A Thesis upon

The Lawrence Water Works.

B. E. Mudge,

1877.
Introduction.

Water Supply, in general.

The supply of water in large towns has now become a subject of such great importance, and involves problems of so extensive and complicated a nature that the best skill and attention of scientists and practical engineers has been called into requisition in its treatment.

In supplying this indispensable element of health and comfort to a large city, water is drawn in many cases several miles distant; it has to be purified and filtered for domestic use; elevated often to a height of hundreds of feet above its original level, and finally distributed through nearly every street and into the interior of almost every house. It will, therefore, be easily conceived that the operations accomplishing these objects require in arrangement and adaptation
Introduction.

No small degree of scientific and technical skill. The subject of impounding reservoirs for power purposes and of distribution, save in an extremely limited and general sense will in this be avoided, they requiring in themselves distinct treatment.

Water being one of the primary wants of human life, the earliest records of civilization contain accounts of the digging of wells, of the Pools of Solomon, which were even dealt with a scheme for supplying Jerusalem with water. In Assyria, Persia, Egypt and particularly Rome extensive works for the conveyance of water, in open channels or subterranean tunnels, have been in existence from remote antiquity. It is only since the beginning of the sanitary movement, occasioned by the repeated visitations of cholera, beginning about the year 1832, that the subject of water supply has seriously occupied public
attention. As the rivers and surface sources of supply near chief seats of population are becoming every day more contaminated with sewage, the refuse of manufactures and domestic cess-pools, etc., one of two alternatives must be adopted to remedy the evil; either to institute a complete and efficient system of drainage for this offal, or to supply the inhabitants with comparatively pure water, which latter alternative can be effected in various ways to be noticed. The former of these is practically impossible; for however skillfully the drainage projects may be executed, the water of wells and surface sources of supply will always be more or less contaminated. It being only for hygienic purposes that systems of drainage are employed, it becomes then, essential and indeed exceedingly convenient that thickly populated districts should be furnished with a constant supply of
as nearly pure water as the region affords, many considerations entering into the selection, where there may be a choice, regarding which, availability, economy of construction of works and the quality, are the main points of consideration. This increase or introduction of water into a city necessitates additional attention to drainage for its removal after having been soiled.

The various sources, quantity, quality, ways of purifying, modes of conducting, pumping, storing and distributing, are, then, the chief topics for consideration in the present theme.

Sources.

Rain is, of course, the original source of all water supplies. The portion of this rain water which is neither evaporated nor absorbed by plants and the ground permanently
will, according to the nature of the material upon which it falls, rapidity of fall, condition of the atmosphere, slopes, local drains and other circumstances, either run directly from the surface, or percolate through the pores of the soil into streams, or it sinks deeper into the ground, following through the crevices of the porous strata as capins at the outcrop as springs, or collecting in the porous strata it is drawn thence by means of wells.

The following will serve as a classification from which supplies can be directly drawn.

I Surface collection.

(a) Streams.
(b) Lakes. {Natural.
(c) Springs.
(d) Artesian wells.
(e) Shallow wells.

Dew, ice, snow, distilled water, deserve mere mention.
I

Surface Collection.

Rain water as it is formed in the upper regions of the atmosphere is the purest existing in nature; but in descending it absorbs of whatever impurities, as gases, soot and other particles, organic and inorganic, floating about the surface, and which are particularly abundant in populous towns or cities.

Dr. Angus Smith, who examined water which was collected near Manchester Eng., the direction of the wind being most favorable, says: "It becomes clear from experiments in town districts, even a few miles distant from a town, is not a pure drinking water; and that if it could be got direct from the clouds in large quantities, we must still resort to collecting it on the ground in order to get it pure".

In a barren district of rock or sand, destitute of vegetation and remote from town pollution, water with little organic impurity can be
obtained. Here, the least available annual rain-fall of the gathering ground should equal the maximum demand.

II.

(a) Streams.

River-water is a collection of surface or shallow and deep spring water, a considerable amount of which has been brought in contact with the ground, absorbing to a greater or a lesser extent saline and organic matter; these impurities depending upon the composition of the rocks and strata of the river bed. The chief objections to river water are, its variable temperature, depending upon the alteration in the rapidity of flow, and the exposition to the sun's rays of its extended surface in the region of shallows and marshy, its liability to become turbid and polluted by sewage from towns by underground
Drainage or tributaries. On the other hand, the supply from larger rivers is boundless and unceasing; those issuing from lakes are more pure as the suspended matter has time to be precipitated. In the description of the works under consideration the self-purification of rivers will be dealt with.

(b) Lakes

Natural
Artificial
Ponds may act as receptacles of surface water, or originate from deep seated sources, and are generally enlargements of rivers. Subject, as they are, to less variation in temperature, if shallow, they are apt to absorb vegetable matter, but having sandy or rocky banks they are very valuable for water purposes.

c) Springs

Spring water is recommended preeminently to the eye and palate by its clear and agreea
qualities, its uniform temperature throughout the year; and where there are springs from which sufficient water can be collected for towns, it should be preferred to all other sources of supply. There are but few instances in which these are available; yet in mountainous regions a nearly constant and abundant amount has been obtained, as that which supplies Vienna. Springs are more permanent at the base of hills than in a flat country.

(d) Artesian Wells.

The water of artesian wells being so long in contact with earthy matter is very apt to be contaminated with mineral salts.

Wells sunk in hard rock may require no lining at all; if they pass through sandy strata they require a lining of brickwork, sometimes set in cement a foot or two above the way. For an artesian well a common
well is dug first of a tolerable depth and breadth, and then a boring is made from twenty to three or four hundred feet in depth. As soon as the impervious layer is bored through and an impervious strata reached, the water issues through the bore into the well (which acts as a sort of sifter), and either overflows or is pumped up to the desired level. From this well of 3 revelle near Paris, in 1860, 200,000 gallons daily were obtained. This well when first sunk yielded 900,000 gallons daily, but it will be seen the supply has considerably diminished with time. It is about 1500 ft. deep (being one of the deepest borings ever made) and more than 1700 ft. If it is lined with copper tubing, begins with a diameter of 12 inches and goes down to 3½ inches in diameter. The temperature is about 82° F., increasing 1° F. for every 50 feet below the surface as a rule. There is a well in Woolwich, Eng. in chalk 590 ft. deep, which
14,000,000 gallons in 24 hours. The well near London—the Ainswell Hill well—near the source of the New River and only 171 ft. deep, is said to yield two and a half million gallons in 24 hours. Deep wells should invariably be covered and carefully protected from filtrative and superficial ooze.

(3) Shallow Wells.

These collect their water from strata near the surface, and on account of its being colorless, colorless and pleasing to the taste, this water is preferred by many, though most foully polluted with the filth of men and animals, which sinks into the ground in streets, yards, and stables, and then chains through the cemeteries before it reaches the well.

Dr. Brown of New York says, this water is rendered in the highest degree unwholesome in spite of its agreeable taste. He considers
the health of a populous city as depending more upon the purity of its waters than upon the quality of all the rest of its provisions together.

Quantity.
The depth of rainfall of a district has extraordinary varieties, both as to place and time. For instance, as regards time, the tropical rainfall is almost all at one part of the year. With us it is variable. Rainfall measured by its depth in inches, being greater in mountainous regions, and on the leeward side, if they are not high enough to penetrate the clouds; but if they are, it is greater on the windward side, because the clouds do not get over the tops to the other side. For the supply of water the important points to be known are the least amount that has ever been known to fall in a year in a
district (the minimum annual fall), and the distribution of the rain throughout the year, especially the longest drought, this being the time most useful of precaution. The measurement of this rainfall is a matter of considerable skill if no records for a long series of years (or at least) has been kept, and will now be very briefly described.

Place rain gauges, as many as possible, all over the district to be examined, on the hills, in any, and in the valleys and regularly examined at certain fixed times. Then the records of all three gauges must be compared with the results given by the nearest rain gauge that has been observed for a considerable number of years, to get a relation between the rain that falls on the district and rainfall at the nearest place from which reliable data can be obtained; and from this relationship the longest drought and the probable least
annual rainfall can be determined. Mr. Hawkesley gives the following useful rule: Subtract from the average rainfall of a place for 20 years one-sixth of it, and the average annual rainfall for the three driest years during that period will be the remainder. If from the average annual rainfall for 20 years a third part be taken, there will be left the amount of rain fallen in the driest of these 20 years, and if an average of these three be taken and a third added to it, this will give pretty nearly the amount of rain in the wettest year.

With these rules and the known area of the district, allowance being made for evaporation and absorption, the average available annual rainfall can be obtained, with other necessary data. Various means are adopted for measuring the flow of rivers, as weir gauges, etc.; but on account of their extent must be omitted here. Impounding reservoirs should, according to many engineers,
Hold a six months' demand. This amount can be easily estimated, the gallons per head and the number of people to be supplied being known. The gathering ground should if possible be so large that the least available annual rain fall upon it is sufficient for the demand. Often the floods are made to supply the shortage by storing.

**Quality**

As regards the purity of water for domestic use, the essential condition is that the situation of the source and construction of the works shall be such as to prevent pollution from animal and experimental matters as well as from kitchen refuse. The hardness should be such that the water can be used for all domestic and manufacturing purposes without disinfection on economical grounds. Spring water, ground water and filtered river water
May fulfil the required conditions, local circumstances determining the preference. Since water may undergo change frequent examination is desirable. Water should be bright, clear and free from all suspended matter, without odor, cool and refreshing to the taste. It should contain only a small amount of "total solid matter" in solution and should be free from all organic matter, either already putrefying or capable of putrefaction. Of all the mineral ingredients, the alkaline earths together should not amount to more than the equivalent of 16 parts of lime in 100,000 parts of water. The soluble salts should form only a small portion of the entire solid matter, and above all, the water should contain only very small amounts of the sulphates of magnesium and of the alkalies and nitrates. The chemical character and the temperature of the same shows vary at different times of the year only within
quality.

Narrow limits. The chief impurities known to be in water may be enumerated as follows:

Organic carbon, organic nitrogen, ammonia, nitrogen as nitrates and nitrites, previous sewage and animal contamination,

alkalies, chlorine,
chlorides (sodium, sulphates) (potassium, bicarbonate) (calcium, magnesium, gypsum, silica, alumina, salts of lime and iron,

and carburated, sulphurised and phosphurised hydrogen and carbonic acid gas.

Nitrates are harmless but indicate previous sewage contamination.

The effect of sewage contamination on health was observed on an immense scale in a certain district of London where water was supplied by two rival companies, the two mains running often side by side, and some houses taking from one and some from the other company.

The whole inhabitants were living alike in all respects save one - viz. that one company almo
its water from high up the Thames, where it was of comparative excellence, while the other drew its water from low down the river, where it was profusely contaminated with town drainage. Among this population there were more than 4000 deaths from cholera, and when the epidemic had subsided an inquiry was made from house to house as to the deaths and to the water supply of the small houses where they had occurred. Using all force, the result was, that the death rate was 3½ times as great among the families supplied by the water near the town as in those supplied by water from above, showing the extreme importance of careful attention to the purity of water for drinking purposes.

A number of methods of analysis have been in use, none of which give results as to the absolute amounts of the different impurities; yet they are of immense value in determining relatively...
For prospecting for a supply of water, a solution of castile soap and alcohol is useful to compare how much of this solution is required in a given amount of the water from the surveyed district to make a froth lasting three minutes, with the amount required to cause a similar effect in the same quantity of a previously prepared water containing a known amount of calcium. This rough comparison can be employed by the engineer for more careful tests requiring chemists in their application.

Purification.

Settling and filtration are the most efficient of clearing water of noxious matter on the large scale when combined, especially when rivers water is used, which in times of flood it is very liable to be turbid. This subsidence should precede filtration; though it often follows pumpi
in the service of distributing reservoirs.

Great stillness and considerable depth of water augments settling power. It is expedient to have partitions in the settling reservoir to prevent agitation.

Streams of different qualities by mixing facilitate both processes. The supply should be drawn from the top and not from the bottom.

Filtration may be of two kinds: downward and upward. Water may either be forced on to the surface of the filter and allowed to pass through, or it may be conducted beneath the filter, and allowed to rise through the material. An artificial filtering basin is usually constructed by clearing a nearly level floor (of greatly varying area), but having a slight inclination towards the centre line, and made water tight by plastering the sides and bottom with clay. On this floor are laid a series of layers of gravel and broken stone, etc., coarse near the floor but growing
Purification.

Gradually finer towards the top where the chief filtering material—fine sand—is placed.

Thus:

- Fine sand
- Coarse sand
- Gravel pea size
- Gravel nut size
- Broken stone

Shells are used in England in place of one or the other of these. Currents of water hinder efficient filtration. It is obvious that the sand on the top arresting most of the impurities by itself (the impure materials penetrating only about 3/4 of an inch) needs frequent cleaning by scraping it off and renewing or washing it. Channels conduct the filtered water to the mains.

Another form of filtering gallery is composed of a series of brick drains or perforated pipes, come coted as shown in the following figure.

Sometimes the bottom of the bed is laid with bricks separated the width of a brick, the lower part
of the basin being used to conduct away the collected water. A profitable rate of filtration is about 1/2 cu. ft. of water per hour per sq. ft. of surface.

Quite often when water is to be drawn from rivers the material forming the banks of the same may be used for filtering purposes in any of four ways, viz.:

I. By extending a filtering gallery along the river, formed of arched stones, with porous base and sides, but with the roof generally solid and impervious.

II. By sinking shallow wells, deep, deep and of greater diameter than common wells, along the margin of the river bank.

III. By erecting on the river bank a curved embankment, its ends joining the river bank and enclosing a basin of water for the supply.
IV. By arranging a system of pipes perforated with narrow slits near the river, connected at intervals by collecting wells.

It may happen in any of these cases that all the water collected is intercepted in its way towards the river, especially if there is an upward slope from the river on the side of the gallery.

The theory of filtration is understood to be not entirely mechanical, but partly chemical, though not strictly chemical but adhesiveness.

Substances removed from water by filtration are:

1. Suspended matter (that left after settling).
2. Organic matter, as plants and animal dregs.
3. Dissolved matter to a certain extent.

(2) depends upon the thickness of the bed and the rate of flow. River pool water is harder after than before filtration as it assumes to itself some
Purification.

of the lime of the keels, though it is purified in other respects.

The process of clarification is performed.

(1) By the adhesion of salts or organic matter.
(2) By oxidation.

This oxidation is enhanced by an intermittent flow.

When water containing substances in suspension passes through a medium provided with fine pores, it is, of course, purified of the suspended matter unable to pass through the pores. But this straining process is not all. A large mass of sand or gravel, or especially animal charcoal (wood charcoal containing soluble salts) or almost any porous substance, will not only hold back all suspended matter not able to pass through, but will by virtue of the air between its pores and the close contact of the minutely separated particles of the water oxidizes such substances in solution as are
Conducting.

capable of oxidation, and these are for the most part ammonia and putrescible or decaying matter so dangerous when left in drinking waters. Numerous instances might be cited showing the efficacy of this process, but descriptions of them are accessible to all; yet it is safe to say, there are few ponds and rivers the waters of which about in certain seasons of the year need to be subjected to its cleansing properties.

Conducting.

In many cases the most desirable water may not be that nearest at hand and in some instances all suitable water is situated at a considerable distance from the community wishing its use. In either case conduits of varying sizes and characters, according to the quantity of water to be conveyed and the nature of the surface over which it is laid and then...
which it is tunnelled, are a necessity.

In a few instances, as in Rome, water has been found sufficiently elevated to be forcibly gravitation alone to the desired heights in the city. When this is not the case, water being conducted to a pumping station is by this means forced to the required elevation to be distributed. The conduits may be open or covered, for the former their shape may be semicircular, half square, or half hexagon; and for the latter, elliptical, egg-shaped, etc., depending upon the superior cement earth or masonry. All aqueducts and conduits of whatever shape should be well ventilated and be furnished with escape valves for air within. The aqueducts of Rome were upon the grandest possible scale, in tiers of three, one above the other, introducing arches of immense size and beauty, inverted siphons and other peculiarities requiring in their
Pumping.

construction great skill and a knowledge of principles with which they have not until recently been accredited. These were of stone and lead, but they may be built of brick, iron, wood, and cement and clay pipes. The fall and velocity should be regulated to circumstances, as the depth and volume of water to be delivered, etc. In its course identical falls tending to create the water, alternating with level or nearly level lengths, to fix velocity and prevent undue washing, a conduit may be intercepted. Large pipes should not be laid under an embankment where there is much direct pressure, but should be protected with an arch of some sort, with room for examination to prevent accidents.

Pumping.

In order that water may reach the various heights for fire and domestic purposes, it
Pumping.

must either have sufficient head or be directly forced to these heights from below by pumping. As for the apparatus or pump for performing the work notice will be given it farther on.

The two systems, NC ally and Reservoir, each have their advantages and disadvantages now to be briefly investigated.

The NC ally is particularly adapted to fire and the Reservoir system to domestic purposes.

The Reservoir system cannot subserve both fire and family demands; for the pressure needed for fires is too great for the pipes in buildings; yet a reservoir has a large amount stored at a definite pressure and requires but the mere attaching of hose to the hydrants for the water to be at hand. Of the engine in the NC ally system has a weak point it would be most likely to break when working under the greatest pressure in time of need. A duplicate
Storing.

Engine could seldom be put into working order at a moment's notice; therefore, in regard to fire the Holly system is doubtful at best, these being besides a large loss of economy in running an engine at its minimum speed required for simple distribution; these engines must also have a capacity for fire and domestic consumption, and for the latter purpose the engine must be kept running continually. Nearly all the cities that have adopted the Holly system have no elevation suitable for a reservoir site and are compelled to use stand pipes.

A combination of these two systems is in practice at Lawrence, which will appear in the description of the works, forming one of their most useful features.

Storing.

The extent of storage in reservoirs depends upon the
Supply. If the maximum flow from the source equals the maximum demand, the storage may be the least possible. If the source is a river, the capacity should be such as to carry the consumers over the time of freshets and to allow settling, especially if filtration is not employed. The reservoir should be deep to prevent animal and vegetable growth and if small covered. Many engineers recommend five or six months supply to be stored providing against the greatest droughts that can occur. Reservoirs into which an almost unlimited supply can be continually pumped require but about 150 days supply in advance.

As to the site of an impounding reservoir, steep sided valley converging to a narrow outlet across which an embankment can be built is the best configuration existing. Distributing reservoirs should be sufficiently elevated to allow water to supply the town by gravitation, though not too high causing
great rush of water. The inclination of the rocks and strata is of primary importance in selecting a reservoir site, as anticlinal and synclinal strata will conduct away the water, while the only good formation to hold water is the synclinal. In small reservoirs where the whole of the bottom and sides can be paved, all loose soil having been previously removed, little attention need be paid to the preceding. When these principles have been observed the chief loss of water is caused by evaporation, depending upon the climate of the place and the extent of surface exposed. Springs under an embankment are an intolerable evil, and should be avoided as no drainage can safely and effectually hinder their process of destruction.

Distribution.

The constant system, wherein the pipes are
Distribution.

kept continually charged with water, is generally adopted for convenience, durability of pipes, and the purity and coolness of the water; yet should the pipe fittings be imperfect enormous waste is the consequence. A few of the objections urged against the intermittent system are, the expense of erecting and repairing the house cisterns, the waste from leakage and overflow, the trouble to keep them clean, as they generally have no covers, and the limited supply which often causes great distress among the poorer classes. At Wolverhampton, e.g., it is said, there was a saving effect by changing from the intermittent to the constant system of 200 gallons per head per day.

A single system of supply is preferable to a double as manufacturing interests require for their purposes a water of nearly the same character as that required for domestic use, the same conditions satisfying both needs. The citizens
Distribution.

of New York are considering the feasibility of a separate system for fire purposes which in very large cities may be deemed advisable. Cities as large as London and Paris require separate systems to supply distinct districts.

Granting these few principles relating to water-supplies in general to be quite correct, a description and criticism of the construction of the Lawrence Water Works will now be undertaken, showing how far they conform thereto and at the same time exposing some few very apparent faults existing principally in the minor details.
River Pollution.

Before entering upon a detailed description of the works it may not seem amiss to consider two questions of extreme importance in any water supply, viz., quantity and quality. After much investigation the Merrimac River was chosen as the source from which water was to supply the city, and as its quantity is practically unlimited, the only remaining question is, what of its quality. This river has its rise in the beautiful Lake W⁴nnebago, from which, perhaps, no finer source exists in the country, being fed mostly by clear, mountain streams... Concord River, however, which enters it at Lowell, passes through a long marshy country with a sluggish current, and consequently carries with it into the Merrimac considerable objectionable matter. The various mills and other manufacturing establishments located on the banks of the Merrimac at Concord, Manchester,
River Pollution.

Mashua and Bowell also discharge great quantities of impurity into the river, and so that many persons have complained against using the water for domestic purposes believing it to be hurtful.

But one of the most remarkable qualities of running water is that of self-purification. It has been repeatedly shown that when the most noxious matter has been thrown into a stream running with even a tolerable velocity, all traces of it have disappeared in the course of a few miles. Portions of it are undoubtedly absorbed by the growth of aquatic vegetation; other parts are removed and consumed by fishes and other animal life; but to chemical action is due the most important part of the process of purification," says Mr. Rice. Dr. Frankland says: "There is no process practicable on a large scale by which that noxious material (sewagematter)
River Pollution,

can be removed from water once so contaminated, and therefore I am of the opinion that water which has been once contaminated by sewage or manure matter is henceforth unsuitable for domestic use."

The results of experiments by mixing filtered London sewage with water, and well agitated and exposed freely to the air and light every day, by being sprayed in a sleniter stream from one vessel to another, falling each time through three feet of air, the effect which would be produced by the flow of a stream containing 10 per cent. of sewage for 100 1/2 miles respectively, at the rate of one mile per hour, showed that the organic carbon was reduced 6.4 per cent. that of organic nitrogen 23.4 per cent. during the shorter flow, whilst during the flow of 192 miles at the same rate, the amounts of these two substances were only reduced 21.1 and 23.3 per cent. respectively.
River Pollution.

It is shown that the oxygenation of this organic matter is chiefly affected by the amount of atmospheric oxygen dissolved in the water, with dissolved oxygen being well-known to be chemically more active than the gaseous oxygen of the air. We may safely infer that there is no river existing long enough to effect the destruction of sewage by oxidation. Other scientific men assert that, practically speaking, water becomes sufficiently pure after even a short flow, but the fact relating to the Thames contamination observed under the head of "quality" preceding, pretty thoroughly discredits this statement.

Notwithstanding all that may be said upon the above question, the water of the Nassau was found by careful analysis to be much nearer pure than the best well water of the city. In July 1875 two samples of water were selected and forwarded to
River Pollution.

D. Dana Bayes, State Assayer, for analysis, Mr. Bayes reports as follows:

"Upon analysis, one United States gallon, 2.31 cubic inches of water was found to contain:

- Sample marked A. (water from well water in the city)
  - Organic and volatile matter, 15 grains
  - Mineral and saline matter, 23.25 "
  - Total weight of impurities, 38.25 "

This water has an offensive color and taste, especially after standing in a warm place for a few hours.

- Sample marked B. (water from Filter Valley)
  - Organic and volatile matter, 1.08 grains
  - Mineral and saline matter, 4.75 "
  - Total weight of impurities, 5.83 "

This sample is colorless and colorless.

Another assay was made, since this as follows:

- Sample marked (D), (from another good well) had a total weight of impurities of 17.52 grains, that marked (C), (from river near River Conduit) had 4.45 gr."
Description

of total impurities. Therefore there was no necessity for further testimony.

Description

Description of the Lawrence Water Works.

The system adopted to supply the city is primarily that of gravitation, and to secure such a level a reservoir was indispensable, which involved the necessity of forcing the water from the level of the river to the required elevation. The most available location for the pumping machinery was found upon investigation to be located on the north bank of the Merrimac River.

Here the necessary buildings were erected, consisting of an engine house, boiler house, and coal shed, all connected and continuous. The buildings are of faced brick with freestone trimmings, with the coal shed being at the level
Pumping Station.

Of the ground, constructed of brick arches, laid
on wrought iron pipes, a layer of gravel
over this, and the whole covered with cement.
The coal can thus easily be handled over
the roof and dumped into the coal rooms
through a cuttle without re-handling.
The buildings rest upon a solid foundation
of rubble masonry, laid in hydraulic cement,
which extends to a depth of twenty-two feet
below the floor line of the basement.
The Engine House is sixty-six feet square on
the exterior, and fifty-six feet from floor line
to apex of roof. The Boiler House is fifty-five
feet nine inches by fifty-five feet, and forty-two
feet six inches high. The coal rooms have
a storage capacity of eight hundred tons
of coal. The chimney is located at the west
end of the boiler house, passing up through
the coal room, and is in height one hundred
and thirty-eight feet above the floor line.
Inlet Pipe.
The supply for the pumps which is taken directly from the river is introduced through a conduit extending from the Pumping Station into the river one hundred and seventy feet for thirty-eight feet from the buildings the conduit consists of brick masonry (Pl. I).
From this point a cast iron pipe, thirty-six inches in diameter, is carried out one hundred and thirty-two feet farther, the river and being bounded with solid stone masonry. At the point of inlet, at ordinary stage of the river, the water is twelve feet mepa the.

Filter Gallery.
In order to provide a supply of filtered water, necessary in certain seasons of the year, for both domestic and manufacturing purposes, it became necessary to construct an artificial Filter Gallery.

The tests of Mr. Rice pointed out the most
eligible location, and one was built from the pumping station east along the bank of the river (as I, page 22), then finished feet long and eight feet in horizontal and vertical diameter. (Pl. I.). In building it the earth was excavated to a depth of fifteen feet below the crest of the Company's dam, when a stratum of clear, coarse gravel was reached. The side walls are built of rubble masonry laid in cement and roofed in with an arch of brick masonry. At the bottom are cross braces of granite blocks eight feet long and one foot square on ends, laid ten feet apart and filled to the surface with small stones. The gallery as at present constructed is capable of furnishing a large quantity of water, but not sufficient for a full city supply when the maximum consumption is reached, yet within the last month, April 1877, a deep trench has been excavated quite near the gallery.
Pumping Machinery.

Connecting with the river, allowing much less filtration than previously and it is hoped a more abundant supply can be obtained. I hoped it prove insufficient, which is not improbable, there are several methods which can be adopted to increase the quantity, the most feasible of which is to extend the present gallery from the river inlet pipe and the filter's gallery, the water is admitted into a gate chamber where it is delivered into the pump well whence it is taken by the pumps. Water may be drawn from both at the same time, or from either one at will, two sliding gates controlling it perfectly.

Pumping Machinery.

The pumping engines were built by J. P. Marr, N.Y.O., at the Port Richmond Iron Works, Philadelphia, from the designs and under
the patent of C. J. Leavitt, Jr., of Cambridge, Mass. They are overhead beam engines, with compound cylinders, and are both coupled to the same fly wheel shaft by cranks set at right angles with each other.

The Bingham Pumping Engine was the first engine constructed in accordance with the patent. The following description is substantially taken from the first annual report of the Public Water Board, of Lynn:

"The marked feature of the engine consists in locating the steam cylinders under the main beam centre and inclining them outwardly so that their pistons are connected to opposite ends of the beams, and in consequence move in opposite directions at the same time.

By this construction the steam passages connecting the cylinders are made short and direct, being not more than one-fourth the average length of similar passages in ordinary compound
Pumping Machinery

engines. The connection of the pistons to opposite ends of the beam reduces the strain on the main bar and the framework at least fifty percent.

and affords an opportunity of connecting the pump to one end and the crank to the other end of the beam in such a manner that the least amount of space is occupied by the engine while at the same time there is complete accessibility to all the parts; this arrangement also allows the stroke of both steam pistons, of the pump bucket and the throw of the crank to be equal, which is a desirable feature. The cylinder valves are piston ring slides, having a short horizontal movement imparted by revolving cams, the whole being arranged in such a manner as to give the most economical distribution of steam with a minimum liability to wear and arrangement. The speed of the engine is accurately controlled by a ball governor which acts directly upon the admission valve through
the cut off." The pumps (one to each engine) are of the bucket and plunger construction, known as the "Thomas Ditton," they are fitted with bushed beat values of brass, of which there are seven in each for suction, and four for delivery (in addition to the bucket valve) by which a unusually large water way is secured. All parts of the engines and pumps are carried by heavy bed plates, which are securely bolted to massive pairs of brick masonry, capped with immense granite blocks, which form the base for the engine beds. The main framing consists of eight hollow columns of great strength, which support the headstocks to which the beam feedstocks are secured. The feet of the columns are stepped into recesses in the bed plates, and each pair are braced near the middle of their length by heavy girders. There are also cross girders between the headstocks at the top and between the column girders almost
Pumping Machinery.

The top of the cylinders. The cross head guides are braced from the headstocks by vertical frames which accommodate the expansion of the cylinders; they also carry the beam galleries.

A few of the principle dimensions are as follow:

- Diameter of high pressure cylinders: 18 inches
- Low: 38
- Working barrel of pumps: 26½
- Pump plungers: 18½
- Fly wheel: 30 ft.
- Length of stroke of steam and water pistons: 4½ ft.
- Length of crank between centres: 16
- Between and centres of beams: 2¼ ft.

- Length of stroke in air pumps: 2½ ft.
- Breadth of engines over all: 204½ in.
- Length: 42 6½ in.
- Distance from top of beams vertically to bottom of pumps: 5½ ft.

The capacity of each engine is two hundred thousand gallons per hour, at a speed of sixteen
revolutions per minute. The piston rods, cross-heads, plunger rods, beam centres and crank pins are all of steel. The cranks and shafts are of wrought iron. The boilers were designed by Mr. Beavitt, and constructed by Mr. D. Robinson, at the Robinson Boiler Works, East Boston. At both places where these engines have been in use (Lynn & Lawrence) accidents have happened owing as far as has yet been ascertained to improper construction and to no fault in the principle of the design.

The pump valve box at Lynn broke letting the valves fall into the wells with great noise but no other damage. At Lawrence the low-pressure cylinder of one engine cracked completely round and had it not been for the knowledge and vigilance of the engineer who discovered a loss of work for pound of coal (gradually increasing) fearful results might have followed.
Force Main.

The pumps discharge into a force main line of cast iron pipe thirty inches in diameter, laid in the centre of Ames St. (PL VII), extending to the reservoir, and in extreme length about five thousand feet. For the first seven hundred and fifty feet from the pumping station the pipe is cast very heavy; the next section's lighter in proportion until about one third away the ordinary size pipe is continued to the reservoir; this graded strength being necessary on account of the increased pressure near the pumping station.

In order to use the 20 inch main on Water St. if the giving out of the 20 inch main on River Hill should ever occur, and it should be desirable to supply the city from the reservoir through Water St., it was necessary that the force main should at all points be laid lower than the bottom of the reservoir. This obliged the constructors either to tunnel
Emery's Hill at the height of land or cut along the hill until a proper place was reached. It was decided that, in the end, tunnelling would be the cheaper and less calculative because damage to the abutments. An open cut was made, therefore, into the hill until a twenty-eight-foot face for the tunnel was made. The boring was then begun and carried through the hill a distance of 900 feet, the mouth and end of the tunnel being a few feet south of Russell Street. In all, it is six feet high and seven feet wide, egg-shaped with flattened bottom, and is built of brunt brick laid in hydraulic cement, with a well and manhole to give free access, and should it become necessary to make repairs requiring more pipe, they were purposely made large for the admission of pipe. Sufficient inclination is given the tunnel to ensure drainage, and at the south end a drain pipe conducts away the drainage.
water. (Pl. III). The force main enters the reservoir bank at the south-west corner, it is extended longitudinally through this bank (an extremely poor plan) to a point opposite to the centre of the middle bank (which divides the two basins) where it turns and is carried along the middle bank to the overfall (Pl. III) when it is turned upwards with a quarter turn of four-foot six-inch radius, the water being discharged through a bell-shaped pipe, especially adapted for this purpose, upon a stone platform, from which it falls down over six granite steps ten feet wide into the basins, or by using flash boards, can be turned into either at will. This method breaks up the mass and thoroughly aerates all the water pumped into the basins thus further tending to purify it. The top of the overfall is at the same height as the main bank. Before proceeding further it will be well to denounce the practice of
running a pipe under an embankment, the evil effects of which in this particular case are quite striking; for water has drained about the pipe causing the stone pitching upon the interior of the reservoir to settle and erode, opening large cracks or fissures which the frost in winter will accentuate and augment.

The steps of the overfall having been laid in cool weather, the mortar freezing before it was set, has been nearly all washed away, and the water following back along the force main in this middle embankment came very nearly sandishing that half of the embankment covering the pipe. Further destruction was prevented by packing wholly over the overfall, sandishing the aeration a mere show. Some have seriously questioned the use of this overfall from the beginning of its construction, the water not needing aeration. At a point just below the south bank of the reservoir a 20-in. pipe is connected with
the force main and extending to the 30 inch distributing main which it intersects at about seventy-five feet south of the facade. This 30 inch was designed to answer several purposes. With this line the water may be forced into the distributing main and thus into the effluent gate chambers, thence into either or both basins as desirable. Again, if from any cause the water should become low, or if the water should be the result of the basins could be filled in this manner, avoiding the pumping against a twenty-eight foot head which would be the case when the water shall be discharged at the overfall. As the basins filled the head would increase, yet there would at the commencement be a saving. Another great beauty of this system is that it admits of introducing or forcing the water directly into the street mains through Water and Canal street.
Reservoir.

The difference in level of this cross pipe and the top of the overfall (about 40 feet) acting precisely in the nature of the stand pipe, and if for any cause the speed of the engines should be accelerated to an extent to endanger the pipes if not guarded against, the water would escape at the overfall, thus relieving the engines and mains of any unnatural strains. The city of Lawrence claims to be the first to be supplied by a duplication or by a combination of the reservoir and direct pumping system.

Reservoir. (Pt. II) (Pumps not shown)

'Tis here that the Commissioners committed their greatest error, in choosing the reservoir site upon Boackwell's Hill to near Emery's Hill, before alluded to in regard to the tunnel, would have answered the purpose in every way as well, with the addition of...
Reservoir.

twenty five feet (at least) more head to the water, now found the reservoirs at Prospect Hill, and entirely obviating the necessity of tunneling, also shortening the force main about three quarters. These advantages were probably not overlooked, and the only way of accounting for their not being observed is to suppose there existed some personal difference between the owner of the E. F. Smith and the Commissioners, which is removed.

The Reservoir is of rectangular form, seven hundred and thirty feet long, and four hundred and eleven feet wide measured on top of the centre of the embankment, and twenty-eight feet deep, with this division embankment forming two basins, having a total capacity of 40,000,000 gallons when filled to the high water mark, which is twenty five feet from the bottom. The top of the division embankment is fifteen feet lower than the other embankment.
Reservoir.

so that when the Reservoir is full to the high water mark, that is three feet from the top, there will be three feet of water over the division embankment, thus making it appear as one basin. Each basin is two hundred and sixty-three and one-half feet long by three hundred feet wide measured on the bottom.

The embankments are twenty-seven feet wide at the top (nearly enough), with inside slopes of one and a half horizontal to one vertical, and outside slopes of two horizontal to one vertical making them one hundred and twenty-five feet thick on a line at the bottom of the basin. The north and east bank of the north basin and the south bank have a step of twenty feet in width on the outside forming a supplementary bank. All the soil was removed and used for covering the banks and when the original ground was sloping, horizontal steps were entered
Reservoir.

its surface and the banks started on them as a base, and formed from earth free from all perishable material, built up in layers and carefully rolled and well watered. The top of the embankment has a gravel walk in the centre ten feet wide, the rest of the top and outside slopes are covered with soil and sown with lawn grass seed. Whenever the bank was natural a lining of fascine was applied two feet thick. Whenever the bank is artificial a fascine wall was built in the centre beginning at about twelve feet below the level of the bottom of the Reservoir, with a width of twelve feet (as Mr. Rawlinson says about one third of the height, \( \frac{1}{3} \times 12 \approx 4 \)) being stepped in, one foot in every five until it reached within two feet of the top of the embankment. The bottom of each fascine is covered with fascine two and a half feet thick, and is connected with the slope fascine, also
Gate Y Conna. (Pl. III.)

On the middle of the south bank is the Gate Y Conna. The foundations of which are of granite and extend eleven feet below the bottom of the Reservoir (see Pl. III.) The bottom of the well are at the grade of the bottom of the Reservoir and are built to the

is extended under the artificial embankments to connect with the pendle walls in the centre. The centre pendle walls are connected with the slope pendle by rises walls so that no water can escape without going through a wall of pendle. The material for pendle was a sort of silt found upon the reservoir grounds. The pendle was well spread and watered and washed possibly rolled in thin silt layers. The slopes are faced with rubble passing laid on a layer of crushed stone. The bottom of the basins is faced with round cobbled stones on a layer of gravel.
gate house.

To be with cut faced as plain masonry, quarry faced being used for the water front and much portions of the sides as are shown above the slope paving. The rest of the stonework is of rubble masonry. There are two arched openings in the water front on the west side see (Pl III) six feet wide, for the passage of the water from the south basin into the wells. The water is drawn from the north basin by a thirty inch pipe running from the gate house across the south basin through the division embankment (see Pl II) under the overflow, nearly to the north side of the north basin. This pipe rests on brick piers, twelve feet apart, through the basins, and six feet apart under the division embankment (see Pl III), and is two feet above the basin. The bottoms of the two arched openings are six feet two and seventeen inches above the bottom of the basin, allowing water to be drawn at either of these two heights. The upper one has been found
Gate House.

Useless and unplanned up. There are two small wells, six by eight feet, and one large well, six by twenty-two feet square. (See plan B. 111.)

The small wells are furnished with wire screens in the centre. The east well has a gate for the lower opening. The large well has an opening gate for the lower opening from the east well, which is at the same level as the thirty inches pipe leading into the west well. The large well has grooves for top planks dividing it in the centre, and showed it be necessary to empty it. Half of it can be used while the other half is empty. From this large well (see plan) two thirty-inch pipes lead through a solid wall of masonry ten feet thick, into the gate vault, which is twelve by twenty-one feet square, and about nineteen feet high. This gate vault is lined with brick and has two chimneys four feet in diameter, built to the top of the bank just in front of the main
Gate House.

house and provided with lights for the gate vault (see Plan P. III). In each of the thirty inch pipes is a stop gate. These gates have the valve divided so that one fifth part of it can be opened at a time, thus relieving the pressure gradually. The entrance to the gate vault is from the outside (see reservoir plan P. III.) through an arched passage way five feet wide, seven feet high and about sixty feet long. The passage way is built of rubble masonry with an arch of brick two feet thick (see Plan, P. III.). The two thirty inch pipes pass through the wing walls outside the passage way and running downs
wars join in a "T piece" outside the bank forming the distributing main pipe (P. III).

The foundations of the Gate House are built forty feet square, with wing walls on the water front to join the slope paving, and wings on the sides up to the grade of the bottom of the Reservoir then narrowed in
Over Fall

Any one entering steps to thirty-one by twenty-four feet square at the level of the top of the bank (see plan) then this a brick gate House is built thirty feet square and twenty feet high. There is a wall of poulle from ten to twenty feet thick around the foundations joining the poulle wall in the centre of the bank and of the same height.

Over Fall. (PLIII)

Near the middle of the division embankment is the overfall and end of the force main pipe. The distributing pipe, as before stated, runs through this embankment resting on brick piers six feet apart. The piers are collared round the pipe, and seven of them built up to within seven feet of the top of the embankment (see PLIII). Then large flat stones as stretchers are laid across, and cross walls of brick are built up on these to support the stone steps of the overfall. The spaces between these walls
Drainage.

are filled with concrete.

Drainage of Reservoir, (P 111)
The reservoir can be drained to within two feet of the bottom by the thirty inch distributing pipes. Below that depth it is drained by sixteen inch pipes one in each basin. These sixteen inch pipes were made of cement, the north one was nearly entirely washed away last spring by the drainage water from the hill near the reservoir. Both pipes have flap valves on the inside of the reservoir and must be reached by diving when the reservoir is full, a very disheartening state of affairs for supplying.

As I made a complete survey of the whole work in company with the superintendent who very kindly explained everything minutely, as well as instructing me with a large number of plans & have been able to treat the subject with some degree of completeness and must accordingly wish it may satisfy the desired ends.

Rescued. 

B. C. Ninelsen.
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