HONOLULU’S WATER SUPPLY

by

G. K. LARRISON, HYDRAULIC ENGINEER

March, 1923
Honolulu, T. H., March 17, 1923.

W. A. Wall, General Manager,
Water Works Department,
Honolulu, T. H.

Dear Sir:

In accordance with your letter of January 23, 1923, I am submitting herewith a brief of existing reports on the water supply of the City of Honolulu.

I am also submitting for your consideration statements and recommendations relative to the future water requirements of the City of Honolulu. These statements and recommendations are offered as a result of more than 10 years study of this problem from the view point of an interested citizen-engineer, and as a possible help to you in working out the big problem now confronting you. As stated in the report, many of the improvements suggested or recommended are already planned by your Department.

In addition to the unrestricted assistance I have received from you and your assistants, I want to acknowledge valuable assistance from Messrs. Grainger and Getz, Engineers of the Honolulu Iron Works; the Hawaiian Electric Company, the City and County Engineer and Building Inspector, and Mr. S. W.
Tay, Sanitary Engineer for the Territory of Hawaii. The latter has briefly reviewed and criticized this report and is of the opinion that, "The estimated population for 1973 is entirely too high and is not based on reliable data."

Very respectfully,

G. K. Larrison
Hydraulic Engineer.
EXHIBITS.

I. Graph showing drop in Artesian Well Head in central Honolulu basin from 1899 to 1922.

II. Maps showing existing mains in Honolulu's distribution system, proposed replacements and extensions, and proposed new reservoirs.

III. Graph showing predicted population of Honolulu.

IV. Graph showing increases in attendance at various public schools.

V. Graph showing increases in consumers served in various districts by the Hawaiian Electric Company from 1918 to 1922.

VI. Table showing water pumped by various pumping plants of the Water Works Department from 1905 to 1922.

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Mr. G. K. Larrison,
Honolulu, T. H.

Dear Sir:

I wish to inform you that your appointment to investigate and brief all existing reports etc. on the water supply of the City and County of Honolulu was confirmed by the Board and a few of $1000.00 allowed for the entire work.

Yours very truly,

W. A. Wall
General Manager
Water and Sewer Works Depts.

WAW:EC
PART ONE.

BRIEF OF EXISTING REPORTS RELATIVE TO WATER SUPPLY OF HONOLULU.

GENERAL RESUME OF EXISTING REPORTS.

(For complete brief see pages 2 to 14)

Artesian Supply is failing and must be conserved to furnish the greater part of the water supply of the city.

Spring and Normal Surface Run-off should also be utilized and flood storage be considered as a potential future supply for the city.

Development of High Level Ground Water by Tunneling is recommended.

Metering all privileges is recommended.

Growth of the Population of Honolulu to 175,000 in 1937 is predicted.

It is recommended that a "complete and detailed investigation, survey and report upon every phase of every possible water source should be made by an expert hydraulic engineer, each possible source being reduced to the common basis of:

1. Principal cost per million gallons, and
2. Operating cost per million gallons."
PART I.

EXISTING REPORTS.

At least 150 reports, letters, memoranda, and newspaper articles, all dealing more or less directly with the problem of Honolulu's water supply are available. These include voluminous and detailed reports, pertaining almost entirely to sources of supply, by commissions appointed by the Territory of Hawaii and the City and County of Honolulu, a comprehensive report on high level underground water by Professor Harold G. Palmer, Geologist, a report by a water works committee of the Honolulu Chamber of Commerce, and many reports by the Territorial Superintendent of Public Works, the U.S. Geological Survey in co-operation with the Territory and (after June 30, 1914, the date on which the water system was transferred from the Territory to the City and County of Honolulu) the Department of Water and Sewer Works of the City and County of Honolulu.

Of this mass of valuable data, there are three outstanding reports, all made within the past six years, which contain summaries of previous reports and data and
which have admirably covered the question of existing and proposed supply. Only two of these, the Territorial Report on Artesian Water and Professor Palmer's Report on High Level Underground Water, were completed. The investigation of the City and County Water Commission was stopped (on the grounds of economy) before the work was much more than well started. However, this latter report as submitted contains the most complete collection of data pertaining to all possible sources of supply (excepting artesian water) ever compiled.

These three reports are:


**Territorial Artesian Report - 1917.**

This report deals almost entirely with Oahu artesian wells and demonstrates, conclusively, the following conditions in December, 1916:

(a) Between Diamond Head and Red Hill four separate and distinct artesian basins exist. Because of lack of borings or wells, the limits of these basins have not been closely defined but are only approximate, as follows:
BASIN No. 1. Diamond Head to somewhere between Manoa stream and McCully Street. The approximate static head on December 10, 1916, was 25.0 feet above sea level.

BASIN No. 2. From the western limits of Basin No. 1 to Pauoa stream. Static head December 10, 1916, about 30.0 feet.

BASIN No. 3. Pauoa stream to Kalihi stream. Static head December 10, 1916, about 31.0 feet.

BASIN No. 4. Kalihi stream to Red Hill. Static head December 10, 1916, about 29.0 feet.

(b) The draft on wells on one basin does not affect the head of wells in adjacent or other basins, but does affect the head of other wells in the same basin.

(c) The head, or height to which water rises in wells when they are not discharging or leaking, varies with the rainfall on the upper valleys and mountain ridges.

(d) The heads in Basins 1, 2 and 3 are steadily and surely falling because of overdraft and leakage from wells within these basins, largely exceeding the replenishing supply from rainfall. There have been large seasonal variations in heads due to periods of extreme drought and rainfall, but the average heads, year in and out, have gradually fallen about 12 feet.
since 1889, an average of about two-fifths of a foot per year. (See Exhibit I).

(e) When all of the 109 active wells between Diamond Head and Red Hill were flowing or being pumped at normal capacities in December, 1916, about 57 M. G. D. of artesian water was being drawn from the artesian basins. Of this amount, about 40 M. G. D. came from wells located between Diamond Head and Kalihi stream. Of these amounts, the city water works system was receiving only about 12.3 M. G. D.

The above quantities did not include underground leakage.

(f) The Commission recommended the exactment of a Territorial law which would

1. Clearly define artesian water and wells;
2. Clearly define waste from artesian wells;
3. Require owners or users of privately owned artesian wells to observe the same rules and restrictions placed on users of water of the City system by the Water Works Department;
4. Require drillers of wells to keep and file within 90 days, with the Territorial Division of Hydrography, a complete and accurate log or record of strata penetrated.
This report was in accordance with a resolution adopted by the Board of Supervisors and approved by the Mayor on June 23, 1915. The Commission was instructed to:

1. Ascertain the present status of the water supply of Honolulu;
2. Investigate and determine whether or not an adequate supply of water can be secured for Honolulu;
3. Make necessary surveys;
4. Make necessary preliminary explorations;
5. Do necessary preliminary water development.

On December 11, 1915, on the grounds of economy, the Board decided to suspend the investigations but allowed the Commission sufficient funds and time to complete work already started and to make a report thereon. A final and complete report has not been authorized or made.

The City Commission report, like the Territorial artesian report, deals almost entirely with sources of supply, with additional brief statements relative to the history, value and descriptions of the existing system, "the cause of present conditions", the cost of water served and the existing and prospective demand.
CAUSE OF PRESENT CONDITION. "Is due to no one man or body of men", but to:
1. Rapid growth of the city;
2. Belief that the artesian supply was inexhaustible;
3. Excessive irrigation demands;
4. Sewage system demands.

VALUATION. The Commission fixed the value of the system in 1916 at $1,539,107.44, and the estimated cost of duplication, at that time, at $1,948,506.70.

DAILY PER CAPITA CONSUMPTION. From 55 gallons in 1861 to 350 or 400 gallons in 1913, and back down to 275 gallons, with 6,740 privileges of which only 897 were metered, in 1916.

PRESENT AND PROSPECTIVE DEMAND. The population of the City grew from 6,000 in 1847 to 68,000 in 1916. A population of 175,000 in 1937 was predicted.

POSSIBLE SOURCES OF ADDITIONAL SUPPLY.

The Commission decided that possible sources of additional supply might be obtained from:
1. Surface and spring waters from the southern slopes of the Koolau range;
2. The artesian basins by pumping;
3. Development tunnels;
4. Surface and spring waters from the northern slopes of
the Koolau range, to be brought to the city by concentrating ditches and tunnels and a tunnel through the Koolau range in Kalihi Valley.

**SURFACE AND SPRING WATERS FROM THE SOUTHERN SLOPE OF THE KOOLAU RANGE.**

The Commission finds that storm water may be economically stored in upper Nuuanu and Kalihi Valleys and less economically stored in upper Palolo Valley; also that Manoa storm flow may be feasibly diverted by tunnels into No. 4 Reservoir in upper Nuuanu Valley. The Commission also states that the following quantities may be obtained from the various valleys under what it terms "Normal Flow". The question of existing water rights is dealt with very meagerly.

**PaloLo.** Roughly estimated at 2 M. G. D. Existing records too meagre to give accurate statement. Water and land almost entirely owned by Government.

**Manoa.** About 3 M. G. D. Water nearly all owned by private interests.

**Makiki.** All low water run-off now used by Water Works Department. Believes tunneling should not be attempted, might injure spring flow.

**Pauoa.** Reports of quantity available vary from...
375,000 to 1,000,000 gallons daily. Estimates of cost of purchase and plant to deliver water should be secured.

NUIANU. Government now controls nearly all flow. Supply now polluted and unsanitary.

KALIHI. About 3.5 million gallons available, nearly all owned and utilized by private interests. Electricity might be developed.

MOANALUA. No water available. It was estimated that all valleys might be depended upon to furnish an additional total of 12 M. D. D., exclusive of possible stored flood water and existing irrigation requirements amounting to about 12 M. G. D.

SURFACE AND SPRING WATERS FROM THE NORTHERN SLOPES OF THE KOOLAU RANGE. Mr. Jorgensen estimated that 7,778,700 gallons daily might be collected from windward springs and streams and delivered to the city via a tunnel through Kalihi ridge. He also estimated that the main Kalihi tunnel would develop an additional 7,778,700 gallons daily, making a total of about 15 M. G. D. Estimated cost of project, $995,540.00.

DEVELOPMENT TUNNELS. The above proposed Kalihi tunnel and a recommendation to not allow tunneling in Makiki Valley
are the only tunneling operations referred to in the report.

**ARTESIAN WATER.** No report was made because of Territorial report. It is stated, however, that "it is the opinion that it will be unsound to abandon the use of surface waters and substitute the use of pumped artesian water for two reasons, viz; 1. That the expense of pumping is too high; 2. That the surface water in question cannot be spared."

The Commission recommends:

(a) Nuuanu water be protected by excluding road drainage, a filter plant below Reservoir No. 1, and a man-tight fence along both sides of the Pali Road to exclude trespassers.

(b) That all surface run-off from the seven valleys, Palolo to Moanalua, inclusive; the windward Oahu springs and the water which may be developed in the proposed Kalihi tunnel, be considered as potential sources of supply.

(c) That available artesian water be used, leaking artesian wells be plugged, and the drilling of new wells be limited until the artesian well heads recover.

(d) That an hydraulic engineer make a "complete and detailed investigation, survey and report upon every phase of every possible water source, - each source being reduced to the common basis of:
1. Principal cost per million gallons, and
2. Operating cost per million gallons."

PROFESSOR H. G. PALMER'S REPORT ON HIGH LEVEL GROUND WATER.

This report deals entirely with high level ground water which may be developed or increased by tunneling. After describing rather carefully and in detail the geologic formations of the areas examined and the most favorable conditions under which water may be expected, he recommends the following:

AREAS UNFAVORABLE FOR THE DEVELOPMENT OF GROUND WATER.

The valleys of the south branch of Halawa, Kela-wahine, Moanalua, Opu branch of Makiki, Kaea and Pukele branches of Palolo, Kapahulu, Kapalama, Waialae, Wailupe, Niu and the valleys eastward therefrom.

FAIRLY FAVORABLE PROJECTS.

The middle and lower reaches of Kalihi, Kemana Iki of Kalihi, Herring and main branches of Makiki, upper and Lulumaha branches of Nuuanu, upper Palolo, and Pauoa valleys.

MAJOR AND FAVORABLE PROJECTS.

The proposed Kalihi tunnel to bring windward spring and stream water to Honolulu, upper Manoa Valley, and a tunnel from the foot of Lulumaha Falls in upper Nuuanu Valley in under Mt. Konahuanui.
Professor Palmer warns against the assumption that the geologist is able to accurately forecast results. While evidence can be adduced to show that a project will probably be successful or unsuccessful, it is entirely impossible to forecast the amount of water which may be obtained. He also points out the exceptionally difficult conditions under which the geologist must work in Hawaii because of the heavy vegetation which covers outcrops and the inaccessibility of the upper valleys due to lack of trails.

ADDITIONAL REPORTS.

A preliminary report, (final report never authorized or completed) made by a water committee of the Honolulu Chamber of Commerce on April 25, 1921, deals entirely with sources of supply and the possible development of electricity.

NUUANU. Measurements and estimates made on March 23 and 29, 1921, indicate a total available supply of about 8 M. G. D., between 700 and 1050 feet elevations, which may be used to augment the city's supply. This quantity, apparently, does not include water now furnished by the reservoirs.

MANOA. The development of springs in the upper valley is recommended.

PALOLO. The tunnel work already started is commended and further development is urged. The possibility of
developing additional electricity is suggested but it is also suggested that the developed water be measured for a quite a period of time" before the power plant is designed.

The Committee recommends the following in Nuuanu Valley:

(a) The construction of a 3 million gallon concrete reservoir above Reservoir No. 1 to store spring and tunnel water.

(b) The continuation of the tunnel development work then being done by the Water Works Department on the Ewa side of the Valley and the driving of an additional tunnel on the Lual-Kaha side of the Valley.

The report of the Superintendent of Public Works for the year ending June 30, 1913, contains much valuable data including a "History of the Honolulu Water Works" by T. F. Sedgwick, and an appraisal of water works and sewer properties by A. C. Wheeler. The latter report contains complete descriptions of pumping plants, reservoirs, manholes, Venturi meters, pipe, fittings, etc., and places a valuation on the same (the same later used by the City Water Commission). It also contains much valuable data on population and per capita consumption of various mainland cities and the cost and value of metering.
The report of the General Manager, Water and Sewer Works Department, dated January 10, 1915, recommends spring development by tunneling and a sea water high pressure fire system to be bounded by Punchbowl, Vineyard, Liliha, Iwilei and King streets.

The reports of General Managers of the Water Works Department from 1915 to 1918, all urge that the city be metered.

A report on the artesian system was made in 1922 by a committee of the Honolulu chapter of the American Association of Engineers, which reviewed and commended the report of the Artesian Commission of 1917, invited attention to the fact that the artesian head is still falling and recommended legislative relief.
PART TWO

RECENT ACTIVITIES PERTAINING TO HONOLULU'S WATER SUPPLY.

RESUME

(For complete data see pages 16 to 21)

ARTESIAN WELL HEADS - Still falling but less rapidly.

DEVELOPMENT TUNNELS - Work done thus far has been generally successful. Further work should be done.

PUMPING PLANTS - Capacities increased from 1919 to 1922, from 18.3 to 34.0 million gallons daily.

RESERVOIRS - New 2.5 million gallon concrete reservoir completed in Nuuanu;

DISTRIBUTION SYSTEM - Extended from total about 127 miles in 1916 to about 161 miles in January, 1923. Many replacements and improvements made.
PART II.

RECENT ACTIVITIES.

ARTESIAN WELLS.

The decrease in head since December, 1916, has continued, but at a reduced rate of about three and one-half inches per year instead of about four and one-half inches per year, as was the case previous to 1917. (See Exhibit I). This is accounted for in two ways:

1. The practical suspension of well drilling within the city area;

2. The recasing and repairing of a number of leaking wells and wells improperly capped, all in violation of existing laws. The Territorial Division of Hydrography, in early 1920, working in cooperation with the Territorial Attorney General, took up with the owners of 18 leaking wells the question of repairing these wells. At least five of the wells have been satisfactorily repaired or recased.

The Honolulu Chapter of the American Association of Engineers is active in arousing the public to the danger of the artesian well situation.
DEVELOPMENT TUNNELS

NUUANU VALLEY.

In 1919, the spring located between Nuuanu reservoirs 2 and 3, was cleared and opened up and a pipe line laid to deliver this water to Alewa Heights, part of the McInerny Tract and Kalihi-Uka. Some work was also done on three others, resulting in small quantities of water.

In 1920 and 1921 six tunnels, totaling in length about 3,000 feet, were driven in upper Nuuanu Valley by the Water Works Department, at elevations 810 to 1028 feet. These tunnels were connected to the city system with wood stave pipe. Records of the Water Works Department show the cost of these tunnels and pipe to have been about $43,200.00, and the combined discharge from all tunnels to be as follows:

<table>
<thead>
<tr>
<th>DATES</th>
<th>COMBINED TUNNEL DISCHARGE (M. G. D.)</th>
<th>ALEWA HEIGHTS SPRING DISCHARGE (M.G.D.)</th>
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</thead>
<tbody>
<tr>
<td>1921</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb. 11</td>
<td>5.6</td>
<td>0.57</td>
</tr>
<tr>
<td>Mar. 19</td>
<td>3.0</td>
<td>0.61</td>
</tr>
<tr>
<td>&quot;</td>
<td>3.4</td>
<td>0.56</td>
</tr>
<tr>
<td>Apr. 14</td>
<td>3.4</td>
<td>0.56</td>
</tr>
<tr>
<td>&quot;</td>
<td>3.2</td>
<td>0.56</td>
</tr>
<tr>
<td>May</td>
<td>2.2</td>
<td>0.35</td>
</tr>
<tr>
<td>&quot;</td>
<td>3.2</td>
<td>0.50</td>
</tr>
<tr>
<td>Aug.</td>
<td>2.5</td>
<td>0.14 (?)</td>
</tr>
<tr>
<td>Oct. 10</td>
<td>5.2</td>
<td>0.68</td>
</tr>
<tr>
<td>Nov. 1</td>
<td>4.8</td>
<td>0.68</td>
</tr>
<tr>
<td>Dec. 27</td>
<td>5.8</td>
<td>0.68</td>
</tr>
<tr>
<td>1922</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan. 15</td>
<td>6.7</td>
<td>0.68</td>
</tr>
<tr>
<td>Feb. 12</td>
<td>5.1</td>
<td>0.56</td>
</tr>
<tr>
<td>Mar. 9</td>
<td>5.9</td>
<td>0.56</td>
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Additional records covering the dry months in 1922 are, unfortunately, fragmentary and incomplete.

On June 24, 1922, H. A. R. Austin and S. W. Tay, both capable hydraulic engineers, estimated the combined tunnel discharge at between 1.25 and 1.5 M. G. D. This was after a very dry period of about three months.

On December 26, 1922, the tunnels were visited by the Manager of the Water Works, Messrs. Burchard and Carson of the U. S. Geological Survey, and the writer. At this time, after about two months of comparatively dry winter weather, the tunnels were discharging at a rate of between 5 and 6 million gallons daily. On January 26, 1923, after the big storm, the writer saw a combined discharge of at least 9 M. G. D.

Judging from available records, it is believed that existing Nuuanu tunnels have been discharging between 1 M. G. D. in dry weather, and 10 M. G. D. after long wet periods. In addition to the tunnel discharge, the records show that Alewa Heights spring has been delivering from 140,000 to 680,000 gallons daily. On January 26, 1923, after heavy rains and with Reservoir No. 4 spillway running with a six inch head, the tunnel water was as clear as artesian water.

PALOLO VALLEY.

A tunnel about 280 feet deep has been driven into
the right bank of Waiaimoa stream just below the lower falls and Kaau crater, in upper Palolo Valley. On October 29, 1921, the local U. S. Geological Survey Office measured the tunnel discharge as 150,000 gallons daily. On August 27, 1922, the same authority found 190,000 gallons daily. On January 16, 1923, after heavy rains, the writer saw 340,000 gallons daily discharging over the weir at the tunnel portal and considerable additional leakage around the ends of the weir. The cost of this development work was $4,000.00.

MAKIKI VALLEY.

In 1920, three prospect tunnels were opened up in upper Makiki Valley. Work has been suspended due to the lack of funds. About 100,000 gallons daily have been developed thus far. The work has cost about $4,000.00 to date.

KALIIHI VALLEY.

Three tunnels totaling in length about 500 feet were driven in 1922. Two were completed and the third (highest) was stopped on account of lack of funds after being driven in about 50 feet. About 200,000 gallons daily were being discharged on January 10, 1923. A combined discharge of 800,000 gallons, after heavy rains, has been reported by the Water Works Department.
MANOA AND PAUOA VALLEYS.

Development tunnels planned but no funds available.

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PUMPING PLANTS AND RESERVOIRS.

Since 1919, the pumping capacities of all pumping plants have been increased from 18.3 to 34.0 M. G. D., but the total covered reservoir capacity of about 9 million gallons for clear water has not been increased since 1913. A new concrete reservoir of 2.5 million gallons capacity is now being erected near Nuuanu open Reservoir No. 1. This structure is designed to be used as a distributing reservoir for Nuuanu tunnel water.

DISTRIBUTION SYSTEM.

The distribution system has been extended from a total length of about 105 miles of pipe of all sizes in 1913 to about 127 miles in 1916, and about 161 miles in January, 1923. In addition to these extensions, many miles of replacements with larger pipes have been made, especially since 1918. (See Exhibit II).

FIRE HYDRANTS.

In 1913 there were 430 and 34 private fire hydrants. In 1916 the city owned and operated 562 hydrants and in January 1923, this number had been increased to 804.
PURIFICATION.

There are no filtration plants and only Nuuanu surface water is chlorinated.
PART THREE.

FUTURE POPULATION, PER CAPITA REQUIREMENTS and WATER REQUIRED.

(For complete date and discussion see pages 24-46.)

RESUME

Predicted Population of Honolulu in 1973 - 400,000

Predicted Population of Various Parts of Honolulu in 1973 -

(a) Kalihi Pumping Plant Area 125,000
(b) Beretania Pumping Plant Area 80,000
(c) Kaimuki Pumping Plant Area 100,000
(d) Nuuanu Supply Area 40,000
(e) Upper Kalihi, Manoa and Palolo Valleys and adjacent Heights 55,000

PER CAPITA DAILY REQUIREMENTS -

(a) Present 300 gallons daily
(b) Recommended (after metering) 175 " "

INDUSTRIAL AND COMMERCIAL REQUIREMENTS -

Now about 3 M. G. D. or 10 per cent of total
Probably never more than 15 per cent of total.

FIRE PROTECTION -

6,000 gallons per minute should now be available for
down-town or congested district fires; when city population exceeds 200,000, this should be increased to 12,000 G. P. M.
For sparsely settled districts, 500 G. P. M. should be available.

Salt water system not needed.

Fire hydrants should be standardized, - not over 250 feet apart in down-town or congested districts and 400 feet apart in outlying residence districts. Should never be put on less than 6-inch mains and should be regularly tested.

**TOTAL WATER REQUIRED**

For entire city in 1973 70 M. G. D.
PART III.

HONOLULU'S FUTURE WATER SUPPLY.

All plans, estimates and recommendations contained hereinafter, are based on the estimated requirements of Honolulu fifty years hence and during the intervening years. This period is generally accepted among engineers as the limit beyond which the ordinary course of human and civic affairs cannot be even approximately foreseen. Fifty years is also a very conservative estimate of the "life" of cast iron water mains.

The writer has freely interviewed present and past officials and employees of the Water Works Department and many of the plans and recommendations contained herein are in accordance with plans and suggestions already formulated and recommended by these men.

It should be kept in mind that the time and funds allotted for this report do not permit the working out of detailed plans and cost estimates dealing with the sizes of mains, design of pumps, etc., required fifty years hence. It is the writer's intent to endeavor to only broadly outline a plan and policy which will control the expansion of and improve-
ments to the distribution system and the necessary improvements to and increases in the supply, storage and fire protection facilities - as these are required from time to time - so that these will probably conform to and be used as parts of the plant required to serve the city when its demands will be four or five times as great as they are at the present time.

POPULATION TO BE SERVED.

It is estimated that the City Water Works Department will be called upon to serve a population of about 400,000 in 1973. (See Exhibit III). This estimate is based on

(a) CORRESPONDING GROWTH OF COMPARABLE CITIES. Exhibit III shows the growth of Honolulu (city area proper) since 1896, - the date of the probable first reliable census, - and of 9 mainland cities whose growth may be considered as due, in some degree, to the same causes which have caused in the past and which may cause in the future, the population of Honolulu to increase. However, it should be kept in mind that no two cities are absolutely identical as to influences which may cause population increases and Honolulu is especially unique in this respect, due, primarily, to its isolation and the nature of its industries. It must be admitted that the cities selected for comparison of growth have but one outstanding
feature in common with Honolulu - climatic attraction. Six of the mainland cities are also seaports. Outside of these two factors, there is little in common except the fact that practically all American cities with populations exceeding 50,000 are growing.

Exhibit III also shows the rate of increase, by decades, of the mainland cities before and after they have passed the 83,000 mark, - the population of Honolulu in 1920 according to the federal census.

(b) LOCAL PREDICTIONS. Exhibit III also shows predictions of the population of Honolulu in 1943 by local real estate offices and by the editor of the Honolulu Star-Bulletin. Dozens of "Kamainas" and all of the local utility corporations have been interviewed, but only those quoted have ventured predictions. Considering the recent rapid growth of the pineapple industry, the probabilities of great increase in tourist traffic and manufacturing possibilities, the prediction curve is believed to be conservative. This curve predicts the following:

<table>
<thead>
<tr>
<th>YEAR</th>
<th>POPULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>120,000</td>
</tr>
<tr>
<td>1940</td>
<td>180,000</td>
</tr>
<tr>
<td>1950</td>
<td>240,000</td>
</tr>
<tr>
<td>1960</td>
<td>305,000</td>
</tr>
<tr>
<td>1970</td>
<td>380,000</td>
</tr>
<tr>
<td>1973</td>
<td>400,000</td>
</tr>
</tbody>
</table>
RELATIVE GROWTH OF VARIOUS PARTS OF THE CITY.

Reliable data relative to the growth of various parts of the city are very meagre. The population of the various districts of the city as reported by the 1920 census enumerators, are available, but an effort to obtain similar data collected for the 1900 and 1910 census has been unsuccessful.

Much valuable information has been obtained from school attendance records for the various city schools, but these can only be used in a general way because of the fact that when certain schools become crowded, the school authorities are forced to arbitrarily limit the attendance and sometimes detach a number of pupils and send them to some other school not located in the district in which the pupils live. However, the data furnished are valuable in showing relative growths covering limited periods of time. (See Exhibit IV).

Exhibits V, VI, VII and VIII show the increase by districts in numbers of consumers of electricity sold by the Hawaiian Electric Company from 1918 to 1922, the quantities pumped by the various pumps of the Water Works Department from 1905 to 1922 inclusive, the increase in number of consumers served by the Water Works Department from 1915 to 1922, and the estimated costs of building for which permits were issued for the various districts from 1919 to 1922 inclusive.
Efforts were made to obtain similar data from other local utility companies but their records were in such shape that an immense amount of labor and several months of time would have been required to segregate the data so that these could be used in this report. Available tax records, voter's registration and vital statistics were also examined but were found to have the same status as those of most of the utility companies.

The 1920 federal census shows that out of the total population of 83,327, almost 86 per cent were distributed in the following 8 districts:

<table>
<thead>
<tr>
<th>DISTRICT</th>
<th>POPULATION</th>
<th>PERCENTAGE OF TOTAL (83,327)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central - (Bounded by Liliha, Wyllie, a line back of Punchbowl crater, Wilder Ave. and Piikoi Streets)</td>
<td>35,500</td>
<td>42.6%</td>
</tr>
<tr>
<td>Kaimuki</td>
<td>7,705</td>
<td>8.0%</td>
</tr>
<tr>
<td>Kalihi</td>
<td>5,705</td>
<td>6.6%</td>
</tr>
<tr>
<td>Kapalama</td>
<td>13,167</td>
<td>15.8%</td>
</tr>
<tr>
<td>Makiki and Punahou</td>
<td>5,184</td>
<td>6.2%</td>
</tr>
<tr>
<td>Manoa</td>
<td>2,028</td>
<td>2.4%</td>
</tr>
<tr>
<td>Nuuanu (above Wyllie)</td>
<td>1,725</td>
<td>2.1%</td>
</tr>
<tr>
<td>Waikiki</td>
<td>2,178</td>
<td>2.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>83,327</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

It should be noted that nearly one-half (42.6%) of the total population in 1920 resided in the central district, within an area of about 1,800 acres, or about 3 square miles (a density of about 20 persons per acre). The
maximum density of 101 per acre occurs only in one small area in the down-town Oriental district.

RELATION OF POPULATION AND WATER SUPPLIED.

Exhibit VI shows the quantities of water pumped by the various pumping plants of the city. These records are said to be somewhat erroneous up to and including 1921 and therefore should be used with discretion. In addition to the pumped water, Nuuanu surface, tunnel and spring water has supplied Nuuanu and upper Kalihi Valleys and a small part of the central district in the vicinity of Punchbowl crater. This quantity was generally conceded to be about 3 M. G. D. up to 1920 and, since that time, considerably more, - due to tunnel and spring development work. Makiki springs and Palolo spring and tunnel water also partially supply Manoa and Palolo Valleys. These sources of supply will be more fully discussed in a later chapter.

During extremely wet and dry periods, the pumped supply has necessarily increased or decreased accordingly. Pumping plant repairs have also increased the load on other plants from time to time. However, these records show that the demand on the Beretania and Kalihi pumping plants, notwithstanding the increased gravity supply from Nuuanu tunnels and springs, has increased more rapidly during the past few years.
than the demand on other pumping plants. They also show that all plants have required additional equipment to meet the growing demand and that during the past four years the demand has increased at a much more rapid rate than during any previous four year period.

Exhibit VIII shows the approximate areas served by the various pumping plants and other sources of supply and the approximate population of these areas according to the 1920 census:

<table>
<thead>
<tr>
<th>SOURCE OF SUPPLY</th>
<th>1920 POPULATION</th>
<th>AREA SERVED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalihi Pumps</td>
<td>27,000</td>
<td>2,000 Acres</td>
</tr>
<tr>
<td>Beretania Pumps</td>
<td>25,000</td>
<td>2,300 &quot;</td>
</tr>
<tr>
<td>Kaimuki Pumps</td>
<td>9,000</td>
<td>4,000 &quot;</td>
</tr>
<tr>
<td>Wilder and Makiki (a)</td>
<td>2,000</td>
<td>600 &quot;</td>
</tr>
<tr>
<td>Palolo Tunnels</td>
<td>1,000</td>
<td>300 &quot;</td>
</tr>
<tr>
<td>Pacific Heights Spring</td>
<td>300</td>
<td>50 &quot;</td>
</tr>
<tr>
<td>Nuuanu (b)</td>
<td>13,500</td>
<td>2,000 &quot;</td>
</tr>
</tbody>
</table>

(a) Wilder Avenue pumps and Makiki spring supply most of this water. During dry periods when the discharge of the spring is low, the supply is augmented by Beretania pumps and an electric booster pump which lifts the Beretania water and spring water stored in Makiki reservoir during the slack night periods. Wilder Avenue pumps supply the eastern and lower part of Manoa Valley.

(b) This supply comes from the 4 flood storage reservoirs,
a recently developed spring and a number of development tunnels recently driven in upper Nuuanu Valley.

ESTIMATED POPULATIONS TO BE SERVED WITHIN AREAS NOW SERVED BY EXISTING PUMPING PLANTS AND OTHER SOURCES OF SUPPLY.

KALIHI PUMPING PLANT AREA.

This area contains the pineapple canneries, railway yards and shops, docks and approaches, Territorial prison, Kalihi Receiving Station, Insane Asylum, Kamehameha Schools, gas works, oil tanks and other industrial plants. Exhibits IV and V show that, with the exception of possibly certain parts of the central district served by the Beretania pumping plant, the population of this area has increased more rapidly than in other districts. Exhibit X, (map of the Kapalama section by the Planning Commission) shows that the greater part of the area is suitable for homes and is still sparsely settled. It is probable that both the Kamehameha Schools and the Insane Asylum will, sooner or later, be moved to more remote and less valuable locations. It is also probable that the canneries and other industries in the Iwilei Districts will continue to develop into a large industrial center with its concomitant demands for employees' homes in the vicinity.

It is estimated that the area now served by the
Kalihi pumping station will contain a population of not less than 125,000 in 1973, to be supplied in addition to large industrial and fire protection requirements.

BERETANIA PUMPING PLANT AREA.

This area contains the "Down town" commercial area, most of the harbor docks and waterfront, the theatres, most of the churches, hotels and boarding houses, Fort Armstrong and the Quartermaster area, the Federal and Territorial buildings, several parks, the iron and steel fabricating shops, and other industries. It is estimated that at least one-fourth of the 2300 acres is now used for other than residential purposes and that this proportion will increase to at least one-half of the total area.

It is also estimated, however, that the greatest growth in apartment houses and hotels will take place within this area and that while the demand for water for residences will not increase as rapidly as in the Kalihi area, the demands for service to hotels and apartment houses, commercial and industrial purposes and shipping will increase much more rapidly than in other districts, with the possible exception of the Iwilei industrial section.

The eastern part of this area (Kewalo and the west end of the Waikiki reclamation project) contains large
available spaces suitable for building.

It is estimated that water supply for approximately 80,000 persons, in addition to the fire protection and industrial needs will be required in 1973.

**KAUMUKI PUMPING PLANT AREA.**

This area includes much agricultural and what is now considered waste land suitably located for residential purposes. The Waikiki reclamation project, the large Kahala section now used almost entirely for agricultural and dairy purposes and the now sparsely settled Kapahulu section, all offer great possibilities for home building. Fort Ruger and Fort De Russy military reservations, the Territorial Fair Grounds and Kapiolani Park are the only large areas which would have to be considered as not available for residential purposes. It is believed that a commercial center of considerable size will develop in the vicinity of Waialae Road and 12th Avenue. The excellent climate of this section is sure to draw many homeseekers as the city grows. It is estimated that at least 100,000 persons will live in this area in 1973.

**NUUANU SUPPLY AREA.**

Approximately 10,500 of the total 13,500 persons served by the Nuuanu supply in 1920 were located in about 550
acres in lower Nuuanu Valley below Bates Street and in the Punchbowl district. There have been times, when the Nuuanu supply was curtailed on account of drought, that this area had to be served by the Kalihi and Beretania pumping plants. This section is now fairly thickly settled but on account of its proximity to the city's commercial center, it is very probable that many apartment houses and hotels will be built within its limits. The greater part of upper Nuuanu Valley is contained in water reserves which probably will not be opened for home building.

It is estimated that the population of lower Nuuanu and Pauoa Valleys and that portion of the Punchbowl and Makiki districts now served by Nuuanu water will be approximately 40,000 in 1973.

UPPER KALIIHI, MANOA AND PALOLO VALLEYS AND ADJACENT HEIGHTS.

It is not anticipated that the populations of the "heights" and upper valleys will increase with anywhere near the same rapidity as in the lower portions of the city. It is estimated that the recent and present tendency of the more "well to do" financially, to get away from the growing congestion of the lower parts of the city and to build homes on the higher levels and in the upper valleys, will probably continue with increased intensity. However, the ability of
this type of citizens to purchase privacy in the nature of large ground areas and the remoteness of these upper and outer residential districts from commercial and industrial centers, indicate that the density of population per acre will remain comparatively low for many years to come.

It is estimated that the combined population of these areas will not exceed 50,000 or 60,000 in 1973.

PER CAPITA REQUIREMENTS.

It is estimated that about 85% of the total city population is supplied by the city water system, or a total of about 71,000 persons in 1920 and about 80,000 (85% of 94,000) in 1923. The total privileges in 1920 were 8,851, of which 2,140 were metered, and in 1922 there were 10,268 of which 2,458 were metered.

In 1920 (a very dry year), the records show that the city pumps delivered an average of about 21 M. G. D. The recorded discharges of Beretania and Kaimuki pumps are now known to have been too high. Allowing a 10 per cent discount on the recorded discharge of these two pumps leaves a net discharge of about 19.7 M. G. D. of pumped water. It is estimated that Nuuanu, Makiki and Palolo Valleys furnished an additional 3.5 M. G. D., or a total supply of about 23.2
M. G. D. Of this, about 2.5 M. G. D. was used for shipping, industrial and commercial purposes. Allowing a further reduction of about 30 per cent for system leakage and public uses, leaves a net of 14.5 M. G. D. or a net domestic daily per capita consumption of about 200 gallons, with a gross daily per capita consumption of about 310 gallons.

In 1922 (a normal year except for a 4 months very dry period from April to July inclusive), the city pumps delivered an average of about 19.7 M. G. D. Nuuanu, Makiki and Palolo Valleys furnished an additional estimated supply of about 4.5 M. G. D., - a total of about 24.0 M. G. D. Of this amount, about 3.0 M. G. D. was used for commercial and industrial purposes and shipping. Allowing an additional 30 per cent for system losses and public purposes, leaves a net daily domestic per capita consumption (80,000) persons of about 185 gallons, with a gross daily per capita consumption of about 300 gallons.

In 1922 the Kaimuki pumping station delivered about 5.6 M. G. D. to approximately 10,000 persons (including combined garrisons of Fort Ruger and Fort De Russy of about 500) with practically no commercial or industrial demands. It is in this area that the greatest irrigation demands exist, because of the custom of endeavoring to grow grass and vegeta-
tion on almost bare rocks, coral ledges and sand. Allowing a 30% loss for leakage and public purposes in this area, leaves a net per capita daily domestic consumption of about 390 gallons, with a gross daily per capita consumption of about 560 gallons.

These consumptions are beyond all reason and are due principally to:

(a) WILLFUL WASTE AND CARELESSNESS. - due to the fact that more than three-fourths of the privileges are not metered and there is no incentive for saving water.

(b) LEAKAGE. - due to the fact that the Water Works Department has no inspection division and no systematic checking up of leakage,

(c) HIGH IRRIGATION DEMANDS - due to the perennial growing period and to the tendency in many parts of the city to attempt to grow grass and vegetation on coral, rocks and volcanic sand by pouring on huge quantities of water instead of spending the necessary funds to properly cover the surface with good soil. Here again the lack of meters is largely responsible.

REASONABLE PER CAPITA CONSUMPTION.

Water consumption may be sub-divided into the following:
1. Domestic use, including yard and garden irrigation;
2. Commercial and industrial use, including hotels, stores, factories, canneries, etc.;
3. Public use, including fire protection, street cleaning, public school use, fountains, etc.

In addition to these, reservoir and pipe leakage must be considered.

According to data compiled by the Water Works Association in 1915, in thirty-five American cities varying in size from 3,500 to 730,000 population and located from northern New York to southern California, the daily per capita domestic consumption including "water not accounted for", ranged from 27.2 to 85.9 gallons. Of these, the city of San Diego, California, with a population of about 85,000 (and with a climate similar to that of Honolulu), had a daily per capita consumption, including all water used and lost in every way, of 80.6 gallons. San Diego is completely metered.

Allowing liberal quantities for domestic uses with daily bathing, for perennial irrigation, reasonable reservoir and distribution system losses, fire protection and industrial and commercial requirements, a daily per capita supply of 175 gallons is considered ample for Honolulu, and the necessary
steps should be taken to reduce it to this limit. It is be-
bieved that metering is the remedy.

INDUSTRIAL AND SHIPPING REQUIREMENTS.

Industrial requirements served by the Water Works
Department have been comparatively low due to the fact that
many industrial concerns and public and semi-public institu-
tions have their own artesian wells and supplies. With the
gradual lowering of the artesian head and the consequent ne-
cessity for more pumping facilities, there has been a recent
turning to the city Water Works Department for water. There
have been only two artesian wells drilled in Honolulu since
1916 and only one of these for industrial purposes.

The total industrial supply (including army reser-
vations) furnished by the Water Works Department in 1920,
amounted to about 2.4 M. G. D., while shipping demands
amounted to about 150,000 gallons daily. Industrial, commer-
cial and shipping requirements now amount to about 10 per-
cent of the total consumption. It is not probable that
industrial, commercial and shipping requirements will in-
crease at any faster rate than the domestic requirements,
but, should the city and county acquire all existing sources
of supply and prohibit the drilling or development of
additional sources, the ratio of industrial and commercial water to other requirements will probably increase.

It is probably safe to assume that this class of service will never require more than 15 per cent of the total supply, and that probably 90 per cent of this quantity will be required in the areas now served by the Beretania and Kalihi pumping plants. However, further study of this problem should be made.

**FIRE PROTECTION.**

**WATER REQUIRED.**

One of the principal objects for which water works are constructed is to provide ample fire protection for the community. The total quantity of water used per year for this purpose is only a very small percentage of the total consumption, but when needed, it must be delivered quickly and at sustained quantity. Honolulu has been very fortunate in having but few disastrous fires in its history. However, a few recent fires have illustrated the danger due to inadequate mains, dead ends and inadequate number of fire hydrants.

According to a pamphlet issued by the National Board of Fire Underwriters, on "Standard Schedule for Grading Cities and Towns of the United States, with Reference to their Fire
Defences and Physical Condition", in 1917, - the "Fire Flow" required for cities of various populations is as follows:

<table>
<thead>
<tr>
<th>POPULATION</th>
<th>FIRE FLOW (Gallons per minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80,000</td>
<td>8,000</td>
</tr>
<tr>
<td>100,000</td>
<td>9,000</td>
</tr>
<tr>
<td>125,000</td>
<td>10,000</td>
</tr>
<tr>
<td>150,000</td>
<td>11,000</td>
</tr>
<tr>
<td>200,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Over 200,000 population, - 12,000 G. P. M. with 2,000 to 8,000 gallons additional for a second fire.</td>
<td></td>
</tr>
</tbody>
</table>

It is estimated that the quantity of water which should always be available for individual fires in outlying districts where houses are small and not close together, should not be less than 500 G. P. M. In the down-town or other congested districts, 6,000 G. P. M. should be available in 1923 and the quantity should be increased to 12,000 G.P.M., with an additional supply of 6,000 G. P. M. held in reserve in case of a second fire, in 1945. Distribution system mains and distribution reservoirs should be planned accordingly (See pages 75 to 86 ). All of these estimates are based on the assumption that sufficient and efficient fire pumping engines and hydrants are available.

A salt water fire protection distribution system for the down-town district has been considered and rough
estimates of the cost thereof prepared by the Water Works Department. It is believed that a fire boat should be always available for shipping and wharf protection, but so long as the fresh water supply seems adequate for all needs, salt water should not be resorted to for fire protection of stores, warehouses, hotels, etc., where salt water would cause much greater damage to contents than fresh water. In an emergency, fire pumping engines can at the present time be run along side of sea walls and wharves and effectively pump sea water onto fires which may be located within 500 or 600 feet of the water front.

Separate high pressure systems, designed to eliminate the use of pumping engines, are very costly and are also dangerous in case of broken mains.

FIRE HYDRANTS.

The total number of fire hydrants served by the city’s distribution system in January, 1923, was 804, of which 64 were privately owned. All hydrants were installed and are maintained by the Water Works Department. With about 214 miles of streets (Fort Shafter to Kahala inclusive) it is obvious that many more hydrants are needed.

The maximum distances between hydrants in the downtown or other congested districts, should not exceed 250 feet,
and in outlying residence districts, 400 feet. Hydrants should be so located that at least two fire streams not over 500 feet long may be applied to opposite sides of a fire in the outlying residence districts, and at least 16 streams may be centered on a fire in the down-town or congested district. Practical experience has shown that single hose lines should not exceed 500 feet in length for good service and a 300 foot limit in length is much more desirable. For lengths exceeding 500 feet, it is much better practice to use two lengths of hose and "siamese" these into a single nozzle. (See pages 396 to 409 and 643 to 652 of "Conveyance and Distribution of Water for Water Supply", by Edward Wegmann, - for further and detailed data on this subject).

Fire hydrants should, of course, be standardized. The standard hydrant adopted by the Hawaiian Department for all army posts in Hawaii in accordance with specifications prepared by the writer, require that all hydrants have two 2-1/2" hose and one 4" steamer outlet; all outlets to have independent gate valves and National Standard Threads, to be installed on no main less than 6" in diameter and to have a gate valve installed between the main and the hydrant so that the hydrant can be cut off without interruption of service in the main.
All hydrants should be inspected and tested for flow and pressure (Pitot tube) at monthly intervals at least.

**OTHER PUBLIC USES.**

In addition to fire protection, the greatest demand made on the water system for public purposes is for park and school ground irrigation. The demands for public buildings, sewer flushing, street cleaning, etc., are not excessive.

**TOTAL WATER REQUIRED.**

It is believed that facilities to deliver into the mains a mean daily supply of 175 gallons per capita will provide an abundance of water for all legitimate purposes, including reasonable leakage losses. According to Exhibit III, the following quantities will probably be required:

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ESTIMATED POPULATION</th>
<th>WATER REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1923</td>
<td>95,000</td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>120,000</td>
<td>21.0 M.G.D.</td>
</tr>
<tr>
<td>1940</td>
<td>180,000</td>
<td>31.5 &quot;</td>
</tr>
<tr>
<td>1950</td>
<td>240,000</td>
<td>42.0 &quot;</td>
</tr>
<tr>
<td>1960</td>
<td>305,000</td>
<td>53.4 &quot;</td>
</tr>
<tr>
<td>1970</td>
<td>380,000</td>
<td>66.5 &quot;</td>
</tr>
<tr>
<td>1973</td>
<td>400,000</td>
<td>70.0 &quot;</td>
</tr>
</tbody>
</table>

These estimates are all based on the condition that all privileges will be metered.

It is also estimated that the mean daily requirements in 1973 for the various areas to be served by the Water Works Department, with the city completely metered, will be as follows:
<table>
<thead>
<tr>
<th>AREA</th>
<th>ESTIMATED POPULATION</th>
<th>WATER REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaliihi Pumping Plant</td>
<td>125,000</td>
<td>22.0 M.G.D.</td>
</tr>
<tr>
<td>Beretania Pumping Plant</td>
<td>80,000</td>
<td>14.0 &quot;</td>
</tr>
<tr>
<td>Kaimuki Pumping Plant</td>
<td>100,000</td>
<td>17.5 &quot;</td>
</tr>
<tr>
<td>Lower Nuuanu and Punch-bowl Area</td>
<td>40,000</td>
<td>7.0 &quot;</td>
</tr>
<tr>
<td>Manoa Valley</td>
<td>25,000</td>
<td>4.5 &quot;</td>
</tr>
<tr>
<td>Other Upper Valleys and Heights</td>
<td>30,000</td>
<td>5.0 &quot;</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>400,000</td>
<td>70.0 &quot;</td>
</tr>
</tbody>
</table>
PART FOUR.

AVAILABLE SOURCES OF SUPPLY.

(For complete discussion see pages 47 to 58).

RESUME.

<table>
<thead>
<tr>
<th>Source</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artesian water</td>
<td>40 M. G. D.</td>
</tr>
<tr>
<td>Tunnel Water (dry weather)</td>
<td>10 M. G. D.</td>
</tr>
<tr>
<td>Springs and dry weather stream run-off</td>
<td>15 M. G. D.</td>
</tr>
<tr>
<td>Stored flood water</td>
<td>15 M. G. D.</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>80 M. G. D.</strong></td>
</tr>
</tbody>
</table>
PART IV.

AVAILABLE SOURCES OF SUPPLY.

Four classes of water supply are available:

(a) Artesian water;
(b) Springs and normal low surface run-off;
(c) Infiltration tunnels;
(d) Stored flood water.

ARTESIAN WATER.

The 1917 Territorial Water Commission report shows that in December, 1916, about 57 M.G.D. of artesian water was being taken from the four basins located between Diamond Head and Red Hill, and about 40 M.G.D. from the three basins located between Diamond Head and Kalihi stream, - all in addition to underground leakage. The records also show that the overdraft and consequent lowering of head in the Kalihi-Red Hill basin is not nearly so great as in the other three. No water is pumped from this basin by the Water Works Department. This supply will be required probably within 20 years. When the supply is required, a battery of wells should be drilled and the discharge therefrom either delivered to Kalihi pumping plant or an additional plant installed on the Ewa side of Kalihi stream.

Because of repairs to well heads and valves in 1921, the closing in 1922 of the artesian well formerly used by the
Hawaiian Electric Company for condensation purposes (which formerly discharged nearly 3 million gallons of water daily into the harbor) and the fact that there have been only 2 wells drilled in the Honolulu city area since 1916, it is believed that the daily draft from the four basins has not been increased since 1916, notwithstanding the increased draft in the artesian basins by the 3 large city pumping plants. Furthermore, through the efforts of the Territorial Division of Hydrography, sufficient wells with underground leakage have recently been recased to effect an estimated saving in underground losses of about 5 M.G.D. Notwithstanding these improvements, the artesian well heads in the basins located between Diamond Head and Kalihi stream continue to fall year by year; however, the average mean fall since 1916 has apparently been at a reduced rate of about 3.5 inches per year instead of the previous fall of about 4.5 inches per year.

It is estimated by the engineers who have carefully studied this problem that the four artesian basins under the city may be depended upon to furnish about 40 M.G.D. without overdraft or permanent lowering of the artesian heads.

This 40 M.G.D. of pure clear available water must be conserved as the main supply to be depended upon to serve the city. The Government (preferably the City and County of
Honolulu must acquire or control all existing wells (both old and new) between Wailupe and Fort Shafter Military Reservation and must prohibit the drilling of additional wells by private parties within these limits. Every privately owned well in this area is taking water from the same sources which now supplies the city water system or which must be depended upon to supply the city water system in the near future.

SPRINGS AND NORMAL RUN-OFF.

It is probable that the normal low water discharge of springs and streams located between the city limits at elevations high enough to supply the city system by gravity will not aggregate more than 5 M.G.D. Lower level discharge, however, which would be available for pumping, and which are now largely used for irrigation of rice and taro, will probably add at least 10 M.G.D. more. A few high level springs like the "Alewa Heights" spring located at elevation 850 feet in upper Nuuanu Valley, which was recently cleaned out and which is said to be delivering about 500,000 gallons daily to Alewa Heights and upper Kalihi Valley, as well as the Kalihiwai spring, at elevation about 600 feet, in upper Pauoa Valley, which has a dry weather discharge of around 300,000 gallons daily, and which is only being used for irrigation, should be utilized to the utmost. Low level springs and stream run-off must be considered as potential sources of supply when the
demand has exceeded the other available supplies.

It is estimated that at least 15.0 M. G. D. can be secured from these sources in normal dry weather. The greater part of this supply would have to be pumped up to filtration plants.

PROPOSAL TO BRING WINDWARD SPRING AND SURFACE WATER TO HONOLULU VIA A TUNNEL.

This project has been recommended by both Mr. J. Jorgensen, as a member of the City Water Commission, and by Professor Palmer. However, I think the latter has probably been mislead by Mr. Jorgensen's very low estimates of cost and high estimates of water to be found in windward springs and to be developed in the proposed main tunnel. Mr. Jorgensen estimates the cost of this tunnel at $ 955,540.00, detailed as follows:

1. Tunnel - Kalihi-Kaneohe, 8100 ft @ $40.00  $324,000.00
2. Side Tunnels p Kaneohe-Waihee, 37420 ft @ $12.449,040.00
3. Trails, Camps, etc. 5,000.00
4. Pipe Line - Kalihi Valley 600 feet elevation to Kalihi Road and School Street - 15,500 ft 24" Pipe @ $5.00  77,500.00
5. Development tunnels above main line  100,000.00

Total  $ 955,540.00
This estimate makes no provisions for the purchase of the water rights for the estimated "7,778,700" gallons per 24 hours to be diverted from its present use. It also states that 15,500 lineal feet of 24" pipe (supposedly cast iron as it cannot be believed that an engineer would specify wood stave pipe for a project of this magnitude) can be placed for $5.00 per lineal foot. The Honolulu price of 24-inch Class "C" pipe (average head of 300 feet) at the present time (February 10, 1923) is about $10.00 per lineal foot ($60.00 per ton). The price of 24-inch wood stave pipe for 300 foot head is $5.30 per lineal foot. It is estimated that 15,500 lineal feet of 24-inch cast iron pipe in place in this project would cost approximately $330,000.00, and the same quantity of wood stave pipe about $155,000.00. The writer questions the "7,778,700" gallons of high level spring and low water run-off said to be available for this project. Short time measurements made in the winter months (in this case in February, 1916) are practically worthless for determining the mean annual or low water discharges of springs or streams.

Unless this project could be undertaken in conjunction with a vehicular tunnel, it should be considered only as a last resort after all other sources had failed.
INfiltration Tunnels. (See also pages 17 to 20).

Nuuanu Valley.

Available discharge records are meagre and not very satisfactory, due to poor design and installation of weirs and broken records. It is believed, however, that the existing Nuuanu tunnels will discharge not less than 1 M. G. D. in extremely dry weather and somewhere around 10 M. G. D. after heavy rains. The cost of this water as compared with pumped or artesian or filtered surface water is very low. The 1922 cost per million gallons of water pumped from the 3 large pumping plants was about $41.30, sub-divided as follows:

(a) Operating Costs 50.0% $20.65
(b) Interest on Bonds 18.0% 7.43
(c) Sinking Fund 8.3% 3.43
(d) Service Department 9.7% 4.01
(e) Overhead and Engineering 6.0% 2.48
(f) Maintenance and Repairs to Pumping Plant 4.3% 1.40
(g) Reservoirs, Tools and Equipment, Fire Hydrants and General Supplies 4.6% 1.90

Total 100.0% $41.30

The pump operating cost varied from $44.83 for the Beretania high lift (224 feet) steam pump to $15.10 for the Kalihi steam pump (174-ft head).
It has been estimated that the cost of a slow sand filtration plant to deliver 6.0 M.G.D. would be about $250,000.00 and the cost of operation from $6.00 to $8.00 per million gallons.

The cost of the Nuuanu development tunnels, and the wood stave pipe connecting these with the city distribution system, is said to be about $43,200.00. Three million gallons daily is surely a most conservative estimate of the year 'round average tunnel discharge, and it is probable that the average is considerably higher than this. At the average operating cost of pumped artesian water of about $20.65 per million gallons, this water is worth about $22,000.00 per year.

Additional tunnels should be driven in the vicinity of Lulumaha. It is believed that this additional tunneling will develop a dry weather supply of clear tunnel water large enough to supply all of the area originally supplied in lower Nuuanu Valley and the Punchbowl district by the old Nuuanu reservoir system and in addition, in wet weather when the tunnel discharges are greatly increased, - a considerable portion of the lower areas now served by Beretania and Kalihi pumps.

PALOLO VALLEY.

The tunnel here has replaced the old spring which formerly discharged about 20,000 gallons daily in dry weather.
Available discharge data indicate that the discharge from Palolo tunnel will vary somewhere between 150,000 gallons daily, in dry weather, to 500,000 gallons daily after long periods of heavy rainfall. It is believed that this discharge can be more than doubled by drilling additional tunnels in this vicinity.

The original 6-inch galvanized iron pipe line as located down the bottom of the valley has been washed out by floods in spots and the broken portions temporarily replaced with sections of 2-inch pipe. Any big flood is liable to put the line out of commission as it is now located, and a new line should be constructed near the top of the ridge on the Ewa side of the Valley. The cost of the Palolo tunnel is said to have been about $4,000.00. At $20.00 per million gallons, a dry weather discharge of 150,000 gallons daily is worth about $1,200.00 per annum. It is believed that this quantity can probably be doubled by driving additional cross tunnels from the existing main tunnel.

**KALIHI AND MAKIKI VALLEYS.**

About $25,000.00 has been expended for tunnels thus far in Kalihi and Makiki Valleys. The Kalihi dry weather discharge probably ranges between 100,000 and 200,000 gallons daily. The cost was about $10,000.00. Work on two favorable
projects farther up the valley has been suspended on account of lack of funds. The work in Makiki has thus far been unsuccessful, but higher level shallow prospect tunnels seem to justify Professor Palmer's prediction that the chances of finding high level underground water in this valley are fairly good. No attempt at tunnel development work in upper Manoa Valley has been made. According to Professor Palmer's report, this is one of the most likely places to find water.

TUNNEL WORK JUSTIFIED.

In the writer's opinion, work already done is more than justified by the results obtained and further work along this line should be done, especially in upper Manoa Valley. It is believed that sufficient tunnel work may be developed to supply all of the city located above the 200 foot level and during wet weather, to supply sufficient water to serve part of the lower levels, thus permitting the shutting down for considerable periods of time of some of the pumping units.

The question of whether these tunnels will affect existing low level springs and the artesian basins, is not taken very seriously, for, even should this happen, the lower springs and artesian basins cannot be deprived of any more water than is taken out above and the additional value of the water as a high level gravity supply over any supply which would have
to be pumped, is obvious. Furthermore, it should be kept in mind that the tunnel water is a perfectly clear and practically pure supply which will probably not even require chlorination. For laundry purposes, this water is much "softer" and much more desirable than artesian.

It is estimated that tunnel water may be developed in all Honolulu upper valleys to the extent of about 10 M.G.D. in normal dry weather and at least twice that amount during long wet periods. It is believed, however, that accurate, well designed and installed measuring devices should be installed at once to measure all tunnel discharge and at least five years continuous records of discharge (including four dry seasons) obtained before permanent pipes are installed. In the meantime, small wood stave pipes (as are now installed in upper Nuuanu Valley) may be installed at low cost to deliver the tunnel discharge to the city's distribution system and reservoirs.

STORED FLOOD WATER.

Flood storage facilities in upper Nuuanu Valley, consisting of four open reservoirs with a total capacity of about 550 million gallons, are capable of furnishing a normal dry weather daily supply of about 3.0 million gallons, except in periods of extreme drought when the supply practically fails. This water is composed of run-off from practically uninhabitated
water reserves but with danger of pollution because of the public highway which passes through the entire length of the valley and the difficulty in keeping "hikers" from trespassing. While this supply is chlorinated and there is little danger of epidemic from it, this source, after a heavy rainfall, is muddy and distasteful and is unfit for human consumption.

Additional feasible storage reservoir sites exist in upper Nuuanu, Kalihi and Manoa Valleys. The project recommended by the City Water Commission to divert flood water from upper Manoa Valley and deliver the same by tunnels to the existing No. 4 reservoir in upper Nuuanu Valley, is also feasible.

WAIAHOLE WATER.

The water license issued by the Territory of Hawaii to the Waiahole Water Company, under which the latter pays the Territory $15,000.00 per annum for water formerly discharged by Waiahole springs, provides that the Territory may take back (at the Waiawa portal) this water whenever it is required for public purposes, as follows:

In 1942 - 4 M. G. D.
In 1952 - 6 M. G. D.
In 1962 - all water.

As this original spring water is now mixed with surface run-off within the main tunnel, it is impossible to segregate it from the surface and, at times, flood water run-off.
This source of supply should be kept in mind as an additional 6 or 7 M.G.D. should the time come when other more desirable and accessible sources of supply are exhausted. It is feasible to take delivery of the water at the Waiawa (south) portal of the Waiahole tunnel and deliver it by pipe line to No. 1 reservoir (El. 393 feet) in Nuuanu Valley.

It is estimated that sufficient flood water (including Waiahole supply) can be stored at elevations high enough to provide a gravity filtered supply of about 15.0 M.G.D. in normal dry weather.

**TOTAL AVAILABLE SUPPLY.**

1. Artesian water 40.0 M.G.D.
2. Springs and normal low stream run-off 15.0 "
3. Infiltration tunnels 10.0 "
4. Stored flood water 15.0 "

Total 80.0 M.G.D.
PART FIVE.

PUMPING PLANTS AND RESERVOIRS.

(For complete description and discussion see pages 60 to 72)

RESUME

EXISTING PUMPING PLANT CAPACITY - 34 M. G. D.

EXISTING STEAM PUMPING PLANTS OBSOLETE AND INEFFICIENT.

EXISTING ELECTRIC PUMPS in good order but more expensive for regular service than modern steam pumps.

MODERN STEAM PUMPS should be adopted as standard units for regular service and the replacement of the old steam plants with these new units should be started at once.

ELECTRIC MOTOR DRIVEN CENTRIFUGAL PUMPS should be adopted for intermittent service, such as boosting.

SERVICE RESERVOIRS with capacities equal to at least half the normal daily requirements and so located as to be available for excess tunnel water should be provided. The proposed 6 million gallon reservoir to be located back of Punchbowl Crater should be constructed in 1923, to provide dry weather night storage for Beretania pumping plant as well as wet weather excess tunnel discharge. The proposed 1.5 million gallon Round Top reservoir should be constructed also in 1923 to relieve the existing dry weather shortage in Manoa.
PART V.

EXISTING PUMPING PLANTS AND RESERVOIRS.

The City is now regularly operating 6 pumping plants of which 2 are used only for boosting purposes; 4 of these plants pump artesian water and have a combined maximum capacity at normal heads of about 34.0 million gallons daily. The two booster plants have a combined capacity of about 1 M. G. D. at normal loads. The 4 "supply" plants can deliver water to 6 covered reservoirs with a combined capacity of about 8.0 million gallons. One of these, located in lower Makiki Valley at 160 feet elevation, is used for storage of excess Makiki Spring water and also as a relay reservoir for water pumped by the Beretania pumping plant (when the Makiki Spring discharge is low) for use in Manoa Valley. An electric pump (720,000 gallons daily capacity) lifts water from this reservoir to upper Manoa Valley.

Three additional covered reservoirs with a combined capacity of 920,000 gallons are located in Palolo, Alewa and Pacific Heights and are used to store and distribute spring and tunnel water. A new 2.5 million gallon concrete reservoir in upper Nuuanu Valley, designed to store tunnel water, is now practically complete. An old uncovered masonry reservoir
of 720,000 gallons capacity is located at elevation about 250 feet at the junction of the Pukele and Waiamoa branches of Palolo Valley. This reservoir is not used at the present time and is in poor condition. In 1919, a 300,000 gallon capacity concrete reservoir was constructed at the old open reservoir site at about 740 feet in upper Makiki Valley, to be used to store spring water. The bottom is said to have collapsed permitting muddy storm water to enter and the reservoir is not used at the present time.

The 1913 report of the Superintendent of Public Works to the Governor of Hawaii, contains a complete history and inventory of the Water Works Department and equipment at that time. All pumping plants existing at that time are described in detail in that report. Fuel oil is used for generating steam at the 3 large plants. Briefly, the pumping plants and reservoirs as these exist today, are as follows:

BERETANIA PUMPING PLANT AND RESERVOIR.

One "Blake" cross compound horizontal type steam pump installed in 1895, recently overhauled and now in fair condition. Capacity 4.0 M.G.D. against 164-ft. head.

One "Rierson" cross compound horizontal type steam pump installed in 1910, in fair condition. Capacity 3.5 M.G.D., against a head of 325 feet.
One "Allis-Chalmers" electric motor driven 8" single stage centrifugal pump installed in 1920, capacity 3.0 M.G.D. against a head of 164 feet.

Total capacity of Beretania pumping plant 10.5 M.G.D.

**Sources of Supply.** Two 10-inch artesian wells 580 feet and 615 feet deep, respectively, driven in 1895, and two 12-inch ar­tesian wells 607 feet and 616 feet deep, respectively, driven in 1909. The casings of the two older wells are believed to be worn out. When all three pumps are operating at full capacity, the supply is unequal to the draft.

**Reservoir Capacity.** 1.5 million gallons, located at elevation about 150 feet on the makai slope of Punchbowl near the intersection of Prospect and Alapai Streets. This reservoir capacity is entirely inadequate. During extremely dry periods when Makiki springs fail, the Beretania plant also pumps water to Makiki reservoir from which the Makiki booster pump lifts water to Manoa Valley.

**Kalihi Pumping Plant and Reservoir.**

One "Allis-Chalmers" vertical triplex single acting steam pump installed in 1899, capacity about 5.0 M.G.D. against a head of about 200 feet. This pump has been operating almost continuously for about 23 years without a general over­hauling and is, apparently, still in fair condition.

One "Allis-Chalmers" single stage 10" centrifugal pump operated by a "Kerr" steam turbine, installed in 1918, capacity 5.0 M.G.D. against a head of 185 feet. This unit is in good condition but is used but rarely because of high operating cost. Total capacity of Kalihi pumping plant,
about 10 M. G. D.

SOURCE OF SUPPLY. Three 12-inch artesian wells 495 feet, 475 feet and 460 feet deep, respectively. The first well was drilled in 1900 and the two latter, in 1899. Apparently all wells are in fair condition.

RESEVOIR CAPACITY. 3.2 million gallons, located at about elevation 170 feet, on slope of Kapalama ridge, on east side of upper Kalihi Valley.

KAIMUKI PUMPING PLANT AND RESERVOIRS.

Two "Risdon" cross compound horizontal type steam pumps, each capable of delivering 3.0 M.G.D., against a head of 300 feet. One pump installed in 1898. The second pump was purchased "second-hand" from Hawi Plantation Company and was installed in 1915. Both pumps and boilers have recently been overhauled and are in fair condition.

One "Allis-Chalmers" electric motor driven unit, composed of a 400 H.P. motor and two 8-inch single stage centrifugal pumps set in series, - capacity 5.5 M.G.D., against 300-ft head, - installed in 1920. This unit is in excellent condition.

Total pumping capacity 11.5 M. G. D.

SOURCES OF SUPPLY. Four 12-inch artesian wells, - two drilled in 1898 are 260 feet deep; the remaining two, drilled in 1912 are 236 feet and 245 feet deep, respectively. All
wells are apparently still in good condition.

RESERVOIR CAPACITY. Kaimuki reservoir, capacity 683,000 gallons, located at elevation about 240 feet on ridge back of Diamond Head, and Diamond Head reservoir, - capacity 876,000 gallons, located at elevation about 150 feet on Waikiki slope of Diamond Head. Total reservoir capacity about 1.5 million gallons.

WILDER AVENUE PUMPING PLANT AND RESERVOIR.

One "Deane" vertical motor driven Triplex pump, - capacity 1.5 M.G.D., against head of 265 feet. Installed in 1914. This unit is used only as a relief pump because of continuous gear breakage and noise and is now in poor condition.

One "Allis-Chalmers" electric motor driven 6" single stage centrifugal pump, installed in 1920, - capacity 2.0 gallons daily, against a head of 260 feet.

Total pumping capacity 3.5 M. G. D.

RESERVOIR CAPACITY. Rocky Hill reservoir, capacity 726,000 gallons, located at elevation 267 feet on grounds of Oahu College in lower Manoa Valley.

MAKIKI PUMPING PLANT AND RESERVOIR.

One "Allis-Chalmers" electric motor driven 2 stage 4" centrifugal pump with 75 h.p. motor, - installed in 1920, capacity 720,000 gallons daily, against a head of 300 feet.
This unit is in good condition and is used to boost stored Makiki spring water or water relayed from Beretania pumping plant.

Two old Triplex pumps, one driven by a 3-cylinder "Standard" gas motor and the other by a 50 h.p. electric motor, are in bad condition and out of commission. The first of these is installed in a shaft 125 feet below the surface of the ground and is connected with the surface with pump rods 125 feet long. This pump formerly lifted water from a 12-inch artesian well about 800 feet deep. The well is said to be in good condition.

The second unit was used for the same purpose as the present centrifugal pump. The two old pumps had capacities of about 1.0 M.G.D., against a head of 130 feet and 0.5 M.G.D., against a head of 250 feet, respectively.

This plant can also deliver water to Rocky Hill reservoir (capacity 726,000 gallons) in Manoa.

**Reservoir Capacity,** (from which water is boosted)

759,000 gallons.

**Pacific Heights Plant.**

A small electric motor driven 6 stage 1" centrifugal pump, located on Pacific Heights, at about elevation 650 feet, is capable of boosting about 20 gallons per minute (288,000 gallons daily) of Pauoa Spring water to three small
reservoirs and tanks located at about elevation 900 feet. During existing dry weather when Pacific Heights Spring fails to supply the requirements, a small gas motor driven pump is operated at the lower Pauoa Springs to pump water up to the electric booster pump.

**PUMPING PLANT EQUIPMENT REQUIRED.**

Recent mainland practice has demonstrated decisively that, except in rare instances where large hydro-electric projects furnish very cheap power, self contained steam pumps in large units, are much more economical than electric pumps. Among the larger cities which have either adopted steam in preference to electricity or which have tried and discarded electricity for steam, are Buffalo, Chicago, Cleveland, Kansas City, Louisville, Milwaukee, Pittsburg, St. Louis, and many others.

With old partially worn out and obsolete horizontal type steam pumps, which are probably 30 per cent less efficient than modern vertical triple expansion steam pumps, the local Water Works Department is pumping water at approximately the same cost as the new electric motor driven centrifugal pumps.

The advantages of the steam pump over the electric pump are:
(a) **Self-contained units.** - Not subject to shut down on account of power plant or transmission line break down.
(b) **More efficient.** - Due to directly applied power.
(c) **More economical.** - In large units working the greater part of the time, probably 30 per cent cheaper operation and maintenance.
(d) **Greater flexibility** of each unit to serve varying loads.
(e) **Longer service.** - Estimated that the life of steam pumps is probably 40 per cent longer than for electric motor driven units.

The disadvantages are:
(a) Much greater first cost.
(b) Larger housing facilities required.
(c) More competent personnel required.
(d) Dirtier and noisier than electric pump.

Fuel shortage would affect both types equally.

It is estimated by competent local pump engineers that the difference in first cost between the steam and electric plants required at any one period would be amortized by saving in operation cost in from 8 to 10 years. (See Exhibit IX).

Each pumping plant should always have in reserve at
least one pumping unit and about one-third of its total pumping capacity.

It has been the experience of most mainland cities using pumped water that it is cheaper to install and operate sufficient additional pumping units to take care of peak loads, than to provide sufficient reservoir capacity for this purpose. However, Honolulu is now receiving a considerable amount of water by gravity from tunnels and springs, and it is probable that in the future surface and stored flood water run-off will have to be supplied to augment the other sources of supply. These gravity supplies require storage facilities.

The existing Nuuanu tunnels are now discharging during wet weather more water of excellent quality than can be absorbed by the distribution system during slack diurnal periods and by available suitably located reservoirs (including the new 2.5 million gallon Nuuanu reservoir). This cheap surplus tunnel water, now being wasted, would replace costly pumped water during periods of peak demands if storage facilities were available. On the other hand, during dry periods the tunnel discharge is and probably will continue to be low enough so that the distribution system could absorb it all at all times. When this is the case, the available storage space could be economically utilized for storing pumped water during
periods of slack demands.

Also, Honolulu is very fortunate in having conveniently located foot hills suitable for reservoir sites.

It is, accordingly, believed that reservoir capacity for about one-half the daily normal requirements should be available to provide for the peak demands and that each pumping plant should (in addition to its reserve equipment) be equipped with pumping facilities to provide for only the mean normal daily requirements.

It is also believed that standard pumping units should be adopted and adhered to wherever possible. At the present time the most flexible and suitable pumping unit would be one of about 7.5 M. G. D. capacity against a normal head of about 300 feet. Each of these units could be regulated so that it could serve less than half of its normal capacity economically and could likewise be speeded up considerably if the occasion demanded. After the population has doubled its present size, larger sized units would undoubtedly be more economical. However, it is believed that in selecting equipment for each plant, the important factor of flexibility should be kept in mind so that the pumping capacity may be increased or decreased economically to allow for seasonal demand fluctuations and the widely varying quantities of cheap tunnel water available.
It is also believed much more economical to at once begin to scrap the old steam pumps and to install new standard units than to keep the old pumps operating. Existing steam pumps at the various City pumping plants are from 23 to 29 years old. Recent overhauling (except Kalihi steam pump) have put these plants in fairly good shape, but, as previously stated, it is estimated that their efficiency is probably 40 per cent less than modern pumps.

It is now costing approximately $0.09 per million gallons per foot head to operate these pumps. According to Exhibit XI, the cost of operating the new pumps should not exceed $0.053 per million gallons per foot head.

**SERVICE RESERVOIRS REQUIRED.**

It is estimated that service reservoir capacities of at least half of the normal daily requirements should always be available for each pumping plant and so located that these may also be used for tunnel and other gravity supplies.

The present total service reservoir capacity is about 12.0 million gallons, including the new 2.5 million gallon Nuuanu reservoir. Of this, however, about 3.5 million gallons are limited to tunnel and spring water supplies and cannot now be reached by the pumping plants.

Beretania and Kaimuki pumping plants and Manoa Valley
are now lacking in reservoir capacities. The Beretania plant is served by Punchbowl reservoir (elevation 170 feet), capacity about 1.5 million gallons. It can also pump into lower Makiki reservoir (elevation 160 feet), capacity about 750,000 gallons, - a total of about 2.25 million gallons. The Kaimuki plant is served by Kaimuki reservoir (elevation 248 feet), capacity about 683,000 gallons, and Diamond Head reservoir (elevation 150 feet), capacity about 876,000 gallons, - a total of about 1.5 million gallons. Kalihi has reservoir capacity of about 3.2 million gallons (at elevation 170 feet) and Wilder and Makiki booster pump may deliver into Rocky Hill (Manoa) reservoir (elevation 267 feet), capacity about 726,000 gallons.

The present plans of the Water Works Department include two additional service reservoirs designed primarily for tunnel water storage and distribution. One of these is to be of 6.0 million gallon capacity and located in the saddle back of Punchbowl crater, at elevation (top) of about 320 feet. It is believed that the construction of this reservoir within the next year is desirable, to serve both for wet weather tunnel discharge and dry weather pumped water night storage.

The second reservoir now planned is a 1.5 million gallon unit to be located on the slopes of Round Top at elevation about 500 feet. The high elevation is selected to provide
a gravity supply for upper Manoa valley. This reservoir is now needed to serve the upper valley, but it is believed that its elevation should be dropped to about 400 feet. This lower elevation will permit the proposed tunnels in upper Manoa Valley to be driven at lower levels than otherwise, if this should be found advisable, and will also bring it within the efficient service range of the existing Makiki booster pump. It will also be high enough to serve practically all of the houses in upper Manoa Valley. Should later tunnel development work in Makiki and Manoa Valleys prove successful, the Makiki booster plant can be shut down at least the greater part of the year and this reservoir used for tunnel or spring water storage and distribution. This reservoir should be constructed in 1923 as the fairly thickly settled portions of middle and upper Manoa Valley now has inadequate service in dry weather.
PART SIX.
DISTRIBUTION SYSTEM, INSPECTION, WATER RATES, and SERVICE ZONES.

(For complete description and discussion see pages 75 to 86.)

RESUME.

DISTRIBUTION SYSTEM. A base plan designed to meet estimated needs 50 years hence should be adopted as rapidly as street lines and grades are fixed by ordinance, and all replacements and extensions made accordingly.

EXISTING SYSTEM just grew, was not planned for future expansion. Now has 161 miles of pipe of all sizes down to 1-1/2 inches.

DISTRIBUTION SYSTEM REPLACEMENTS AND EXTENSIONS now planned by Water Works Department should not be made until base plan is adopted.

INSPECTION DIVISION should be organized at once. Will more than pay for itself in saving of leakage, etc.

WATER RATES. Now too low, should be based on "fixed service" and "consumption" charges and should be sufficient to provide for:

(a) Operation and Maintenance

(b) Bond Interest and Sinking Fund Payment

(c) Fund for Replacements, Improvements and Extensions
All consumers should be placed on same basis except shipping, which should pay adequate increased rates to cover additional service required.

WATER WORKS DEPARTMENT should be reimbursed for service for development of electricity, purchase, maintenance and inspection of fire hydrants and for fire protection service.

SERVICE ZONES. Create water service zones and limit service thereto.
PART VI.

DISTRIBUTION SYSTEM.

Honolulu's distribution system has expanded in accordance with no general plan looking toward the demands of even a decade in advance, but generally as protests of citizens over lack of water or pressure for domestic use, or fire protection, have resulted in local replacements and extensions made to still these protests. During the past two or three years many replacements, made with a view of early future requirements have been made and the Water Works Department is now planning additional replacements and extensions which would greatly improve the system. However, I can find no plan based on the estimated demands of the city beyond the next five years. Exhibit II shows existing mains and proposed immediate improvements.

The following table shows the growth of the distribution system since June 30, 1913, the date on which the system was turned over to the City.

TOTAL LENGTHS OF PIPE OF ALL SIZES IN DISTRIBUTION SYSTEM (all sizes down to and including 1-1/2").

<table>
<thead>
<tr>
<th>TIME</th>
<th>TOTAL LENGTHS IN MILES</th>
</tr>
</thead>
<tbody>
<tr>
<td>June, 1913</td>
<td>105</td>
</tr>
<tr>
<td>December, 1915</td>
<td>122</td>
</tr>
<tr>
<td>December, 1918</td>
<td>136</td>
</tr>
<tr>
<td>December, 1922</td>
<td>161</td>
</tr>
</tbody>
</table>
The approximate lengths of various sizes of mains in December, 1922, were as follows. These include all wood stave pipes recently installed to deliver tunnel water, Palolo Valley 6-inch line and the Nuuanu Reservoir No. 4 30-inch line.

<table>
<thead>
<tr>
<th>SIZE OF MAIN</th>
<th>LENGTH IN MILES</th>
</tr>
</thead>
<tbody>
<tr>
<td>30&quot;</td>
<td>2.0 (a)</td>
</tr>
<tr>
<td>18&quot;</td>
<td>5.3</td>
</tr>
<tr>
<td>15&quot;</td>
<td>1.8 (b)</td>
</tr>
<tr>
<td>14&quot;</td>
<td>1.4</td>
</tr>
<tr>
<td>12&quot;</td>
<td>15.0</td>
</tr>
<tr>
<td>8&quot;</td>
<td>26.0</td>
</tr>
<tr>
<td>6&quot;</td>
<td>40.5</td>
</tr>
<tr>
<td>4&quot; to 1-1/2&quot; (approximate)</td>
<td>62.0</td>
</tr>
</tbody>
</table>

Total (a) Reservoir No. 4 to electric plant.
(b) Luakaha weir to Reservoir No. 1

According to Exhibit II, replacements and extensions planned for 1923 include the following:

<table>
<thead>
<tr>
<th>SIZE OF MAINS</th>
<th>TOTAL LENGTH IN MILES</th>
</tr>
</thead>
<tbody>
<tr>
<td>4&quot;</td>
<td>5.5</td>
</tr>
<tr>
<td>6&quot;</td>
<td>47.0</td>
</tr>
<tr>
<td>8&quot;</td>
<td>11.5</td>
</tr>
<tr>
<td>12&quot;</td>
<td>15.0</td>
</tr>
<tr>
<td>18&quot;</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Total 79.9

About 50 per cent of these improvements are to be made in Kaimuki in connection with the proposed road improvement district.

While these proposed replacements and extensions are urgently needed at the present time, it is believed that
they should be temporarily abandoned until a base plan to meet the estimated requirements of from 30 to 50 years hence can be worked out. It is estimated that this plan can be worked out within the next six months.

**BASE PLAN FOR DISTRIBUTION SYSTEM.**

A base distribution system plan should be prepared. This plan should be prepared on the theory that all mains put in place will remain there for not less than 50 years.

In planning these mains it is believed wise to limit the size to 24 inch and to meet the growing requirements by installing secondary mains on parallel streets. The proposed 4-inch mains should be discarded and 6-inch mains adopted as the minimum.

Except under unavoidable circumstances, dead ends are to be avoided and the whole system should be well equipped with gate valves to permit the segregation of small areas in case of trouble. If the vicinity is not sufficiently built up to justify the installation of fire hydrants at the time the main is laid, tees and gate valves should be installed at proper intervals so that hydrants may be quickly installed at some future time without interruption to the service.

The writer believes that the laying of service mains under street pavements, wherever it can be avoided, is a mistake.
and that these mains should be laid between sidewalks and gutters, with service loops (usually 2 inch) carried across streets.

This base plan must gake cognizance of the following fundamental necessities:

(a) FIRE HYDRANTS: Ability to deliver not less than 12,000 G.P.M. to fire hydrants located within 500 feet of a possible fire in the down-town or other congested district, and not less than 500 G.P.M. to fire hydrants located within 500 feet of a possible fire in the outlying small residential districts.

(b) DOMESTIC REQUIREMENTS. Ability to serve the "peak" demands due to the habits of the people.

(c) COMMERCIAL AND INDUSTRIAL. Ability to serve industrial and commercial needs 50 years hence, including hotels, clubs, etc., insofar as these can be foreseen. This phase should be given further careful study.

(d) PUBLIC REQUIREMENTS. Ability to serve schools, public parks, sewer flushing, etc., at regular intervals.

These mains can be dug up, service connections made, and fire hydrants installed or removed with no damage to pavements or interruption to traffic. In down-town districts where sidewalks extend to the curb and are congested with foot traffic
or cover basement extensions, this, of course, cannot be done.

All mains should have at least 30 inches of earth cover between the outside of the bells and the bottom of the pavement, as a safeguard against breakage by heavy truck or other loads.

*A city plan with established street lines and grades is absolutely essential before any large mains can be installed,* and the Water Works Department is surely justified in hesitating to install mains where any doubt exists as to the permanency of the installation. In this connection, various departments of the city should keep all other departments whose plans could possibly be affected, advised well in advance of any proposed work. This policy should also be extended to and expected of all privately owned utilities using the streets either above or below the pavement.

**INSPECTION DIVISION.**

The Water Works Department should immediately organize and equip an inspection division whose duty will be to continually inspect and test for leakage and breakage of mains and service connections. House to house pressure tests for service leakage and Pitot tube or fire hose meter tests for losses in mains should be made regularly at monthly intervals.

It is believed that this inspection work will result
in savings that will greatly exceed the cost of the work. This work can also be co-ordinated with the preparation of detailed plans showing the location, size, depth, etc., of mains, valves, etc., now being prepared. The personnel of this division should in 1923, consist of one assistant engineer, two assistants and two inspectors.

The following equipment should be ordered for this work:

Two (2) Pitot tubes with recording devices.

Two (2) 2-inch compound type meters with connections threaded to fit 2-1/2" fire hose.

Six (6) Small pressure guages calibrated to read from 10 to 80 pounds pressure.

Two (2) Pressure guages, 10 to 80 pounds, to screw on 2-1/2" fire hydrants outlets.

Two (2) Aquaphones.

WATER RATES.

FINANCIAL POLICY.

Municipally owned and operated water works should furnish service at cost, but just what may be considered "Cost" is a question of policy to be determined by the proper authorities. At the present time the cost of Honolulu's water is supposed to include only the items of operation and maintenance, bond interest and sinking fund payments and the income is in-
adequate to meet even this cost. There should be added a fourth item, -a

REPLACEMENT, IMPROVEMENT AND EXTENSION FUND.

Annual inventories should be made and valuations fixed on all physical property and real estate, writing off depreciations and writing on improvements, extensions, etc.

The Committee on Depreciation of the American Water Works Association adopted in 1920 the following "depreciation" schedule:

**PROBABLE LIVES OF WATER WORKS ELEMENTS.**

The Committee on Depreciation of the American Water Works Association summarized broadly in its final report the conclusions drawn from data collected by it concerning the life of the elements of a water works plant. In still more condensed form the figures are:

<table>
<thead>
<tr>
<th>Element</th>
<th>Life in Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large storage reservoirs, well located</td>
<td>75 to 150</td>
</tr>
<tr>
<td>Heavy earth or masonry dams</td>
<td>75 to 150</td>
</tr>
<tr>
<td>Large masonry conduits and tunnels</td>
<td>75 to 150</td>
</tr>
<tr>
<td>Cast iron pipe, large</td>
<td>75 to 125</td>
</tr>
<tr>
<td>Cast iron pipe, small</td>
<td>30 to 70</td>
</tr>
<tr>
<td>wrought iron or steel pipe, large</td>
<td>30 to 75</td>
</tr>
<tr>
<td>wrought iron or steel pipe, small</td>
<td>25 to 40</td>
</tr>
<tr>
<td>Wood stave pipe, large</td>
<td>30 to 60</td>
</tr>
<tr>
<td>Services, wrought iron and steel</td>
<td>15 to 30</td>
</tr>
<tr>
<td>Services, wrought iron and lead</td>
<td>40 to 80</td>
</tr>
<tr>
<td>Small distribution reservoirs</td>
<td>50 to 75</td>
</tr>
<tr>
<td>Stand-pipes, wrought iron and steel</td>
<td>30 to 60</td>
</tr>
<tr>
<td>Stand-pipes, reinforced concrete</td>
<td>50 to 60</td>
</tr>
<tr>
<td>Valves</td>
<td>40 to 60</td>
</tr>
<tr>
<td>Hydrants</td>
<td>30 to 50</td>
</tr>
<tr>
<td>Meters</td>
<td>20 to 30</td>
</tr>
<tr>
<td>Pumping machinery, high duty, large units</td>
<td>35 to 60</td>
</tr>
<tr>
<td>Pumping machinery, high duty, small units</td>
<td>25 to 50</td>
</tr>
<tr>
<td>Pumping machinery, ordinary direct-action</td>
<td>25 to 50</td>
</tr>
<tr>
<td>Pumping &quot;[\text{pumping machinery}] centrifugal, not geared&quot;</td>
<td>20 to 30</td>
</tr>
<tr>
<td>Pumping &quot;[\text{pumping machinery} centrifugal, geared&quot;</td>
<td>15 to 25</td>
</tr>
</tbody>
</table>
Steam engines
Boilers
Electric generators and motors
Filter plants, masonry
Filter plants, wood
Buildings, masonry
Buildings, wood
Stacks, masonry
Stacks, steel

<table>
<thead>
<tr>
<th>Life in Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam engines</td>
</tr>
<tr>
<td>Boilers</td>
</tr>
<tr>
<td>Electric generators and motors</td>
</tr>
<tr>
<td>Filter plants, masonry</td>
</tr>
<tr>
<td>Filter plants, wood</td>
</tr>
<tr>
<td>Buildings, masonry</td>
</tr>
<tr>
<td>Buildings, wood</td>
</tr>
<tr>
<td>Stacks, masonry</td>
</tr>
<tr>
<td>Stacks, steel</td>
</tr>
</tbody>
</table>

* In slow-growing and small cities, 50 to 90 years.

Explanatory remarks and qualifying conditions are given in the report, which has been printed as a 38 page supplement to the September Journal of the American Water Works Association. Discussion of the entire report on depreciation, for presentation to next year's convention of the American Water Works Association, is invited by J. M. Diven, secretary, 47 State St., Troy, N.Y.

I can see no good reason why this schedule should not be as affective here as on the mainland, especially when we can eliminate the freezing hazard.

The annual value of the system and plant should be fixed as the "capital stock" and a "dividend" rate of say 5 per cent thereon be fixed to provide for normal replacements, improvements and extensions, - in addition to the rates fixed for operation and maintenance, bond interest and for sinking fund payments.

The present system and plant are so inadequate and obsolete that it is estimated that approximately $2,250,000.00 (see Cost Estimates) will be required in the nature of "Capital
stock" in the next three years, in addition to the water receipts, to put the system on an efficient basis. Of this amount about $750,000.00 is now available. With these funds the Department should be able to keep ahead of normally required replacements, improvements and extensions with its "dividends". In this way it is believed that there will soon be established a revolving fund which will permit the complete amortization of outstanding bonds and which will put the department on a sound business basis.

**FOR EXAMPLE:** Assuming that the 1925 valuation of the system and plant to be fixed at $7,000,000.00; the outstanding 4.5 per cent bonds at $1,000,000.00 and the 5.0 per cent bonds at $2,250,000.00; the mean annual sinking fund payments at 2 per cent; the operation and maintenance cost at $327,500.00; and the gross amount of water served at 12,000 million gallons, -

<table>
<thead>
<tr>
<th>Operation and Maintenance</th>
<th>$327,500.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Interest</td>
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</tr>
<tr>
<td>4.5% on $1,000,000.00</td>
<td>45,000.00</td>
</tr>
<tr>
<td>5.0% on $2,250,000.00</td>
<td>112,500.00</td>
</tr>
<tr>
<td>Sinking Fund - 2% on $3,250,000.00</td>
<td>65,000.00</td>
</tr>
<tr>
<td>Replacement, Improvement and Extension Fund</td>
<td>$350,000.00</td>
</tr>
<tr>
<td>5% on Valuation of $7,000,000.00</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$900,000.00</td>
</tr>
</tbody>
</table>

This should work out a rate of about $0.075 per thousand gallons.
PRESENT WATER RATES.

Existing water rates are too low and are inadequate to meet the cost of operation and maintenance, bond interest and sinking fund requirements. These rates are less than half the average household rates charged by the average mainland city of equal or larger population than Honolulu, (See Exhibit XI).

PROPOSED METHOD FOR FIXING RATES.

First of all, as frequently and persistently mentioned in this report, every privilege should be metered at the earliest possible date, and in addition to the consumption charge, either a flat meter charge, based on the size or capacity of the meter, or a "fixed service charge" made. Should the flat meter charge be adopted, the rate should be ample to cover maintenance, reading, testing and renewal when the meter is worn out.

In some cities this meter charge is absorbed in a "fixed service charge", with an additional consumption charge. "The fixed service charge" covers the cost of service and does not vary as the amount of water consumed, but as a constant charge comprising two elements of cost, - namely, the capacity or readiness to serve cost and the consumer's cost. The capacity or readiness to serve cost is the cost of labor, material and interest appurtenant to that part of the plant which is idle when the normal demand exists, but which is held in readip
ness to supply the maximum demand. The consumer's charge covers the cost of reading meters, etc. and varies but little." The "capacity or readiness to serve" charge for each privilege is also based on the maximum capacity of the service meter. "This fixed service charge is made whether the consumer has used water or not as the water plant must be held in readiness at all times to deliver his maximum demand". (For full discussion on this subject, see an article entitled "Economic Aspect of Water Works Management", by V. Bernard Siems, Associate Civil Engineer, Water Works Dept., Baltimore, Md., on pages 89 to 92 inclusive, of the January 10, 1923 number of "Engineering and Contracting". Quotations above are taken from this article.)

The "fixed service" charge is undoubtedly the most just and reasonable scheme yet devised and should be adopted by Honolulu.

After the "fixed service" charge, the consumer should be charged according to the water delivered to him. With an abundance of water there should be a downward sliding scale as the quantity of water used increases, but at the present time, with the existing tendency to waste water, it is believed that all consumers should pay the same rate per thousand gallons, except shipping which should pay adequate increased rates to cover additional service required.

The Water Works Department should also be relieved of its present burden of expense due to maintenance and opera-
tion of that part of the Nuuanu gravity supply used entirely to develop electricity and also of the bond interest and sinking fund payments due on this portion of the system. It should also be reimbursed in some way for fire protection service, for the additional bond interest and sinking fund charges it has to pay because of the fact that the system and water supply facilities have to be much greater to provide proper fire protection than for all other purposes and also for the purchase and maintenance of fire hydrants. The Water Works Department of the City of Baltimore received a flat annual payment of $40,00 per hydrant for fire protection service.

SERVICE ZONES.

Water service zones should be created and service limited to these areas. The present tendency of citizens building up small residence districts in remote places and upper valleys, far from existing water supply facilities, and then demanding service is unfair to the Water Department and tax payers.

These zones should include only such areas as are sufficiently settled to make adequate returns for the capital outlay and service required without placing unfair burdens upon the balance of the system.
PART SEVEN.

RECOMMENDATIONS FOR PERIOD 1923 - 1925, and ESTIMATES OF COST.

(For complete data see pages 88 to 94).

RESUME.

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funds Required 1923 to 1925</td>
<td>$2,250,000.00</td>
</tr>
<tr>
<td>Funds Available</td>
<td>$750,000.00</td>
</tr>
<tr>
<td>Additional Funds Required</td>
<td>$1,500,000.00</td>
</tr>
</tbody>
</table>
PART VII.
RECOMMENDATIONS.

It is recommended that the following changes and improvements be made in the period 1923 to 1925. These are all most urgently needed at the present time but, most important of all, is some immediate definite action required to stop the existing waste and leakage from the artesian basins. Next in importance is the necessity for completely metering all privileges.

1. ARTESIAN SUPPLY.

Ask the 1923 Territorial Legislature to pass an Act authorizing the City and County to:

(a) Condemn and acquire every existing well between the western boundary of Wailupe and the eastern boundary of Fort Shafter military reservation, and to prohibit drilling of new wells within this area by private corporation or person; or

(b) Condemn and acquire all wells known to be leaking, or in bad condition, or abandoned by their owners; to regulate the flow from other existing wells; and to prohibit the drilling of new wells, - all in the area specified in the above sub-paragraph (a); - or

(c) Prohibit drilling of new wells in this area.
In case the Territory fails to provide some remedial measure to stop the present waste, or to provide funds for the investigation and enforcement of the existing law, the City and County should take over this responsibility insofar as the area outlined above is concerned.

II. ARTESIAN WELLS REQUIRED.

Each pumping plant to be equipped with one 12-inch artesian well for each 2.0 million gallons of water pumped from this source. All wells should be at least 50 feet apart. There should be drilled within the next year the following wells to augment the existing wells:

Kalihhi Pumping Plant - 4 12-inch wells.

(Now has 3 12-inch wells 23 years old.)

Beretania Pumping Plant - 4 12-inch wells.

(Now has 2 10-inch wells drilled in 1895, probably in bad condition, and 2 12-inch wells drilled in 1909.)

Kaimuki Pumping Plant - 3 12-inch wells.

(Now has 2 12-inch wells drilled in 1895, probably in bad condition, and 2 12-inch wells drilled in 1912.)

III. METERS.

Install meters on all privileges.

IV. DISTRIBUTION SYSTEM.

Prepare base plan to serve estimated demands 40 to 50
years hence and make all replacements and permanent ex-
tensions in accordance therewith. Prepare this plan only
for those portions of the city where the street lines and
grades have been established by ordinance.

V. TUNNELS.

Complete tunnels now started in Kalihi, Makiki and
Palolo Valleys and drive additional tunnels in east side of
Nuuanu and Palolo Valleys and in upper Manoa and Pauoa
Valleys.

VI. PUMPING PLANTS.

Adopt for regular pumping service, standard steam
pumping units consisting of vertical triple expansion
steam pumps, each capable of delivering 7.5 M.G.D.,
against a head of 300 feet and install one each (with nec-
essary new boilers) at Kalihi, Beretania and Kaimuki pump-
ing plants, scrapping one old horizontal cross compound
type steam pump at each of the two last named plants.

Adopt for intermittent boosting service, standard
electric motor driven centrifugal pumps, each capable of
delivering 5.0 M.G.D. against a head of 240 feet. In-
stall one each of these units (with small pump house) at
the existing Punchbowl reservoir (to boost Beretania
pumped water to the proposed new 6 million gallon reservoir
to be located back of Punchbowl crater) and one at the existing Rocky Hill reservoir (to boost Wilder Avenue pumped water to the proposed new 1.5 million gallon reservoir to be located on the lower slope of Round Top).

Connect the Beretania booster pump to the proposed 6 million gallon reservoir with an 18-inch cast iron pipe line.

Connect the Rocky Hill booster pump to the proposed 1.5 million gallon reservoir with a 12-inch cast iron pipe line.

VII. RESERVOIRS.

Construct the proposed 6 million gallon reservoir back of Punchbowl crater and connect same to existing 18-inch line at Judd Street with a new 18-inch cast iron pipe line.

Construct a new 1.5 million gallon concrete reservoir on lower slopes of Round Top, to serve Manoa and Makiki districts, and connect same with existing Makiki booster pumping plant with a 12-inch cast iron pipe line.

VIII. WATER SERVICE ZONES.

Establish water service zones and limit service thereto.

IX. WATER RATER.

Immediately raise all water rates 50 percent until a
new water rate schedule based on "fixed service" and "consumption" service can be worked up. This new schedule to be high enough to provide for:

1. Operation and Maintenance;
2. Bond Interest and Sinking Fund Payments;
3. Replacement, Extension and Improvement Fund.

Charge all privileges except shipping the same rate.

X. DISCHARGE RECORDS.

Install on all tunnel outlets, springs and other possible sources of supply, continuous record measuring devices and maintain same for at least 5 years before installing permanent pipe lines. Enter into agreement with the local office of the U.S. Geological Survey to operate and maintain these devices.

XI. INSPECTION DIVISION.

Organize an inspection division to make regular monthly house to house and main inspections, to locate and repair leaks, broken pipe, etc.

XII. PERSONNEL.

Increase engineering and cost accounting personnel to properly provide for investigations, surveys, plans, specifications, contracts, inspection, inventories, and cost accounting.
Funds Required for Period 1923 to 1925.

I. Meters.

15,000 Meters 5/8" to 1-1/2" at average price of $15.00 $225,000.00
15,000 Meter Boxes at $2.50 37,500.00
Installing Meters and Boxes - 15,000 at $6.00 90,000.00
Total 352,500.00

II. Artesian Wells.

11 Wells - 5,200 ft at $9.00 47,000.00

III. Pumping Equipment and Accessories.

3 Standard Steam Pumping Units (with boilers, etc.) 540,000.00
2 Standard Electric Pumps and Shelters - 18,000.00
Pipe Lines, booster plants to Reservoirs -
6000 ft 18" C.I. Pipe in place at $12.50 75,000.00
2000 ft 12" C.I. Pipe in place at $7.50 15,000.00
Total 648,000.00

IV. Reservoirs.

1 6 million gallon Reservoir $225,000.00
1 1.5 " " 60,000.00
5,000 ft 18" C.I. Pipe in place at $12.50 - 62,500.00
1,800 ft 12" C.I. Pipe in place at $7.50 13,500.00
Total 361,000.00
<table>
<thead>
<tr>
<th>Section</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. TUNNEL WORK AND TEMPORARY PIPE LINES.</td>
<td>$150,000.00</td>
</tr>
<tr>
<td>VI. DISTRIBUTION SYSTEM AND NEW FIRE HYDRANTS</td>
<td>$500,000.00</td>
</tr>
<tr>
<td>VII. ENGINEERING, INSPECTION AND COST ACCOUNTING</td>
<td>$90,000.00</td>
</tr>
<tr>
<td>VIII. CONTINGENCIES AND INCIDENTALS.</td>
<td>$101,500.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2,250,000.00</strong></td>
</tr>
</tbody>
</table>
ON FILE IN WATER WORKS OFFICE
TOO BULKY TO BE BOUND IN THIS REPORT

EXHIBIT II
Honolulu, T. H. February 28, 1923.

Mr. G. K. Larrison,
Honolulu, T. H.

Dear Sir: -

Referring to your verbal request we are pleased to give you the following information regarding the cost of installing and operating steam driven and electrical driven pumping machinery.

As a basis for this comparison we have, at your suggestion, considered units having a capacity of seven and a half million gallons per day against a head of 300 feet. For these conditions we have made estimates covering Vertical Triple Expansion steam driven pumping engine and electrical driven centrifugal pumps.

The Vertical Triple Expansion pumping engine having a capacity of seven and a half million gallons per day against a head of 300 feet, would cost approximately at the present day prices $160,000, delivered and erected. The necessary boilers to operate this pump would cost in place about $8,000. The motor driven centrifugal pump for the same conditions including the necessary electrical equipment would cost about $15,000 in place.

The Committee on Depreciation of the American Water Works Association in its final report, gives the following values for the life of various types of equipment:

High duty pumping machinery large units 35 to 60 years
Pumping machinery, centrifugal pumps not geared - 20 to 30 years
Boilers 15 to 30 years

Using the minimum values and allowing six per cent interest rate, a life of 35 years would require an annuity of 0.9 per cent. A life of 20 years would require an annuity of 2.72 per cent and a life of 15 years, an annuity of 4.3 per cent.

EXHIBIT XI.
G.K.L.

Assuming that the maintenance repairs and supplies for each type of pumping machine would be two per cent, and for the boilers five per cent, the total charge against each type would therefore be for the V.T.E. 8.9 per cent, centrifugal 10.7 per cent, and boilers 15.3 per cent.

The V.T.E. type of pumping engine is an extremely economical unit and would require approximately only 9900 barrels of oil per year, on the assumption of continuous operation 24 hours per day, 365 days in the year. Assuming the cost of fuel oil to be $2.00 per barrel, the total cost of fuel per year would be $19,800.

It is our understanding that you are contemplating recommending some type of pumping machinery which would be the standard for all municipal pumping stations and under these circumstances the above assumption is justified. Had you been considering a single pump installation, it might be necessary to take into account the percentage of time during which the pump was in operation.

A motor driven centrifugal pump for the same conditions operating with a pump efficiency of 82 per cent and a motor efficiency of 92 per cent would require 3,440,000 K.W. hours per year. Taking the cost of current of 1.3 ¢ per K.W. hour this would give a figure of $55,000 for the cost of current.

It is a little difficult to estimate the cost of attendance, which would undoubtedly be somewhat greater with the steam driven type than with the electrical driven. It is manifestly wrong to base attendance charges on having full crews to operate a single pump. We have therefore assumed that the amount chargeable to each type for attendance would be for the V.T.E. $8,000 per year, and for the centrifugal pump $5,000 per year.

Combining the above items of expense for each type, would make up the total yearly charge. We find that for the V.T.E. unit this would amount to about $43,260 and for the motor driven centrifugal about $61,600. It is therefore evident that there would be a saving in favor of the steam
driven type of $18,340 per year. Capitalized at the yearly charge assumed above for the steam driven equipment, this would justify an additional expenditure of about $200,000. In other words you could more than double the price paid for this type of equipment and still pump water more cheaply.

The cost of pumping based on the above figures would be $15.80 per million gallons pumped for the steam driven type compared with $22.50 for the electrical type. Another way of expressing it would be that with oil at $2.00 per barrel the electric current would have to be purchased at about 1¢ per K.W. hour to break even.

All of our figures above are slide rule calculations and are therefore not exact.

There are of course other considerations in making a selection of a type of pumping equipment than mere cost of installation and operation. The V.T.E. type of machine has great flexibility. It will operate over a wide range of head and capacity at very nearly maximum economy, the reduction in efficiency from full load down to one-half capacity, being not more than five or six per cent.

A motor driven centrifugal pump is essentially a constant capacity machine and variations in either head or capacity can only be obtained at considerable sacrifice in efficiency.

As regards the reliability of the steam driven type, we refer you to the records of the V.T.E. pumping engine which has been in operation at your Kalihi station for over 20 years. We are giving you on the attached sheet the names of 30 large cities in the United States which have installed the V.T.E. type of pumping engine. We are also giving you a list of 45 smaller cities where the demand was not sufficient to justify a V.T.E. unit, and where horizontal cross compound steam driven units are being used. We do not know any large city in the United States which uses electricity for pumping its main water supply.
In many of these cities the motor driven pumps may be used for booster stations, or for pumping water to filters, or some similar purpose where the other type is not suitable. A motor driven centrifugal pump suitable for pumping 5 million gallons per day against a head of 240 feet, would cost approximately $10,000 installed. Pumps of this type would be used to advantage in pumping from a reservoir to higher levels in Honolulu.

Many cities in the United States have gone very thoroughly into the question of the type of pumping equipment to use. In some cases the price of electric current was so low that it at first seemed that this type would be justified. We have here copies of many of the reports made by experts for these cities, and some of them are very complete in all their details and represent an extensive and unbiased opinion. The few large cities which have tried the electric type, have so far as we know, all gone back to steam.

We trust that the foregoing analysis is what you desire but will be very glad to give you any other information which we have available.

Very truly yours,

(Signed) Wm. H. Getz

MERCHANDISE DEPARTMENT
Louisville, Ky.           Chicago, Ill.  
Milwaukee, Wis.          Baltimore, Md.  
Cleveland, O.             New Orleans, La.  
Grand Rapids, Mich.      Newport, R. I.  
Phillipsburg, N. J.       Terra Haute, Ind.  
Springfield, O.           Toronto, Ont.  
Peoria, Ill.              Reading, Pa.  
Toledo, O.                Omaha, Neb.  
Kansas City, Mo.          Boston, Mass.  
Wheeling, W. Va.          St. Louis, Mo.  
San Antonio, Tex.         St. Paul, Minn.  
Nashville, Tenn.          St. Paul, Minn.  
Washington, D. C.         Albany, N. Y.  

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Indianapolis, Ind.        Marlborough, Mass.  
Michigan City, Ind.       Fremont, Neb.  
Bellefontaine, O.         Iowa City, Ia.  
Tulsa, Okla.              La Crosse, Wis.  
Ashtabula, O.             Los Angeles, Calif.  
Lorain, O.                Topeka, Kas.  
Allentown, Pa.            Winfield, Kas.  
Jacksonville, Fla.        Waco, Texas  
Kansas City, Kas.         S. Bend, Ind.  
Newton, Iowa              Independence, Kas.  
Sheboygan, Wis.           Mason City, Ia.  
Durham, N.C.              Temple, Tex.  
Kenosha, Wis.             La Porte, Ind.  
Marshalltown, ia.         Fargo, N. D.  
N. Tonawanda, N.Y.        Oskaloosa, Ia.  
Cedar Rapids, Ia.         Logansport, Ind.  
Woodbury, N. J.           Montclair, N. J.  
Perth Amboy, N. J.        New Haven, Conn.  

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WATER SUPPLY STATISTICS.

Tabulation of Data from over 1,000 Cities in the United States and Canada.

<table>
<thead>
<tr>
<th>State</th>
<th>Average Highest Meter Rate Per 1,000 Gallons</th>
<th>Average Best Commercial Rate per 1,000 gals.</th>
<th>Average Yearly Minimum</th>
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EXHIBIT XII.
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<thead>
<tr>
<th>State</th>
<th>Average Highest Meter Rate Per 1,000 gallons</th>
<th>Average Best Commercial Rate per 1,000 gals.</th>
<th>Average Yearly Minimum</th>
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<tbody>
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