## CHAPTER XI

# Natural Filters: Basins and Galleries

"Natural filters" originated in Europe early in the nineteenth century. Haltingly at first, then rapidly, their use was introduced in America during the last half of the century. Supposed by many to be more efficient and less costly than "artificial filters," they soon gave way to slow sand filters in Great Britain, but continued in favor a long time in France, while in America they gave way to both slow and rapid filters after the late 1880's, or to wells or gravity sources of upland water.

"Natural filters" were built alongside rivers or lakes in permeable alluvial deposits. Usually they were open-jointed conduits built in trenches which were then backfilled. Rarely they were shallow open basins with unpaved bottoms. In theory, they yielded water from the adjacent turbid river or lake, clarified by lateral filtration through 20 to 50 or more feet of sand or gravel. In fact, their yield was largely from the underground flow. To that extent, filter galleries were horizontal instead of vertical wells.

The first filter gallery on record was built in 1810 by the Glasgow, Scotland, Water Works Co. immediately after the crude filters of Thomas Telford had failed (see Chap. V). In addition to being the first, the gallery is notable for three reasons: Boulton and Watt designed a submerged pipeline, with flexible joints, to bring the water from the gallery beneath the Clyde to the existing pumping station; these pump makers disclaimed responsibility for the success of the gallery and urged another attempt with filters instead; about 1830, adjacent lands were flooded to increase the yield of the gallery.

About 1818 the Cranston Hill Water Co., at Glasgow, forced by public sentiment to abandon an intake in a downriver stretch of the polluted Clyde, built a filter gallery near that of its rival company. To the consternation of the second company, the yield of its gallery was so loaded with iron that it was unusable. Consequently, it built a second and then a third set of filters—which were only partly successful (see Chap. V).

### *Filter Gallery at Toulouse*

The second city to be provided with water by "natural filtration" was Toulouse, France, in the early 1820's. The development of this project indicates a mistrust of the "artificial filters" of the period; a choice of "natural filtration" based on analogy drawn from ordinary wells; and the conversion of an open filter basin into a closed filter gallery due to the earliest recorded instance of algae troubles in a municipal water supply.

After the destruction of a Roman aqueduct in the Middle Ages, says Imbeaux (1), Toulouse depended on a comparatively tiny flow of water piped from a spring to a single fountain; on spring water sold by merchants; on water "good to drink" brought to the city by boat from the Garonne; and on public and private wells. At some unstated date, filters of unspecified nature were established at the Samaritain and by licensed starchmakers. From other sources it appears that as early as 1771, Charancourt, when seeking a French patent, presented a certificate from the authorities of Toulouse stating that his process of water treatment was in successful use in that city, but what the process was he did not disclose (see Chap. IV).

Monsieur Lagane, impressed with the inadequacy of the water supply of his city, and wishing to provide a memorial to his wife, willed 50,000 livres to the city in 1789 to be used for the introduction of water from the Garonne. He stipulated that the water must be "pure, clear and pleasing to the taste." The legacy was contingent upon the completion of a "conduit" within six years after the decease of Madame Lagane. Not until April 2, 1817, did she die. On that very day a commission on fountains was created. Its leading member was the engineer, Jean Francois D'Aubuisson, who has been described as the "soul" of the enterprise. He became historian of the new water works (2).

Some method of purifying the water of the Garonne was necessary to meet the terms of the legacy. Four plans for artificial filters were considered and rejected in 1817–20. The commission then invited further proposals.

Abadie, whose plans for pumping equipment were finally executed, proposed that masonry compartments filled with sand and gravel be constructed on the bank of the Tounis Canal. Water would be passed through the filtering material laterally to a pump in the center. Reverse-flow wash, made feasible by local conditions, could be used to clean the filters. Viribent, a local architect, "proposed as a substitute a method used for some years in the establishments that furnish all the potable water to the inhabitants. Here it is purified in traversing, not horizontally, a mass of sand, as proposed by Abadie, nor from above, as in the ordinary filter fountains, but from below and with many repetitions." These two plans were submitted to the Toulouse Academy of Sciences and referred to a committee. Magues, who reported for the committee, said that "when the water of the Garonne was very dirty it was not completely purified when passed in succession through four beds of gravel and sand, each 4 ft. deep, and that 1 sq.m. of these beds, placed one above another, would not clarify 20 cu.m. or one *pouce* in 24 hours." (This would be at the rate of about 20 mgd. per acre of ground space.) Following the "inclination" of Magues and influenced by the fact that local wells always yielded water which was "abundant and limpid," the city decided to dig a test pit or infiltration basin.

Dependability of the proposed filter pit was questioned by D'Aubuisson. Prudence, he said in his *Memoir,* led the water commission to investigate "artificial clarification." Thereupon it called to its aid an architect named Raymond, who had built artificial filters in the city. Raymond submitted plans for a filter to be located near the site chosen for a pumphouse; the nature of this plan is not stated. He assumed that, to produce one *pouce* (20 cu.m. or 5,284 gal.) of water per second, 5 sq.m. of filter surface would be required at a cost of 500 francs per unit, or 100,000 francs for the 200 *pouces* required. This seems to have been considered prohibitive (2). (The yield of Raymond's filter would have been about 4 mgd. per acre.)

Decision to build a test pit or infiltration basin was made in 1821. As executed, this was an excavation in sand and gravel near the Garonne. It was elliptical, 8 × 14 m. at the bottom and 3.1 m. deep (26 × 46 × 10 ft.). Three pumping tests by means of a screw of Archimedes led to the belief that by an enlargement of the basin the desired 200 *pouces* (about 1 mgd.) of water could be obtained. The excavation was enlarged to a bottom area of 10 × 108 m. (approximate), or some 11,622 sq.ft. Many gagings showed a yield of 88 to 98 *pouces* or less than half of what was needed. At first the basin yielded very good water but in following years "aquatic plants" appeared due to the "sun's rays" and "strong heat." Various means employed to remedy the evil "were without effect; the reptiles gained; and these

Fig. 4.

Coupe en travers de la Galerie filtrante N° 3 de Toulouse.

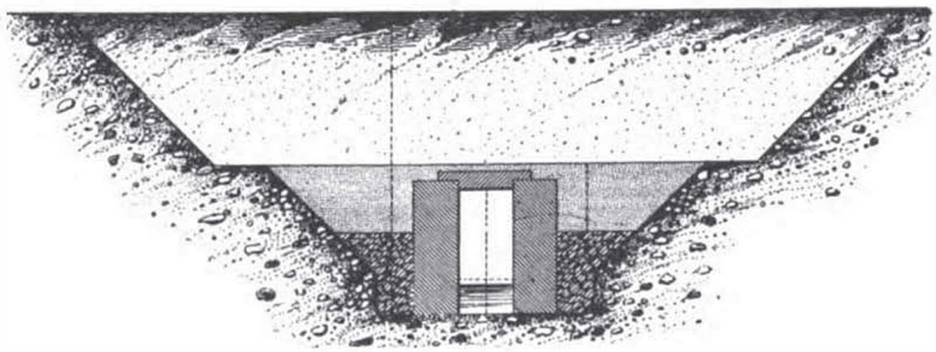

Fig. 5.

Galeries filtrantes de Toulouse.

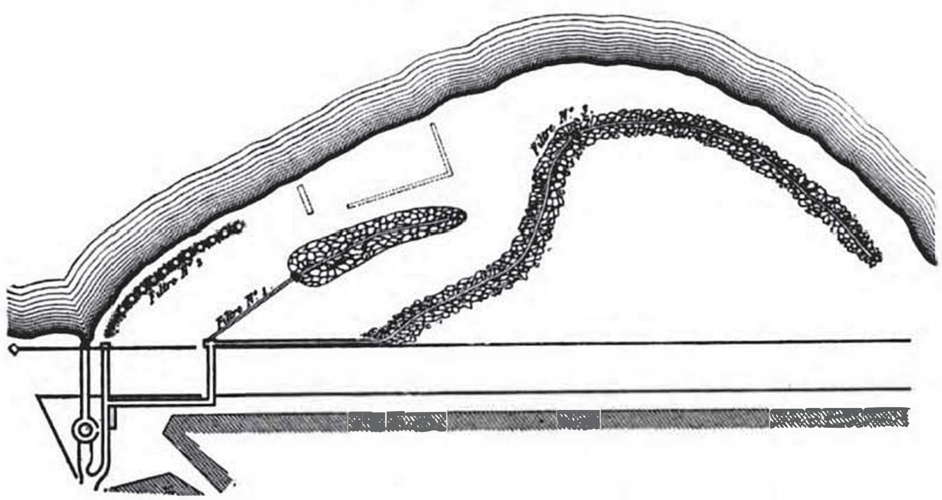

FIG. 56. FILTER BASIN AND GALLERIES AT TOULOUSE, FRANCE

Small open basin of early 1820's gave rise to algae nuisance; open-jointed conduit built on bottom of basin and basin refilled with gravel and sand; other filter galleries subsequently added

(From Darcy's *Fontaines Publiques de la Ville de Dijon,* Paris, 1856) plants, these animals, died and putrefied in a water lukewarm, making it very bad. Finally it became absolutely intolerable." A committee of the Toulouse Academy of Sciences reported that the water entering the basin was good, but that that leaving it was corrupt.

Covering so large an area as the basin was considered to be impracticable. Instead, at the suggestion of D'Aubuisson, the bottom of the basin was cleaned, "a little aqueduct of brick simply superimposed" was built the length of the basin, well-washed pebbles were placed to the height of the mean level of the river, then smaller pebbles, then sand and other material until the top of the dike was reached. By this means good water was obtained. Its yearly range of temperature was from 17 to 8°C., or 63 to 38°F. "Precious advantage," declared D'Aubuisson. "Cool in summer, it presents an agreeable drink coming from the fountain; warm in winter, it guarantees our fountains from freezing" (2).

Thus did Toulouse afford the first large-scale example of tastes and odors from algae growths in a public water supply and show that they could be prevented by excluding light and air. Thus, also, did it provide the first example of an infiltration basin and then become the second-known city to have a water supply from a filter gallery.

The dates of the various stages of the basin and its conversion into a gallery are uncertain. It is known that, although the city decided to try a "natural" filter in 1821, various delays occurred, involving particularly the design and construction of the pumps. It may be assumed that water from the enlarged basin was delivered in 1825 and from the gallery in 1827, possibly later. A second gallery was soon built, and in 1864 a third, says Kirkwood (3). These galleries, supplemented by springs, supplied Toulouse for about a century (1).

### *Natural Filtration at Nottingham and Perth*

Soon after the conversion of the Toulouse filter basin into a filter gallery, "natural" filters were also built at Nottingham, England, and at Perth, Scotland. At Nottingham a filter basin was built alongside the River Trent, with a filter gallery extending upstream. These, and the entire water works, wrote Water Engineer B. W. Davies (4), "were designed at the very early age of 25, by the father of modern water engineering, the late Thomas Hawksley, who was then engineer to the Trent Waterworks Co." The filter basin and gallery were put into use in August 1831.

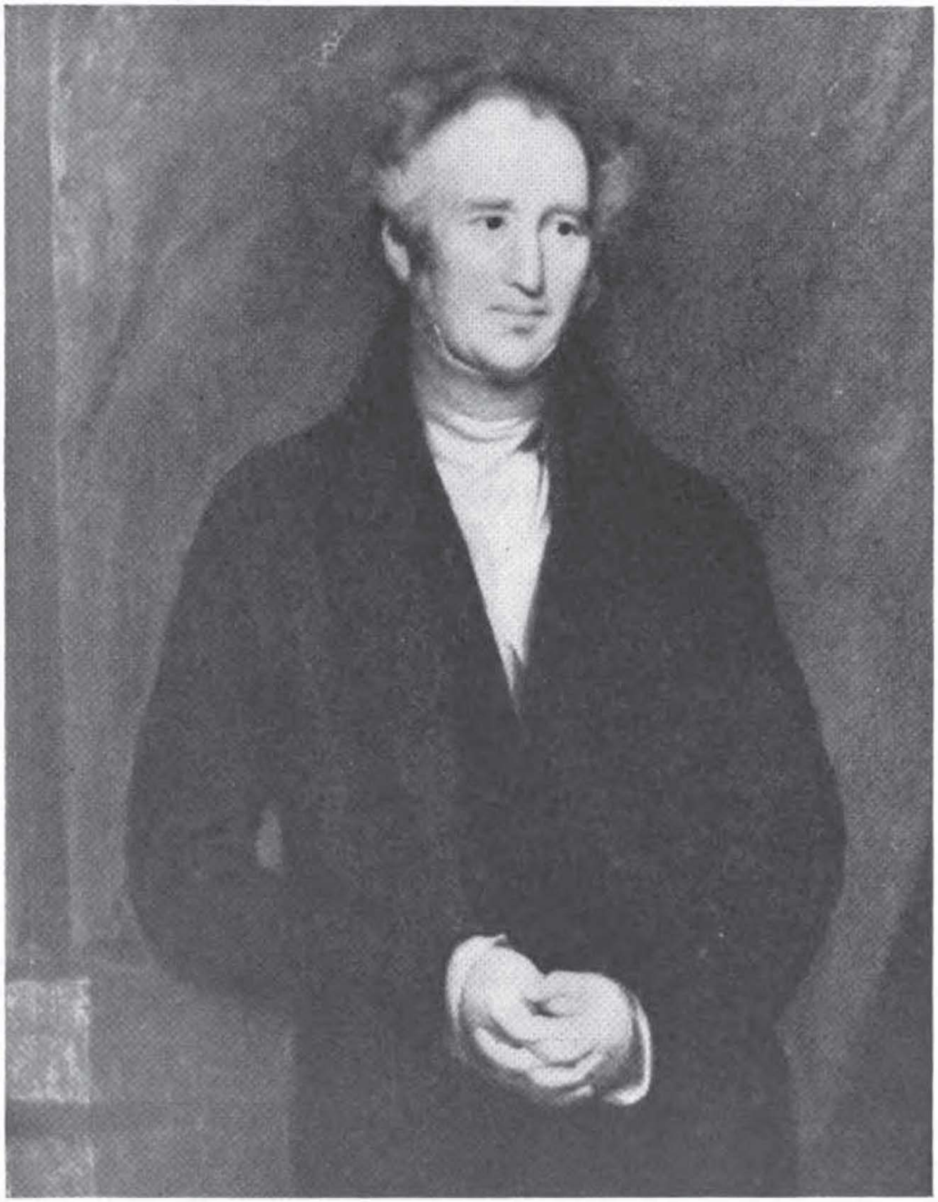

FIG. 57. ADAM ANDERSON (EARLY 19TH CENTURY)
Designer of filter gallery for Perth, Scotland, placed in service in 1832 and used for a full century
(From reproduction of a painting by Thomas Duncan supplied by Cyril Walmesley, Engr. & Mgr., Perth Water Dept.)

Testimony of Hawksley before a British commission a few years after the Nottingham system was completed shows that the filter basin there, like the one at Toulouse, was subject to growths of *Conferva*. These were removed at three-week intervals in the summer and six-week intervals in the winter by pumping out the water and sweeping the bottom with a broom (5). Hawksley assumed that the water from the river percolated through 150 ft. of sand and gravel into the basin and gallery. The current of the stream, he said, cleaned the bed of the river opposite the basin and gallery. This doubtless explains why both remained in service for many decades.

At Perth, the filter gallery was designed by Dr. Adam Anderson, Rector of Perth Academy, who investigated various possible sources of water supply from 1814 to 1829 and was engineer for water works put into operation by the town in 1832. From a copy of a report made by Dr. Anderson in 1834 (6), it is evident that he studied various sites for the filter gallery before choosing the one adopted and that to these studies may be attributed a century of service by the gallery. These studies included driven-well tests to show underflow water levels and hardness determinations. They are the most scientific and extensive found among the descriptions of filter galleries built in the nineteenth century.

Records of only a few filter galleries built in Europe after the one at Toulouse have been found. One was included in water works built at Vienna in 1836–41. In the fifties, galleries were constructed at Derby and Newark, England; Lyons and Angers, France; and perhaps at Genoa, Italy.

## *Kirkwood's Report*

This brings our story down to James P. Kirkwood's European observations of 1866. His classic *Report on the Filtration of River Waters, for the Supply of Cities as Practised in Europe* (3) included illustrated descriptions of filter galleries at Perth, Scotland; Angers, Lyons and Toulouse, France; and Genoa, Italy. At Lyons there were two galleries and two filter basins. All the galleries were built of masonry and had unpaved bottoms. The latest of the two galleries at Lyons had the abnormal width of 33 ft.

When Kirkwood's report was published in 1869, there were no filter galleries in America but a filter basin had been built at Hamilton, Canada, in 1859, and one was under construction at Newark, N.J. Although Kirkwood described artificial filters seen by him in a dozen European cities and natural filters in only five, it was the latter that impressed American water works engineers.

Immediately following the appearance of the report, a number of filter galleries and two basins were built in America: in 1870 at Whitinsville, Mass.; in 1871, at Schenectady, N.Y., Columbus, Ohio, Indianapolis, Ind., and Des Moines, Iowa; in 1872 at Lowell, Mass., and (a filter basin) at Waltham, Mass.; in 1874 at Decatur, Ill.; in 1875 at Brookline and Lawrence, Mass.; in 1878 at Rutland, Vt.; in 1880 at Nashville, Tenn., and Ft. Wayne, Ind.; in 1888 at Green Island and Hoosick Falls, N.Y., and at Springfield, Ill.; in 1891 at Reading, Mass. This is not a complete list. After that, few natural filters were built in the United States. In Canada, Toronto built a filter basin in 1875.

Massachusetts, owing partly to geological conditions, was far ahead of the other states in the number of natural filters built. According to a comprehensive paper by Kingsbury (7), 23 filter galleries and five basins were built in the Bay State in the period 1870–1934, but only five galleries and one basin (Waltham) were in use in 1939, of which none furnished the entire supply for its town. By dates of inauguration, the galleries were: Brookline, 1876; Taunton, 1876; Wellesley, 1884; Newton, 1890; Shirley, 1903; and Great Barrington, 1904.

### *Des Moines Filter Gallery*

Most noteworthy of all the natural filters in the United States is one completed by the Des Moines Water Works Co. in 1871 and still in use by the city, much extended, more than 70 years later. From its length of about 3½ miles in 1938 the city drew its entire supply of about 14 mgd. In dry periods, adjacent land is flooded with water from the Raccoon River, which the gallery parallels. In 1907 Alvord, Burdick & Howson (8) concluded that, with further extensions, the gallery would be capable of supplying the city indefinitely. These conclusions were based on studies of ground water levels in the valley of the Raccoon and of water levels in the river and in the pump well. These and other data indicated that the water in the gallery came largely from the river. So far as appears from other sources of information these were the most complete if not the only scientific studies of the origin of the yield of a filter gallery made since those by Dr. Anderson at Perth about 80 years earlier.

Following the early French filter galleries already mentioned, two notable ones were built in that country: at Nimes in 1871 (9), and at Nancy in 1875 (10, 11). Among still other galleries in France are those described by Debauve and Imbeaux (10) as existing in 1905 at Albi, Carcassonne and Vichy. These authors also mention galleries at Dresden and Essen in Germany; at Bologna, Italy; and at Budapest, Hungary.

A unique development of an additional water supply for Moose Jaw, Saskatchewan, Canada, was reported in 1940 (12). Water is collected in a filter gallery along the South Saskatchewan River and pumped to an open canal leading 68 miles to a 50-acre saturation storage reservoir, formed by removing 2 ft. of top soil above a stratum of sand from 20 to 30 ft. deep. From this the water is collected by 192 well points spaced 15 to 30 ft. apart.

## *Theory and Fact*

Since Kirkwood's report (3) was doubtless the fountainhead of American ideas on natural filters, it is unfortunate that he was not more clear and consistent on the origin of their yield. Apparently he had in mind that some but not all of the water came from the underflow down and across the valley in which they were built. In one place he said that the natural filters at Lyons "are technically filtering galleries but in reality they are collectors or conduits for gathering the water already filtered by natural processes." Whether the water thus collected came from the river or the underflow he did not specify but the context gives the idea that some of it came from the underflow. In his foreword Kirkwood declared that the yield of a filter gallery is "mainly derived from the adjacent stream."

Professor William Ripley Nichols of Boston, writing on natural filtration nine years later, but after there had been some experience with it in the United States, aptly said:

> The most favorable situation for a gathering well, basin or gallery is . . . in the neighborhood of a lake or river . . . because: (1) at such a place there is almost certain to be a decided movement of the ground water towards the stream; (2) the water from the river can make up any deficiency caused by the removal of the ground water.
>
> It was formerly supposed, and is so even now by many persons who have not made a study of the subject, that in such cases the water is entirely from the river, and filtered by passing through the intervening sand and gravel. While I would not deny that in some cases a considerable amount of water

comes from the stream. I believe that, as a rule, the smaller proportion of the water is thus derived, and in many cases none at all. (13)

Nichols then elucidates his theories at some length, citing the much greater hardness of water from wells and filter galleries in Massachusetts, France and Germany than the water of adjacent rivers and ponds. He summarized his own studies of the yield of the Waltham filter basin, showing that it came from the underflow. He urged that careful studies be made before adopting "natural filtration," including the sinking of perforated well points, regularly spaced, at right angles to an experimental dug well.

Shortly after the date of Nichols' paper, John T. Fanning brought out his *Water Supply Engineering*, which for years was the bible of American water works engineers (14). He noted that wells, filter basins and galleries were sometimes constructed "in the porous margin of a lake or stream, down to a level below the water surface, where the water supply will be maintained by infiltration." In some cases, he said, filter basins are intended to intercept the flow from the land side quite as much as the flow from the water side, this idea being supported by analyses and temperature observations.

From Nichols and Fanning American water works engineers might have learned that the origin of the yield of natural filters could be determined by observations of temperature, hardness (or other analyses) and water elevations. Few if any appear to have done so until the Des Moines studies of 1907.

In view of the early abandonment of most of the natural filters on the one hand and the long service of a few on the other it is pertinent to ask for an explanation. Aside from general obsolescence, such as changes to new and more productive sources of supply, the chief reason for abandonment or material decline in the yield of filter galleries and basins was lack of proper engineering study to choose sites or determine whether local conditions warranted their adoption as sources of supply. Such studies would have included the probable division of yield between the adjacent body of water and the underflow, and particularly the liability of clogging of the material between the river or lake and the gallery or basin. On the subject of clogging Kirkwood wrote after visiting in 1866 five European cities having natural filters:

The river water which finds its way into the deposit of sand or gravel where the galleries are placed, must have deposited somewhere the sediment held in suspension while in the river channel. I could not learn, however, that the filtering galleries became unserviceable from any such causes. The deposit which takes place upon the river bottom in the ordinary and in the low stage of its water is removed, it is asserted, in times of floods, when the bottom is scoured of all its light matter, and the coarser earths composing it become in this way periodically exposed. (3)

Kirkwood laid stress on the alternate clogging and clearing of the river bottom. In the Des Moines report of 1907, mention is made of the fouling of shoals in the river. It is important to point out that consideration should also be given to the sealing of the river bank and to the chances that a gallery located parallel to a convex bank is more likely to be kept clean by scour than one alongside a straight or concave bank. The effect of the width of channel in relation to scour should also be considered.

Little has been said regarding the design of filter galleries. All have a family resemblance but like members of other families there are notable individual differences. Structurally, all are long conduits but of varying cross-sectional sizes and shapes. As a rule, they have had arched tops, with tight joints; open-jointed side walls, but sometimes tight-jointed except for openings near the bottom; and either unpaved or open-jointed bottoms. The material usually has been brick, stone or concrete, sometimes vitrified pipe, rarely wood.

Furthest from the family type was the original filter gallery built in 1880 on an island in the Cumberland River at Nashville, Tenn. It was a stone-filled iron cage, 152 ft. long, 6 ft. high and 10 ft. wide, inside. The framework of the cage resembled that of a bridge. Each side wall had an upper and lower chord of 18-in. channel beams. Vertical iron rods spaced 2 in. apart in the clear, extending from chord to chord, served as braces. Two-inch horizontal tubes extending between the top and bottom chords afforded cross bracing. These tubes butted against the beams and were held in place by rods passing through the tubes and channel beams and secured by nuts. Diagonal tie rods were provided. Both ends of the cage seem to have been similar to the sides except that near the bottom of the outlet end there was a long rectangular opening, connected by a reducer to a 36-in. pipe leading to the pumping station. In constructing the gallery a trench was dug on a level with the river bottom. The cage was then erected and the gravel removed from beneath it until the cage rested on bedrock. A cover of "railroad iron" was then added and the trench backfilled to a depth of 20 ft. (15, 16).

Elm planks were used to form all four sides of a filter gallery built at Springfield, Ill., in 1888 and of a second built in 1889. Each gallery was $3\frac{1}{2} \times 4$ ft. in cross-section. The planks were $3 \times 8$ in. laid to leave $\frac{1}{8}$-in. spaces between them. Coarse gravel and then sand were placed around the structures (17). Porous rings of reinforced concrete, $36 \times 36$ in., placed $1\frac{1}{4}$ in. apart, were used in 1911 to extend one of the galleries (17).

Hemlock "filter boxes" with sides of galvanized wire of 2-in. mesh were laid in a trench at the edge of Lake Erie at Painesville, Ohio, in 1893 or 1894. They were 14 in. wide, 20 in. high, 8 ft. long, and

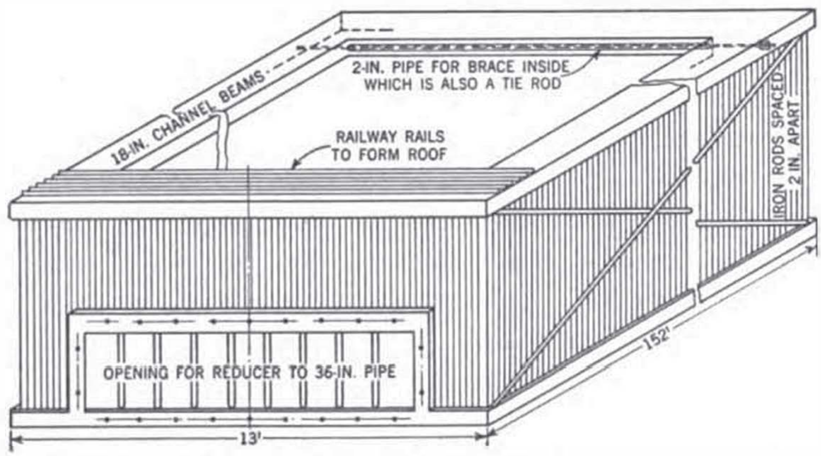


FIG. 58. FILTER GALLERY AT NASHVILLE, TENN., 1880

Originally iron crib, $13 \times 152 \times 6$ ft. high, filled with stone; later additions: 1. sidewalls of stone roofed with stone slabs, the whole surrounded by quarry spalls, around and above which was screened gravel; 2. new gravel (in use in 1889) substituted; 3. cylindrical brick conduit penetrated by 3-in. drains on sides, with broken stone beneath and on sides (1898)

(From sketch by Robert L. Lawrence Jr., Supt. & Chief Engr., Nashville Water Works, based on description in *Tenth Census of United States*)

placed end to end. The trench was over 4 ft. wide and was carried $6\frac{1}{2}$ ft. below the lake level. Two feet of gravel, coal and charcoal were placed on each side and above the top of the boxes, and sand was laid above that. Wave action was to keep the sand clean (18, 19).

Perforated vitrified pipes were laid at Stonehaven, Scotland, in 1931, to collect water from a gravel stratum beneath and adjacent to a stream. The pipe discharged into a well $4 \times 40$ ft. in plan and 9 ft. deep. The pipe and well were located above a submerged dam built across the valley and carried down to impervious material (20, 21).

### *Possible Revival of the Filter Gallery*

The possibility of reviving the filter gallery seems worth considering where local conditions appear to be favorable. Comparative cost estimates might be made after studying all the factors controlling the yield: character of the stratum of permeable material; depth and slope of the water table, both down and across the river valley; probable rate and volume of flow into the gallery, from both the land and the water side; comparative temperature, hardness, iron and manganese contents of the river water and of the underflow, the latter as observed in test wells essential to an investigation. Most of these factors have been used as studies preliminary to developing underground water for city and irrigation supplies. Some of them have been employed, though but rarely, in studying the feasibility of "natural filters."

In considering the possibility of constructing a "natural filter" (or a gallery rather than wells for underflow collection) there would naturally be taken into account trenching and backfilling by motor power instead of the manual labor employed on most of the old galleries; also to be considered in connection with the gallery structure would be various improved means for producing the units, such as large blocks of terra cotta or concrete and precast concrete rings, plain or reinforced, porous or perforated.

## Chapter XI

# Natural Filters: Basins and Galleries

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## Chapter XII

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