CHAPTER XVII

Algae Troubles and Their Conquest

Four chapters of unsurpassed interest in the history of water treatment have been unfolded between the discovery of "little animals" in 1675 by Leeuwenhoek and the present widespread utilization of copper sulfate as an efficient algicide. The chapters may be characterized as (1) discovery, observation, speculation and rationalization; (2) European troubles and remedies, the latter centering on exclusion of sunlight from small reservoirs containing ground waters; (3) American plagues and studies, for the most part baffling because pertaining to surface waters stored in reservoirs too large to be covered; and (4) discovery of copper sulfate as an algicide and the evolution of various means for its application to large reservoirs.

Discovery, Observation, Speculation and Rationalization Leeuwenhoek to Dwight, 1675–1796

Leeuwenhoek.—"In the year 1675, I discover'd living creatures in Rain water, which had stood but a few days in a new earthen pot, glazed blew within." So wrote the self-educated Dutch naturalist, Antony van Leeuwenhoek, in 1676. Of several kinds of organisms described by Leeuwenhoek in his letter to the Royal Society of London (1), those he observed in rain water "put forth two little horns, continually moving themselves." This led him to call them "living Atoms," little "animals" and, individually, "Animalcula."

King.—In a series of observations on animalculae, reported in 1693, Dr. Edward King (2), noted that after steeping oats in rain water some nine or ten days he could easily see, by his best microscope, "seven or eight sorts of animalcula . . . all very nimble in their motions." In a decoction of herbs, he "saw little creatures like Eels . . . with a wriggling motion." In remarks directed to those "that disbelieve Microscopical Experiments: . . . who may as well deny the use of spectacles," King noted that a minute quantity of spirit of vitriol, put on a fine needle and introduced in a drop of water containing "some hundreds of these animalcula . . . very nimbly frisking about [causes them] to spread themselves, and tumble down seemingly dead."

Harris.—In observations made in 1694–96, John Harris, an English clergyman, saw what appear to have been green algae in one case and blue algae in another (3). On April 27, 1696, with a "much better microscope" than the one previously used, he "look't on a small Drop of green surface of some Puddle-water, which stood in my Yard. This I found to be altogether composed of Animals of several shapes and magnitudes; but the most remarkable were those which I found gave the Water that Green Colour, and were Oval Creatures, whose middle part was of a Grass Green but each end clear and transparent. They would contract and dilate, tumble over and over many times together, and then shoot away like Fishes." May 18, 1696, Harris "look't on some of the Surface of Puddle-water which was bluish, or rather of a changeable Colour, between Blue and Red." There follow these reflections on the origin of the organisms seen by the microscope:

How such vast numbers of Animals can be thus (as it were at pleasure) produced, without having recourse to Equivocal Generation, seems a very great difficulty to account for. But tho' the resolving it that way makes short work of the mystery (for 'tis easie enough to say they are bred through putrefaction) yet the asserting Equivocal Generation, seems to me to imply more absurdities and difficulties, than perhaps may appear at first sight: I wish therefore, that this matter would a while employ the thought of some ingenious and inquisitive Man (3).

Rutty.—"Seeds of the alga fluviatilis" are mentioned in 1757 by Dr. John Rutty of England (4) as often occurring in rain water; also seeds of "mosses, and little mushrooms, which last appear to the naked eye in the form of slime or mouldiness." Rain water, he said, was greatly variable in its solid contents, depending upon the "different degrees of heat of the exhaling sun,, the winds that bring it, the different soils from which it was exhaled, and different seasons of the year." In spring and summer "it commonly contains the little eggs of animalcules." Its aptness to putrefy "is easily amended by boiling, which presently destroys the animalcules, which, with other sediment, drop to the bottom." Three drops of spirit of vitriol, or five drops of spirit of salt per quart of water, would prevent putrefaction. Standing water of pools or reservoirs was not considered by Rutty, but in *A Methodical Synopsis of Mineral Waters* (4), he discusses "common water," in the form of rain, snow and dew, as "nature's own distilling."

Priestley.—In one of the volumes recounting his extensive studies of air, Joseph Priestley, English chemist (5), asserts that in water, upon exposure to the sun, and particularly spring water, a green substance was formed that was a copious source of vital or dephlogisticated air.* He believed that this substance belonged neither to the vegetable nor to the animal kingdom, but was unorganized filmy matter deriving its color by exposure to the sun.

Ingenhousz.—A few years later the Dutch royal physician and naturalist, Jan Ingenhousz (6), wrote that after three years of study he decided that Dr. Priestley examined the green substance only when it was in an advanced stage, and that had he examined it from its origin, he would have seen it giving indications of animal life. Ingenhousz confirmed Priestley's observations that the green matter on the surface of water was produced much more copiously and rapidly when animal or vegetable substances were added to the water. After noting that other species of insects were sometimes intermixed with those of a green color and expressing the belief that only the latter could produce dephlogisticated air, he concluded that probably the green species were the result of putrefaction of organic matter in the water. That, he thought, explained why the green kind was not produced spontaneously in water that had been boiled; but he acknowledged, says a reviewer of Ingenhousz's *Experiments* (16), "that they are generated in fixed air, notwithstanding it be putrescent."

In concluding his notice of the *Experiments,* the reviewer expressed surprise "that this intelligent and respectable philosopher has so strong a propensity to revive the exploded doctrine of equivocal or spontaneous generation." The reviewer thought it was absurd to maintain "that *corruption*" or the dissolution of animal and vegetable bodies into their "respective elements, should become the immediate parent of organization. . . . Surely it were much easier to believe the existence of *ova* . . . or of germs inconceivably minute, making every part of nature their nidus, and waiting to be developed by putrefaction, and by various other circumstances."

Dwight.—The citations thus far made will suffice to give the earliest observations of algae and related organisms in water and speculations on their mode of generation. Late in the eighteenth century Timothy Dwight, President of Yale College from 1795 until his death in 1817, made observations on organisms flourishing at times on natural bodies

* "Phlogiston. Principle (1635–1743) assumed to form a necessary constituent of all combustible bodies and to be given up by them in burning."—*Std. Dictionary.*

of water in New England, their probable origin and theories correlating them to the prevalence of certain diseases in the neighborhood (7).

Late in September 1796, Dwight saw a narrow "lake" in Marlborough, Mass. He was told by a Mr. Williams, owner of one of the farms on the margin of the lake, that "no endemic prevailed there" (Vol. 6; 1: 346). "It has been commonly supposed," Dwight continued, "that standing waters are insalubrious in countries subjected to such intense heat as that of a New England summer. The supposition is almost, if not quite, absolutely erroneous, so far as New England is concerned." Dwight remarked on the abundance of ponds and lakes in New England, and added:

> I suppose vegetable putrefaction to be especially considered the cause of autumnal diseases. That [it] may be an auxiliary cause of these evils may, I think, be rationally admitted. But that it is the sole cause, or even the principal cause, may be fairly questioned. This putrefaction exists regularly every year; the diseases, in any given place, rarely. The putrefaction exists throughout the whole country; the diseases, whenever they exist, are confined to a few particular spots. [They cannot be due to stagnant waters, because they] are found on plains, in vallies, on hills and even on the highest inhabited mountains.

Dwight then relates experiments "a number of years since" with ground pepper put into a tumbler of water. After a few days, the microscope showed "an immense number of living animalcules"; two or three days later, the microscope showed none "in some scum." After two or three days more, they reappeared. "This astounding process continued until the water became so foetid as to forbid further examination." From these observations Dwight concluded that there was a succession of eggs laid by the organisms. Returning to the spread of diseases he concluded:

> Whatever instrumentality vegetable putrefaction may have, I am inclined to suspect, for several reasons, that animalculine putrefaction is the immediate cause of those disorders, whatever they are, which are usually attributed to standing waters. It will, I believe, be found universally, that no such decease [*sic*] is ever derived from any standing waters which are not, to a considerable extent, covered with a scum; and perhaps most, if not all of those that have this covering, will be found unhealthy. The New England lakes, so far as I have observed, are universally free from the thinnest pellicle of this nature, are pure potable water, are supplied from adjacent springs, and are, therefore, too cool, as well as too much agitated by winds, to permit, ordinarily, the existence of animalcules (7).

European Troubles and Remedies: 1825–55

Toulouse, France.—Aquatic plants attributed to the strong heat of the sun's rays appeared in the water of an infiltration basin built in the sand at Toulouse, France, soon after it was put into use in the early 1820's (see Chap. XI). Year after year, the growths—described as reptiles, plants, animals—died and putrefied in the lukewarm water until it became intolerable. Various efforts to stop the growths (unfortunately not described) being futile, the open basin, at the suggestion of D'Aubuisson (8), was converted into a "little aqueduct" or filter gallery, after which the water was "an agreeable drink." This is the first record of an algae-infested public water supply, and the first specific example of an effective preventive.

Nottingham, England.—Owing perhaps to a cooler climate, Thomas Hawksley, noted English engineer (9), had less trouble with conferva in a filter basin completed in 1831 at Nottingham, England, than did D'Aubuisson and his associates at Toulouse. Hawksley removed the growths about once in three weeks in summer and in six weeks during the winter, by pumping out the water and sweeping the bottom of the basin with a broom. This basin was, however, supplemented by a closed filter gallery.

Warrington, England.—A troublesome growth of "animalcules" at Warrington was stopped in the 1840's by covering a reservoir. The supply, says J. F. Bateman, a civil engineer (10), was gathered from slopes of cultivated land. After the water was "rendered perfectly pellucid" by filtration through sand it was delivered to a reservoir not over 6 ft. deep. This "very soon became filled with animalcules." He then installed a copper wire strainer of 60 strands to an inch to intercept the organisms but clearing it was so difficult that he ultimately covered the reservoir with flagstones supported by beams and pillars. This was entirely successful.

London.—Partly to prevent organic growths, all reservoirs storing filtered water within five miles in a straight line from St. Paul's Cathedral, London, were required by Parliament in 1852 to be covered from and after August 31, 1855. Filtration was also required of all water for domestic consumption supplied within the metropolis from and after December 31, 1855, except water pumped from wells into a covered reservoir or aqueduct, without exposure to the atmosphere. In the statistical tables for the eight metropolitan companies contained in his book of 1884, Colonel Sir Francis Bolton, water examiner for the London metropolitan area (11), lists 53 covered reservoirs for filtered water. None held more than about 9 mil.gal. (U.S.). No greater improvement in water works construction, wrote Bolton, was ever effected than covering the London reservoirs, thus "protecting the water from all atmospheric impurities, as well as from light and heat. Reservoirs which when open required cleaning out twice a year, owing to vegetable growth, aerial impurities, and animal life constantly accumulating therein, were found to be perfectly free from any objectionable deposit for five years after being covered over."

Berlin.—In Berlin, according to William Lindley, Engineer of the Berlin Waterworks Co., filtered water from the River Spree, on standing in tanks became "covered with confervae and vegetation of various kinds; the water lost its transparency and became so turbid as to resemble the slush of the London streets." The managers thought it necessary to stop water distribution once a month and clean the tanks. On Lindley's recommendation, the tanks were covered and the growths stopped immediately. This was brought out in a discussion of a paper read in 1867 (12). The date of covering was not mentioned but the supply from the Spree was introduced in 1853.

American Plagues and Studies: 1845–91

Boston, Mass.—American annals of algae control begin at Boston November 18, 1845, with a report by John B. Jervis, Chief Engineer of the Croton Water Works, New York City, and Prof. Walter R. Johnson, of Philadelphia (13). These "two important engineers from abroad," were engaged to report on various possible sources of water supply for Boston. Long Pond, Spot Pond and the Charles River were considered, temperatures at various depths taken, samples of water collected and subjected to both microscopical and chemical analyses. In water from all three sources, "infusorial insects" were found. After saying that animalcules, in themselves, were not harmful, the engineers named conditions under which they might be troublesome, anticipating to a considerable degree the conclusions drawn decades later by FitzGerald of Boston, Forbes of Brookline and Rafter of Rochester. In summer, said Jervis and Johnson, few water sources are without animalcules. They did not intend "to assert that a source *may not,* from its shallowness, stagnancy, high temperature, and other causes, become offensive on account of its excessive productiveness of animalcules." None of the sources considered was objectionable in this respect. Diking off shallow areas of Spot Pond, in case it was utilized, was discussed. Long Pond, afterwards known as Lake Cochituate, was recommended as a source of supply. Appended to the Jervis and Johnson report was one by Professor J. W. Bailey, dated September 30, 1845, containing a tabulation of "the various species of infusoria" found by him, keyed with "orders, plates and figures of Ehrenberg's *Infusionsthierchen.*" This monumental work had been published only a few years earlier—in 1838.

It seems safe to say that the Jervis and Johnson and the Bailey reports presented the earliest notable studies of algae and related troublesome organisms in public water supplies made in America. This assumption is all the safer because at the close of 1845 there were only 70 water works in the United States.

Apprehensions of tastes and odors, reviewed by Jervis and Johnson, proved to have been too lightly dismissed, when, six years later, the Lake Cochituate supply was put into use. In October 1854, the water had a marked peculiar taste—fishy to some, cucumbery to a great majority of consumers. A disagreeable smell sometimes accompanied the bad taste. E. N. Horsford and Charles T. Johnson were engaged to ascertain the cause (14). Johnson stated that the trouble did not originate in the pipes, but in Lake Cochituate; that it was not due to animal putrefaction but to vegetable fermentation and that the water contained nothing deleterious. A remote cause for this fermentation was thought to be the long drought, summer heat and unusually low water in the lake.

Due to the vagaries of nature, or because the attention of the water authorities was centered in other matters, twenty years passed before the annual reports of the Cochituate Water Board recorded further serious troubles from organic growths. Early in October 1875, wrote Joseph P. Davis (15), engineer for an additional supply, complaints of bad tastes were received—the water tasted like fish oil to some, dead leaves to others but it was a "cucumber taste" to most. On October 23, samples of water were taken from Lake Cochituate, at all depths, but no peculiar taste could be detected. The next day Brookline and Chestnut Hill reservoirs were visited. At the latter only a slight taste was found, but overnight the taste spread through 500 mil.gal. of water in one division of the reservoir. On turning off the reservoir, taste in water from the mains stopped. On resuming use of the reservoir April 1, 1876, there was no trouble from taste.

Davis engaged William Ripley Nichols, Professor of Chemistry at the Massachusetts Institute of Technology, who was then rising to deserved fame as an authority on the quality of water, to study the problem. Nichols called to his aid Dr. W. G. Farlow, Assistant Professor of Botany at Harvard University, and Edward Burgess, Secretary of the Boston Society of Natural History. All three were baffled. Farlow in a report dated December 15, 1875 (15), named various organisms found in the Chestnut Hill reservoir. He concluded that the cucumber taste was not caused by "any living plant undergoing decomposition that could be detected by the microscope." Burgess reported (15) that no "microscopical animals of any kind" had been found in large numbers. Nichols, in his covering report of April 1876 (15), confessed that he was "quite in the dark as to the cause." There was no proof, he said, that the water would injure a healthy person. There the matter stood—beyond the ken of a chemist, a botanist, and a zoologist!

Thinking it advisable to make one more effort to find the cause of contamination of the Boston water supply, a committee of the city council engaged Ira Remsen, Professor of Chemistry at Johns Hopkins University, to investigate the subject. This he did November 4–17, 1881 (16). In his report he stated that the cucumber taste in the water, which had occurred several times from 1854 on, had affected the Croton water supply, New York City, in the winter of 1881, in apparently the same way. It had given trouble at New Haven, Conn., in 1864, 1865 and 1872; at Hartford in 1871; at Norwich, Conn., for several years in succession. Other places similarly affected at one time or another were Keene, N.H.; Holyoke and Lynn, Mass.; Albany, N.Y.; York, Pa.; and Jacksonville, Ill. In the winter of 1881, Remsen said, he had investigated similar trouble at Baltimore; but his results like those of all others who had carefully studied the subject had been unsatisfactory.

At Boston, careful chemical examinations made by Remsen showed that of five sources containing the largest amounts of albuminoid ammonia, only the Bradlee basin of the Chestnut Hill Reservoir and Farm Pond were being used. Peculiar substances retained by screens at the Farm Pond gate house were submitted to Professor Farlow who identified a freshwater sponge. Professor Alpheus Hyatt, of the Boston Society of Natural History, pronounced the organism to be *Spongilla fluviatilis* Auct. Remsen said the evidence was almost conclusive "that this sponge is the whole cause of the present difficulty" at Boston, and probably of many other cases of trouble. He suggested drawing off the water of Farm Pond, searching diligently for the sponge, removing it, then refilling the pond from Basin No. 2 through a restricted channel. The committee to whom Remsen reported stated

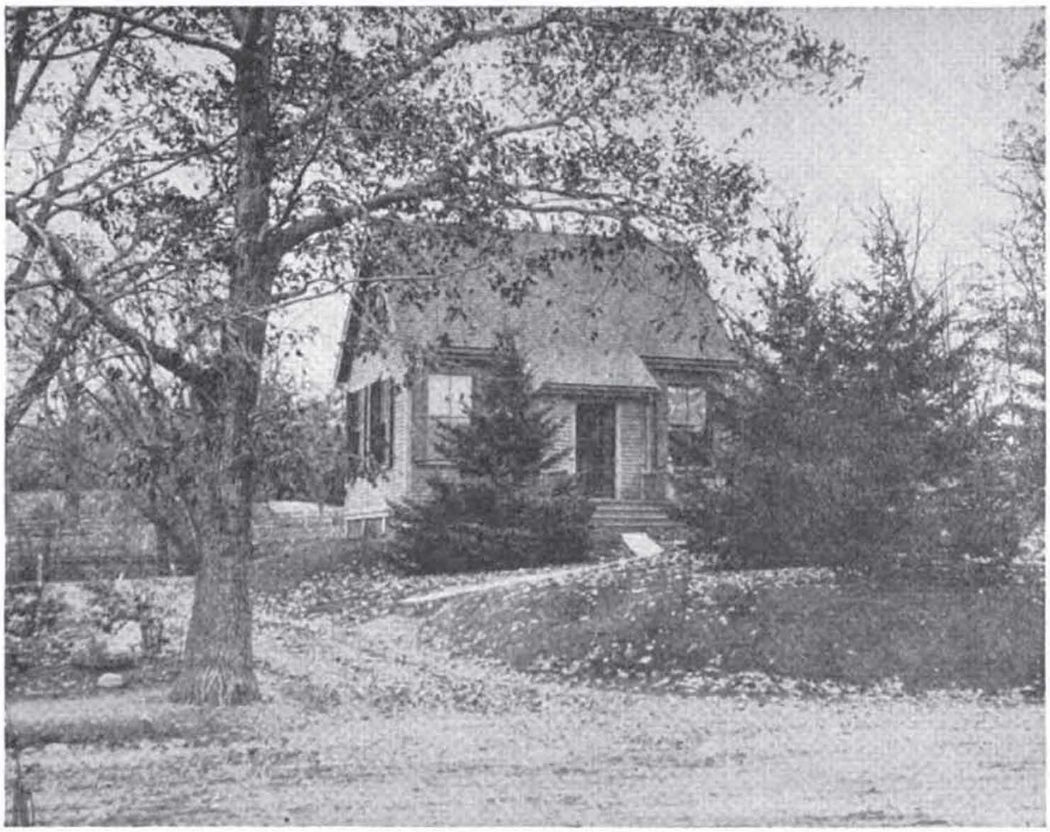

FIG. 71. FIRST BIOLOGICAL LABORATORY ON AN AMERICAN WATER WORKS SYSTEM, CHESTNUT HILL RESERVOIR, BOSTON WATER WORKS

Opened September 1889 under direction of Desmond FitzGerald; later supervised successively by George C. Whipple, F. S. Hollis and Horatio N. Parker (From an 1892 photograph supplied by Parker, City Bacteriologist, Jacksonville, Fla.)

that the city engineer found it impracticable to empty Farm Pond completely. The committee advised that a permanent conduit should be built across or around the pond so it could be cut out of service in case the trouble was repeated. Instead of acting on the recommendation, the city constructed a flume and a ditch.

The Sudbury Aqueduct, fed by huge impounding reservoirs, was put into use in 1878. Desmond FitzGerald, who had been construction engineer on this project and was for many years operating engineer of the western division of the Boston water works, conducted filtration experiments and studies of micro-organisms in the waters under his charge from 1888 to 1894 (17).

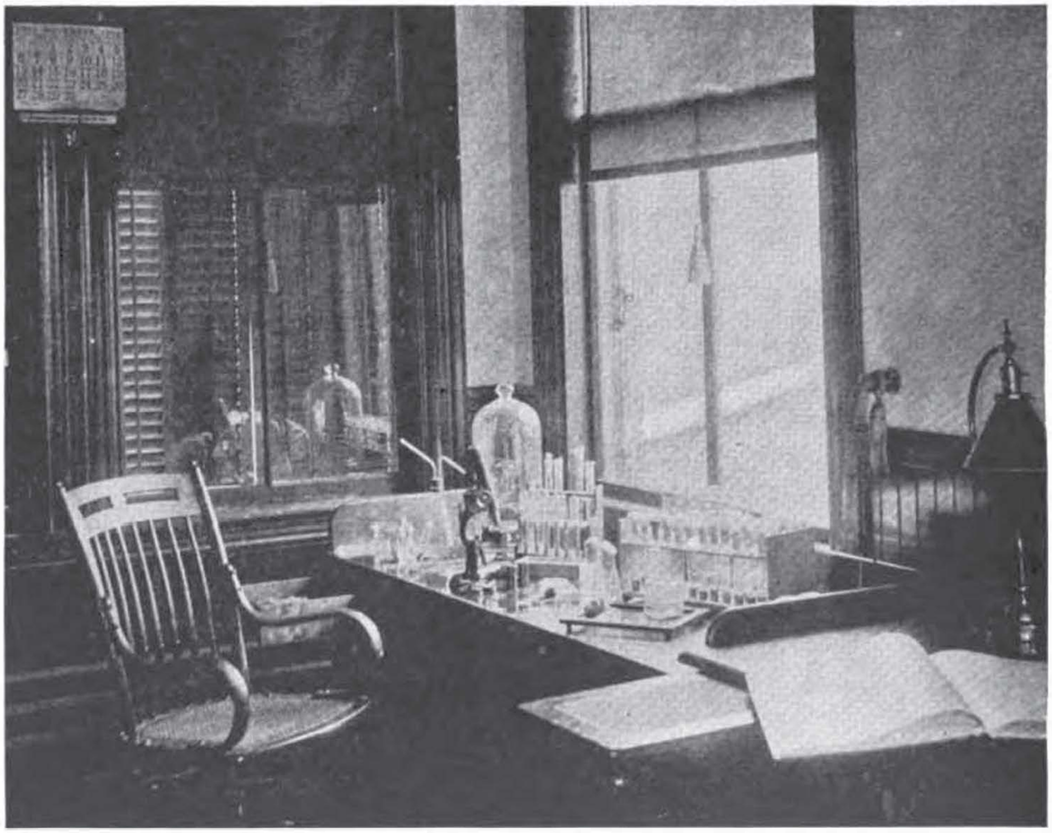

FIG. 72. INSIDE VIEW OF CHESTNUT HILL RESERVOIR LABORATORY

Originally only examinations for micro-organisms made, but, beginning in latter part of 1891, bacterial determinations also undertaken; note date on calendar is November 1892

(From photograph supplied by Horatio N. Parker; made at the time that he was assistant to George C. Whipple)

At the Chestnut Hill Reservoir he established what is believed to be the first biological laboratory connected with an American water works system. In his report for 1889, FitzGerald said that experimental filters of sponge and other materials had been operated for the removal of micro-organisms and that construction of additional filters had been ordered. In his report for 1890, he stated that weekly biological examinations had been made of the water in all storage and distribution reservoirs, at surface, mid-depth and the bottom, including number and kind of organisms. In addition, during that year 90 special investigations had been made of the water in brooks feeding the reservoirs and the effect of swamps. These data, he said, would be useful in planning improvements of the water whenever undertaken. No major improvements of existing supplies were made nor was his vast accumulation of data on micro-organisms published. This was largely due to the construction of works for an additional supply. Some of FitzGerald's data, presumably, led to the expenditure of millions for stripping the site of the Wachusett Reservoir on the Nashua River to remove organic matter which might cause disagreeable tastes and odors.

Baldly put, the immediate practical lessons derived from a half century of studies of tastes and odors in the surface water supplies of Boston by FitzGerald and his predecessors, were to avoid shallow flowage and to strip reservoir sites of organic matter. More far-reaching results were the correlation of various micro-organisms with tastes and odors, which became useful after the advent of copper sulfate treatment for algae control in the first decade of the twentieth century.

Albany, N.Y.—Bad tastes and odors in small impounding reservoirs of the water supply of Albany, N.Y., began in 1852 and recurred at unpredictable intervals thereafter (18). They were studied with untiring zeal by George W. Carpenter in his long superintendency of the water works. In August 1852, said the water commissioners in their annual report, the water became unfit for use. The cause assigned by Carpenter was animalcules which overspread the bottom of one of the reservoirs and decomposed there. Tastes and odors recurring in the next three years led a committee of the city council to state October 29, 1855, that "no more alarming event, short of the actual visitation of a pestilence, can befall a large city than the sudden poisoning of its water supply at the commencement of the hot season."

After a comparative respite of ten years the plague recurred in 1865. In his report for that year, Carpenter said that it was "impossible to convince some that water so impregnated can possibly be innoxious." The local health board invited Professor Ten Eyck and several physicians to visit and examine the reservoir. On August 11, 1865, they reported that although they appreciated the inconvenience caused by the bad water they could state that thus far it had not been injurious to health. There was no more sickness than usual in the city and no more in those parts where bad water was distributed than in the rest of the city.

Frequent microscopical examinations of the trouble-giving water, Carpenter stated in his report, were made by Professor Ten Eyck, who found the impurities to be minute vegetable organisms, similar to those described by James R. Chilton and John Torrey in their reports to the Croton Aqueduct Board, New York City. Examined with a microscope, wrote Carpenter (18), "the water appeared to be filled with minute organisms, resembling fine threads of glass or lines of light," extending in all directions, with beautifully developed structures. They were motionless. A plate in Carpenter's report for 1865 reproduced a drawing by Professor Ten Eyck, showing filaments magnified 1,000 diameters. Carpenter's final words were: "What the origin of this particular form of algae may be, or whether its development can be checked by counteracting influences, are questions which cannot, as yet, be satisfactorily answered. We know, however, its form, size and laws of growth; and, what is far more important, that it is not deleterious to health."

By 1866, Carpenter was convinced that the processes of nature finally leading to the destruction of algae and infusoria "cannot be hastened by any artificial means yet discovered." All the means of destruction, "some feasible and some chymerical," yet suggested, he declared in his 1866 Report (18), were based on the assumption that the water in which the organisms grow lacks oxygen. But "if it were possible to charge the water with an additional quantity of oxygen, by a force-pump or by exposing it, through the action of a large water-wheel to the atmosphere (both of which have been suggested) the foreign matter, the real cause of the offensive taste and odor, would remain."

In his report for 1872 (18), Carpenter said that the impurities occurring in the Rensselaer lake supply were not confined to any particular season, having appeared in spring, summer and autumn, while in November 1872, for the first time in years, the cucumber taste appeared for a short time in Lower Tivoli Lake. In this report, Carpenter summarized "well-established facts" as to taste and odors gathered from many cities. His tentative conclusion was "that the impurities were climatic," and that the atmosphere was the great reservoir of spores, which develop under favorable conditions of air and water, thus accounting for their erratic appearance.

Commenting in his report for 1875 (18) on recommendations for filtration, Carpenter noted that "some filtered water, when exposed in uncovered basins, is more liable to become offensive than when it is turbid." Carpenter's summing up of his experiences with taste and odors during 20 years was a "counsel of despair" as to remedies, tempered with the statement that "however offensive the impurities, they are not deleterious to health." Introduction of a supply from the Hudson River in 1875, to supplement the gravity sources, lessened when it did not eliminate algae troubles. But unfiltered Hudson water substituted for an occasional nuisance a scourge of typhoid, not checked until filters were put into use in 1899 (see Chap. VI).

Trenton, N.J.—"Unpleasant smell and taste" of the water supply of Trenton, N.J., in the summer of 1855 caused uneasiness among the citizens. State Chemist Wurtz was called on to make an investigation. Chemical analyses of samples of the Delaware River water then being pumped to a 1.4-mil.gal. reservoir, of water from the reservoir itself and of water from springs which had recently been delivered to consumers, assured Wurtz that the river water was chemically satisfactory. He then had a pupil examine the contents of the reservoir. The water showed several varieties of animalcules, lichens and minute plants. Sediment at the bottom of the reservoir was

———almost wholly composed of forests of minute plants through which roamed herds of such animals as *volvox globator,* 'globe jelly,' *vibric anser,* or 'goose animalcule' and several specimens of *Bacillaria* and *navicala.* On the surface of the water he found a slight green scum which when magnified resolved itself in collections of *cercalia mutabilis,* an animal production characteristic of stagnant water. Numerous large green water weeds may also be found floating in the reservoir. . . .

Open reservoirs, in which water is kept standing for several days to stagnate in the heat of the sun are perfect hot-beds for the growth of animal and vegetable life. . . . The breeding of those microscopic creatures, under favorable conditions, is so rapid that in a very few hours the water will become alive with them. It was to one of these animals, a species of cyclops, that the so-called 'fishy' taste and smell of the reservoir water, which has at two or three periods been found so annoying, was due (19).

Wurtz then suggested that the reservoir be covered, thus depriving the "organic germs of the light and heat of the sun, which constitute their means of life, and they will cease to germinate" (19). No earlier

American specific suggestion for covering a reservoir to prevent algae growths has been found.

New York City.—Professor John Torrey, leading American botanist of his time, made a classic report in the summer of 1859 on tastes and odors in the Croton water supply of New York City, after a visit to Croton Lake (20). He attributed them to a "microscopic conferva-like plant, which abounds in a volatile odorous principle, soluble to some extent in water." This, he said, "is the first time it has been offensively brought to our notice. Even when it was most abundant in the Croton, I do not believe it communicated any unwholesome quality to the water."

Schenectady, N.Y.—William J. McAlpine, a leading American water works engineer for many years, proposed a simple plan in 1867 to avoid the organic growths that were more and more frequently causing worry and disgust to American water works officials and citizens. He wrote:

> Stored water is sometimes defiled for a few days by the rapid generation and decay of vegetable matter and animalculae. This requires the conjunction of a high temperature and quiet atmosphere, *and perhaps a certain electric condition of the latter* [author's italics]. These conditions occur . . . after long intervals of time. The plan proposed would enable the supply [from Sand Creek] to be taken directly from the stream without storage (21).

Springfield, Mass.—Notorious among cities periodically afflicted with intolerable tastes and odors from algae growths in surface water supplies is Springfield, Mass. When, in July 1873, Phineas Ball, of Worcester, advised taking a gravity supply from Higher and Broad Brooks, rather than pumping it from the Chicopee River, he gave as reasons the "present purity" of the water from the brooks. The water commissioners, in their first report (22), said that the greater part of the Ludlow Reservoir basin was swampy and covered with sprouts and small wood. The site was not cleared except for the removal of old stumps from a part of the area. Sand was spread over a few acres near the outlet of the reservoir. Removal of all stumps and grubbing, ploughing, cleaning and sanding the entire bottom—445 acres—the water commissioners stated, "was beyond the means at command." Moreover, they knew of no city, supplied in like manner from artificial ponds of this size, where such a work has been attempted, and they have not been able to learn that any serious trouble has arisen where similar sources of supply had been drawn upon (22).

In support of the belief or hope that the organic matter in the bottom of the reservoir would cause no trouble, the commissioners cited a letter from F. T. Stanley, President of the New Britain, Conn., Water Co., written late in 1874. He stated that the bottom of his company's reservoir was not cleared when constructed because it would have been financially impracticable. After having been filled for seventeen years the bottom was still covered with stumps. For the past twelve or fourteen years it caused but little complaint. On a Thursday in September 1874, the shores were lined with green vegetable matter, which disappeared the following Saturday. Whether "discoloration" was caused by the decomposition of aquatic plants along the shores of the reservoir or of stumps in the bottom was unknown. After quoting this report from New Britain, the Springfield commissioners stated that they anticipated no annoyances from the impurities mentioned. Three brooks and many springs discharged into the reservoir. Its large area gave opportunity for winds to sweep over its surface, agitating and aerating the water more than would be possible in a smaller reservoir.

Ball's construction report described a "filter" built across the lower end of the reservoir, consisting of excelsior in frames extending 100 ft. between masonry walls, abutted by parallel walls of dry rubble, filled between by sand. Water was turned into the mains December 31, 1874. The filter, which was not completed until August 7, 1875, was soon abandoned as useless. At least that was the official explanation. Rumor had it that the excelsior portion of the filter collapsed during the first night it was in use. However that may have been, the self-assurances of the water commissioners that there would be no algae trouble were swept away with the coming of warm weather in 1875. The Ludlow Reservoir was cut out from the system. As companions in greater misery, the water commissioners cited Boston, Worcester, Holyoke, New Britain and other towns. They appealed to Professor William Ripley Nichols of the Massachusetts Institute of Technology for advice. His studies, reported January 1, 1876, did not extend beyond a visit to the Ludlow Reservoir, and chemical analyses of the water. He stated that Engineer Ball had observed, the previous summer, "a peculiar alga belonging to the *Nostoc* family." Nichols did not think that the organism need cause the slightest anxiety. He did not hesitate to commend the water for general use. He believed that if the reservoir were kept full the condition of the water would improve in time.

Although Nichols' report was of little practical value, the water commissioners, as if to check up his consolatory pious hope, engaged him to make a continuous study of their troublesome water problems, which he carried on for two years.

Because of heat and drought in 1876, the feeders to the Ludlow Reservoir delivered but little water. In the city the water was at times disagreeable in taste, odor and color. In the hope of remedying this, an 8-in. pipe was laid from the Ludlow supply main and discharged into a brook feeding the Van Horn distributing reservoir. By this means, the report for 1876 said, the water was agitated, and largely divested of its disagreeable qualities, so that little or no complaint was made.

Nichols reported January 1, 1877, that during the past year he had made weekly chemical analyses of Ludlow Reservoir water and also microscopic examinations of the minute vegetable organisms in the water. Dr. W. G. Farlow, Professor of Botany at Harvard University, identified the few organisms found as *Clathrocystis aeruginosa*. Nichols had seen abundant growths of that plant in other ponds and reservoirs. The New Britain Reservoir had had a similar growth annually. He was still hopeful that if the Ludlow Reservoir was kept reasonably full while the water was unpleasant, the inconvenience would become shorter. Filtration, as a small experimental filter had shown, would remove much of the troublesome matter and could be satisfactorily done by individual consumers. To make it efficient on a large scale the effluent should be piped to consumers without exposure to air.

After two or three years of comparatively little trouble, the character of the water became town talk in 1881. The subject had been investigated from geological, botanical and zoological viewpoints by the most accomplished savants in the country, the annual report for 1881 said. Trials of filtration showed that the multitude of minute particles in the water soon choked up the sand. In its report for 1882, the water board summarized answers to a questionnaire sent out by the New York health board. Of 143 reporting water works in the United States and Canada, 60 had experienced more or less trouble from algae.

Flirtations with the possibility of filtration and other palliatives went on for some years. Superintendent Hancock, in his report for

1886, expressed the opinion that the troublesome vegetable life was brought into Ludlow Reservoir from the Belchertown Reservoir, which flooded a swampy area and sent down a vast amount of decaying vegetation. After noting that the Ludlow Reservoir had been ponded for twelve years, which he thought was long enough to eliminate a large part if not all of the original organic matter in the reservoir, he said if nothing but good water were put into the reservoir all would be well. The water commissioners, in their report for 1886, stated that an inspection of the Belchertown Reservoir showed that water from it was unfit for use, since in its passage through two miles of mucky swamp it gathered much vegetable matter and germs of algae. They proposed bypassing a brook that emptied into the Belchertown Reservoir. This was done in 1887. Other diversions were made as was also provision for draining water from the Ludlow Reservoir at different levels.

The taste-and-odor problem was so far from being solved in 1889 that the water board turned its attention to mechanical filtration. A report by the State Board of Health, September 13, 1889, discouraged the adoption of mechanical filtration and suggested turning the streams entering the Ludlow Reservoir directly into the mains or else substituting water from a new supply. In 1891, the waters of several brooks were turned into a main leading into the city. Ludlow Reservoir was emptied of water and fish in 1893 and a new gate installed for drawing water from the bottom of the reservoir.

No algae appeared during 1894. The "Ludlow odor" was absent. Analyses by the State Board of Health placed the water high among the water supplies of Massachusetts. But alas! On September 15, 1895, the thermometer at Ludlow Reservoir fell to 33°F. and the fall turnover came earlier than usual. On September 20–22 the temperature rose to 90°, the highest of the season. A rapid growth occurred and for several weeks the water was in bad condition. By drawing on water stored in recently acquired reservoirs, it was possible to empty the Ludlow Reservoir and refill it with fresh water, after which the water was again good.

Algae were rampant for two months in 1896, rendering the water unusable. Again the Ludlow Reservoir was shut off. During the hot seasons of 1897 and 1898 this experience was repeated. In 1899, the reservoir was emptied, staked off in squares of 100 ft. and the bottom sounded. Mud and other objectionable material was found to depths of 20 to 46.5 ft. To remove all this muck would be impracticable. Conditions undoubtedly would have been improved by covering the bottom with sand and dividing the reservoir into two basins so that one could be emptied each year, but that would have reduced the storage capacity.

Water brought into the Ludlow Reservoir from additional sources, including mill ponds never properly prepared for storing water, had made the supply worse rather than better. This the State Board of Health reported on July 24, 1899, in response to a request for advice. Neither removal of mud from the bottom of the reservoir nor from parts of it, with the remainder covered with sand, the board said, was feasible. It had recommended filtration experiments in 1897 but the water board had done nothing. The state board knew of no experiments on water like that in question. Therefore it gave general approval to a plan submitted by Percy M. Blake (23) for a supply from a branch of the Westfield River, provided organic matter were removed from the bottom of the proposed reservoir.

Unwilling to give up its old supply, the water board decided to experiment on rectifying it by filtration. For that purpose the city council, in July 1901, authorized the expenditure of $12,000. Under Blake's direction, gravity sand filters were built and operated. With water in its usual summer condition, a single filtration failed to remove the taste and odor, but aeration of this effluent, followed by a second filtration, was successful. After more than a year of experimentation, in which the state board collaborated, Blake reported in 1902 (23) that it had been shown that all the taste, color and odor could not be removed from Ludlow water at all times. He advised the city to go to the Westfield River for a new supply and the State Board of Health concurred. In October 1902, the city council created a special water commission. It reported to the council on March 23, 1904, transmitting a joint report by Samuel M. Gray and George W. Fuller and a separate report by Elbert E. Lochridge dealing with filtration and aeration experiments (24).

Anabaena, said the engineers, had always been the main cause of tastes and odors in the existing supply. These organisms, which with others had been mentioned by Blake, seemed to overgrow and dominate others in the summer, but in winter animal organisms had "produced somewhat disagreeable odors." Remedial measures mentioned and dismissed by Gray and Fuller were: the removal of 2,000,000 cu.yd.

of the worst part of the reservoir bottom; the piping of air into the bottom of the Ludlow reservoir to prevent stagnation; ozone treatment; and seeding of the reservoir with organisms antagonistic to *Anabaena*. Copper sulfate, studied at that time by the U.S. Department of Agriculture, was considered but data were not available when requested in June 1903. Gray and Fuller concurred in Blake's opinion that when *Anabaena* were not present in "epidemic form," single filtration would produce a satisfactory supply from the Ludlow Reservoir, but when such epidemics continued for one to five months it would not be possible to eliminate them by filtration and aeration without excessive cost. Filtered water from other sources would be financially practicable. A supply from the Westfield River was advised.

Grasping at a straw to save abandonment of the Ludlow supply, the water board wrote to the State Board of Health on May 31, 1904, for approval of experiments with copper sulfate. The state board arranged with Dr. Moore, of the U.S. Department of Agriculture, to experiment with that agent at a reservoir, not in use, where *Anabaena* had appeared. The organisms disappeared after the reservoir was thus treated, but the state board, always ultra conservative, found almost as much copper in the reservoir 24 hours later as had been applied. It regarded it "essential to determine what became of the copper." It could not advise its application to the Ludlow Reservoir "until its probable effect" was more definitely known. Meanwhile it was trying copper sulfate at abandoned reservoirs.

Clinging to the Ludlow supply, the city council and mayor, in August 1904, requested the water commissioners to construct immediately a single filtration plant at Ludlow, even though Gray and Fuller had advised that it would be inadequate when *Anabaena* were at their worst. The cost was limited to $300,000. Allen Hazen and George C. Whipple were engaged to prepare plans and specifications. Hazen reported on November 30 that single filtration would not supply good water during the *Anabaena* season; that prefilters would raise the cost to $350,000; and that at times pumping would be necessary to supply the proposed filters. He advised postponement of the filtration project until an expected report from the Massachusetts Board of Health was received and studied.

Doggedly, the commissioners instructed Hazen to proceed but Hazen stood his ground. On December 2, the water board requested the city council to authorize an investigation of the possibilities of Little River, as advised by Hazen. Obstinately, the council, on December 19, ordered "further development of the Ludlow sources." The mayor, now convinced of his previous error, vetoed the order on December 27. The council being unable to muster votes enough to override the veto, left the whole matter in the air at the close of 1904.

At last, the water commissioners, in their report for 1904, threw up the sponge, putting the blame for 30 years of trouble on "the assurance of the expert authorities of the earlier years," that the "water of Ludlow Reservoir would undergo self-purification." *Anabaena* had appeared from July 22 to October 7, 1904, "calling forth again the oft-repeated demand of our citizens" that "water that can be used in the house, store and factory, be provided, at whatever cost."

Allen Hazen was engaged to investigate Little River as a source of supply. He soon reported that without filtration it would be better than Ludlow water with a single filtration. The city council, after waiting until October 9, 1905, hung like a dog to a bone to the Ludlow system. Plans for intermittent filtration of Ludlow water in summer were made by Allen Hazen. The filters were put in operation July 7, 1906. They were used in summer for some years, first for Springfield, then for an adjacent town. Finally, water from a new gravity source, developed with Hazen as engineer of design and E. E. Lochridge as chief construction engineer, was delivered to the city December 21, 1909. The water was settled, aerated, passed through covered slow sand filters, then, without exposure to light, flowed eight miles to a reservoir. Thus by abandoning an old supply for a new one, rather than the promised self-purification of the reservoir or any of various palliatives tried, did Springfield escape from the algae nuisance which for decades had made Ludlow Reservoir water notorious.

Poughkeepsie, N.Y.—At Poughkeepsie, N.Y., tastes and odors in the filtered water were noted in the annual report of the water works for 1875. The filter was bypassed for a time. To forestall a repetition of the trouble the temperature of the raw water was watched so direct service could be used. In 1877, microscopic studies made by Cornelius Van Brunt were of material aid to Superintendent Davis in operating the works. Algae growths in the clear-water basin led in 1891 to roofing it with timber and covering the roof with earth. Clogging of the filter by algae was mentioned by Superintendent Fowler in a paper read in 1898 (25) (see Chap. VI).

Hudson, N.Y.—Observations at Hudson, N.Y., on summer tastes and odors, caused by micro-organisms, were recorded by Engineer J. B. G. Rand in a report made in 1875, directly after the construction of slow sand filters by the city. He correlated these data with air and water temperatures at the river pumping station and at the filters, 300 ft. higher. He recommended that both the filters and the clear-water reservoir be covered to prevent trouble from ice and from aquatic growths (26) (see Chap. VI).

Brookline, Mass.—All the American troubles with algae, thus far reviewed, were in surface water supplies. At Brookline, Mass., however, water from a filter gallery was the source of trouble. The works were put into use on May 27, 1875. In 1878, there were complaints of the quality of the water. The trouble was attributed to the entry of swamp water into a vitrified clay conduit. The report of the water board for 1885–86 noted a peculiar taste and odor in the water, occurring after November 1. On that date, pumping sixteen hours a day was stopped, as had been done in the two years preceding. Algae were found in the open receiving reservoir six days after it had been cleaned to the bottom stone. Growth of algae, the report said, was always more rapid after a cleaning, because in the process a multitude of small fish that fed on the algae were lost, while the germs of a new crop of algae were present when the reservoir was refilled, but the fish to destroy them were still lacking. From May 1 to November 1 of both 1884 and 1885, when the pumps were worked sixteen hours a day, and water was supplied direct from the galleries, there were no complaints of the quality of the water. From this, it was inferred that exposing the water to the sunlight caused the troublesome growth. Timidly, the board suggested that the pumps be run sixteen hours a day the year around, keeping the reservoir constantly full for emergencies, but it did not feel justified in adding $75 to $80 a month to operating expenses. Two years later, the board noted that a special committee had stated that primarily the water was satisfactory but could not be kept free from taste and smell as the works were then being operated. Remedial alternatives were: running the pumps 24 hours a day, with all connections between the reservoir and consumers shut off, which was not recommended; or, covering the reservoir, which was advised. To support its advice, the committee said that roofing the high-service tank had ended all complaints from consumers in that district.

Fayette F. Forbes, Superintendent, who previously has kept modestly in the background, asserted that the unpleasant taste was due wholly to algae growth. Frequent microscopical examinations detected growths and correlated them with changes in pumping or drawing water from the reservoir. "With our present knowledge, nothing but a total exclusion of light" from the reservoir "can wholly stop this trouble." Forbes, who had begun microscopical examinations in 1887, was probably the first water works superintendent to do so regularly and use his observations in operating the works in his charge. He published three papers on the subject and one on covering the Brookline reservoir (27–31). After some delay, a covered reservoir was put into use January 1, 1893. Eleven years later, a second one was completed. In 1911, a third reservoir, for high service, went into operation. All three were designed by Forbes (28).

Denver, Colo.—Charles P. Allen, Chief Engineer of the Denver Union Water Co., stated in 1896 (33) that algae growths in reservoirs storing water from a filter gallery had been stopped by roofing the reservoirs with 12-in. boards spaced about 1½ in. apart, laid north and south. With boards laid east and west, algae grew as fast as if the reservoir was not covered. About a third of the roof area was composed of doors which could be kept open or closed. Three reservoirs, with capacities of 6, 12 and 15 mil.gal., had been covered. Before adopting this plan, experiments were made with small reservoirs, some lined with concrete, some with asphalt, some with earth; some covered and some not. The kind of lining used made little difference in algae growths.

Copper Sulfate: 1904–42

After 80 years of failure by water works engineers to prevent tastes and odors from algae, except by covering small reservoirs, George T. Moore and Karl F. Kellerman proved that copper sulfate was an efficient algicide. Their reports published in 1904–05 (34, 35) on studies begun in 1901, were given publicity in the technical press and before chemical and water works associations (36). Within a few years, the first appearance of algae organisms in water supplies was speedily followed by the application of copper sulfate by means of boats, either by spraying it on the surface or, more commonly, from bags immersed in the water. Row boats soon gave way to motor boats, particularly for large bodies of water. Various methods of applying copper sulfate were described by Hale in 1930 (37). Among these was wholesale treatment of water flowing through enormous aqueducts, first used late in 1919. The paper was a comprehensive review of the whole subject of controlling micro-organisms. It included a classified tabulation of organisms, their characteristic tastes and odors, the dosage of copper sulfate required for their control, and also, for some organisms, the chlorine dosage required.

Artificially created turbidity to prevent or lessen filter clogging by algae growths was introduced at Huntington, W.Va., in 1924; Evanston, Ill., in 1925; and Louisville, Ky., in 1927. At Louisville, wrote W. H. Lovejoy, Superintendent of Filtration in 1928, the sediment in one compartment of the settling basin was dredged out and delivered to the other, from which the water went to the filters (38). But "since 1936 and up to the present time," wrote Lovejoy, August 28, 1942, "pre- and superchlorination have supplanted turbidity for combating algae and lengthening of filter runs. Prechlorination at 20–30 lb. per mil.gal. has been highly successful in solving this problem."

Prechlorination of water applied to slow sand filters was introduced by Ilion, N.Y., in 1929. The object was to prevent algae growths on the filters, increase the length of the filter runs between cleanings and permit bypassing the filters during fires. Postchlorination had been practiced for many years. Copper sulfate has been applied to the storage reservoir by means of a hydraulically operated hypochlorinator since November 1941. In previous years the height of the algae season in the reservoir had been January, but there was no trouble in January 1942. In the old days, states Supervising Engineer Earle J. Trimble (39), the filters were scraped about once in three weeks. Prechlorination and continuous application of copper sulfate has increased the runs to at least ten weeks.

The Butte, Mont., Water Co. had algae troubles in its main reservoir from its construction in 1892 until the announcement of the copper sulfate treatment in 1904 by Moore and Kellerman. Numerous experiments, including aeration, during that period were ineffectual in removing the odor and taste of vegetable algae during the summer months. The reservoir was treated with copper sulfate in the summer of 1904 and the treatment has been continued with great success ever since. In 1900, an additional supply was procured from the Big Hole River, from which it is pumped across the Continental Divide. passing through two reservoirs of 13 mil.gal. each before it reaches the distribution system. This supply is treated with chlorine and ammonia at the pumping station, but during the low water season of the river, algae trouble developed in the 31 miles of influent pipeline, causing a slight taste and odor in the city water. To overcome this, Superintendent M. W. Plummer designed an automatic machine to inject a regulated amount of copper sulfate and lime at the intake of each reservoir. Manager Eugene Carroll writes (40) that the water supply has been entirely satisfactory, without taste or odor, ever since the use of copper sulfate treatment for vegetable algae was first applied in 1904.

Broadcasting copper sulfate in the form of crystals was introduced by the Los Angeles Bureau of Water Supply early in 1935. The chemical was distributed from a specially designed apparatus mounted on a boat. By using crystals of smaller and smaller size the copper sulfate could be supplied to the top layer and succeeding lower depths of water. When reported in 1935 the method was in the development stage but had been used extensively. Reduced amounts of copper sulfate and increased efficiency were indicated (41). On January 12, 1942, R. F. Goudey, Sanitary Engineer for the Water Works Bureau, wrote, for use here, that this method of "copper sulfating reservoirs" had been adopted not only by Los Angeles but also by the city of San Diego and the San Diego County Water Department; and by three eastern cities, which obtained equipment from the Utility Fan Corporation. That concern states that it shipped one of its copper sulfate distributors to Newburgh, N.Y., in 1941.

A change in the method of applying copper sulfate to Skaneateles Lake was made in 1938 by the water division of Syracuse, N.Y. Instead of dragging the agent in bags fastened to a motor boat, a concentrated solution of it was sprayed from nozzles mounted on outriggers attached to a motor boat, thus covering 50-ft. lanes (42).

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CHAPTER XVII

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CHAPTER XVIII

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