousand citizens." On the same day the council appointed a committee to consider a proposal that had been made to supply Albany with pure spring water for $1,000,000. As in the case of schemes to bring down a gravity supply from the Adirondacks, on which reports were made by Col. John T. Fanning, a civil engineer (94), nothing came of the project.

Attacks on the Hudson by the council and others led the water commissioners to call on Professor Chandler a second time to report on the quality of the Hudson. His report of January 31, 1885, was even more disastrous than his endorsement of 1872, because meanwhile much had been learned by others, but overlooked or ignored by him, about water-borne typhoid. Notwithstanding this and the increasing pollution of the Hudson, the professor persisted in declaring the supply safe and did not even suggest filtration (96).

Chandler said he had been asked if his opinions of 1872 had not been changed by subsequent events, and specifically whether new methods of analysis, "especially microscopic and culture experiments, may not record the presence of dangerous organisms which would escape every method of chemical analysis," and whether the "knowledge of zymotic diseases has not advanced to such a degree as to compel different conclusions; and finally, whether the test of experience in the city of Albany has not demonstrated the danger of making use of this source of water supply."

An emphatic "No" was the answer to all these questions. He did not claim "that chemical tests will detect the specific poisons of zymotic diseases in water" but, he added, no method of investigation yet proposed will do this "except the actual production of the diseases, and no one has ever found in a river-water the specific poison of any zymotic disease." He said that the only reliable authority who has claimed to have found disease germs in water was Dr. Koch, who "thinks he observed the cholera bacillus in a water tank [reservoir] at Calcutta in which persons suffering from cholera bathed and washed their clothes." In the course of a long discussion of bacterial examinations of water, Chandler "waxed sarcastic," thus:

> Under these circumstances it would appear that counting the number of bacteria that will develop in gelatin, or in the culture media, on the addition of a sample of water, is not a very reliable method of determining the danger of water for domestic purposes, although some enthusiastic microscopists, carried away by their skill in raising bacteria in their microscopic gardens, have said that the days of chemical analysis of water supply are numbered. . . .
>
> When the biologist learns to detect in water 'the specific poisons of zymotic diseases,' and to distinguish them from harmless organisms that we eat, drink, and breathe with impunity all our lives, then we may set up biological analysis as superior to chemical analysis, for selecting drinking water.
>
> Up to the present time, however, biological analysis will not tell us anything with regard to the Hudson River water that we do not already know. The river receives a small amount of drainage, and thanks to the oxygen and the micro-organisms, it becomes so thoroughly purified that, when it reaches the Bleecker Reservoir for distribution to Albany, it may be drunk without danger to health (96).

A very different opinion on the quality of the Hudson River water from that expressed by Professor Chandler was given a little later by Professor William P. Mason of Rensselaer Polytechnic Institute at Troy. The Albany Board of Health, which does not seem to have concerned itself with the water supply before, engaged Mason to determine "whether the influence of Troy sewage is felt in the Albany water supply." In a masterly report dated April 23, 1885, and based on analyses of many samples of water taken from above Troy down to Albany, Mason declared that "the influence of the Troy sewage is felt just below Troy," and "there is no material change for the better by the time the water reaches Albany." Slight "evidence of selfpurification" was due to dilution. On the evidence obtained, and because no other adequate source of supply was apparent, Mason advised sedimentation and filtration of the Hudson. He urged construction of a proposed intercepting sewer to prevent the return of Albany sewage to the water intake (97).

On December 19, 1883, the council, by 19 to 0 vote, denied a requisition of the water commission for $400,000 to enlarge the Hudson River plant. The council refused it on the ground that the water was "detrimental to the health of the citizens," and that the commission had failed to submit plans for the work. A blanket report on various subjects referred to the council's water committee during the previous three months was submitted on April 6, 1885. Seven hearings had been held at which many citizens and the water commissioners had been heard. "A very large proportion of the citizens," the committee reported, "are anxious to be relieved from the necessity of using water contaminated with sewage." Professor Chandler's report was characterized as face saving, merely backing up his report of thirteen years before. After declaring that the Hudson supply contained sewage from Albany on the up-tide and Troy on the down-tide, the committee recommended "a different source of supply or proper filtration of the present supply."

Of "many valuable suggestions" for a new supply the committee was impressed with the "Drive Well System" of William D. Andrews & Bro., New York, then "in successful operation in Brooklyn." Forty wells already driven on lowlands north of the city had convinced the owners that adequate supplies could be obtained from that source.

Finally, the law committee of the city council reported that "little or no relief" could be expected from the water board and proposed a "new and impartial commission" to investigate "various improvements and sources of supply." By a vote of 15 to 0 the council adopted the report. Six weeks later (May 22, 1885) the legislature created a special commission to tackle the water problem. The commission was given six months to submit to the council a general plan and estimate for a new supply or the purification of the old one or else retire. If the council approved the plan, the commission was to proceed with its execution at a cost of not over $1,200,000. This looked like business, but twelve years of planning and counterplanning passed before construction of filters was started and two more before filtered water was turned into the mains.

William E. Worthen was engaged as engineer and Professor Albert R. Leeds as consulting chemist. On November 20, 1885, the commission transmitted to the council reports by Worthen and Leeds, a proposal from the Newark Filtering Co. to build mechanical filters and offers from Andrews & Bro. to supply water from driven wells. Worthen submitted estimates for a new gravity supply from the Hudson above Glens Falls, from the Mohawk River, from Norman Kill, and from Wyant's Kill, east of the Hudson. He also outlined a plan for supplementing the existing gravity system. Leeds (98) proposed a dual supply, consisting of driven wells, aerated, and Hudson River water, both aerated and filtered.

Leeds' report is as notable for being up-to-date as was Chandler's, ten months earlier, for being antiquated. But unfortunately, as later events showed, he was influenced by a commercial bias. This lay in his advocacy of aeration and filtration, in both of which he had or was soon to have financial interest (99).

He had been engaged, Leeds said, to inquire into the available sources of pure and wholesome water and what, if any, method could be adopted for its purification. He had also been authorized to make experiments on purifying the existing Hudson River supply. He had considered the relative advantages of "(a) artificial oxidation—so-called aeration methods; (b) natural and artificial filtration; (c) combinations of (a) and (b)." His "experimental method" consisted of an analysis of the raw water followed by treating the water with air under pressure and then by filtration. The difference between analyses of the raw and treated water indicated the "benefit possible through artificial methods of purification." From the "gratifying results" of his laboratory experiments with oxidation and filtration, Leeds concluded that there would be no practicable obstacle to the application of these methods on a large scale to city water supplies.

After reviewing his data on various surface sources of supply he rejected all except the Hudson at Albany. This, he assumed, could be so purified [oxidized?] and filtered as to eliminate "organic matters dangerous to health" and "organized particles in the form of germs capable of injuring health." The only water analyzed that met Leeds' approval was from a test well recently put down north of the city—probably a part of the driven-well project then brewing.

The citizens of Albany, Leeds declared, were "drinking a residual portion of the sewage of Troy and a part of their own sewage," and

Troy was drinking unoxidized sewage from points above it on the Hudson. Legislative action and "a humane and wise public opinion" should compel these and all other communities "to reclaim their sewage before emptying the purified effluent into a flowing stream." He added that "simple, economical and completely effectual methods of doing this are known and practiced by sanitary engineers." Even so, no one can be guaranteed a safe water supply "unless it can be thoroughly purified immediately before use. This can be done artificially and naturally" (98). Strong doctrine far ahead of the times!

In 1885, there was no united public opinion in Albany or elsewhere demanding the legislation proposed. No state had adopted such legislation. No American city was treating its sewage effectively, if at all. Only three cities had slow sand water filtration plants. Rapid or mechanical filtration was on the threshold with only one or two little-known plants operating on municipal supply.

Leeds' conclusions on the quality of the various sources were accepted by the special commission in its report of November 30, 1885, but instead of endorsing his recommendations for a joint supply from wells and the Hudson, each treated, the commission advised, as its final choice, driven wells for the main supply and improvements to the existing near-by gravity sources. But if the council did not approve driven wells, aeration and filtration of the Hudson was advised.

The estimated cost "for aeration and filtration complete" was "say $200,000." The estimate was based on an informal proposal by the Newark Filtering Co., under date of August 26, 1885. The company offered to install a plant to supply 20 mgd. of "bright, clean and wholesome water," produced by means of seven pressure filters 30 ft. in diameter. The intention was, the proposal said, to employ "our new method of purification by the use of metallic iron, which method has been perfected by our Mr. [John W.] Hyatt and obviates the use of alum."

This is the first known offer to install mechanical filters on so large a scale. The special water commission said that the "system will involve the aeration of the water by forced air." As for "microbes or bacterial life," the commission added, no method had yet been suggested which would "destroy such life in water in large quantities except at enormous expense." But Mr. Hyatt had shown to the commission "plans for a system by which he claims such destruction may be effected at reasonable expense."

For some years the water supply question at Albany continued to be in a muddle unparalleled in the history of American water works. The driven-well fiasco resulted in a large expenditure by the special water commission with nothing to show for it except a thousand useless wells and pumping machinery held in storage. The city sued the contractor on its guarantee but so far as can be learned recovered nothing. In the course of this fiasco, the commission obtained legislation authorizing it to let contracts without competitive bidding.

Double filtration was suggested October 7, 1889, by a Committee of Thirteen that had been in existence four years. After characterizing the driven-well project as a "great and costly experiment" that had failed, the committee advocated diversion of the sewage below the intake and double filtration of the Hudson River through sand to free it from floating impurities before it was pumped to the upper reservoir, then through charcoal to remove "impurities detrimental to health." If Albany would build sewage treatment works on the island below the city (which was done years later) there was reason to think it would "be able to enjoin" Troy and other cities on the Hudson from pouring their sewage into its water.

To release the stored machinery, the special water commission, the old water commission and the city council agreed to let the machinery be used to reinforce the Hudson River pumps. Finally, the special commission threw up the sponge and the old water board regained power for a time. It advised filtration of the Hudson but was never given power to build a plant.

Another special water commission was authorized in 1892. The mayor then appointed seven water commissioners whose duty it was either to improve the existing supply or procure "pure and wholesome water" from another source. Subject to approval by a two-thirds vote of the council, the new commission might adopt and execute plans at a cost of not over $500,000. About this time, George W. Carpenter, who had been superintendent of water works for 39 years, was succeeded by George I. Bailey. He, too, as the act of 1850 required, was an engineer. The new commission reported to the council on December 5, 1892, in favor of a Kinderhook Creek supply. Accompanying this recommendation were reports from Clemens Herschel and J. J. R. Croes, consulting engineers, and reports by others on biological and chemical analyses. The Herschel-Croes report was brief and said nothing on the quality of the Hudson. The council immediately approved the proposal for a supply from the Kinderhook by a vote of 11 to 6.

The Kinderhook project hung fire during 1893, but on December 18, Frederick P. Stearns, chief engineer of the Massachusetts State Board of Health, reported on the comparative merits of the Kinderhook, unfiltered, and the Hudson, filtered. He declared against continuing the use of the Hudson, adding that a water once polluted, even though frequently filtered, "cannot be compared favorably with unpolluted water, such as can be obtained from Kinderhook Creek." Death came to the Kinderhook project, however, in 1894 by means of pressure brought on the legislature. A contract was let for a 5-mgd. pump to supplement the Hudson supply.

No progress toward a better supply was made for two years. Allen Hazen, then of Boston, recommended slow sand filtration of the Hudson in a report approved and transmitted by the water commissioners to the council February 13, 1897 (100). After various delays, an act abolishing the old water board was passed by the legislature, rejected by the city on a close vote (unanimous vote required), then repassed by the legislature and signed by the governor. On June 1, 1897, Hazen was appointed chief engineer of filtration works to be built by the new commission. The plant designed by him was put in use by stages from July 27 to September 6, 1899. Hazen's construction report, dated December 29, 1899, appeared in the report for that year (100). (For other descriptions, see References 101, 102, 103.)

The abnormally high general death rate, the incidence of typhoid and presence of diarrheal disease at Albany for many years past, said Hazen in his report of 1897, reflected the pollution of the Hudson at Albany. A comparison of the typhoid death rates of Albany, without filtration, with Poughkeepsie and Lawrence, and with various foreign cities having filtered supplies from polluted rivers, was decidedly unfavorable to Albany, Hazen said. Comments on mechanical filtration occupied eight pages of Hazen's report.

Estimates showed that mechanical filters would cost much less than slow sand filters and that capitalized construction and operation costs would be somewhat less. But, said Hazen, no city had yet used rapid filtration for water so highly polluted as the Hudson. Slow sand filtration was recommended as "the only system which has been demonstrated to be capable of purifying such a source of supply."

On March 1, the council received a long communication from the New York Filter Manufacturing Co. designed to show that the "American" would be less costly than the "European" system of filtration. Although the communication was merely "received" by the council, it led the Medical Society of Albany County to obtain a public hearing at which its committee expressed the belief that physicians of Albany were practically unanimously in favor of slow sand filtration.

The purification plant designed by Hazen received water from a new intake two miles above the old one. Eleven fountain aerators discharged into a settling basin from which water passed to eight filters of an area of 0.7 acre each. At a filtration rate of 3 mgd. per acre, and one filter out of use for cleaning, the plant had a capacity of 14.7 mgd. The walls, floors and roofs of the filters and clear-water basin were of plain concrete, Hazen not yet being fully sold on reinforced concrete. Bailey was credited with the general plan. A chemical and bacteriological laboratory was provided.

A bacterial efficiency of 99 per cent, said Hazen, in a paper read January 3, 1900 (103), had already been attained. It was expected that a great reduction in the city's death rate for water-borne diseases would follow. The plant removed "part of the color and all of the suspended matter and turbidity."

An extension of the water intake from the back to the main channel of the river was put into use August 24, 1907. Experiments extending through 21 months showed, said Wallace Greenalch, then commissioner of public works, that with both presedimentation and prefiltration, a slow sand filter operating at 6 mgd. could produce as good water as with water presettled only at half the rate, and that, considering capital cost, double filtration would be cheaper than single (104). Sixteen sand and gravel prefilters or scrubbers, having a total area of 0.3 acre, went into operation on October 29, 1908.

Hypochlorite of lime was applied to the water at various points beginning on June 26, 1909. Coagulation in the settling basin was used 111 days in the year 1913–14. The next year the prefilters received coagulated water 259 days, partly due to repairs to the final or slow sand filters. In 1915–16, the water applied to the slow sand filter was coagulated only 67 days, because of the increased cost of sulfate of alumina due to the war demand for sulfuric acid.

Conditions at Albany early in 1920 led Theodore Horton, the chief engineer of the state department of health, to advise conversion of the prefilters or scrubbers into "straight mechanical filters," changing one of the basins containing the slow sand filters into settling reservoirs, use of coagulation throughout the year, and substitution of cast iron for the deteriorated steel conduit leading from the purification plant to the pumping station (105).

The *Esch. coli* load carried by the Albany purification plant, declared George E. Willcomb, chemist and sanitary engineer of the works in his report for 1920–21, "is one of the greatest borne by any works in this country." Cohoes, Troy and Watervliet were the chief contributors of sewage to this load. Willcomb suggested joint sewage works, "embodying oxidation and disinfection of the effluent." The conduit from the filters to the pumping station, said the water works report for 1921–22, was "in a dangerous condition." In the report for the following year the prefilters were reported to be in bad shape with half of their area clogged and cracked.

It was evident that a new supply was imperative. Pending that, improvements of the filters were to be made. To design these, Hazen & Whipple were engaged. The work was carried out in stages and completed late in 1925. A account of the improvements was published by Hazen in 1926 (106), stating that when he

——undertook reconstruction of the treatment works in 1923 he believed, as he did in 1897, and does now, that an unpolluted gravity supply from upland sources is best for Albany. The pollution of the present source has doubled since 1899. Very few American cities take water from sources so badly polluted. . . . [The old settling reservoir not having been built for coagulation], pumping the coagulated water to the prefilters broke the floc into finely divided turbid matter which passed into and sometimes through the filters.

Chief among the many improvements designed under the direct charge of Chester M. Everett, of Hazen & Whipple, were: a new 10-mgd. coagulation and sedimentation basin; two sets of aerators, one in advance of and one after the prefilters; conversion of the prefilters or scrubbers into mechanical filters; inspection and repair of the 48-in. conduit from the reservoirs to the pumps, primarily to maintain excess pressure on the conduit during floods, thus preventing leakage into the conduit of polluted water from the canal in which the conduit was laid; changing the old settling reservoir to provide storage between the prefilters and final filters. Construction costs during 1923–25 were almost $700,000—for improvements to serve only until a new gravity supply was introduced.

A typhoid outbreak in the spring of 1924 brought the cases for 1923–24 up to 169 and the deaths to 14, compared with 61 cases and 2 deaths the previous year. After internal inspection of the steel filtered-water conduit, Theodore Horton attributed the outbreak to leaks in the pipe. Numerous damage claims were brought against the city by or in behalf of sufferers from the typhoid outbreak. A test case led to an award of $3,000 damages. This was sustained by the appellate division of the Supreme Court on June 28, 1928, and by the Court of Appeals February 13, 1929 (107). It was held that the water supply became polluted by an overflow of the Hudson River into the Erie Canal and thus into the steel conduit and that the city delayed for at least ten days putting into use a chlorination plant at the lower end of the conduit. The other claims involved lesser accounts.

Convinced at last that the Hudson River pumping and filtration works must be abandoned for a gravity supply from sparsely populated gathering grounds, the city began taking action to that end in 1926. Nicholas S. Hill Jr., New York City, after investigating 24 possible sources of supply within a radius of 50 miles of Albany, advised taking Kinderhook Creek, east of the Hudson, as had been recommended several times before (108). On July 6, Robert E. Horton, of Albany and Schuylerville, was appointed as consulting engineer and directed to investigate sources west of the Hudson, lying chiefly in Albany County. In a report on October 11, 1926, he recommended Hannacrois and Basic Creeks, to be supplemented later by Catskill Creek (109). This source was adopted. The main elements of the project were an 11-bil.gal. impounding reservoir, a 4-ft. conduit 20 mi. long and a distribution reservoir at Loudonville. No filters were proposed but they were required by the State Water and Power Commission. Horton had not thought filtration necessary, as there were only 315 residences on the drainage area of 49 sq.mi., and the two reservoirs would provide 400 days' storage (110), nor had Hill proposed filters.

The project was carried out with Whitman, Requardt & Smith as engineers and Robert E. Horton as consulting engineer. The purification plant had a capacity of 32 mgd. It included coagulation, sedimentation, chlorination and provision for the use of lime to control acidity and alkalinity. The plant went into partial use November 10 and full use December 3, 1932. The old Hudson River filters were then abandoned, after having been used 33 years.

Algae troubles in the impounding reservoir were first met by applying copper sulfate from a boat. In February 1941, *Synura* appeared after the lake froze over. An attempt was made to control taste and odors by applying activated carbon to the water ahead of the filters. This being ineffective, free residual chlorination was used with fair success. It produced a woody taste but complaints diminished considerably. Latterly, the entire reservoir has been successfully treated with copper sulfate just before it freezes.

Manganese has been high at times, particularly in July to September. This is attributed to drawing water from close to the bottom of the reservoir throughout the year to avoid surface growths of algae and supply cool water in summer. Before the summer of 1942, iron and lime were substituted for the usual aluminum sulfate coagulations at such time to provide the pH value of 9.0 required to precipitate the manganese. In the summer of 1942, H. C. Chandler, the supervising chemist (111), adopted a plan used by him on other supplies. Lime only was added to the settled water just ahead of the filters, raising the pH to 9.0 and precipitating the manganese on the filters. During these two months the manganese reached a high of 3.47 and an average of 1.87 ppm. and was reduced to a minimum of 0.10 and an average of 0.20. Meanwhile the use of aluminum sulfate was continued.

During the period from 1871 to 1935 the typhoid death rate per 100,000 ranged from 171 in 1888 to 0 in 1926. Omitting the earlier years, the half-decade averages were 78.6 for 1888–90; rose to 91 for 1891–95; fell to 83.8 for 1896–1900; dropped to 21.8 for 1901–05 and then, except for one slight rise, fell steadily to an average of 1.1 for 1931–35. For 1936–40 the rate was 1.2. The single year 1939 showed no death; for 1940 the rate was 0.8, all reported as non-residents; in 1941 there were no deaths from typhoid.*

Introduction of unfiltered water from the Hudson to supply only a part of the city was followed by an increase in the typhoid death rate. In the nine years after filtration typhoid cases decreased 66.8 and typhoid deaths 70 per cent compared with the previous nine years. Sea-

* These and other figures to follow, together with the comment here presented, are based mainly on statistics and other information supplied for use here by Theodore Horton and George E. Willcomb. The more recent figures are from the annual review of "Typhoid in Large Cities of the United States," published in the *Journal of the American Medical Assn.* It should be understood that the figures for the 1870's and in lesser degree for some years later were probably incomplete and otherwise deficient, as in most American cities of the period.—*M. N. B.*

sonally, the decrease was 84.6 per cent in cases and 76 per cent in deaths for November–April and 61.2 and 60 per cent for May–October. This indicated that typhoid in the cold months came largely from the water supply and in the warm months from the typhoid fly and returning vacationists.

In the nine years before filtration, typhoid cases totaled 3,854; in the nine years after filtration they fell to 854. But in 1909–17 the cases rose to 993. This rise was largely, if not wholly, due to a typhoid epidemic in April and May 1913, attributed by Theodore Horton to a freshet that flooded the filters (112). The epidemic of May–June 1924, already noted, with 104 cases, attributed to the break in the steel filtered-water conduit, brought the typhoid rate for that year to 12.6 per 100,000, but the average for 1918–26 was only 4.6, compared with 16 in the preceding nine years. The first full year after the near-by unfiltered sources of water supply had been shut off and the entire city supplied with water from the revamped Hudson River purification works was also the first year during which no typhoid cases were reported. In the previous eighteen years these improvements had been made: prefilters in 1908; hypochlorite used intermittently from 1909 on; liquid chlorine in 1915; coagulation at intervals from 1913 to about 1925 and continuously thereafter (114).

Albany suffered from typhoid fever for many decades because of blind persistence in drinking untreated water from one of the most heavily polluted rivers in America. The ravages of typhoid, although lessened, continued after the city built one of the best filter plants ever designed. This plant was of the slow sand type, long used abroad but never employed here for so large a city. Addition of prefilters, coagulation and chlorination, combined with skillful operation, worked marvels but after many years the city decided to go further afield and obtain a gravity supply from a sparsely populated area. It was assumed that this would not require filtration. To the amazement of its expert engineers and the city authorities, the state agency, which by that time had sanitary control of new water projects, insisted that the new supply be filtered. Meanwhile, slow sand filters had so far given way to rapid filters that the latter were built for the new supply. In epitome, Albany is typical of American cities that persisted in using polluted water at their door, despite the necessity for purifying it sooner or later, instead of going to a more distant and purer source—and even so being compelled finally to use some measure of treatment.

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CHAPTER VI

Slow Sand Filtration in the United States and Canada

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