REPORT ON THE FILTRATION OF THE NUUANU WATER SUPPLY

HERING
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OF

HONOLULU, H. I.

BY

RUDOLPH HERING,
HYDRAULIC AND SANITARY ENGINEER.

NEW YORK

1897.
REPORT

ON THE

FILTRATION OF THE NUUANU WATER SUPPLY,

HONOLULU, HAWAIIAN ISLANDS,

BY

RUDOLPH HERING,

Hydraulic and Sanitary Engineer.

To Mr. S. B. Dole,

President of the Hawaiian Republic,

Honolulu, Hawaiian Islands.

Sir,—While investigating the preliminaries for presenting to you a report upon the sewerage and drainage of Honolulu, I received a request from Mr. W. O. Smith, Attorney-General and President of the Board of Health, to furnish also a report upon the filtration of the Nuuanu water supply, pointing out means for improving its quality and rendering it healthful, clear and palatable. In accordance therewith I have prepared certain plans, specified in Appendix B, and the following report.

Acknowledgments should be made of my indebtedness to Mr. W. O. Smith, Mr. Frank S. Dodge, Mr. W. E. Rowell and Mr. Andrew Brown, for the information and assistance furnished with reference to the question under consideration.

Very respectfully yours,

RUDOLPH HERING

NEW YORK, 1897.
I.—PRELIMINARY.

The City of Honolulu is supplied with water from two sources—artesian wells in the city, and streams in the Nuuanu Valley.

The artesian water is obtained from wells which draw from a water table rising around the foot of Punch Bowl to about 40 feet above mean tide. The quantity of water which is said to be available from this source is at least 6,000,000 gallons per day.

It was not stated on what data this assertion was made, nor by what test this conclusion was reached. I have no doubt, however, that this amount of artesian water is available, and it seems probable that much more may be obtained.

The rainfalls in the mountains are quite heavy, as may be seen from the carefully kept records of the Hawaiian Meteorological Bureau. The streams are found to bring down but a small fraction of the rain water. Making a suitable allowance for evaporation, a large proportion of the water sinks into the soil and the porous rocks of the island, and reaches the ocean subterraneously.

The quality of this water is said to be entirely satisfactory. It is perfectly clear, its taste is good, and it has no organic pollution.

The public supply is obtained from two pumping stations. The older, or Makiki pumping station, situated at the foot of the mountains, in the valley of the Makiki stream, furnishes about 1,250,000 gallons per twenty-four hours, if the pumps run continuously. It is stated that the water is obtained there from one well 8 inches in diameter. The elevation of the pumps is about 150 feet above mean tide, and the water rises in the wells to about 40 feet above the same level. It is lifted into the Makiki reservoir by engines having the pump plungers in the well. This reservoir is at an elevation of 150 feet above mean tide, and has a capacity of 685,283 gallons.

The new pumping station is located at Beretania and Alapai streets, at the foot of Punchbowl Hill. There are two
wells, 10 inches in diameter, about 60 feet apart. The elevation of the ground at the pumping station is 30 feet above mean tide; the elevation of the reservoir is 170 feet above the same level, and has a capacity of 1,500,000 gallons. The engines pump about 2,000,000 gallons per day of about ten hours. They are intended to supplement the supply from the Nuuanu Valley when this is deficient in quantity. During the rainy season, when less water is used for sprinkling, the pumping at this new station is suspended, as the additional water is not required.

The cost of pumping water at the Punchbowl station is given as $600 per month. The cost of pumping 1,000,000 gallons into the reservoir is, therefore, $10, or about 8 cents per 1,000,000 gallons lifted 1 foot high.

The Nuuanu stream supplies the city with water by gravity. At Luakaha the stream is diverted into a reservoir, called No. 3, which is at an elevation of 808 feet above mean tide, and has a capacity of 10,712,130 gallons. From this reservoir a 15-inch pipe extends about 1,000 feet to another reservoir, called No. 2, at an elevation of 735 feet above mean tide, and having a capacity of 7,301,639 gallons.

Again a 15-inch pipe leads from this reservoir to Reservoir No. 1, situated about 1.2 miles below, at an elevation of 399 feet above mean tide, and with a capacity of 21,304,211 gallons. Before the 15-inch pipe discharges into Reservoir No. 1, the water passes through the Electric Light Station and operates the dynamos which supply the city with light.

These reservoirs are hardly more than ponds, formed by earth dams thrown across the valley. The dams are paved, but the reservoirs have earth bottoms and sides, differing but little from the original surface and retaining a good deal of vegetable matter.

Another reservoir of smaller capacity is situated near the intersection of the Nuuanu road with Judd street. It is fed from a separate stream; its elevation is 90 feet above mean tide, and its capacity only about 364,676 gallons. It is of little importance for the general city's supply.

The reservoirs are too small to act as storage basins for much more than a week's consumption. They are little more than distributing basins.
The quality of the water of the Nuuanu stream is not of the best. Mr. Brown states that at Luakaha the water is never quite clear, but also never very muddy. When it is used at the Electric Light Station, and the upper reservoirs are being drawn down, the water rushing into Reservoir No. 1 stirs up the mud at the bottom, and causes the water therein to become turbid.

At Luakaha, as well as in the reservoirs, the water has generally a vegetable taste and is sometimes slightly bitter. The following analysis, made by Mr. A. B. Lyons, analytical chemist, shows the amount of suspended and dissolved matter. It will be seen that there is considerably more suspended matter in the water of the reservoir than at the source above. The dissolved matter does not differ much. Of the suspended matter about 33 per cent. is organic when the water is taken from the stream, and nearly 44 per cent. when it is taken from the reservoir.

RESULT OF AN EXAMINATION OF THE WATER FROM LUAKAHA AND FROM NUUANU RESERVOIR NO. 1.

In parts per million.

**Luakaha.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended matter (sediment)</td>
<td>3.0</td>
</tr>
<tr>
<td>Mineral matter contained therein</td>
<td>1.9</td>
</tr>
<tr>
<td>Dissolved minerals, dried at 100 degrees Cent.</td>
<td>108.0</td>
</tr>
<tr>
<td>&quot; &quot; ignited</td>
<td>66.0</td>
</tr>
</tbody>
</table>

**Reservoir No. 1.**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended matter (sediment)</td>
<td>7.5</td>
</tr>
<tr>
<td>Mineral matter contained therein</td>
<td>4.2</td>
</tr>
<tr>
<td>Dissolved minerals, dried at 100 degrees Cent.</td>
<td>114.0</td>
</tr>
<tr>
<td>&quot; &quot; ignited</td>
<td>72.0</td>
</tr>
</tbody>
</table>

The following analysis of the water is given in the Biennial Report of the Minister of the Interior, for 1886, page clxx.
<table>
<thead>
<tr>
<th>Date of Collection</th>
<th>Location</th>
<th>Free Ammonia</th>
<th>Albuminoid Ammonia</th>
<th>Nitrogen in nitrates</th>
<th>Chlorine</th>
<th>Hardness in degrees or grains per gall.</th>
<th>Residue at 100 degrees Cent.</th>
<th>Microscopic examination of sediment</th>
<th>General Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 16</td>
<td>Open ditch at Luakaha</td>
<td>.016</td>
<td>.088</td>
<td>.00</td>
<td>20.0</td>
<td>2.49</td>
<td>78.5</td>
<td>Vegetation, Algae, Animals</td>
<td>Good</td>
</tr>
<tr>
<td>&quot; 30</td>
<td>&quot;</td>
<td>.026</td>
<td>.082</td>
<td>.00</td>
<td>20.0</td>
<td>2.49</td>
<td>57.1</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Feb. 16</td>
<td>Reservoir No. 1</td>
<td>.026</td>
<td>.086</td>
<td>10.69</td>
<td>23.5</td>
<td>4.15</td>
<td>120.0</td>
<td>Vegetable debris, inclusions</td>
<td>Good</td>
</tr>
<tr>
<td>March 3</td>
<td>&quot;</td>
<td>.008</td>
<td>.066</td>
<td>2.62</td>
<td>23.7</td>
<td>4.15</td>
<td>157.1</td>
<td>Vegetation, Algae, Animals</td>
<td>Good</td>
</tr>
<tr>
<td>&quot; 30</td>
<td>&quot;</td>
<td>.025</td>
<td>.094</td>
<td>22.1</td>
<td>3.73</td>
<td>107.1</td>
<td></td>
<td>Good</td>
<td>Fair</td>
</tr>
</tbody>
</table>
These analyses were made in 1886, but are the latest I could find. They indicate, from a chemical standpoint, a fairly good water, and it is doubtful whether there would be much difference now in this respect. Modern investigations have, however, indicated that the chemical constituents are not the only guide by which to judge of the healthfulness of water. The small living organisms contained in the water are of much greater importance.

It has been observed and reported that the Nuuanu water contains disease bacteria and protozoa. It is also supposed that it contains the eggs of fluke worms. It is found that persons using this water are occasionally sick with malaria and other diseases known to be communicated through unhealthful water supplies, while persons supplied with the artesian water are not so affected. It is well known that waters in semi-tropical and tropical regions contain the protozoa which cause malaria.

The quantity of water taken from the Nuuanu stream varies with the season. It is stated that for half the year it is 3,000,000 gallons per day, but during dry weather the stream cannot be depended on to furnish more than 1,000,000 gallons per day.

This quantity could be increased by building a storage reservoir in the valley above. I am informed that some years ago such a reservoir was proposed and was called Reservoir No. 4. On account of the fear that should a break occur in the dam there would be serious danger to parts of the city of Honolulu by the flood that would descend the valley it was not built. Its expense was also considered an objection.

The elevation of the water in this reservoir was to be 1,020 feet above mean tide, and the dam was located about 5 miles from the City Post Office. The water-shed above the proposed reservoir was estimated by Mr. Lyons to be about 1 square mile. The area of the reservoir itself was about 50 acres. No engineering difficulties seem to have been anticipated, excepting in reference to the requirement that the reservoir should be water-tight. The estimated cost was stated to me to be $45,000. Not having a survey of the site of the dam, or anything more than a contour survey of the site of the reservoir, I am not able to make a close estimate of cost, but
believe the reservoir, properly built, so as to be perfectly safe, might cost as much as $60,000.

In order to sufficiently protect the city, the dam should be built with great care. It should have a core wall of masonry extending across the entire valley; have long slopes, both on the upper and lower side, and these slopes should be paved so as to prevent washing, in case of an overflow. It would also be necessary to have a strongly constructed waste-way of ample proportions for the discharge of excessive floods. In order to prevent any deterioration in the taste of the water by long contact with vegetation, the slopes and bottom of the reservoir should be cleaned and freed of organic matter, and, if possible, the slopes between the high and low water levels, should, in part, be excavated so as to be quite steep, and thereby restrict the areas of shallow water.

If we neglect the present expense of water storage, and assume the cost of Reservoir No. 4 at $60,000, and further suppose the uniform minimum supply could be increased by this reservoir, 1,000,000 gallons per day, then, allowing for interest, sinking fund and maintenance, the additional water delivered at the lower reservoirs would cost at least $15 per million gallons. This cost is for the water in its natural unfiltered condition.

As the ground-water supply at the present time costs but $10 per million gallons, and as its quantity can be increased at this same rate, it is seen, therefore, that for the purpose of supplying the lower part of the city with water for potable purposes, the proposed Reservoir No. 4 would not be economical. If it is considered, however, that this reservoir would, in addition, be able to furnish power—as it supplies 1,000,000 gallons per day with a head of about 150 feet—such a reservoir would become economical by being utilized to increase the power for electric lighting, which I understand is becoming insufficient.

As the Nuuanu stream furnishes 3,000,000 gallons per day for a large portion of the year, it has, therefore, been considered desirable to ascertain the expense of filtering this quantity of Nuuanu water so as to save pumping ground-water at the Punchbowl Station.

As the artesian well supplies are capable of furnishing all
the water that is necessary for the principal parts of the city, lying below the elevation of the reservoirs, and as the Nuuanu supply can most economically provide for the higher districts of the city, not capable of being supplied from the Punchbowl and Makiki reservoirs, it has been considered feasible to use the Nuuanu water only for a high service supply. The amount of water required for this purpose was assumed at 500,000 gallons per day. It was, therefore, also thought desirable to ascertain the cost for filtering only this amount.
II.—THEORY OF FILTRATION.

In recent years considerable study has been devoted to the subject of filtering water supplies. Scientific research has demonstrated that a number of diseases, such as, for instance, typhoid fever, cholera, summer diarrhoea and malaria, are caused by or hold some relation to certain minute organisms, pathogenic germs and microbes, which are found in the bodies, in the blood or in the discharges of the afflicted persons.

Statistics and research have further demonstrated that water, which had been polluted by such organisms and subsequently taken into the body, was liable to produce the corresponding disease, while water which had been subsequently filtered in a proper manner, did not injuriously affect communities partaking thereof.

Recent experiments have shown under what conditions the removal of bacteria and other micro-organisms is most readily accomplished, and, therefore, the action of filters is now better understood than formerly. It is possible by measurement and calculation to state very closely what results can be obtained by filtering water of a known degree of pollution at a known speed and through porous material of which the character, depth and size of grain are known.

It has been shown that some filters, besides acting as strainers, convert organic matter into mineral compounds while the water is passing through the pores of the material. This conversion requires the presence of bacteria in the pores, as proven in a number of ways, but mainly by the fact that when a sufficient quantity of matter that is poisonous to them is contained in the water, or when a sufficient quantity of oxygen to sustain their life is not available, the process ceases.

When filters are to do their best work, the water should contain but little sediment. Where there is much sediment, a preliminary settling is necessary. The Nuuanu water, after leaving the reservoirs, however, does not require any addi-
tional sedimentation and can, without further treatment, at once be discharged upon filters.

The methods of water filtration available for city supplies may be divided into two classes—slow and rapid. By the slow method we may filter from 5 to 10 cubic feet per square foot of surface per day, and obtain a sure and practically complete removal of bacteria, protozoa and dissolved organic matter. By the rapid method we may filter as much as 300 cubic feet per square foot of surface per day, and obtain a thorough clarification, and a removal of 98 to 99 per cent. of the bacteria, probably all of the protozoa, but practically no dissolved organic matter.

If much dissolved organic matter remains in the water, a renewed bacterial growth may take place. As in the case under consideration, the water would be stored in a reservoir but a short time before use, and as this reservoir would be covered to prevent sunlight and heat from assisting subsequent bacterial growth, there is no reason why the dissolved organic matter remaining would be objectionable.

In the slow method large sand filters are used, and the water percolates through the sand with a uniform pressure and a slow rate of speed, allowing sufficient time for oxidation of the dissolved matter to take place within the pores of the sand. Unlike the rapid method, it does not depend wholly upon a straining action for the removal of the objectionable matter. When the water is not greatly polluted it contains a sufficient quantity of dissolved oxygen to accomplish the oxidation, which, if the works are carefully operated, is very effective. The natural film, which is formed upon the surface of the sand, further assists in retaining the objectionable organisms.

At intervals of perhaps a month, depending on the amount of retained matter, the upper half-inch or inch of the sand must be removed, as it begins to clog the filter. Subsequently, if the raw water is of a suspicious character, it should be allowed to run to waste until another film has formed, to insure the retention of the smallest organisms. The removed sand can be cleaned and used again.

The most important feature of a slow filter is the character of the sand. If the sand is too fine, the filters will in a short time become practically inefficient by clogging. If it is too
coarse, they will not be effective in preventing the matter that should be retained from passing through the pores of the sand.

The best material for filtering water is quartz sand. As such sand would have to be imported from California, its use was not considered feasible on account of the expense.

My examination was confined to the natural sands of the Islands, and also to an artificial sand made by crushing lava rock near the proposed site of the filters. The advantage of the latter material lies in its cheapness, as the haul from the city to an elevation of 370 feet above mean tide would be avoided.

The following table gives the chemical analyses of the sands that were considered. It also gives their mechanical analyses, by which their effectiveness for filtering purposes is judged:

**Chemical Analyses, by Mr. H. W. Clark.**

<table>
<thead>
<tr>
<th></th>
<th>Crushed rock</th>
<th>Hanapepe</th>
<th>Waimea</th>
<th>Waianae</th>
<th>Hilo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insoluble in strong hydrochloric acid</td>
<td>42.86</td>
<td>50.24</td>
<td>54.21</td>
<td>1.44</td>
<td>67.02</td>
</tr>
<tr>
<td><strong>Solution contained:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron, Fe₂O₃</td>
<td>19.28</td>
<td>14.48</td>
<td>16.00</td>
<td>0.28</td>
<td>14.60</td>
</tr>
<tr>
<td>Alumina, Al₂O₃</td>
<td>2.38</td>
<td>8.10</td>
<td>9.52</td>
<td>0.38</td>
<td>3.10</td>
</tr>
<tr>
<td>Lime, CaCO₃</td>
<td>14.16</td>
<td>10.13</td>
<td>3.00</td>
<td>89.06</td>
<td>4.94</td>
</tr>
<tr>
<td>Magnesia, MgCO₃</td>
<td>5.68</td>
<td>4.65</td>
<td>4.18</td>
<td>2.93</td>
<td>3.39</td>
</tr>
</tbody>
</table>

All effervesced strongly with acid.

**Mechanical Analyses, by Mr. Allen Hazen.**

<table>
<thead>
<tr>
<th></th>
<th>Mm.</th>
<th>Mm.</th>
<th>Mm.</th>
<th>Mm.</th>
<th>Mm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective size 10 per cent. less than</td>
<td>0.03</td>
<td>0.20</td>
<td>0.18</td>
<td>0.41</td>
<td>0.18</td>
</tr>
<tr>
<td>Sixty per cent. less than</td>
<td>0.30</td>
<td>0.36</td>
<td>0.36</td>
<td>0.56</td>
<td>0.29</td>
</tr>
<tr>
<td>Uniformity coefficient</td>
<td>10.0</td>
<td>1.80</td>
<td>2.00</td>
<td>1.40</td>
<td>1.60</td>
</tr>
</tbody>
</table>
The Waianae sand is composed entirely of shells, of which calcium carbonate is the principal component. The grains are of the proper size to filter the water. The material may, however, make the water somewhat hard. The lime of the shells is apparently combined with other substances which hold it firmly together so that it might resist disintegration for a long time and not too readily dissolve in the passing water. At my request a small experimental filter was to have been made, to observe whether or not the water passing through this sand would be rendered harder than desirable. I am informed, however, that such experiments were not made.

The four other kinds of sand are composed mainly of particles having the same general composition and indicate a volcanic origin. All would have a powerful decolorizing action, owing to the iron and alumina which they contain.

The sands contain considerable lime and magnesia, and in advance of an actual trial it is impossible to state whether or not they will harden the water materially when it is passed through them. It is not expected, however, that the increase of hardness would be objectionable.

More or less disintegration will take place in using any of the local sands as well as the crushed rock. The material is disintegrated into powder and removed generally during washing. The deficiency must be made good by the addition of new sand from time to time. The amount thus added will probably be very slight.

The following tabular statement gives the filtering capacity of the various sands, their effective size and uniformity coefficient, the depth of sand which would be necessary for the filter, and the cost of a ton of each sand. It also contains a column giving the cost of the sand required to filter 1,000,000 gallons of water per day, and a description of its specific character:
<table>
<thead>
<tr>
<th></th>
<th>Effective size</th>
<th>Uniformity coefficient</th>
<th>Capacity for filtration per acre daily</th>
<th>Depth of sand in feet</th>
<th>Cost of sand per ton</th>
<th>Cost of sand to filter 1,000,000 gallons of water per day</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed rock, screened</td>
<td>0.41</td>
<td>1.40</td>
<td>4,000,000</td>
<td>5</td>
<td>$2.50</td>
<td>$8,167 50</td>
<td>Very good sand, low in alumina, high in iron.</td>
</tr>
<tr>
<td>and washed with hose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Almost entirely calcium carbonate.</td>
</tr>
<tr>
<td>Waianae sand</td>
<td>0.41</td>
<td>1.40</td>
<td>4,000,000</td>
<td>5</td>
<td>2 00</td>
<td>10,890 00</td>
<td>Very good sand, fine and of very permanent character.</td>
</tr>
<tr>
<td>Hilo sand</td>
<td>0.18</td>
<td>1.60</td>
<td>2,000,000</td>
<td>3</td>
<td>3 50</td>
<td>17,968 50</td>
<td>Similar to Hilo, but rather too much alumina.</td>
</tr>
<tr>
<td>Waimea sand</td>
<td>0.18</td>
<td>2.00</td>
<td>2,000,000</td>
<td>3</td>
<td>2 50</td>
<td>14,701 50</td>
<td>Similar to Waimea, but considerably higher in calcium carbonate.</td>
</tr>
<tr>
<td>Hanapepe sand</td>
<td>0.20</td>
<td>1.80</td>
<td>2,000,000</td>
<td>3</td>
<td>2 50</td>
<td>14,701 50</td>
<td></td>
</tr>
</tbody>
</table>

* The hauling from the wharf to the Electric Light Station is estimated at $2 per ton in addition to the above prices.
The effective size is a conventional determination, and indicates that in a given sand 10 per cent. of the grains are smaller and 90 per cent. are larger than this "effective size."

The uniformity coefficient designates the ratio of the size of grain which has 60 per cent. of the sample finer than itself to the size which has 10 per cent. finer than itself.

Among the samples sent, the Waianae sand has the best size of grain.

The Hanapepe, the Waimea and Hilo sands are the natural result of the breaking up of rock similar to that furnishing the sample of crushed rock. The grain is not so small as to make their use impracticable, although coarser sand would in some respects be more desirable. The filters would clog somewhat more rapidly than with coarser sand and the operating expenses would thus be somewhat greater. Their fineness would on the other hand insure a high bacterial efficiency.

The sample of crushed rock sent, is, according to the table (page 11), entirely too fine to be used as an economical filtering material. The grains can, of course, be made of any desired size. It is only necessary to use a coarser screen and also to remove the dust by shaking on a brass wire screen with 60 or 70 meshes to the inch, or by washing, or by both sifting and washing. The grains of sand should not be any coarser than in the sample of sand from Red Wing, Minnesota, sent you in a bottle, and generally used for mechanical filters. As the grains of crushed rock can be given the same size of grain as the Waianae sand, it has been so tabulated on page 13.

It will be seen that this artificial material is the cheapest that can be used for the filter beds. The estimates of cost have, therefore, been made with the expectation of using it. It can be manufactured, I am informed, not very far from the proposed filter basins, and allows of a down-hill haul.

Rapid filters depend, for their sanitary effectiveness, not only upon a carefully selected sand, having grains of definite and uniform size, but mainly upon the artificial coagulation of the organic matter, and the formation of a gelatinous deposit from the water upon the top of the sand. Very little oxidation of organic matter takes place in them. The film which is thus automatically spread over the surface of the filter has
the property of holding back, not only the coarse matter usually contained in the water, but also the minute organisms, such as protozoa and bacteria. The coagulation is produced by adding to the water certain materials, of which alum is the most common. Inasmuch as the necessary amount of alum is very slight and is supposed to be wholly retained in the filter, it will not cause any objectionable results.

As it takes some time for the film to form, usually varying between twenty and forty minutes, it will be necessary after cleaning the filters to allow the water to run to waste until the coagulated material has sufficiently accumulated to retain the objectionable matter. The film is removed, of course, every time the filter is cleaned, which may be once a day, or still oftener if the water is muddy. Considerable skill and care are required, therefore, in operating mechanical filters, if the objectionable matter is to be prevented from passing through at any time and appearing in the effluent water.

The experiments which have been made in Louisville, Ky., with mechanical filters, have not yet been reported. They have, however, been completed, and while no statements of conclusions are available, it is inferred that the filters subjected to experiment require certain alterations to make them effective for the Ohio River water. The city officers are at present designing filters based upon the experience there gained.

There are two methods of operating such filters, namely, by having them open, or by working them under pressure.

The pressure filters have the water forced through them under a considerable, and what is more important, under a varying, head. They are, therefore, not as effective as the other class, called gravity filters, where the pressure is lighter and more uniform. In the latter there is, consequently, less occasion to injure the continuity of the gelatinous film, which makes them preferable for domestic water supplies, where the escape of minute organisms through the film must be prevented.
III.—GENERAL ARRANGEMENT OF THE PROPOSED WORKS.

The location proposed for the filters is a tract of land called Queen Emma Place, belonging to the city, and lying on the Pali Road, about 1,100 feet south of Reservoir No. 1.

The elevation of high water in Reservoir No. 1 is 400.9 feet, that of low water is 386.0 feet above mean tide. The surface of the ground selected for the location of the filters varies from elevation 365 to 372 above mean tide. There is, therefore, sufficient fall to permit the water from the reservoir to enter the filters by gravity.

A reservoir for the filtered water is to be located on the same ground, in order to have a sufficient storage capacity to balance the daily and hourly fluctuations in the draft from the city, and also to furnish a fire reserve. This reservoir is to be covered in order to prevent the deterioration of the filtered water.

The filters themselves are located to the northeast of this reservoir, and will allow the clear water to flow into it by gravity.

Two plans have been made, as requested. One is for natural or slow filters, and the other for mechanical or rapid filters. The plans indicate the arrangements for a plant that will filter 500,000 gallons per day, and, by proper extensions, 3,000,000 gallons per day.

At my request, two parties, the Morison-Jewell Filtration Company and the New York Filter Manufacturing Company, have furnished general designs for filtering the Nuuanu water. These designs I have attached to the plans, as Plates IV and V.

On Plate IV, under the title, there is a general plan showing the relative positions of Reservoir No. 1, the site for the proposed filters and filtered water reservoir, and the stream which is to receive the water used to wash the sand.
IV.—FILTERED WATER RESERVOIR.

The reservoir for filtered water is designed to have storage capacity sufficient to balance the fluctuations of draft from the city for domestic purposes, and to contain a fire reserve of about 15,000 cubic feet. Provision is, therefore, made for a total working capacity of, approximately, 35,000 cubic feet.

The reservoir is completely lined with concrete, in the manner shown on the drawings. The concrete is placed in two layers, between which is a coating of asphalt, so as to insure water tightness.

The reservoir is divided into two independent basins by a wall through the center. This wall is of concrete, 3 feet thick at the top, and 5 feet thick at the bottom. Each basin is divided longitudinally into two compartments by a light 12-inch concrete wall extending from the inlet end, but only to the foot of the slope at the other end.

The inlets for the filtered water are in the outer compartment of each basin, and near the top of the slope. The outlets are in the inner compartments, at the foot of the slope nearest the inlets, and at the base of the heavy wall. This arrangement allows the water to be in constant motion when passing through the reservoir, and thus stagnation and deterioration are avoided.

Each compartment is provided with an overflow, at high-water line, into a drain, which discharges into a near stream.

The main pipe from the filters branches in a valve chamber, situated immediately in front of the reservoir. The valves are for the purpose of controlling the flow of the water to and from the reservoir.

The reservoir is to be roofed with concrete arches 8 inches thick, as shown on the drawings. Between the arches and on the longitudinal walls agricultural drain tiles are to be laid, to carry off rain water percolating through the earth.

It would, of course, be cheaper to roof the reservoir with wood than with concrete. I have preferred, however, to sug-
gest the best and most usual construction. If the saving of
cost is considered a material item, a wooden covering can be
used as a temporary expedient.

The reservoir is completely covered with earth to a depth
of about 6 inches over the crown of the arches. Around its
outer edge a railing should be built, to prevent teams from
drawing heavy loads over it.

The entrances to the different compartments of the reser­
voir are through openings in the roof. These are covered with
cast-iron frames and tight but removable cast-iron covers.
Steps are built into the division wall under each entrance, and
permit of descending into the reservoir. The valve stems of
the outlet pipes are brought up to a point just beneath the
cover over the entrance.

At the points, shown in the drawing of the reservoir on
Plate III, light and ventilation shafts are to be constructed.
Each shaft consists of a rectangular structure, built of con­
crete, and extending about 1½ feet above the top of the earth
filling over the reservoir. A plate of wire-glass, 12 inches
square and ½ inch thick, is placed over the shaft to admit light
when cleaning and inspecting the reservoir. At other times,
wooden covers are to be kept over the shafts to prevent the
glass from being broken and also to exclude light. On two
opposite sides of each shaft rectangular openings are to be pro­
vided, the bottoms of which are at least 8 inches above the
ground. A frame is to be fitted in each opening, with a cop­
per wire screen of fine mesh, to exclude insects and dust.
V.—NATURAL OR SLOW FILTERS.

Plate I contains a general plan of the proposed site for the filters. The design shows a plant of sufficient capacity to filter 500,000 gallons per day, including the necessary filter held in reserve for cleaning or in case of accidents.

The filters are intended to purify the water at the rate of 4,000,000 gallons per acre per day. They are three in number, and each is about 72 feet square at the high-water line. They are so connected by piping that any one of the three beds may be out of service without interfering with the operation of the others.

The unfiltered water from Reservoir No. 1 is distributed to each filter by a 10-inch pipe. The filtered water is drawn off through the regulating apparatus, and passes to the filtered water reservoir.

The valves and piping of the filtered water main and the drain pipe are so arranged that after a filter has been cleaned and is out of service it can be refilled with filtered water from some bed at that time in service. To place a filter in service again after it has been cleaned, the water is first admitted through the under drains until it rises above the surface of the sand. After it has been at rest for a short time, the unfiltered water is admitted over the surface of the filter and allowed to rise to the prescribed height. After the filter has been permitted to stand for a few hours, the regulating apparatus is opened and the filter started, slowly at first and gradually increasing to the prescribed rate of speed.

The filter beds are to be excavated to the required depth and form, the surplus materials being spread in thin layers, properly watered and rolled, to form the embankments surrounding the filters and reservoir.

After the sides and bottoms of the excavated pits for the filters have been properly dressed and compacted to form an unyielding foundation, the concrete lining is to be put in. It should be laid in two courses, the first 6 inches in thickness,
but not monolithic. It should be set in proper forms or moulds, and in blocks approximately 4 feet square, each block being formed in place and in close contact with each adjacent block. The joints between the blocks should be left open, and be slightly wider at the top than at the bottom.

After this first course of concrete is laid, it should receive an asphaltic coating, applied so as to completely fill all the cracks between adjacent and adjoining blocks, and also so as to cover completely the entire surface of this first concrete layer.

The asphaltic coating should be made of the best materials, and applied in the best way known at the time.

Upon this asphaltic layer a second layer of concrete, but only 4 inches in thickness, should be laid. Before the concrete sets, the top surface should be dusted over with neat cement, and rubbed down with a trowel to a hard, smooth and dense surface.

The under drain in each filter-bed is to consist of a channel formed below the level of the bottom of the filter, and covered with concrete slabs placed so that cracks about 1 inch wide will be left between them.

The pipe from the regulating chamber to the under drain should be of cast iron, 10 inches in diameter and laid in concrete in the manner shown on Plate II. There should be a valve at the end of this pipe in the inlet well.

The wells for the regulating chamber and inlet should have the bottom and sides constructed of concrete, built in place, as shown on the drawings. The foundations of the gatehouse should be of concrete. The superstructure may be either of brick or of wood. It should have a door and two windows.

The roads around the filters should be properly graded and macadamized, and the slopes of the embankments around the filters and the storage reservoir should be sodded.

A tramway should be built, as shown on Plate I, to facilitate the transportation of the dirty sand from the filters to the sand washer, and of the clean sand from the sand washer to the filters.

A drain of cast-iron pipe, 10 inches in diameter, should traverse the site in front of the filters, and discharge into the
14-inch vitrified sewer, emptying into the stream near by. The dirty water from the sand washer, as well as the overflow from the filtered water reservoir, should also empty into this 14-inch sewer.

The under drains have been designed for a very small loss of head. The loss in the gravel and drains combined is only ¼ inch, and the total loss of head in the filter, when clean, will be about 2½ inches for a rate of 4,000,000 gallons per day.

The filtering materials are to be made of crushed rock, screened and washed as already described. For the upper 5 feet the material must have an effective size of 0.41 millimeter, with a uniformity coefficient of not over 1.4. This sand is to be supported upon a floor of gravel of the following sizes:

Six inches of gravel of a size of 40 millimeters are to be placed upon the bottom of the filter; upon this 2½ inches of a size of 12 millimeters; upon this 2 inches of a size of 4 millimeters, finishing with a layer 1½ inch thick of a size of 1.5 millimeters.

In placing the gravel in the bottom of the filter, great care must be taken to keep the finer layers of the proper thickness, so that the fine sand will not be washed down into the layers of coarser material. In order to insure success, this particular work of placing the sand must be properly done, with full knowledge of all the conditions and requirements.

In case the excavation for the filters should be in rock, it will not be economical to put them as low as shown on the drawings. In such case it will be cheaper to borrow earth to make the embankments. If rock is used in the embankments, it should be placed so as to form a core wall in the dividing banks, and it can also be put on the outside of the outside banks.

In case the ground is of such a nature that the banks will not stand at a slope of 1½ to 1, they should be made flatter, and thus insure safety against any tendency to slide.

The number of filter beds may be readily increased to meet the demands for filtered water in the future.

With crushed rock sand, as recommended, the total quantity of water which may be passed through the filters between successive scrapings will range from 40,000,000 to 70,000,000 gallons per acre, averaging about 50,000,000.
In order that the filters may give satisfactory results it is necessary that the water should pass through the sand layer at a uniform and not too rapid rate. This uniform motion is to be secured and regulated by the apparatus shown in detail upon Plate II. It consists essentially of a floating weir, connected by a telescoping tube with the main discharging the filtered water into the distributing reservoir. This main terminates in the regulating chamber with a vertical cast-iron pipe 8 inches in diameter; the pipe rising to a height of about 6 feet above the bottom of the chamber. A brass tube slides inside of this pipe. It is 6 inches in diameter and 7 feet long, and has four vertical slots spaced equidistantly around and near the top of the tube. The slots are each 7 inches long and 1 inch wide, their bottoms being 12 inches from the top of the tube. The tube is clamped at its top by a split ring, with a draw bolt, attached to three radial arms, which are riveted at their extremities to an annular, galvanized iron float. The brass tube should be turned to a true cylinder and polished smooth. It slides inside of the 8-inch vertical pipe, through a leather annular packing placed at the top of the iron pipe. This packing allows of a free motion of the brass tube, and is still sufficiently tight to prevent any great amount of leakage.

A short brass cylinder is fitted into the top of the brass tube. It is 6 inches in diameter outside, and has four vertical wedge-shaped slots, spaced equidistantly. This cylinder is carried upon a vertical brass spindle, firmly fixed to it. The spindle passes upward through a cross-piece spanning the top of the fixed long cylinder. The cross-piece is fastened to it rigidly with set screws. At the top of the spindle a long pointer is also rigidly attached, the spindle being free to turn through the cross-piece spanning the fixed tube.

By moving the pointer to different positions, the wedge-shaped slots in the small cylinder, or regulating collar, assume corresponding positions, thus changing the width of the opening through which the water from the regulating well may flow into the sliding cylinder.

As the galvanized iron float will maintain a nearly constant depth of immersion, then, for any given position of the pointer, relative to the float, there will always be a constant quantity of water passing into the tube, and hence a constant
rate of filtration through the sand. By changing the position of the pointer, with reference to the float, the quantity of water passing through the filters may be increased or diminished at pleasure.

In order that the surface of the water may not fluctuate too greatly, and also to insure more uniform results in the working of the filter, the surface of the water over each filter is to be maintained at a constant level. This is to be secured in an inlet well by controlling the flow to the filter through a balanced valve operated by a float. If the water in the inlet well falls, the float descends correspondingly, opening the valve and allowing more water to enter the filter. When the water has reached the proper level, the valve will be partially closed and thenceforth the water level will remain nearly constant.

As the sand for these filters will be expensive, it is necessary to provide means for washing that which is removed in the periodical cleanings. The apparatus shown on Plate I is modeled after a successful plant now in operation in Hamburg, Germany. It consists essentially of a concrete chamber situated near the filtered water reservoir, containing a series of seven cast-iron hoppers with ejectors at the bottom of each. These ejectors are operated by a supply of water to be taken from Reservoir No. 1, under a head of about 30 feet. They are so arranged that when in operation they draw the sand from the hoppers, eject it through vertical pipes to the troughs above, which with the accompanying water carry the sand into the next succeeding hopper, and finally to the box at the end of the apparatus.

The ejectors are specially designed and manufactured by Körtig Brothers, Hanover. They are made of chilled cast iron, and require a careful proportioning of the sizes of the nozzles, openings, and connecting pipes.

Each hopper has an opening at the side near the top, out of which the dirty water flows into a wooden trough running parallel with the hoppers. Some of the fine sand is retained in this trough and the dirty water flows over its edges into a concrete channel. Near the outlet end of this channel, a wooden dam is placed, over which the dirty water flows before finally passing off into the drain.
The dirty sand from the filters is dumped from the cars into the special hopper at the right-hand end of the apparatus, as shown on the plans. The outlet of the hopper is controlled by a sliding gate. Horizontally across the top of the opening controlled by this gate is a pipe connected with the water main from the storage reservoir. It is arranged with a packed joint so as to revolve upon its horizontal axis. The portion of this pipe extending across the opening has two rows of perforations lengthwise of the pipe, the central angle between the two rows being about 120 degrees. In front of the opening, and in the first hopper, is placed a screen box to retain coarse material, the sides and bottom of which are made of wire netting. By partly rotating the perforated pipe, when the water is passing through the perforations under pressure, the amount of dirty sand fed into this screen box and also the amount of water to be mixed with the sand can be controlled.

The mixed sand and water then fall into the elevating hopper and are forced by the ejector through the vertical pipe and inclined trough into the first washing hopper. The sand falls to the bottom of this hopper, is carried by an ejector to the second hopper, then to the third and fourth, and so on to the box at the end of the apparatus. The dirty water passes out of the overflow from each hopper and finally to the drain, the sand and silt being retained in the different compartments of the long wooden trough and the concrete channel. The sand, in passing from the last hopper to the receiving box, traverses the last long inclined wooden trough, and on its way is further washed by the action of two sprays from perforated pipes passing across its top. These sprays drive against the current in the inclined trough.

The bottom of each of the inclined troughs is studded thickly with square wooden pegs, which give the water a twirling motion as it flows from one hopper to the next, thereby increasing the effectiveness of the washing.

The sand is removed from the box at the end of the apparatus by means of scoop shovels, and the operation of lifting it out of the water which flows through this box further cleanses it. This water then falls over a weir situated at one side into the concrete channel, from which it goes to the drain.
The water to operate the apparatus is brought by a 6-inch pipe to a distributing main running parallel with the hoppers. The pipes from this main to the hoppers at each end, are 2½ inches in diameter; the pipes from the main to the other hoppers are each 2 inches in diameter. The spray pipes are 1 inch in diameter. Each hopper and spray pipe is provided with valves for regulating the amount of water supplied. A large valve is also placed in the 6-inch pipe, to cut off the supply entirely when the apparatus is not in use.

To wash the sand will require from 3,200 to 4,800 gallons, averaging about 4,000 gallons, of water for each cubic yard of washed sand. This is about 25 per cent. more water than would be necessary with the ordinary drum washers, such as are used extensively at other places in Europe. On the other hand, the expense for power, operation and maintenance will be much less for this system than for the drum washers, while the first cost of installation will be about the same for either system. The apparatus shown on Plate I has sufficient capacity to wash the sand from at least 4½ acres of filter beds.

In place of this apparatus for washing the sand, it may be preferred, until the plant assumes much larger proportions than it would at first, to wash the sand by means of a hose. The dirty sand may then be dumped in a pile on a brick or concrete platform, having three low side walls with the bottom sloping towards the open side; across the open side a removable wooden dam is placed. The stream from the hose is then played upon the pile of dirty sand, working continually from the bottom edges, until the sand is clean.
VI.—MECHANICAL OR RAPID FILTERS.

Two plans for mechanical or rapid filters are presented to you—one is furnished by the Morison-Jewell Filtration Company and the other by the New York Filter Manufacturing Company.

Both of these filters are used in the United States, and have given more or less satisfaction, depending upon the attention which they have received in construction and operation.

A ground plan and elevations of the mechanical filter plant designed by the Morison-Jewell Filtration Company are shown on Plate IV. The capacity for which this plant is designed is 3,000,000 gallons per day. It consists of eight circular gravity filters, each 12 feet in diameter and 5 feet 6 inches high, arranged in two rows of four each.

Each filter contains a filter bed, consisting of a layer of 4 inches of machine-crushed white quartz, upon which is placed 3 feet 8 inches of Red Wing, Minn., screened sand. Each filter has also a settling tank with apparatus for flushing the same, and the necessary gauge rings, vacuum and friction gauges.

The water is brought to the filters by a 20-inch cast-iron pipe, having branches leading to each separate filter. The inlet to each filter is provided with a valve operated by a float which rests upon the surface of the water. The water flows from the filters through two lines of 18-inch iron pipe, uniting in a special casting, and joined to a 24-inch pipe leading to the filtered water reservoir.

The filters are provided with all the necessary valves and pipes to control the flow of the water to and from the filters, and to permit of washing them by forcing filtered water upward through them by means of electrically driven pumps.

A drain is provided to carry off the dirty water resulting from washing the sand in the filters. Each filter is provided with the necessary stirring apparatus and coagulating ma-
chinery. The power for driving the machinery is to be derived from a motor and dynamo driven by electricity from the Government Electric Light Works.

A plant of sufficient capacity to filter 500,000 gallons per day consists of two Jewell gravity filters, each 11 feet outside diameter and 14 feet high. It is arranged with the necessary machinery, valves, pipes, etc., in the same manner as the plant for 3,000,000 gallons. The main for unfiltered water in this plant would be 10 inches in diameter, and the pipe leading to the filtered water reservoir would be 12 inches in diameter.

In the estimates for each of the above plants, provision is made for a wooden building to cover the filters. The foundations for the building, filters and pipes in the building are to be of concrete.

The New York Filter Manufacturing Company furnishes on Plate V a ground plan and elevation for a set of filters and connections of sufficient capacity to filter 500,000 gallons per day, and an extension of the plant for a capacity of 3,000,000 gallons per day is shown with dotted lines.

The 3,000,000-gallon plant consists of six circular gravity filters, each 15 feet in diameter and 8 feet high, arranged in two rows of three each. The 500,000-gallon plant consists of one filter, 15 feet in diameter and 8 feet high. It is stated that one filter is sufficient, because during the time of washing, the stored filtered water in the reservoir could be drawn upon. I do not consider such provision a safe one, and believe that two filters should be erected, even for supplying the smaller quantity of water, to guard against the contingency of an accident, which might disable the only filter for a longer time than that for which the storage capacity of the reservoir allows.

The filters contain the necessary beds of sand, as indicated in the drawings. The water is brought to and removed from the filters in pipes, the location and sizes of which are also indicated, together with the necessary valves and pipes to control the flow and permit of washing the filters.

The filters are washed by forcing filtered water upward through them, by means of electrically driven pumps. In both cases the filters are provided with all the requisite connections, valves, pipes, etc., as above mentioned. Provisions are made
in the estimates for the same expense for buildings, foundations, etc., as were made in the estimates of cost of the Morison-Jewell filtration plant.

Other items that are common to all plants under consideration are allowed for in a proper manner in the estimates of cost.

Further details can be gathered from the respective companies' catalogues which accompany this report.
VII.—ESTIMATES OF COST, AND CONCLUSIONS.

As already mentioned, it was requested that estimates of cost be furnished for both natural and mechanical filters, supposing them to be used for furnishing 500,000 and also for 3,000,000 gallons per day.

In making these estimates, the same prices have been assumed as those given in Appendix D to the "Report to Accompany Plans for the Sewerage and Drainage of Honolulu," excepting in a few instances, where the difference in the location of the works required a difference in the price. The cost of concrete for the water filters has been assumed at $15 per cubic yard, as its character should be superior to that required for the average sewer work.

The estimates of cost for the filter plant have been made, further, on the assumption that no rock is encountered in excavation in Queen Emma Place.

In estimating the annual cost of operation it has further been assumed that the Superintendent of the electric light station, situated near the filter plant, would superintend also the operation of the latter.

The estimates of cost are contained in Appendix A. A recapitulation is given in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Natural Sand Filters</th>
<th>Mechanical Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500,000 gallons.</td>
<td>3,000,000 gallons.</td>
</tr>
<tr>
<td>Total cost of works.</td>
<td>$37,833.00</td>
<td>$92,000.00</td>
</tr>
<tr>
<td>Annual charges, including interest.</td>
<td>3,689.98</td>
<td>8,120.00</td>
</tr>
<tr>
<td>Cost of filtering 1,000,000 gallons.</td>
<td>20.22</td>
<td>7.41</td>
</tr>
</tbody>
</table>

It is not practicable to obtain a continuous supply of 3,000,000 gallons from the Nuuanu water-shed. It is expected,
however, that such a yield may be available during the entire rainy season, when pumping artesian water could be suspended.

It will be seen from the table that the first cost of the natural sand filters is greater than that of the mechanical filters, and that the actual expenses for operation, including the interest on the cost of construction, are less. The difference in the annual charges is, however, not so great but that local reasons, with which I am not familiar, may enter into the question and decide the preference. If the difficulty of raising the larger sum of money is serious, then it may be preferred to adopt the mechanical filters, and to pay a slightly greater annual sum.

While I am of the opinion that the quality of the water furnished by either system of filtration will be satisfactory, and, with proper care, entirely healthful, on account of the removal of the present causes of disease, yet, if the cost is about the same, and there is no other element affecting the decision, I am of the opinion that the natural or slow sand filters are preferable for the following reasons:

First.—With a slight degree of carelessness there is more opportunity of allowing unpurified water to enter the city's supply by the system of rapid than by the system of slow filtration. With equal skill and conscientious care in operating such works, the results have indicated that there is, on the average, a higher percentage of bacteria removed by the slow filters than by the rapid filters, although the difference is not very great.

Second.—The manner of constructing natural filters, namely, by using permanent materials and little machinery, while the mechanical filters are built of iron or wood and have more parts than the others that are affected by wear and tear, indicates that the life of the latter will not be as long as that of the former. Therefore, it may be necessary, on account of depreciation, to renew parts of the work more frequently in one than in the other case.

Third.—The water necessary for washing the filters will be greater in quantity for mechanical than for natural sand filters. If the quantity of water is limited, this item is of some value, otherwise it is not. Conservative estimates show that
for filtering 500,000 gallons of water daily, the mechanical filters would, in one year, require nearly 2,500,000 gallons of filtered water for washing the sand. On the other hand, the natural filters would, in the same period, require about 1,100,000 gallons of unfiltered water to wash the sand removed by the periodical scrapings.

For the above reasons and qualifications it, therefore, appears that natural sand filtration may be the more satisfactory method for you to adopt.

In conclusion, it should be said that the specifications appended to the “Report to Accompany Plans for the Sewerage and Drainage of Honolulu,” contain also most of the specifications required for the character of the material and labor pertaining to the works for filtering the Nuuanu water. While describing the designs of the proposed filtering works, the information has been given in such a way that any special characteristics not contained in the above-mentioned specifications are herein amplified with sufficient detail to indicate the precise manner of construction.
## APPENDIX A.

### ESTIMATES OF COST.

**I.——NATURAL SAND FILTERS.**

#### a. Capacity, 500,000 gallons daily.

**Cost of Construction.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter basins</td>
<td>$12,304</td>
</tr>
<tr>
<td>Regulating chambers and gatehouses</td>
<td>2,720</td>
</tr>
<tr>
<td>Regulating apparatus</td>
<td>1,759</td>
</tr>
<tr>
<td>Piping</td>
<td>665</td>
</tr>
<tr>
<td>Drains</td>
<td>490</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>7,215</td>
</tr>
<tr>
<td>Tramway</td>
<td>180</td>
</tr>
<tr>
<td>Sand washing apparatus</td>
<td>2,000</td>
</tr>
<tr>
<td>Filtered water reservoir</td>
<td>10,500</td>
</tr>
</tbody>
</table>

**Total cost of works**

$37,833 00

**Annual Cost of Operation and Interest.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>One gatemen, at $2 per day</td>
<td>730</td>
</tr>
<tr>
<td>One laborer, at $1.50 per day, for thirty days each year</td>
<td>45</td>
</tr>
<tr>
<td>Annual cleaning, washing and replacing sand</td>
<td>45</td>
</tr>
<tr>
<td>Proportion of time of Superintendent of Electric Light Station</td>
<td>600</td>
</tr>
<tr>
<td>Interest on cost of works, complete, at 6 per cent</td>
<td>2,269 98</td>
</tr>
</tbody>
</table>

**Total annual charges**

$3,689 98

Cost of filtering 1,000,000 gallons, $20.22.

#### b. Capacity, 3,000,000 gallons per day.

**Cost of Construction.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter basins and appurtenances, complete</td>
<td>$70,000</td>
</tr>
<tr>
<td>Sand washing apparatus</td>
<td>2,000</td>
</tr>
<tr>
<td>Filtered water reservoir</td>
<td>20,000</td>
</tr>
</tbody>
</table>

**Total cost of works**

$92,000 00
Annual Cost of Operation and Interest.
Two gatemen, at $2 per day.......................... $1,460 00
Six laborers, at $1.50 per day, for thirty days
each year............................................ 270 00
Annual cleaning, washing and replacing........ 270 00
Proportion of time of Superintendent of Elec-
tric Light Works................................. 600 00
Interest on cost of works, complete, at 6 per
cent.................................................. 5,520 00

Total annual charges.............................. $8,120 00
Cost of filtering 1,000,000 gallons, $7.41.

II. MECHANICAL FILTERS.

Cost of Construction.
Filters erected on foundations, including
$3,000 for superintendence by the Filter
Company's Engineer for six months........... $6,310 00
Freight and haulage on filters................... 831 00
Electric pumps, motors and installation for
washing the filters............................... 4,025 00
Building, including foundations, piping, etc. 3,187 50
Cost of filtered water reservoir................ 10,500 00

Total cost of works.............................. $24,853 50

Annual Cost of Operation and Interest.
Six tons of alum, including freight and haul-
age.................................................. $480 00
Two laborers, one for day and one for night,
at $2................................................ 1,460 00
Proportion of time of Superintendent of
Electric Light Works............................ 600 00
Interest on cost of works, complete, at 6 per
cent................................................ 1,491 21

Total annual charges............................ $4,031 21
Cost of filtering 1,000,000 gallons, $22.08.
b. Capacity, 3,000,000 gallons per day.

Cost of Construction.
Plant, delivered and erected, including electric pumps and motors, and also $3,000 for superintendence by the Filter Company's Engineer for six months ........ $32,000 00
Haulage on filters and materials ............ 756 00
Electric installation .......................... 1,500 00
Building, foundations, piping, etc .......... 5,310 00
Cost of filtered water reservoir ............. 20,000 00

Total cost of works .................. $59,566 00

Annual Cost of Operation and Interest.
Thirty-six tons of alum, including freight and haulage .................... $2,880 00
Four laborers, two for day and two for night, at $2 ..................... 2,920 00
Proportion of time of Superintendent of Electric Light Works ........... 600 00
Interest on cost of works, complete, at 6 per cent .................. 3,573 96

Total annual charges ................. $9,973 96

Cost of filtering 1,000,000 gallons, $9.11.
APPENDIX B.

List of Plans and Drawings Accompanying this Report.

PLATE I.
General plan, showing the location and arrangement of
the natural sand filters and filtered water reservoir.
Plan, elevation and sections of sand washer.

PLATE II.
Plan, sections and details of natural sand filter.
Plan and section of regulating apparatus.

PLATE III.
Plans, sections and details of filtered water reservoir.

PLATE IV.
Plan and section of mechanical filter plant designed by
the Morison-Jewell Filtration Company.
General plan, showing relative positions of reservoir and
site of proposed filters.

PLATE V.
Plan and section of mechanical filter plant designed by
the New York Filter Manufacturing Company.
Appendix C.

List of Trade Catalogues, etc., Accompanying This Report.


New York Filter Manufacturing Company.

Sample of filter sand from Red Wing, Minn., used by the Morison-Jewell Filtration Company.
ROOM USE ONLY